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DISTRIBUTION AND BEHAVIOUR OF METAMITRON IN VARIOUS SOILS

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Summary Field and laboratory experiments conducted to study the behaviour of the herbicidal compound metamitron in beet field soils of English and German origin are reported. In leaching experiments using 30 cm long columns (5 or 10 cm i.d.) filled with sieved soil samples or cores, leachability of metamitron proved to be slight. No metamitron residues have yet been detected in leachates from 130 cm cores (10 cm i.d.) of beet field soils during a study that has been in progress for 18 months. The adsorptive capacity of soils studied very largely accounts for the slight leachability of the herbicide down in deep soil layers. Penetration of the herbicide down to deep groundwater zones is ruled out by the physical and chemical properties of the herbicide as well as by the results of leaching experiments. The decline of metamitron content in soil measured in long-term experiments was comparable in both the laboratory and the field. Metamitron is degraded to desamino-metamitron in both soil and the aerial parts of beet plants. Evolution of $^{14}CO_2$ from (3-^{14}C) metamitron under the influence of soil microorganisms is further indicative of an opening of the heterocycle.

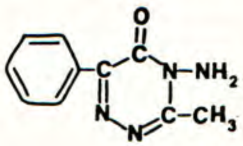
INTRODUCTION

The residual life of herbicides in soil, and hence their biological availability, is very largely governed by climatic conditions and by soil properties. It is upon these physical factors that the leachability of herbicides into deep soil layers also depends. Results of our studies to investigate the distribution and behaviour of the triazinone herbicide metamitron in beet field soils of English and German origin are reported herein.

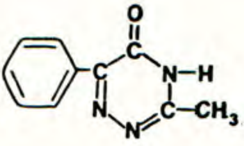
METHODS AND MATERIALS

Metamitron is the common name of the herbicidal compound which chemically is 3-methyl-4-amino-6-phenyl-1,2,4-triazin-5(4H)-one (I) (Schmidt et al., 1975).

Fig. 1 Physico-chemical properties of metamitron (I) and desamino-metamitron (II)



(I)



(II)

	(I)	(II)
H_2O-solubility:	182	53 mg/100 ml H_2O
m.p.:	167-169° C	265° C
LD_{50} rat ♂ per os:	3343 mg/kg	4325 mg/kg

Metamitron is used for the control of weeds in sugar beet either as a soil-applied herbicide pre-planting incorporation or pre-emergence or as a foliar-applied herbicide post-emergence.

The physical and chemical properties of the soils used in the studies are summarized below in Table 1.

Table 1

Physical and chemical properties of soils used in studies

soil	pH ($CaCl_2$)	particles <20 μ (%)	clay (<2 μ) (%)	C (%)	T-value (cation-exchange capacity) (mval/100 g)
Fliesteden	5.9	41.4	12.6	1.1	12.0
Heilbronn	7.0	32.7	8.1	0.96	10.0
Höfchen	5.8	50.6	11.9	0.96	11.3
Laacherhof	6.1	20.5	8.6	1.8	5.6
Leichlingen	6.5	13.5	5.2	1.36	5.9
Ramsey	5.3	–	–	34.4	129.5
Suffolk	7.0	32.7	16.3	1.6	15.3
standard soil					
-No. 2.2	6.9	16.4	6.8	2.89	12.5
-No. 2.3	5.5	25.5	8.6	0.69	6.0

For the leaching studies, soils sampled from sugar beet fields were air-dried and ground to pass through a 1 mm sieve. Cores of undisturbed soil were taken from the same fields with a "Humax" corer (Hug Company, Lucerne, Switzerland). These and the air-dried soils were transferred to glass columns. The columns were 30 cm long and had an inside diameter of either 5 cm or 10 cm. Deionized water was applied to the top of the columns by means of a water pump monitored by an electric clock.

[3-^{14}C] metamitron with a specific activity of 62 µCi/mg was added to the soil as tracer in combination with commercial GOLTIX* 70 % w.p. applied at normal doses equivalent to 5 and 7.5 kg/ha, respectively.

For the degradation studies, the soils were initially moistened to 40 % of their field capacity and kept in the dark for several weeks in flasks stoppered with cotton plugs. The moisture content of the soils was maintained at a constant level by adding water at regular intervals. For the measurements of $^{14}CO_2$ evolution, volatilization flasks containing soils were connected to a CO_2-free air system with flow regulation. The apparatus was designed for air to pass over the soil, then through a concentrated H_2SO_4 trap, and finally through 1N NaOH to trap $^{14}CO_2$. The trapped radioactivity was counted by scintillation techniques.

Metamitron and its degradation products were extracted from the soil successively with water, water/acetone, dichloromethane and chloroform, by continuously shaking for 60 minutes each time. Quantitative analysis of metamitron was performed by GLC using a N-FID (Jarczyk, 1975a). Prior to the GLC determination, the metamitron degradation products were methylated with diazomethane. The lower limit of determination was at 0.05 ppm.

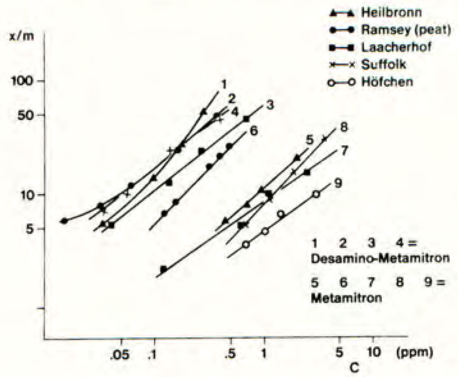
The adsorptive capacity of metamitron was studied on soils, using slurry-type adsorption experiments described by Grover (1975) for determining the Freundlich constant "k".

RESULTS

The adsorption of metamitron correlates to both the C-content and the N-content of the soils. Kerpen and Schleser (1976) recently

*Registered trademark of Bayer AG, Leverkusen, Fed. Rep. of Germany stated this in their report on adsorption and desorption studies. On the other hand, they found that the pH and clay content did not correlate to the adsorption of the soils. We determined the adsorption potential (after Freundlich) of metamitron on other beet field soils (Fig. 2), and obtained k-values at equilibrium concentration C=1 ranging from 4 to 11 μg/g soil, the value for Ramsey peat being approx. 50 μg/g soil. In the light of these relatively high adsorption values, it was expected that the leachability of metamitron in the studied beet field soils would be slight.

Fig. 2 Adsorption isotherms (Freundlich) for metamitron and desamino-metamitron on different soils



Studies to investigate the leaching of metamitron in soils now showed that despite discontinuous simulated rainfall in the laboratory with amounts many times higher than the natural rainfall amounts, only slight amounts of the herbicide passed through both cores as well as sieved soil columns 30 cm high. The moisture level of the soil columns influenced the amount of metamitron leached out (Table 2), a phenomenon which we are still studying.

Table 2

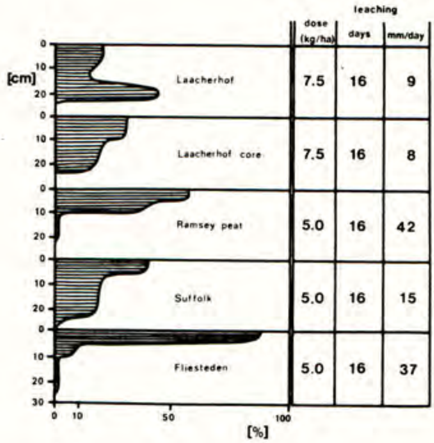
Metamitron (3.5 kg/ha) leaching data from 30 cm soil columns (sieved samples and cores)

Column i.d. (cm)	Soil	Status	Simulated rainfall days	Simulated rainfall mm/day	Leachate (ml)	Leachate metamitron content (%)
5	Leichlingen	dry	25	36	1775	13.1
5	"	wet	25	90	4415	10.7
10	"	wet	28	13	2940	11.5
10	" (-core)	wet	28	14	3090	0.6
5	Laacherhof	dry	25	83	4040	30.5
5	"	wet	25	81	3965	2.9
10	Höfchen	wet	28	14	3010	2.3
10	" (-core)	wet	28	14	3100	0.7

The varying distribution of metamitron in soils of different origin after simulated rainfall in the laboratory is shown in Table 3.

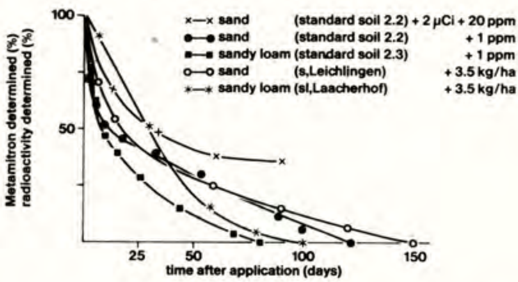
Table 3

Distribution of radioactivity after leaching of [3-^{14}C]metamitron in soils in the laboratory



The analytical determination of the metamitron content in soil in long-term experiments produced comparable results in the laboratory and in the field (Leichlingen and Laacherhof), as demonstrated by the few examples presented in Fig. 3.

Fig. 3 Decline of metamitron in soils (laboratory and field experiments)



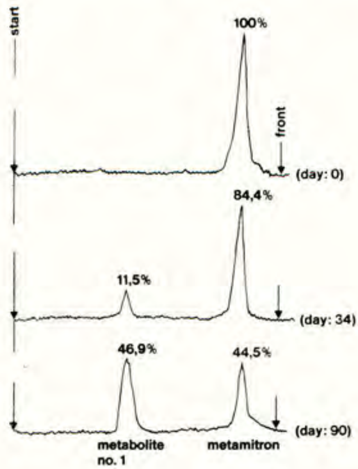
The slope of the radioactivity curve (x-x) differs from that of the other examples and is indicative of formation of radioactive degradation products in the soil.

Metabolism

Because of its good solubility in water, metamitron is quickly absorbed from the soil by the plant (Müller and Sanad, 1976). In beet plants, metamitron is metabolized firstly by desamination to desamino-metamitron (Fig. 1 (II)) (Jarczyk, 1975b). Within two weeks, approx. 95 % of the root-absorbed radioactive metamitron was metabolized in the aerial parts of the sugar beet plants; after enrichment by TLC and isolation, 77 % of this amount was identified as desamino-metamitron by TLC, GLC and MS.

In the soil, degradation of metamitron to desamino-metamitron proceeds more slowly than in the beet plant. The formation of this first principal metabolite in soil is illustrated in Fig. 4 (no. 1).

Fig. 4 Degradation of [3-^{14}C] metamitron in soil (laboratory experiment with standard soil 2.2)



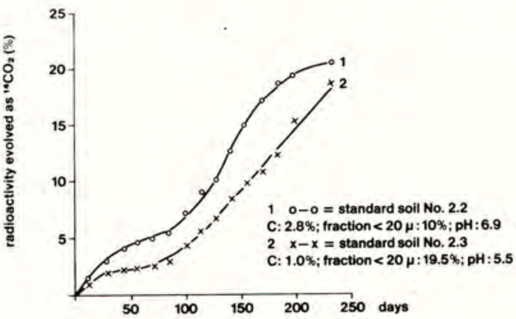
(DC-scanning, silicagel; solvents: $CHCl_3/CH_3OH/NH_4OH$ 68:28:8).

In addition to the initially predominantly formed desamino-metamitron, slight amounts of a further metabolite of hitherto unknown chemical structure were also observed in some soils. Both compounds can be determined by GLC.

In field experiments at our Höfchen and Laacherhof Experiment Stations, metamitron underwent up to 20 % degradation to desamino-metamitron (DA-metamitron). In the laboratory, the Suffolk soil showed the highest degradation rate of all soils studied, with 33 % DA-metamitron formation after 4 weeks at 32° C. In dry soils, no degradation occurred. The degradation of metamitron in soils seemed to be a predominantly microbial process since no degradation occurred in sterile soils incubated at temperatures ranging from 20° C to 27° C. In the soil, DA-metamitron is very greatly adsorbed to soil particles (Fig.2).

Another degradation pathway emerged from long-term experiments with [3-^{14}C] metamitron in soil samples, in which $^{14}CO_2$ was evolved. This is indicative of an opening of the heterocycle in the molecule by microorganisms. Within 230 days, up to 21 % of the applied radioactivity was collected as $^{14}CO_2$ (Fig. 5). In these experiments, light did not influence the formation of $^{14}CO_2$.

Fig. 5 $^{14}CO_2$ evolution from [3-^{14}C] metamitron-treated soils



Loss of metamitron from the soil surface as a consequence of co-distillation with water vapour due to solar irradiation was not proved in our experiments with [3-^{14}C] metamitron. Schmidt (1976) reports that photolytic degradation of the herbicide to DA-metamitron on the soil surface by sunlight is negligible.

DISCUSSION

Our studies on the metabolism of metamitron have not yet been concluded. However, we can already point out that in our long-term metamitron leaching studies on natural 1.3 metre soil columns with simulated field rainfall, which have been in progress for more than 18 months, neither metamitron nor its degradation product DA-metamitron has so far been found in the leachate. On the grounds of the results we have available from laboratory and field investigations, penetration of this herbicide into the groundwater zone can, therefore, be ruled out.

Acknowledgements

Thanks are extended to Frau Gerhardy-Graf, Frau Slawik, Herr Baade, Herr Ellenberger and Herr Lambertz for their valuable technical assistance in these studies.

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THE EFFECT OF CHANGING MOISTURE CONDITIONS ON THE DEGRADATION OF ATRAZINE IN SOIL

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Summary Degradation of atrazine was studied in a sandy soil with moisture kept constant at 4 (air dried soil), 35 and 70% of its water holding capacity. The respective half-lives observed at 23°C were 151, 37 and 36 days. Alternating these moisture levels in definite cycles, resulted in quite different degradation rates for the dry periods.

Résumé Dans une terre sableuse d'une humidité de 4 (sèche à l'air), 35 ou 70% de la capacité absolue en eau, la dégradation d'atrazine a été étudiée. A une température de 23°C, les durées correspondantes, nécessaires à la disparition de 50% de la quantité d'herbicide, se sont montées à 151, 37 ou 36 jours. Un changement périodique de ces humidités de sol a effectué de très différentes taux de dégradation pendant les périodes sèches.

INTRODUCTION

Degradation of a pesticide in the soil depends on its chemical and biochemical reactivity with the various soil components. The rate of these processes is controlled by both, temperature and water. Knowledge of pesticide persistence in the soil is important in avoiding unwanted residues in the following crop. For herbicides this is even more important in respect to carry over. It is a common field experience that soil acting herbicides persist longer under dry than under moist conditions, provided a minimum temperature for decomposition is given.

It has often been demonstrated that high moisture levels speed up pesticide breakdown. From this one may draw the conclusion that in the field, where the soil water content varies drastically, the rate of herbicide decomposition may be highly affected. Therefore, herbicide half-lives found under laboratory conditions, with a constant soil moisture, must be used with caution. However, persistence in the field could be predicted more accurately, if the effect of changing soil moisture on herbicide breakdown is known. A possible way to achieve this, is to evaluate the half-lives for different moisture levels, and to derive from them the resulting persistence of the chemical in a soil with alternating moisture levels. This however, implies that the kinetics of breakdown is not influenced by the previous moisture treatment. One could imagine that in a soil exposed to a dry-wet-cycle, the changed binding conditions of the pesticide in dry soil, may influence its degradation during the following wet period. Similar effects may occur in respect to microbiological breakdown.

To the best of our knowledge, the only relevant investigation in this field, is by Fusi and Franci (1971), who studied the decomposition of atrazine in alternating wet and dry soils. They found an intermediate persistence of the herbicide. However, their experimental data were limited. This paper describes more detailed experiments on atrazine degradation including three moisture levels which were either kept constant during the experiment, or alternated in definite cycles. We also used atrazine because it is one of the more persistent and widely used herbicides, and it is decomposed chemically as well as microbiologically. Therefore, the effect of an alternate water content, if any, should become evident.

METHODS AND MATERIALS

Soil

A sandy soil was used containing 4.1% clay, 4.6% silt, 2.6% organic matter, with a pH($CaCl_2$) of 6.2, and a CEC of 9.23 meq/100 g. The soil was sieved to pass a 2 mm sieve.

Treatment of soil and sampling

The nominal moisture levels which had to be kept constant were: 0.8% = air dry (I), 9% (II), and 17% (III), corresponding with about 4, 35 and 70% of the soil water capacity respectively. At 17% water content the soil could still be handled without clodding. The water contents for II and III were achieved by pouring, step by step, appropriate amounts of water on the air dried soil which was spread as a thin layer on a plastic sheet. The moistened soil was then thoroughly mixed. Atrazine (Gesaprim 50, 45% a.i.) was applied as an aqueous suspension onto the air dried (I) and moistened soils (II and III) with a pipette and was mixed in, to give a nominal concentration of 5 μg/g dry soil. For each treatment 8 kg of air dried soil were used. Treatment I was air dried immediately after herbicide application. For the experiments with alternating moisture levels, additional treatments II and III were prepared. The treated soil was sieved again before storage.

The experiments with alternating moisture levels had the following sequences: II-I-III-II-I-III and III-I-III-I-III-I respectively. The changes in moisture were achieved by adding the appropriate amount of water or by air drying the soil in a thin layer at a temperature of 20 to 25°C. Drying of the soil took 2 to 3 days. The different moisture levels were maintained for a period of 20 days, except for the first and the last periods, which lasted 10 and 35 days respectively.

All treatments were stored in large sized polyethylene bags in the dark at 23 $\pm$ 1°C, over a period of 125 days. Samples were taken in five day intervals and kept frozen prior to analysis. During sampling the soil was aerated and the bags sufficiently shaken to provide even moisture distribution in the soil. To determine the soil moisture content, three subsamples of each treatment were dried to constant weight at $105^{\circ}C$.

Analytical procedure

Air dried 25 g soil samples were extracted with methanol and the extracts were cleaned up on aluminium oxide (Ramsteiner et al., 1974). Atrazine was detected by gas chromatography, using an alkali flame ionization detector (Baumeister and Hurle, 1975). Atrazine recovery was 90% in the range of 0.4 to 5 $\mu g/g$, for all moisture levels.

RESULTS

The results from the experiments with the soil moisture kept constant, are shown in Figs. 1 - 3. The straight lines obtained in semi logarithmic plots indicate that degradation followed first order kinetics. The half-lives derived from the slopes of the regression lines were 151, 37 and 36 days for the dry (I), the medium (II) and the higher (III) moisture levels, respectively. Although the water content in III was twice that of II, the rate of degradation was approximately the same.

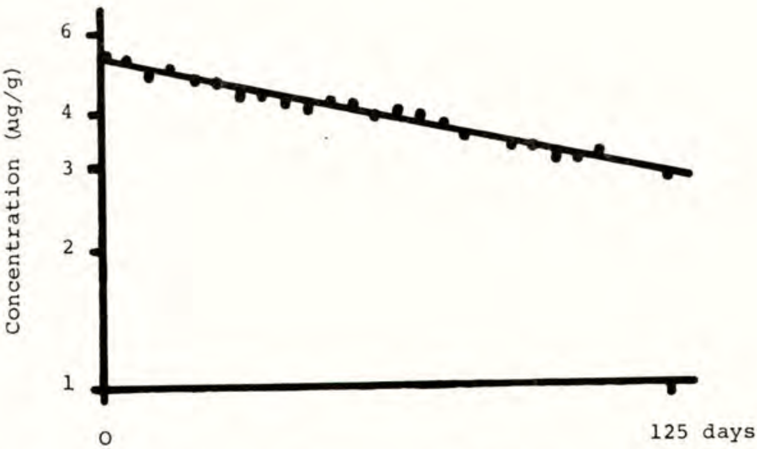

Fig. 1. Degradation of atrazine in air dried soil (I). $t_{1/2}$ = 151 days; r = -0.986.

The degradation of atrazine under the changing moisture conditions is demonstrated in Figs. 4 and 5, and for the sake of a better comparison, data for degradation during the different periods are listed in Table 1. As can be seen from Fig. 4, decomposition under the conditions of the II-I-III cycle was rapid during the first period (II), rather slow in the following (I), and had almost a steady rate until the end of the experiment. When these rates were compared with those obtained under the corresponding constant conditions, that of level I differed greately. The degradation pattern in the III-I-III cycle (Fig. 5) was similar to that of II-I-III. Here again the rate in the dry periods was quite different from that under permanent dry conditions, except for the second period (Table 1). Despite the limited data from each moisture period, the correlation coefficients were fairly high.

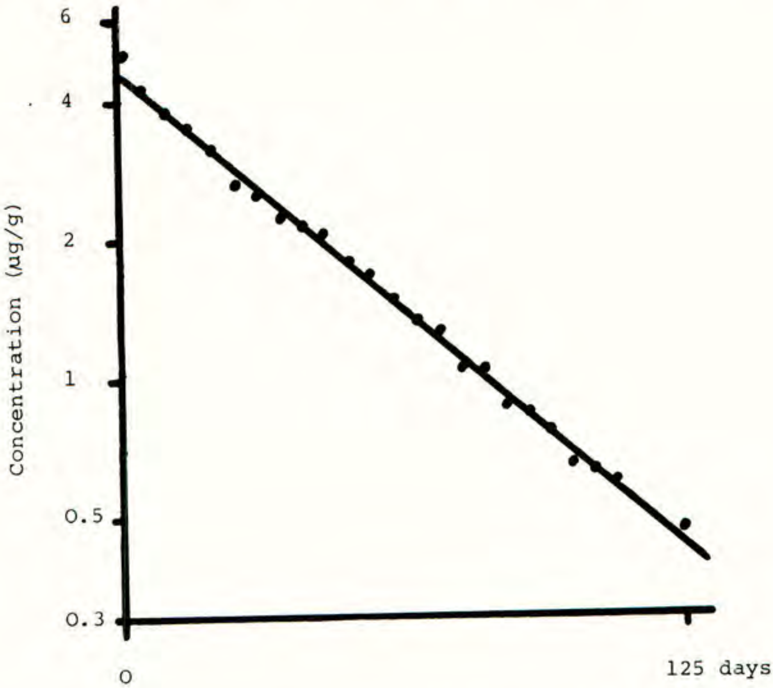

Fig. 2. Degradation of atrazine in soil with 8.4% moisture content (II). t 1/2 = 37 days; r = -0.998.

DISCUSSION

The experiments were designed with three different soil moisture levels, and it was expected that three different degradation rates would be obtained. However, in soils having 35 and 70% of their water capacity, atrazine was degraded at the same rate. This is in contrast to the findings of other workers (Roeth et al., 1969; Obien, 1970; Fusi and Franci, 1971; Skipper and Volk, 1972) who found different degradation rates at similar moisture levels. Possibly, the soil moisture levels used in our experiments, were sufficient for maximal chemical and/or biochemical decomposition in this soil. Degradation in the air dried soil was rather rapid, and since at such low moisture levels degradation by microorganisms is not very likely, the loss of atrazine was supposedly caused by slow chemical hydrolysis. It is well known that clay minerals used as carriers for pesticide dusts, can cause decomposition under dry conditions (Polon, 1973), and therefore the different adsorbents of a soil may have a similar effect.

In the experiments with changing moisture levels, atrazine degradation rates (Table 1) did not correspond precisely to those of the soils with corresponding constant moisture contents (Figs. 1 - 3). Since these rates are based on a rather limited number of data, they may be somewhat erratic compared with the rates obtained at constant moisture levels. However, as can be seen from Table 1, in general, degradation rates in dry periods were more different than those at the two higher moisture levels. In these experiments soil moisture was in most cases somewhat elevated (<1%), and with an increase in soil moisture the degradation rate was also increased to some extent at the higher moisture levels. However, the great differences in degradation rates during dry periods cannot be explained by the slightly different moisture contents, and other reasons must account for this effect. Possibly these discrepancies are caused by changes in the organic matter, due to drying and rewetting of the soil: drying will spread the organic particles, leading to an increased internal surface with additional catalytic sites for pesticide degradation. By rewetting the soil, more of the pesticide would come in contact with these sites, leading to a faster degradation during the next dry period, as it occurred at the 70 - 90 day period and 50 - 70 day period during the II-I-III, and III-I-III cycles respectively.

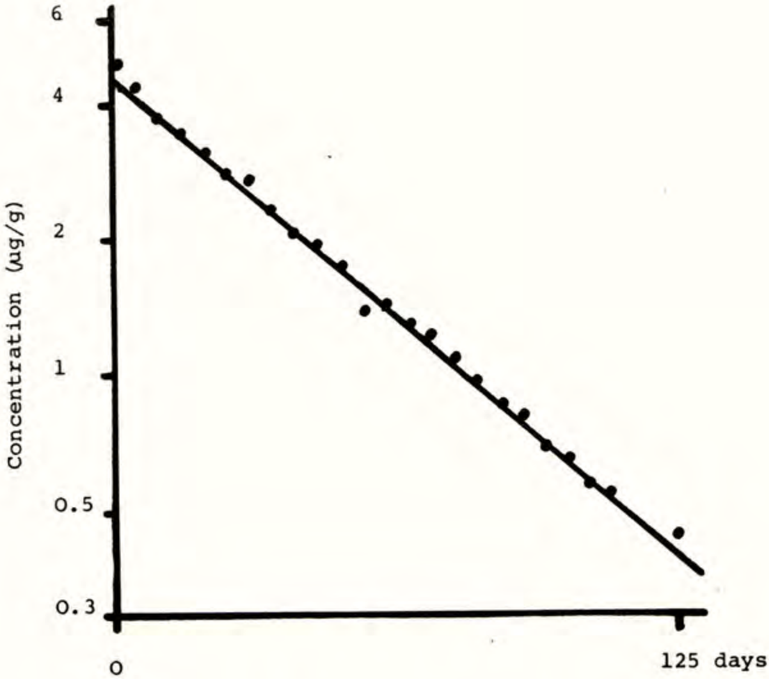

Fig. 3. Degradation of atrazine in soil with 17% moisture content (III). t 1/2 = 36 days; r = -0.998.

Although it is not known what processes are involved, these results show clearly that under the conditions studied, degradation rates obtained with constant soil moistures, do not necessarily correspond with those occurring under alternating moisture levels. More research on this subject is needed, including other herbicides and soils, to achieve a better understanding of herbicide degradation under the varying conditions in the field.

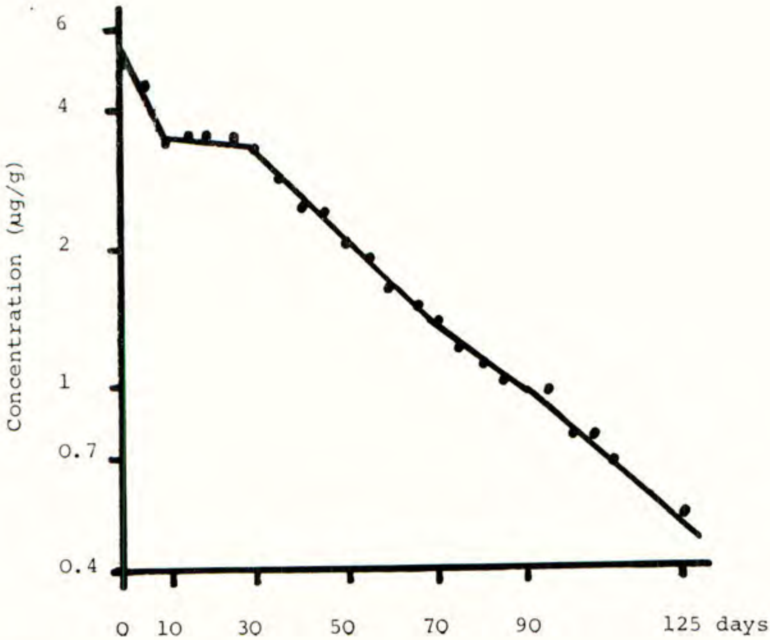

Fig. 4. Degradation of atrazine in soil with varying moisture levels (II-I-III-II-I-III).

Table 1

Data for atrazine degradation under alternating soil moisture conditions

Period (days)	Moisture level and %		Half-life (days)	r	Moisture level and %		Half-life (days)	r
0 - 10	II	8.6	16	-0.992	III	17.6	26	-0.996
10 - 30	I	1.1	358	-0.657	I	1.0	174	-0.682
30 - 50	III	17.8	32	-0.989	III	17.9	31	-0.997
50 - 70	II	9.1	32	-0.995	I	1.4	50	-0.983
70 - 90	I	1.0	44	-0.987	III	17.8	29	-0.998
90 -125	III	16.7	37	-0.988	I	0.8	109	-0.773

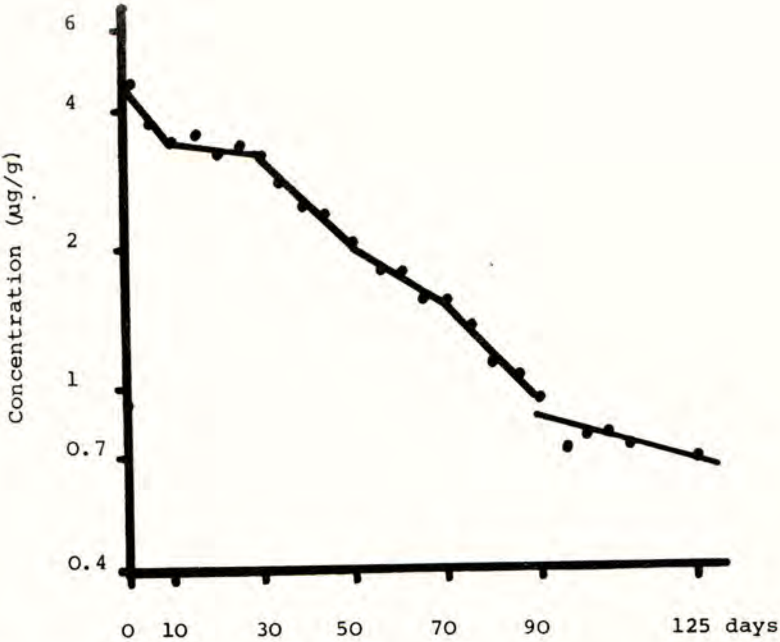

Fig. 5. Degradation of atrazine in soil with varying moisture levels (III-I-III-I-III-I).

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EFFECT OF VARYING WEATHER CONDITIONS ON THE PERSISTENCE OF THREE HERBICIDES IN SOIL

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Summary When prometryne, simazine and propyzamide were incubated in a sandy loam soil at 23-25°C and 12-14% soil moisture, the times for 50% loss of the three herbicides were similar - 30, 37 and 29 days respectively. The effects of temperature on the rates of loss were also similar for the different compounds, but a reduction in soil moisture content decreased the rate of degradation of prometryne more than that of simazine or propyzamide. Using a computer model, the persistence of the herbicides in the field in 3 successive years was simulated. The relative seasonal variations in persistence of the herbicides were simulated satisfactorily, but there were some quantitative discrepancies between observed and predicted residue levels.

INTRODUCTION

The two main factors which affect the rate of herbicide degradation in a particular soil are temperature and soil moisture content. A computer model which takes into account the daily variations in these factors in field soil to enable herbicide persistence to be simulated has been described (Walker, 1974). The model combines the effects of soil temperature and soil moisture content on the rates of herbicide loss, determined under controlled conditions, with agrometeorological measurements of rainfall, evaporation and soil temperature which are used to simulate the field environment.

In recent years, there has been a marked decrease in summer rainfall in many areas of the United Kingdom. At Wellesbourne, for example, the total rainfall recorded in the months May to August inclusive was 249 mm in 1973, 192 mm in 1974 and 118 mm in 1975. This change in the amount of rain resulted in much drier soil conditions, and the purpose of this report is to illustrate how the persistence of three herbicides - prometryne, simazine and propyzamide - was affected. The differences in rainfall pattern also provided an opportunity to examine the potential usefulness of the simulation technique to predict how persistence of herbicides in soil will vary in different seasons.

EXPERIMENTAL METHODS AND RESULTS

Full details of the methods used in both the laboratory and field investigations have been presented elsewhere and only brief mention will be made here.

Laboratory studies

The soil was taken from the surface 5cm of either Little Cherry or Gravel Pits field at the National Vegetable Research Station. The properties of the two soils are similar (Walker, 1976b), both containing about 1.5% organic matter and 15% clay. Commercial wettable powder formulations of prometryne, simazine and propyzamide (all 50% a.i.) were incorporated into the soils, and subsamples were incubated at different soil moisture and temperature levels. Details of the treatments and assay procedures for propyzamide were given by Walker (1973), and for simazine and prometryne by Walker (1976a).

The effects of soil moisture content on the rate of degradation of propyzamide at 23°C and prometryne and simazine at 25°C are shown in Fig. 1. These data are plotted on a log-log scale and show that an empirical equation of the form :

$$H = A \; M^{-B} \qquad \ldots\ldots 1$$

can be used to represent the results, in which H is the half-life at moisture content M, and A and B are constants. The data show that the half-lives of the three herbicides are similar at 12-14% soil moisture but that a reduction in soil moisture content has a much greater effect on the half-life of prometryne than on that of the other two herbicides. The differences between propyzamide and simazine are less pronounced, but simazine degradation would appear to be somewhat more affected by soil moisture content than that of propyzamide.

The effects from temperature on the rates of degradation are shown in Fig. 2. Although only limited data are available, particularly for simazine and prometryne, the results have been interpreted by using the Arrhenius equation :

$$\log \frac{H_1}{H_2} = \frac{\Delta E}{4.575} \left(\frac{1}{T_1} - \frac{1}{T_2} \right) \qquad \ldots\ldots 2$$

in which H_1 and H_2 are the half-lives at temperatures T_1 and T_2 and ΔE is the activation energy. The results (Fig. 2) show a similar temperature dependence for the degradation of all three herbicides.

Field plots

Field plots were prepared in late April or early May 1973, 1974 and 1975. Separate small plots (approximately 6 x 1.5 m) were sprayed with propyzamide (4.0 kg a.i./ha), simazine or prometryne (both at 2.0 kg a.i./ha). The herbicides were incorporated into the surface 3-4 cm by a single pass with a Roterra rotary power harrow. Immediately after spraying and at intervals during the subsequent 19-22 weeks, the plots were sampled and the herbicide content of the soil determined by the methods described previously (Walker, 1973; 1976a; 1976b).

The results are shown in Table 1 in which the data are expressed as percentages of the amounts present initially. The sampling times varied from year to year and occasionally between herbicide treatments and are therefore given as ranges. The data suggest that the herbicides were equally persistent in 1973, that prometryne and simazine were somewhat more persistent than propyzamide in 1974, and that prometryne was appreciably more persistent than simazine which was more persistent than propyzamide in 1976. Comparing between years, prometryne was more persistent in 1975 than in 1974, and more persistent in 1974 than in 1973. The data with simazine also show this trend, but to a lesser extent, and the differences between years with propyzamide were less than those with simazine.

Simulation of persistence

The relevant meteorological records of rainfall (mm/day), evaporation (mm/day) and soil temperature at 10 cm were used in conjunction with the constants derived from the laboratory data in the computer simulation program (Walker, 1974).

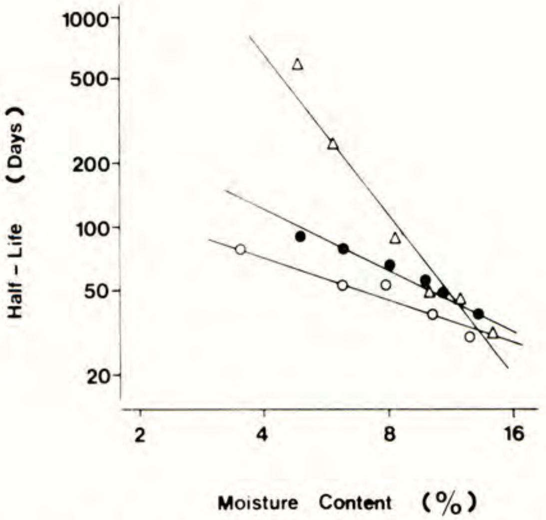

Fig. 1. Effect of soil moisture content on the rate of degradation of propyzamide (O), simazine (●) and prometryne (Δ).

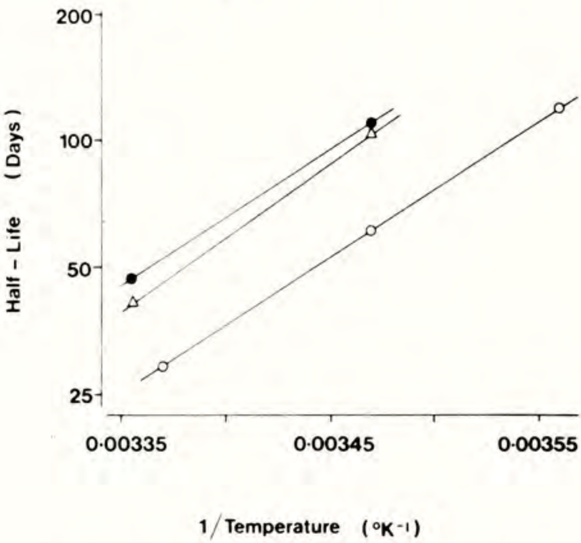

Fig. 2. Effect of temperature on the rate of degradation of propyzamide (O), simazine (●) and prometryne (Δ).

Table 1

Persistence of incorporated treatments of simazine, prometryne and propyzamide

Time	Percentage of initial activity remaining								
	Prometryne			Simazine			Propyzamide		
(days)	1973	1974	1975	1973	1974	1975	1973	1974	1975
21-29	88	84	98	84	84	83	79	94	98
42-44	70	92	83	66	67	79	63	90	90
52-61	52	68	71	41	53	61	50	70	76
83-85	43	51	83	36	38	55	48	39	44
98-105	32	46	66	31	40	45	26	32	34
126-131	29	43	57	28	35	36	23	21	25

The simulated degradation curves for the three herbicides are shown for the years 1973, 1974 and 1975 in Fig. 3 and the variations in the degradation curves between years are shown for each of the herbicides in Fig. 4. The simulation model predicts that the differences in persistence between the herbicides would be small in 1973 and 1974, with simazine and prometryne being somewhat more persistent than propyzamide in each of these years. In 1975, the differences predicted are much greater, with prometryne being appreciably more persistent than simazine which in turn is more persistent than propyzamide. When the herbicides are examined individually (Fig. 4), the differences between years with prometryne are much more pronounced than those with simazine or propyzamide, but with both simazine and propyzamide, the model perdicts that they would be more persistent in 1975 than in 1974 (although the differences are only small with propyzamide), and more persistent in 1974 than in 1973.

A brief summary of the weather during the relevant period in these three years is shown in Table 2. The terms 'above' and 'below' refer to those months when the recorded total rainfall or mean 10 cm temperature was more than 10% above or below the average of the values recorded in all previous years. In 1973 , average temperatures were recorded in May, June and July and in these months, there was above average rainfall. In July and August, rainfall was low. Rainfall in 1974 was low in May and June, but the latter half of the summer was wetter than normal. 1975 was characterised by a cool dry May followed by a very warm June, July and August with exceptionally low rainfall.

DISCUSSION

The changes in total summer rainfall recorded in recent years have been very marked, and concern was expressed that herbicide residues in the soil following the relatively dry summers of 1974 and 1975 would be greater than in previous years. However, during dry summers, there is often an increase in soil temperature and the effects from reduced rainfall on persistence of a particular herbicide will be determined by the relative importance of moisture and temperature in controlling degradation rates. The results in Figs. 1 and 2 show how these effects can vary with different compounds. A rise of 10°C in soil temperature increased the rate of degradation of propyzamide, prometryne and simazine by a factor of about 2.2 (Fig. 2) whereas a reduction in soil moisture content from about 15% (field capacity of the soils examined) to about 3% (the lowest value to which the moisture content of the

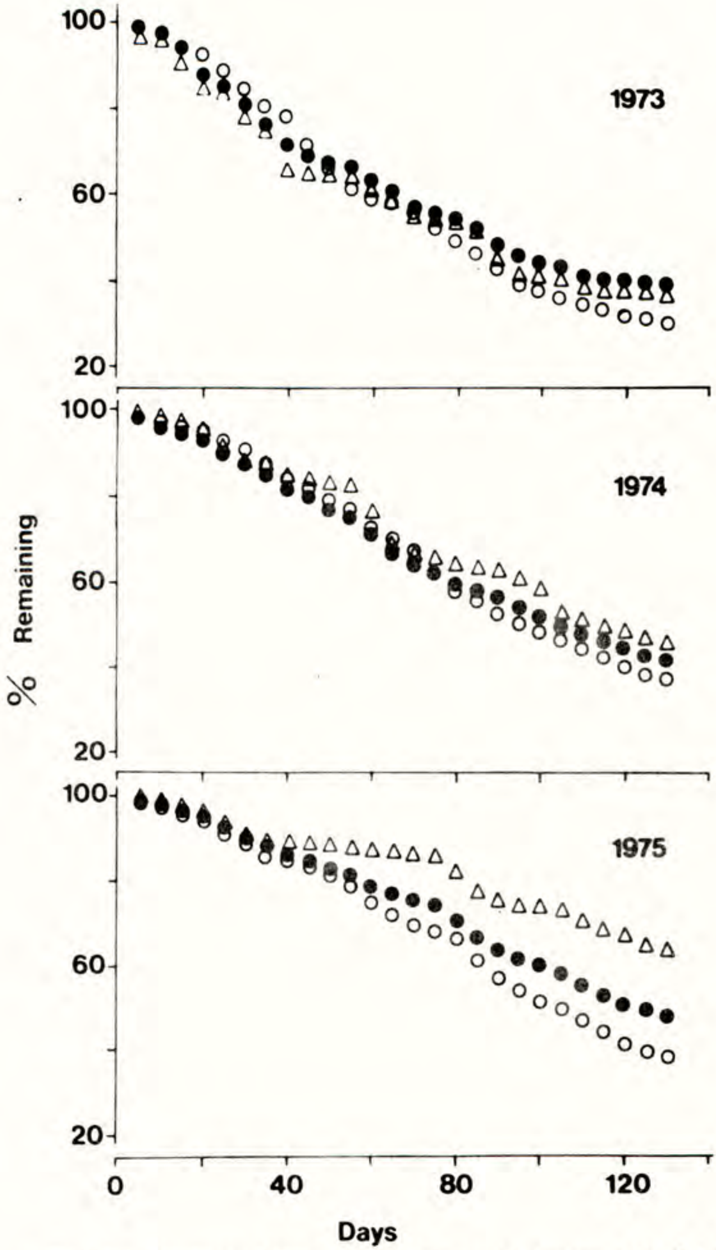

Fig. 3. Simulated disappearance curves for propyzamide (O), simazine (●) and prometryne (Δ) in 1973, 1974 and 1975.

surface 2.5 cm soil falls in the field during prolonged dry spells) decreased the rate of degradation of prometryne, simazine and propyzamide by factors of about 50, 4 and 3 respectively. The temperature dependence of degradation is therefore similar for the three herbicides, but prometryne degradation is much more dependent on soil moisture than that of simazine or propyzamide.

The data in Fig. 3 show how the differences in the effects of soil moisture content on degradation rates might alter the relative persistence of the three herbicides in the field in different years. During the relatively wet summer of 1973 the simulation model predicts very little difference in persistence between the three herbicides. As the soil dries in the late summer, however, propyzamide degradation is less affected than that of the other two herbicides and finally gives the lowest residue level. In 1974, a somewhat drier year, the predicted patterns again are similar but the positions of simazine and prometryne are reversed. In the very dry summer of 1975, the predicted differences between the herbicides are most pronounced with prometryne showing a much longer persistence than simazine which is more persistent than propyzamide.

Table 2

Summary of the weather during spring and summer 1973, 1974, 1975

	1973		1974		1975	
Month	Temperature	Rainfall	Temperature	Rainfall	Temperature	Rainfall
April	below	average	average	below	average	average
May	average	above	average	below	below	below
June	average	above	average	below	above	below
July	average	above	average	average	above	average
August	above	below	average	above	above	below
September	average	below	below	above	average	average

The effects of varying weather conditions on the simulated persistence of each herbicide (Fig. 4) illustrate the differences between them more clearly. Each compound showed an order of persistence of 1975 > 1974 > 1973, and the changes with prometryne were greater than those with simazine or propyzamide. The predicted times for 50% loss of prometryne in 1973, 1974 and 1975 were 85, 105 and > 140 days respectively. Similar figures for simazine were 87, 103 and 120 days, and for propyzamide 78, 95 and 103 days. The simulated degradation curves can be compared with the measured residues (Table 1). There was little difference in persistence between the herbicides in 1973, although propyzamide gave the lowest residue at about 130 days. In 1974, prometryne was more persistent than simazine, simazine was more persistent than propyzamide and this same order was shown in 1975 with the differences between prometryne and the other two herbicides being greater. These effects are generally the same as those predicted by the model (Fig. 3). With the individual herbicides, the observed differences in persistence between years (Table 1) were again similar to those predicted (Fig. 4). Prometryne showed the greatest variations with more than 50% remaining after 130 days in 1975 compared with about 40% in 1974 and 30% in 1973. These differences were apparent at almost all sampling dates. Simazine also showed increased persistence in 1974 and 1975 compared with 1973, but the changes with propyzamide were small.

In general therefore, the simulation model predicted how the relative persistence of the individual herbicides would vary between years and how the persistence of the individual herbicides would be affected. When the data are examined quantitatively

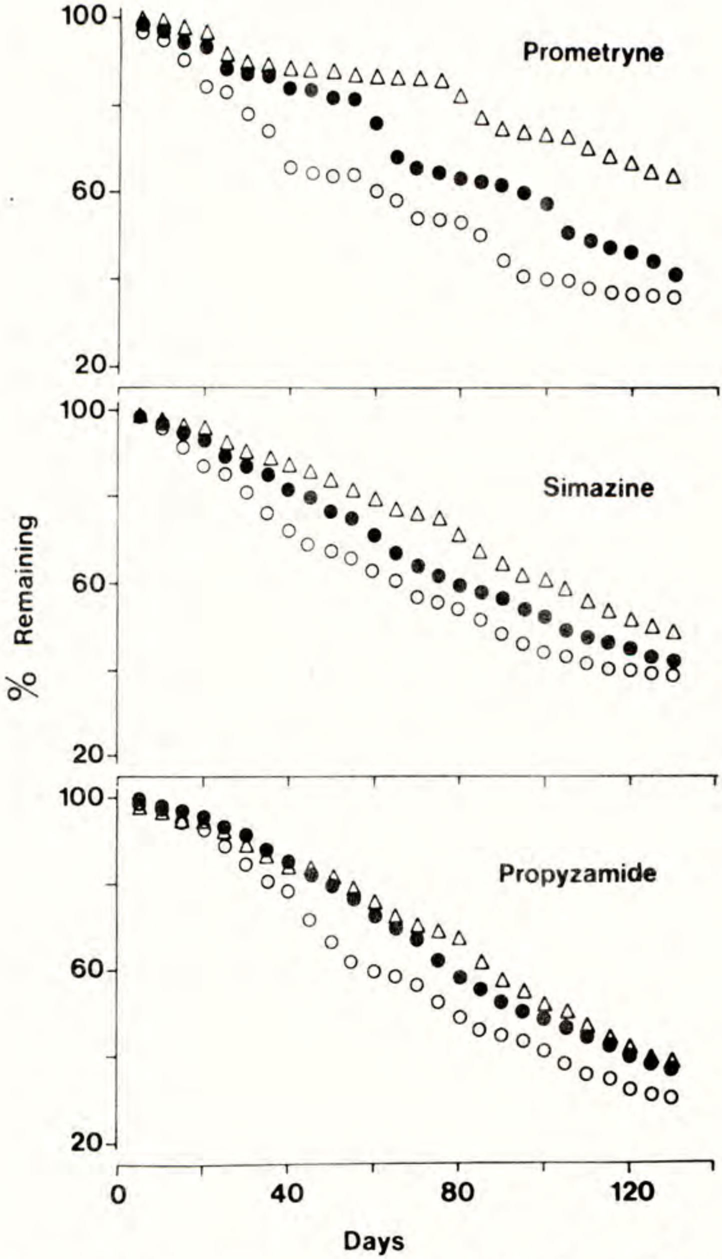

Fig. 4. Simulation of herbicide persistence in 1973 (○), 1974 (●) and 1975 (△)

however, there are discrepancies between observed and predicted residue levels. With prometryne, the agreement is generally acceptable, but with both simazine and propyzamide there is a tendency to underestimate losses in the field. The reasons for these discrepancies are not clear, although propyzamide has a relatively high vapour pressure and Leistra and Frissel (1975) calculated that a significant proportion of the amount applied might be lost through volatilisation during the summer months. Simazine, however, has a very low vapour pressure and such losses cannot explain the discrepancies with this herbicide.

One point which must be stressed is that the data in Table 1 refer to soil-incorporated treatments of the three herbicides. When applied to the soil surface prometryne in particular is lost more rapidly than these data would suggest (Walker, 1976a). Nevertheless, the results from use of the simulation model demonstrate the potential benefit of the technique to show possible effects from varying weather conditions on persistence of herbicides in the field in different seasons.

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VARIABILITY IN THE PERSISTENCE AND MOVEMENT IN THE FIELD OF ABNORMALLY HIGH RATES OF SIMAZINE AND LINURON; SOME WIDER IMPLICATIONS

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Summary Simazine and linuron were applied to field plots in 1971 at 112 kg/ha. Residue contents of samples analysed in the subsequent 5 years were very variable, giving coefficients of variation from 5 to 78%. The few publications that include data on variability suggest that the variations we observed are commonplace and are similar to the variations in the natural properties of the soil. We conclude that fine control of herbicide application rate may therefore not be practicable and that advice to farmers about crops that may be grown in fields containing herbicide residues must make allowances for possible variations.

Two years after application 93% of the simazine recovered remained in the top 5.1 cm and after 4 years 66% of the linuron recovered was also in this layer. In an adjacent experiment, paraquat showed a similar vertical distribution. We suggest that leaching as normally conceived is unimportant at this site, downward movement occurring in the same way as that of soil particles - mechanically or by the activities of macrofauna.

INTRODUCTION

The original object of the experiment was to study the persistence of very high rates of herbicide application, of the sort that might occur after an accidental spillage or careless operation of spray equipment. The results were too variable to be very useful for this purpose but they raise at least two other points of some importance.

METHODS

Plots (2.3 x 13.7 m) were sprayed with 112 kg/ha simazine or linuron wettable powders using 5 passes with an Oxford Precision Sprayer at a rate of 1250 l/ha in spring 1971. The field is a sandy loam overlying gravel and the plots were next to those described by Fryer and Kirkland (1970). The experimental design was a randomised block, replicated four times. The soil was sampled at irregular intervals (see Table 1). In the first two years both treatments were sampled in 5.1 cm layers to a depth of 51 cm using a split liner corer 4.62 cm diam. Thereafter samples were taken from 0-15 cm with a 2.54 cm corer except with linuron in 1975 when samples at different depths were again taken. Ten cores were taken from each plot at all sampling dates except in 1975 when two groups of 10 cores were taken from the linuron plots and each group analysed separately. Samples were air dried sufficiently for the sets of cores to be mixed thoroughly and passed through a 3 mm sieve. They were then stored in a deep freeze while awaiting analysis. Duplicate samples were analysed. Linuron was determined by the gas chromatographic method of McKone (1969).

Simazine was extracted with methanol in the same way as linuron and then measured by gas chromatography using the conditions in McKone et al (1972).

RESULTS AND DISCUSSION

a) Persistence

Values for the residues at each sampling date are given in Table 1.

Table 1

Herbicide residues kg/ha

	4/71	8/71	8/72	9/73	4/74	7/74	11/74	5/75
Simazine								
Mean	119.0	98.6	49.3	19.4	26.5	18.9	14.7	14.8
CV%	12.0	4.8	18.0	26.8	33.6	50.9	14.5	48.6
Linuron								
Mean	115.6	83.2	33.9	11.2	9.6	7.3	5.0	2.3
CV%	6.1	6.8	78.1	44.8	40.3	9.6	56.8	37.0

Because of the variability which developed we cannot make confident statements about dissipation rates. Half lives obtained graphically from the mean values are about 18 months for simazine and 7 months for linuron. These are rather slower rates than Fryer and Kirkland (1970) found on neighbouring plots treated with a lower rate (48 oz/ac) over the period 1963-8 where half lives were about 12-40 weeks for simazine and 8-25 weeks for linuron. The variations in both sets of results, however, are so large that the differences are of doubtful significance. The only assertion we can safely make is that the high doses we used did not prevent dissipation processes.

Although we did not check with this particular soil, our experience is that at the residue levels recorded here the CV of replicate analyses on the same sample would be less than 2.5%, for example McKone (1969) on two very similar soils reported CV's of 1.7% for the estimation of linuron. The size of the "extra-laboratory" variations prompted us to survey the literature from this viewpoint. There is a large body of publications dealing with residues and persistence but many authors are coy in exposing the variability in their results. The most detailed study was made by Taylor et al (1971) in the course of work on the degradation of dieldrin. Two years after application to 0.6 ha plots the dieldrin contents of 108 individual cores (36 each of 21, 29 and 44mm diam) taken from a 36m^2 area showed a 50 fold range. There were no significant differences between the variations from cores of each size. They used these results to estimate the effect of sampling density on the variability of the dieldrin content in bulk samples made by combining different numbers of cores. Their conclusion was that the CV could not be reduced practically below 20%, the value given by 12 cores per sample. In half our samples, CV's were much higher than this but our figures include inter-plot variability whereas Taylor et al were considering variation between samples taken from the same plot. This raises one difficulty in evaluating published figures - plot sizes vary. However, as we suggest below this may be relatively unimportant. A further complication is that variation also depends on the quantity measured, probably because the analytical errors in the laboratory increase as the residue level decreases. For instance Lichtenstein (1960) records CV's for aldrin and heptachlor residues of some 90% at 0.01 ppm but only 12-18% at levels around 1 ppm.

The elapsed time between application and sampling does not seem to be closely related with variability although our results do perhaps show increasing variability with time.. Also Sckroch et al (1971) showed a slight increase in CV from 46% one year after the first application of 3 herbicides to a peach orchard to 57% one year after the 3rd annual application and the results of Smith (1971) working with 18 in^2 microplots gave CV's for triallate residues that rose from 7.5% after 2 weeks to 31% after 21 weeks. The work of Dorough et al (1972) with chlordane showed a less convincing trend as CV's after 1 h (3-50%) were similar to those at 90 d (11-50%), although there was some increase at 180 d (11-81%). These changes should perhaps be seen in the perspective of the observations of Fryer and Kirkland (1970). Using the same spraying equipment that we used they found that deposits on 2 in^2 filter papers randomly placed on the soil gave CV's of 11-60%, a similar range to that which we report.

We might expect greater variations in residues from a single application of a persistent compound than from a series of repeated applications on the grounds that variations due to application irregularities would tend to cancel out. However, the results of Sckroch et al (1971) already mentioned do not support this suggestion and those of Lichtenstein & Schulz (1965) show similar CV's (up to 12.5%) for residues of aldrin and heptachlor measured 6 years after a 25 lb/ac application as those measured 1 year after 5 annual applications of 5 lb/ac.

Thus literature values, though limited in number, and very variable suggest that Taylor et al, are reasonable in suggesting a CV of 20% as a realistic working rule for field experiments.

The figures of Fryer and Kirkland (1970) show that much of the variation must arise from irregular application and it is relevant to compare it with those that occur in the natural properties of the soil. Beckett and Webster (1971) have reviewed this subject and suggested that within fields CV's of the following order exist:-

Area	K	P	Ca	N or OM
0.01 ha	35	40	10-40	10-20
single field	70	45	30	25-30

Between field CV's within one mapped series are about 10% for properties such as sand and clay and 25% for organic matter. Bulk density is perhaps less variable as we have noted in the course of routine analytical work that CV's are in the range 4-10%, figures in agreement with Soane (1971).

Hence variation in most soil properties seems to be similar to that given by residue data. About half the variation within a field may be present in any 1 m^2 so it is probably valid to compare, as we have done, variations in residue results from plots of different size reported in the literature particularly as experimental plots are usually larger than this.

We think that the size of variations in both residues and soil properties is important in at least 3 ways. Firstly, recommendations for re-cropping after crop failure (eg after a dry spring) must recognise that herbice residues may be much higher in some places in the field than would be suggested either by analysis of a few samples or by a simulation model. Secondly, the precision of dosage recommendations is constrained by the variations in soil factors known to affect the performance of soil-applied herbicides, particularly organic matter. Thirdly, although there is clearly scope for improving the precision of spraying equipment, there is little point in designing machinery that gives substantially less variation in application than the variation that exists in the significant soil factors.

b) Vertical distribution

Table 2 shows the distribution of residues down the soil profile.

Table 2

	% residue in layer			
	Simazine 9/73	Linuron 9/73	Linuron 4/75	CV %
0-5.1 cm	93.0	55.3	65.8	17.9
5.1-10.2 cm	3.3	25.2	27.7	15.4
10.2-15.3 cm	1.1	9.4	6.6	16.9
15.3-30.6 cm	1.3	8.2	-	31.8

Between April 1971 and April 1975 the excess of rainfall over evaporation at Begbroke was 329 mm. The distribution ratios between soil and water in slurry adsorption experiments on this soil are about 1 for simazine and 9.5 for linuron. Hence on the basis of chromatographic models we should expect simazine to be more mobile than linuron. The figures for linuron distribution for 1973 and 1975 are virtually the same, yet between the two sampling dates the excess of rainfall over evaporation was 255 mm, about 75% of the total downward water movement that occurred during the experiment. The only explanation we can offer is that the quantity in free solution is a negligible proportion of the whole and that only mechanical movement was important in redistributing the linuron. Thus by 1973, after 2 years of no soil disturbance, the opportunities for mechanical movement would have been less than at the beginning of the experiment because of soil compaction and hence little redistribution occurred subsequently. Support for this suggestion is provided by the distribution of paraquat reported by Fryer et al (1975) in plots less than 100 m away from our experiment. Taking the mean values of their Pq 1 and 3 non incorporated treatments we see that 68.6% of the residue was in the 0-5.1 cm layer, 15.1% in the 5.1-10.2 cm layer, 6.4% in the 10.2-14.2 cm layer and 9.9% from 14.2-35.6 cm. Within experimental error, our figures for linuron are the same and simazine appears to be even less mobile. Since paraquat is completely absorbed it can move only on solid soil particles by falling into cracks and channels, by the agency of macrofauna or by contamination during sampling. Our results suggest that linuron and simazine were similarly immobile. Evans (1948) estimated that the annual soil consumption by earthworms on 8 Rothamsted fields was 1.25-8.7% of the weight of the top 10 cm. Hence over the period of our experiment such movement could be significant. On the other hand a high earthworm population in our plots, which for most of the time were bare of vegetation, seems unlikely. Our view that only mechanical movement occurred is supported by the evidence of Mercer and Hill (1974) who found that radioactive soil particles move down the soil profile to an extent comparable with simazine.

Our analyses were not made sufficiently often to show whether or not leaching occurred immediately after rain, only to be reversed in a subsequent evaporation cycle. However, in view of the limited downward movement over the whole experimental period we think it unlikely. If our mechanistic suggestion is correct, it follows that the 'activation' of soil applied herbicides by rain may not be the result of leaching into the seed germination and rooting zone.

We cannot confidently suggest a reason for the apparently low mobility of herbicide with the mass flow of water but it may be a result of herbicide being trapped in the pores of soil particles after wetting and drying cycles.

CONCLUSIONS

The point to point variations in the distribution of pesticides in the soil and of many soil properties are large. In general the performance of herbicides is uniform and even crop damage from unwanted residues is often more uniform than our data would predict, so that plants seem to average out differences. However, advisers and experimentalists need to be aware of the magnitude of these variations and interpret data with suitable caution.

The movement of herbicides down the profile we report suggests that more attention could profitably be paid to the movement of solutes into and out of soil crumbs.

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THE EFFECT OF A NUMBER OF CHEMICALS USED FOR WILD OAT CONTROL ON SEED PRODUCTION OF THREE RYE-GRASS VARIETIES

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Summary Difenzoquat at 1.00 kg/ha a.i. in 225 l/ha water, chlorfenprop-methyl at 4.67 kg/ha a.i. in 371 l/ha water, benzoylprop-ethyl at 1.12 kg/ha a.i. in 337 l/ha water, flamprop-methyl at 0.56 kg/ha a.i. in 337 l/ha water was applied in the spring of the harvest year in 1975 and 1976 and ethofumesate at 1.99 kg/ha a.i. in 337 l/ha water was applied in late autumn of the 1975 sowing year and the spring of both harvest years on Aberystwyth S.24 and Taptoe Perennial Rye-grass and Sabalan Italian Rye-grass to simulate applications for wild oat control. The results for two harvest years indicate that germination did not appear to be affected. All treatments except difenzoquat gave an indication of seed yield increase on the diploid variety Aberystwyth S.24, particularly ethofumesate which gave significant increases in both years. The tetraploid Italian variety Sabalan showed a tendency for decreased seed yields from all treatments except ethofumesate and the tetraploid perennial Taptoe showed significant yield decreases from all treatments in 1975, which were not repeated in 1976.

Résumé Du difenzoquat à raison de 1.00 kg/ha i.a. dilué dans 225 l/ha d'eau, chlorfenprop-méthyle à raison de 4.67 kg/ha i.a. dilué dans 371 l/ha d'eau, benzoylprop-éthyle à raison de 1,12 kg/ha i.a. dilué dans 337 l/ha d'eau, flamprop-méthyle à raison de 0,56 kg/ha i.a. dilué dans 337 l/ha d'eau ont été appliqués au printemps de l'année de la récolte de 1975 et 1976 et du éthofumesate à raison de 1,99 kg/ha i.a. dilué dans 337 li/ha d'eau a été appliqué vers la fin de l'automne de l'année d'ensemencement de 1975 et au printemps des deux années de récolte à des réplicats de ray-grass anglais variétés Aberystwyth S.24 et Taptoe et de ray-grass italien variété Sabalan pour simuler des applications pour le contrôle des mauvaises herbes. Les résultats pour deux années de récolte font ressortir que ces applications n'ont pas affecté d'une manière significative la germination des graines immédiatement après la moisson. Toutes les applications sauf celle avec du difenzoquat ont montré une augmentation du rendement des semences dans le cas de la variété Aberystwyth S.24 diploïde et éthofumesate en particulier a abouti à des augmentations de rendement importantes dans les deux années. La variété italienne Sabalan tetraploïde semblait avoir une tendance pour des rendements réduits avec toutes les applications sauf avec éthofumesate, et le ray-grass anglais tétraploïd, Taptoe, a démontré une réduction considérable du rendement des semences avec toutes les applications qui ont été faites en 1975 mais qui n'ont pas été répétées en 1976.

INTRODUCTION

This study was made as part of a co-ordinated programme with the Weed Research Organisation and the Agricultural Development and Advisory Service to obtain information on the control of wild oats in rye-grass seed crops following the introduction of the strict statutory seed purity standard for wild oats in the new Seeds Regulations introduced in July 1974 to comply with the E.E.C. Directives. Five chemicals showing promise for wild oat control were studied for their effect on the seed production performances of three rye-grass varieties grown without the presence of wild oats. Observations on the effect of benzoylprop-ethyl and ethofumesate have previously been reported (Evans and Muncey 1974) The work was sponsored by a grant from the National Certifying Authority for Herbage Seeds.

METHOD AND MATERIALS

The trials were conducted at the National Institute of Agricultural Botany farm six miles north of Cambridge where the soil is predominantly a clay loam of the Wicken series. A randomised block design with four replications was employed for each of the three varieties, Aberystwyth S.24 Perennial Rye-grass (diploid), Taptoe Perennial Rye-grass (tetraploid) and Sabalan Italian Rye-grass (tetraploid), and the trials were sown direct (July to September) into seedbeds which had received approximately 75 kg/ha each of Nitrogen, Phosphate and Potash. The S.24 was sown at 13 kg/ha, Taptoe at 20 kg/ha and Sabalan at 22 kg/ha. Alopecurus myosuroides contamination in a small restricted part of the field meant that yield data from only three replications of the Sabalan trial sown in 1975 was finally analysed. Plot size was 1/64 ha (65.4m x 2.4m) for 1975 harvest and 1/61 ha (68.1m x 2.4m) for 1976 harvest.

The trials were managed for optimum seed production. The S.24 trial sown 9 July 1974 was topped three times between September and January to remove excess growth and was top dressed with 63 kg/ha of N. on both the 25 March and 23 April. The Taptoe trial sown 10 July 1974 was similarly topped in early autumn and received the same fertiliser treatment.

Both varieties were sown again on 18 September 1975. They did not require topping in the autumn but both received 63 kg/ha of N. on 26 February and a second top dressing of 63 kg/ha on 29 April and 4 May to the S.24 and Taptoe respectively.

The first Sabalan trial was sown on 29 August 1974 and was top dressed with 63 kg/ha of N. on 25 March. A forage cut was taken on 8 May followed by a top dressing of 94 kg/ha of N. on 12 May. The second trial was sown on 18 September 1975 and managed as for the previous trial. Top dressings were given on 26 February and 9 May and the forage cut was taken on 6 May.

The herbicides used were:

difenzoquat*	- applied at 1.00 kg ai/ha in 225 l/ha water
chlorfenprop-methyl	- applied at 4.67 kg ai/ha in 371 l/ha water
ethofumesate	- applied at 1.99 kg ai/ha in 337 l/ha water
benzoylprop-ethyl	- applied at 1.12 kg ai/ha in 337 l/ha water
flamprop-methyl	- applied at 0.56 kg ai/ha in 337 l/ha water

*Formulation 250 used in 1975 and Formulation 620 in 1976.

The date of application and relative growth stages in relation to 5% ear emergence (E.E.) for each variety are given in Tables 1 and 2.

TABLE 1

Trials sown 1974

Treatment	S. 24		Taptoe
	Date of application	Growth stage	Growth stage
Control (no herbicide)			
difenzoquat	22 April	17 days before E.E.	31 days before E.E.
chlorfenprop-methyl	22 April	17 days before E.E.	31 days before E.E.
ethofumesate (spring)	26 March	44 days before E.E.	58 days before E.E.
benzoylprop-ethyl	9 May	5% E.E.	14 days before E.E.
flamprop-methyl	9 May	5% E.E.	14 days before E.E.

Treatment	Sabalan	
	Date of application	Growth stage
Control (no herbicide)		
difenzoquat	4 June	6 days before E.E.
chlorfenprop-methyl	4 June	6 days before E.E.
ethofumesate (spring)	26 March	76 days before E.E.
benzoylprop-ethyl	4 June	6 days before E.E.
flamprop-methyl	4 June	6 days before E.E.

TABLE 2

Trials sown 1975

Treatment	S. 24		Taptoe
	Date of application	Growth stage	Growth stage
Control (no herbicide)			
difenzoquat	28 April	10 days before E.E.	18 days before E.E.
chlorfenprop-methyl	28 April	10 days before E.E.	18 days before E.E.
ethofumesate (autumn)	11 November		
ethofumesate (spring)	1 March	68 days before E.E.	76 days before E.E.
benzoylprop-ethyl	11 May	2 days after E.E.	5 days before E.E.
flamprop-methyl	11 May	2 days after E.E.	5 days before E.E.

Treatment	Sabalan	
	Date of application	Growth stage
Control (no herbicide)		
difenzoquat	19 May	9 days before E.E.
chlorfenprop-methyl	19 May	9 days before E.E.
ethofumesate (autumn)	11 November	
ethofumesate (spring)	1 March	88 days before E.E.
benzoylprop-ethyl	19 May	9 days before E.E.
flamprop-methyl	19 May	9 days before E.E.

Seed moisture was assessed by infra-red moisture meter and the plots harvested by direct combine as soon as possible after the S.24 and Taptoe seed had fallen below 26% and Sabalan below 40%. A further seed moisture assessment was made by oven drying a sample of the freshly harvested seed, the bulk of which was dried to 12%-14% moisture for storage. The purity of the harvested seed was determined by recording the cleanings of a representative sample of approximately 2.72 kg of the dried bulk and obtaining a purity analysis of the cleaned seed. All yield data is expressed as seed of 99% purity and 14% moisture content.

A 1,000 seed weight figure was obtained from a representative bulked sample of each treatment and germination tests were carried out after cleaning and again in February and June on the 1975 harvested seed to check for any deterioration. Further tests will be carried out on the 1976 harvested seed after storage.

RESULTS

Dry soil conditions in 1976 noticeably affected the level of yield and the seed size.

Aberystwyth S.24 The two years' results in Table 3 were consistent with no treatment giving significant reductions in seed yield or having a noticeable effect on seed quality. Ethofumesate applied in the spring and in the autumn before 1976 harvest gave increases in seed yield of 16%-19% and there were indications of slight increases from chlorfenprop-methyl, benzoylprop-ethyl and flamprop-methyl. There was no noticeable effect on seed quality from any treatment. (Table 4.)

TABLE 3

Aberystwyth S. 24 Perennial Rye-grass

Treatment	Yield of clean seed as % of Control Harvest 1975	Harvest 1976	2 year mean
Control kg/ha (no herbicide)	1,378	954	1,170
difenzoquat	101	91	97
chlorfenprop-methyl	114	103	110*
ethofumesate (autumn)		119*	
ethofumesate (spring)	119*	116*	118*
benzoylprop-ethyl	108	107	108
flamprop-methyl	108	105	107
L.S.D. (P = 0.05)	15.6%	9.2%	9.3%
S.E.	± 5.2%	± 3.1%	± 3.2%

*Significant difference from Control

TABLE 4

Treatment	1,000 seed weight g. Harvest 1975	1,000 seed weight g. Harvest 1976	Germination percentage Harvest 1975 September 1975	Harvest 1975 March 1976	Harvest 1975 June 1976	Harvest 1976 July 1976
Control	2.431	1.712	96	97	91	96
difenzoquat	2.452	1.657	96	97	95	96
chlorfenprop-methyl	2.335	1.672	95	95	90	95
ethofumesate (autumn)		1.755				95
ethofumesate (spring)	2.372	1.722	96	97	96	95
benzoylprop-ethyl	2.306	1.603	95	94	97	91
flamprop-methyl	2.373	1.668	96	92	95	95

Taptoe All treatments gave significantly lower seed yields than the control in 1975, when very good growing conditions for seed production occurred. In 1976 these significant reductions did not occur but there was an indication of lower yield from the benzoylprop-ethyl treatment. There was no noticeable effect on seed quality from any treatment. (Table 6.)

Taptoe Perennial Rye-grass

TABLE 5

Treatment	Yield of clean seed as % of Control Harvest 1975	Harvest 1976	2 year mean
Control kg/ha (no herbicide)	2,442	948	1,695
difenzoquat	87*	106	92*
chlorfenprop-methyl	88*	106	93
ethofumesate (autumn)		98	
ethofumesate (spring)	89*	110	95
benzoylprop-ethyl	85*	94	87*
flamprop-methyl	80*	105	87*
L.S.D. (P = 0.05)	10.0%	15.5%	7.9%
S.E.	± 3.3%	± 5.2%	± 2.7%

*Significant difference from Control

TABLE 6

Treatment	1,000 seed weight g. Harvest 1975	1,000 seed weight g. Harvest 1976	Germination percentage Harvest 1975 September 1975	Harvest 1975 March 1976	Harvest 1975 June 1976	Harvest 1976 July 1976
Control	3.312	2.615	98	98	97	97
difenzoquat	3.401	2.558	97	97	98	97
chlorfenprop-methyl	3.378	2.526	98	97	98	96
ethofumesate(autumn)		2.610				99
ethofumesate(spring)	3.381	2.616	98	97	96	98
benzoylprop-ethyl	3.411	2.518	96	95	98	98
flamprop-methyl	3.307	2.537	96	97	97	96

Sabalan The two years' results in Table 7 were consistent with yield reductions in all treatments, except ethofumesate, which were significant in 1975 and in the two year mean result. There was no noticeable effect on seed quality from any treatment. (Table 8.)

Sabalan Italian Rye-grass

TABLE 7

Treatment	Yield of clean seed as % of Control Harvest 1975	Harvest 1976	2 year mean
Control kg/ha (no herbicide)	2,379	1,203	1,790
difenzoquat	90*	87	89*
chlorfenprop-methyl	88*	89	88*
ethofumesate (autumn)		109	
ethofumesate (spring)	103	103	103
benzoylprop-ethyl	86*	95	89*
flamprop-methyl	87*	88	88*
L.S.D. (P = 0.05)	9.8%	13.1%	7.2%
S.E.	± 3.1%	± 4.2%	± 2.5%

*Significant difference from Control

TABLE 8

Treatment	1,000 seed weight g. Harvest 1975	1,000 seed weight g. Harvest 1976	Germination percentages Harvest 1975 September 1975	Harvest 1975 March 1976	Harvest 1975 June 1976	Harvest 1976 July 1976
Control	4.913	4.110	93	93	90	90
difenzoquat	4.961	4.183	92	88	92	90
chlorfenprop-methyl	4.858	4.133	92	91	92	88
ethofumesate (autumn)		4.195				93
ethofumesate (spring)	4.893	4.190	91	92	93	91
benzoylprop-ethyl	4.852	3.982	94	90	94	89
flamprop-methyl	4.890	4.038	93	90	93	90

DISCUSSION

Despite the severe drought conditions, which resulted in lower seed yields and 1,000 seed weights than with the good growing conditions in 1975, the 1976 results for the treatments, particularly on Aberystwyth S.24 and Sabalan, confirmed the findings for 1975 harvest. The diploid Perennial Rye-grass variety Aberystwyth S.24 gave no definite indication of harmful effect from any treatment; in fact all treatments except difenzoquat suggested a tendency for a slight improvement in seed yield, with a statistically significant improvement in both years from the ethofumesate treatments. Autumn treatment of Aberystwyth S.24 with ethofumesate previously reported (Evans and Muncey 1974) showed a tendency to increase yields, though these were not statistically significant. The tetraploid Italian Rye-grass variety Sabalan showed statistically significant yield reductions from all treatments except ethofumesate in 1975; yield reductions were also obtained for the same treatments in 1976 but were not significant. The tetraploid Perennial Rye-grass variety Taptoe also showed statistically significant yield reductions from all treatments in 1975, but only the benzoylprop-ethyl treatment gave an indication, though not significantly, of yield reduction in 1976. Although only one example of diploid and tetraploid Perennial Rye-grass and tetraploid Italian Rye-grass have been tested, there is an indication that variety groups may react a little differently to the treatments applied and that tetraploid varieties may possibly be more sensitive than diploid varieties.

It should be noted that no visible damage was recorded after application of any treatment to any variety except for leaf burn on Sabalan after application of difenzoquat in 1976, when the plots appeared to grow away subsequently without any serious visible check. The autumn application of ethofumesate had a visible effect on crop appearance and here all varieties showed a check in growth and a darker green colour over winter and also early spring in the perennial varieties and it was noted that the treatment was more palatable to hares grazing the area.

The autumn application of ethofumesate to the 1976 harvested plots showed good control of Poa trivialis (Rough Meadow-grass) and Stellaria media (Common Chickweed) and some self sown barley which was present in the trial area. Some control of these species was also noted from the spring treatment but it was less effective.

There was no evidence of deterioration in seed quality due to any of the herbicide treatments after harvest in both years or after storage of the 1975 harvested seed.

References

Evans, A.W. and Muncey, D.S. (1974) Observations on the effect of three herbicides with promise in the control of graminaceous weeds on the seed production of Rye-grass.

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THE USE OF ETHOFUMESATE IN GRASS SEED CROPS

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Summary This paper summarises the results of trials carried out in the U.K. on Rye-grass, Timothy and Cock's-foot grown for seed. Data on residue decline in Rye-grass and results of germination tests are also included. Ethofumesate combines a high level of control of most of the major grass weeds with outstanding crop safety.

Résumé Ce rapport présente un résumé des résultats des essais effectués en Grande-Bretagne sur le ray-grass, la fléole des prés et le dactyle pelotonné, cultivés pour la production de semences. Les données sur la dégradation des résidus et les résultats des tests de germination sont également inclus. L'ethofumesate allie une activité herbicide importante sur la plupart des graminées à une grande marge de sécurité vis-à-vis de la culture.

INTRODUCTION

In the U.K., grass as a feed for animals is assuming increasing importance, and quality seed is an essential starting point. It is vital to produce seed free of grass weed contamination; herbicides have a major role to play in its production. The properties of ethofumesate as a herbicide for Rye-grass seed crops have been widely reported, (Pfeiffer, R.K. 1969 - Evans, A.W. 1974 - Oswald, A.K. 1974 - Mead, H. 1974 - van Hoogstraten, S.D. et al 1975). This paper updates that information and presents new results on Timothy and Cock's-foot. Data on the residue decline pattern in Rye-grass are also included.

METHOD AND MATERIALS

Throughout the trials, the 20% e.c. formulation of ethofumesate (Nortron*) was used. In 1974/75 Rye-grass sown on 2nd August was treated with a range of doses from 0.75 - 3.0 kg a.i./ha by knapsack sprayer at three different times. The first application was applied pre-emergence on 6th August. The post-emergence applications were sprayed on 19th September and 6th November (48 and 96 days after sowing). Volume of application was 200 l/ha. Assessments were made throughout the season by visual scoring, (10 = unharmed plant, 0 = dead plant).

In 1975/76 a larger number of trials were carried out, including 43 applied by farmers, who used a dose of 1.5 kg a.i./ha pre-emergence of the Rye-grass or 2.0

* Nortron is a Trade Mark of Fisons Limited, registered in many countries.

kg a.i./ha post-emergence. Assessments of weed control in these trials are presented as frequency distributions. In addition, a replicated trial was laid down on Timothy sown on 6th August 1975 and treated with ethofumesate 62 days later. When sprayed, the Timothy was at the 2½ leaf stage and the Common chickweed (Stellaria media) was 23 cm across.

Samples for germination tests were taken in 1974/75 and, after storage, were examined by the Lincolnshire Seed Growers Association.

To establish a Residue Decline Curve, ethofumesate was applied at 2.0 kg a.i./ha to a single plot (30m x 2m) of established S24 Perennial Rye-grass at Chesterford (North Essex) in April 1975. At the time the grass was 23 cm high and tillering. Samples were cut on the day after spraying and at a series of later dates. Total residues of ethofumesate and its metabolites at each sampling are shown in Figure I.

RESULTS

The tolerance of 5 grass species to ethofumesate was examined by application at three different growth stages. The results are presented in Tables 1, 2 and 3.

Table 1

Tolerance to ethofumesate sprayed pre-emergence (3 days after sowing)

Pre-emergence 5.8.74 - assessed on 9.10.74, 6.11.74, 26.11.74

kg a.i./ha	0.75	1.0	1.5	2.0	3.0	U/T
Holcus lanatus	2-2-2	2-2-2	0-0-1	0-0-0	0-0-0	7-9-9
Timothy erecta	7-6-7	7-5-6	5-2-4	3-1-3	1-0-2	8-9-8
Cock's-foot S26	7-7-7	6-6-6	4-3-4	4-2-3	2-0-1	7-8-8
Red Fescue	1-0-0	0-0-0	0-0-0	0-0-0	0-0-0	7-8-8
I. Rye-grass S22	8-9-8	8-8-8	7-8-7	7-8-8	7-7-8	8-9-8

10 = unharmed plant 0 = dead plant

Table 2

Tolerance to ethofumesate sprayed post-emergence (48 days after sowing)

Post-emergence 19.9.74 - assessed on 9.10.74, 6.11.74 and 26.11.74

kg a.i./ha	0.75	1.0	1.5	2.0	3.0	U/T
Holcus lanatus	6-8-6	6-8-6	6-7-4	5-6-2	4-4-1	5-8-8
Timothy erecta	8-8-8	8-8-8	8-8-8	8-7-7	7-6-5	8-9-9
Cock's-foot S26	8-8-8	9-8-9	8-7-8	8-8-8	8-7-7	8-9-9
Red Fescue	7-8-6	7-7-5	8-8-6	7-6-4	7-5-5	8-8-8
I. Rye-grass S22	8-9-8	9-9-9	9-9-9	9-9-9	8-8-8	8-9-8

10 = unharmed plant 0 = dead plant

Table 3

Tolerance to ethofumesate sprayed post-emergence (96 days after sowing)

Post-emergence 6.11.74 - assessed on 26.11.74 and 20.5.75

kg a.i./ha	0.75	1.0	1.5	2.0	3.0	U/T
Holcus lanatus	7-9	9-9	8-9	7-8	5-6	9-9
Timothy erecta	9-9	8-9	8-9	9-9	8-9	8-9
Cock's-foot S26	9-8	9-8	9-8	9-8	8-8	9-9
Red Fescue	8-8	8-8	8-8	7-8	7-7	8-9
I. Rye-grass S22	9-9	9-9	9-9	9-9	8-9	8-9

10 = unharmed plant 0 = dead plant

The efficacy of ethofumesate as a herbicide in Rye-grass is shown by two frequency distribution tables giving % weed control on 13 sites sprayed pre-emergence (Table 4) and on 30 sites sprayed post-emergence (Table 5).

Table 4

Number of sites showing the stated level of grass weed control after application of ethofumesate pre-emergence at 1.5 kg a.i./ha

	100 - 90%	89 - 80%	79 - 70%	69% or below
Poa annua	5	1	-	1
Poa trivialis	2	1	-	-
Alopecurus myosuroides	2	-	-	-
Hordeum murinum	1	-	-	-
Bromus mollis	2	-	-	-
Bromus sterilis	3	-	-	-
Avena fatua	6	1	-	-
Volunteer barley	5	2	-	2
Volunteer wheat	2	-	-	-
Volunteer oats	1	-	-	-

Table 5

Number of sites showing the stated level of grass weed control after application of ethofumesate post-emergence at 2.0 kg a.i./ha

	100 - 90%	89 - 80%	79 - 70%	69% or below
Poa annua	12	2	1	2
Poa trivialis	6	3	1	1
Alopecurus myosuroides	12	2	-	1
Hordeum murinum	1	-	-	-
Bromus sterilis	1	-	-	1
Avena fatua	13	-	-	-
Volunteer barley	15	1	-	2
Volunteer wheat	4	1	-	1
Volunteer oats	3	-	-	1

The effect of seed bed conditions on the efficacy of ethofumesate is shown in Table 6. This table presents results of pre- and post-emergence spraying on 5 sites where the Rye-grass was drilled into a stubble seed bed, and of 13 sites where the seed bed was first well prepared.

Table 6

% control of grass weeds with ethofumesate following minimal cultivation or well prepared seed bed

	Drilled into stubble (5 sites)		Well prepared seed bed (13 sites)	
	Pre-emergence 1.5 kg a.i./ha	Post-emergence 2.0 kg a.i./ha	Pre-emergence 1.5 kg a.i./ha	Post-emergence 2.0 kg a.i./ha
Poa annua	98	100	100	92
Poa trivialis	85	97	95	80
Alopecurus myosuroides	-	-	-	93
Hordeum murinum	95	-	-	100
Bromus sterilis	100	-	-	-
Avena fatua	98	99	99	100
Volunteer barley	80	100	99	85
Volunteer wheat	100	100	100	100
Volunteer oats	90	-	-	-

The tolerance of Timothy to ethofumesate and its efficacy on Common chickweed is shown in Table 7.

Table 7

Comparison of different rates of ethofumesate on S48 Timothy drilled on 6th August and sprayed on 7th October 1975 (mean of 3 replications)

	Dates assessed				
kg a.i./ha	18.11.75	18.2.76	23.3.76	14.5.76	22.7.76
Timothy					
0.75	8.0	8.0	8.0	7.3	6.7
1.0	8.3	7.7	7.7	7.0	8.0
1.5	8.3	7.7	7.7	7.7	8.3
2.0	7.7	7.0	6.7	7.3	7.7
U/T	7.7	6.7	6.7	5.0	2.3
Common chickweed (Stellaria media)					
0.75	5.3	1.7	1.7	3.0	Removed
1.0	5.3	1.0	0.7	1.3	by hand
1.5	4.7	0	0	0.7	on 24th
2.0	4.7	0	0	0	June
U/T	7.7	7.0	7.7	9.0	1976

10 = unharmed plant 0 = dead plant

Results of germination tests and 1000 seed weight in Rye-grass and germination tests on Timothy are given in Tables 8 and 9 respectively. The crop residue decline curve (Figure I) is based on the fresh weight of grass.

Table 8

Germination % and 1000 seed weight of Rye-grass after application of ethofumesate at 1.0 and 2.0 kg a.i./ha post-emergence in 1974

Site No.	Variety	Type	2 kg a.i./ha G%	2 kg a.i./ha 1000 seed wt	1 kg a.i./ha G%	1 kg a.i./ha 1000 seed wt	Untreated G%	Untreated 1000 seed wt
1	S101	P. (D)	-	-	83	1.102	86	1.150
2	S24	P. (D)	-	-	94	1.914	95	1.702
3	Premo	P. (D)	-	-	90	1.718	86	1.685
4	Tiara	I. (D)	-	-	86	1.665	91	1.630
5	Sabrina	H. (T)	-	-	88	4.688	90	3.474
6	S24	P. (D)	90	1.897	95	1.996	91	1.991
7	S24	P. (D)	87	1.644	93	1.738	93	1.567
8	S24	P. (D)	92	1.847	-	-	91	2.023
9	S24	P. (D)	92	1.036	93	1.195	91	1.139

P = Perennial I = Italian H = Hybrid D = Diploid T = Tetraploid

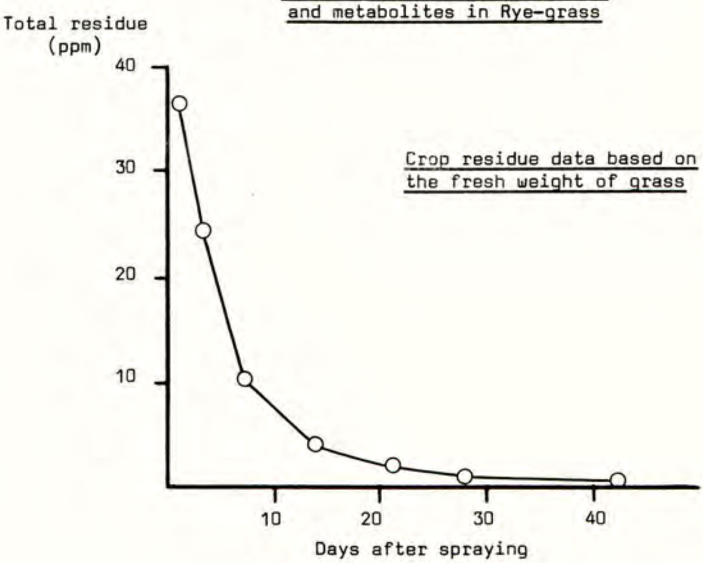
Table 9

% germination of Timothy after application of 2.0 kg a.i./ha of ethofumesate post-emergence in 1975

Site No.	Variety	2.0 kg a.i./ha	Untreated
1	S51	98	98
2	Erecta	92	96
3	Maris Paviour	96	90

Figure I

Total residue of ethofumesate and metabolites in Rye-grass



DISCUSSION

The results in Tables 1-3 show that pre- or early post-emergence spraying of Italian Rye-grass (Lolium multiflorum) even at 3.0 kg a.i./ha of ethofumesate has little effect on the Rye-grass. This statement is true for all 153 varieties of Perennial, Italian, Hybrid and Westerwold Rye-grasses tested to date. This level of safety is of considerable practical benefit as is the flexible time of application.

With Timothy (Phleum pratense) and Cock's-foot (Dactylis glomerata), spraying pre-emergence gives a slight check at doses up to 1.0 kg a.i./ha and a severe check at higher doses. However, post-emergence spraying of both, even as early as 48 days after sowing (Table 2), shows only a slight check at 2.0 kg a.i./ha. Similar tolerance is indicated in Table 7 where Timothy sprayed 62 days after sowing showed no check compared with the untreated. Thus, application of ethofumesate can be recommended on Timothy and Cock's-foot provided that they have been established for two months.

The results of applying ethofumesate to Red Fescue (Festuca rubra) show that this variety is very susceptible to pre-emergence application. Although it becomes more resistant with age, it cannot be sprayed with safety so soon after establishment as Cock's-foot or Timothy. However, we consider that Red Fescue may be safely sprayed one year after establishment.

The very high degree of grass weed control obtained under practical conditions is clearly shown in Tables 4 and 5. This consistency has been a characteristic feature of our own and collaborators' trials. The control of Wild-oat (Avena fatua) has been outstanding, as has the control of volunteer cereals in most cases.

Effective weed control in different types of seed bed (as shown in Table 6) is also of significance. Excellent weed control was obtained on both types of seed bed, although the results suggest that, under minimal cultivation, the higher post-emergence dose of 2.0 kg a.i./ha offers greater reliability.

The control of Common chickweed (Stellaria media) by ethofumesate is well shown by the results in Table 7. Although doses as low as 0.75 kg a.i./ha gave a good initial effect, this declined with time. At the commercially recommended doses of 1.5 and 2.0 kg a.i./ha however, excellent season-long control was obtained. The value of removing Common chickweed early in the life of Timothy is known and so is the difficulty of correct hormone timing. This characteristic of ethofumestate therefore offers considerable side benefit in addition to the main attribute of controlling the grass weeds.

The germination results (Tables 8 and 9) show that ethofumesate is completely safe on Rye-grass at doses of up to 2.0 kg a.i./ha. The results on Timothy, limited though they are, suggest that ethofumesate is equally safe on this variety. Further tests are in progress to confirm this.

The residue decline data (Figure I) shows clearly that the initial residue falls rapidly during the first 7 to 14 days, followed by a slower subsequent decline. This probably indicates an initial rapid loss through weathering, followed by a slower dissipation due to the processes of metabolism. The low residue levels in the crop ensure a high margin of safety to grazing livestock.

1974/75 was a season of exceptional wetness, whereas 1975/76 was one of exceptional drought. However, the efficacy results of both years' trials suggest that ethofumesate is a safe, reliable, broad spectrum herbicide for grass seed crops, and offers an important step forward for the farmer.

Acknowledgments

The help given by Mr. H. Mead, ADAS, Cambridge, and by many of the N.S.D.O. staff at Newton, Cambridge, is greatly appreciated. Gratitude is also due to the many farmers who allowed liberties to be taken with their crops, and in particular to Mr. H. Kindred.

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CONTROL OF LOLIUM SPECIES IN RED FESCUE BY A PHENOXYPHENOXY-ACID COMPOUND

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Summary A report is given on the different tolerance of several forage grasses to a compound of the phenoxy-phenoxy-propionic acid group with the code number HOE 23 408. Because of the very high susceptibility of Lolium species and the extreme resistance of Red Fescue to HOE 23 408 this compound was found to be appropriate to control Lolium species in Red Fescue grown for seed. It is especially important to remove the Lolium plants from the field of this turfgrass species because it is not possible to separate Lolium seed from Fescue seed by mechanical seedprocessing.

Résumé Un rapport a été établi sur la différence de sensibilité de plusieurs graminées fourragères vis-à-vis du groupe chimique de l'acide phénoxy-phénoxy-propionique portant le code HOE 23 408.

A cause de la très forte sensibilité des espèces de Lolium et de la résistance extrême du fétuque rouge vis-à-vis du HOE 23 408, on a trouvé ce composé approprié pour combattre Lolium dans le fétuque rouge cultivé en vue d'obtenir des semences. Il est très important de supprimer les plantes de Lolium dans les champs de semences de cet espèce de gazon car il n'y a aucune possibilité d'enlever la semence de Lolium du fétuque rouge par une séparation mécanique des semences.

INTRODUCTION

During our investigations with herbicides in forage crops we tested a new product with the code number HOE 23 408. It is a phenoxy-phenoxy-propion acid derivative which was developed by the Hoechst A.G. Frankfurt. The chemical name is 2- [4-(2', 4'- dichlorophenoxy)-phenoxy]-propionic acid methylester. This product, a selective foliar herbicide, is effective against Avena spp. and Setaria spp. (Langelüddeke P. et al. 1975).

In the spring of the year 1974 nine newly sown grass species (3 leaves) as well as eight established grass species (some tillers) were treated with 1.25 l and 2.50 l/ha a.i. of HOE 23 408 in order to test their reactions to that new compound.

The seedlings of Festuca pratensis, Meadow Fescue, Phleum pratense, Timothy, Trisetum flavescens, Golden Oat-grass and diploid Lolium perenne, Perennial Rye-grass were already completely killed by the low dose while a few plants of tetraploid Perennial Rye-grass survived. All plants were killed by the higher dose. A few single plants of Dactylis glomerata, Cock's-foot, Poa pratensis, Smooth Meadow-grass and Lolium multiflorum, Italian Rye-grass recovered after the treatment. Italian Rye-grass, sown in August and treated in the 3 leaves stage, was totally killed. Only Red Fescue was extremely resistant to this compound already in the seedling stage.

After the treatment of the one year old grasses the growth of diploid and tetraploid Perennial Rye-grass completely broke down. Meadow Fescue, Golden Oat-grass, Timothy and Cock's-foot were differently damaged. Accordingly the yield of the seed was more or less reduced. The yield of the Red Fescue and the Smooth Meadow-grass seed was not influenced.

Because of the high susceptibility of the Lolium species and the extreme resistance of the Red Fescue to HOE 23 408 trials were carried out to control Lolium in Red Fescue. The problem is that there is a lot of Lolium seed in the soil, especially after catch crops or former seed crops. It is not possible to separate the seeds of the two grass-species with a seed-winnower. Therefore, a herbicide which controls successfully Lolium in seed crops of the turfgrass species of Red Fescue without damaging the crop would be an important economic achievement.

METHOD AND MATERIALS

In 1975 8 kg/ha Red Fescue cvs. Lifalla, Odra and Golfrood were sown in mixtures with 0.4 kg/ha of the three different Perennial Rye-grass cvs. NFG, Printo and Diana. Every seedmixture contained also 0.4 kg/ha of Italian Rye-grass cv. Tiara.

On 6th June 1975 1.26 l/ha a.i. of HOE 23 408 were sprayed on that mixture consisting of Red Fescue (3 leaves stage) and Lolium species (3 - 4 leaves stage). There were five replications. Altogether 45 plots were treated, the same number of plots remained untreated as a control.

On 26th August 1975 this treatment was repeated to kill some few Lolium plants which probably germinated after the first treatment.

On 2nd May 1975 HOE 23 408 was also sprayed in another trial with a logarithmic sprayer (beginning with 2.52 l/ha a.i.) in the diploid Perennial Rye-grass cv. NFG and the tetraploid cv. Taptoe sown on 2 nd May 1974.

RESULTS

On the mixed sown plots which had been treated with 1.26 l/ha a. i. HOE 23 408 the Lolium plants changed their colour from green over. yellow to brown and were found killed after five weeks. The Red Fescue was able to grow without competition, whereas the Red Fescue on the untreated plots was suppressed by the rapidly growing Lolium species.

3 slides

Later on some Lolium plants could be found on the treated plots. ost of them probably germinated after treatment. On an average 2 lants /m^2 of both L. perenne and L. multiflorum were counted on 18th ugust 1975. There were no differences between the L. perenne cultiars. A second treatment with 1.26 l/ha a.i. of HOE 23 408 was carried out in order to kill later germinating Lolium plants which unforunately developed many tillers because there was no competition with escue. Only 0.06 plants /m^2 of L. perenne and 0.3 plants /m^2 of L. ultiflorum survived this second treatment.

4 slides

Logarithmic spraying of HOE 23 408 has shown some differences etween Lolium cultivars. In the range of 0.36 l/ha to 0.50 l/ha a.i. 7 % of Taptoe canopy, but only 20 % of cv. NFG were killed. The ifferences decreased at higher doses. In the range of 1.40 l to .84 l/ha a.i. 98 % respectively 97 % of the plants were controlled, nd in the range of 1.84 l to 2.52 l/ha a.i. of HOE 23 408 the anopy of the two varieties was almost completely killed. An effiiency of 99 % was assessed.

DISCUSSION

Without doubt the control of grass-weeds in grass-seed-crops is ifficult. A bigger problem is the elimination of volunteer plants f forage- or turfgrass species in seed crops of other species. The equirements of seed purety of lowly growing turfgrasses are very igh. In former times I was often asked by breeders and grass seed rowers for a possibility to control Lolium species in seed crops of ed Fescue turf varieties. Now we have this phenoxy-phenoxy-propioic acid derivate HOE 23 408 which suits well to this purpose. Reently good experiences in practical seed growing were already made ith this method.

Acknowledgements

The author thanks Mrs. U. Witek for technical assistance.

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THE TOLERANCE OF FOUR RYEGRASS CULTIVARS TO FOURTEEN CHEMICALS WITH KNOWN GRASS CONTROL PROPERTIES

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Summary The tolerance of four cultivars of perennial and Italian ryegrass to a range of herbicides, some already marketed and others under investigations, which have known activity against *Avena* spp and *Alopecurus myosuroides* is reported.

INTRODUCTION

Comparitively little information is available on the tolerance of seed crops of forage grasses, which are subject to EEC regulations on purity, to the effects of herbicides primarily intended for application to cereal crops for control of weed grasses. Not only are there specific but also cultivar reactions to herbicides and the report is an attempt to update work already reported (Mead et al 1974). Other workers (Oswald and Haggar 1974) have also reported work of this description.

METHOD AND MATERIALS

Four varieties of Ryegrass cv S24 diploid Perennial Ryegrass, cv Premo diploid Perennial Ryegrass, cv Maris Ledger tetraploid Italian Ryegrass and cv RvP diploid Italian Ryegrass were sown on 20 May 1975 on a sandy loam at commercial seed rates in four separate blocks. Strips of these blocks were sprayed logarithmically with the chemicals. Starting doses were set considerably in excess of the manufacturer's dose for cereals to determine, if possible, the maximum tolerated dose.

All spray treatments were applied with a modified van der Weij sprayer using Allman "O" jets. The volume was 450 l/ha at 2.21 bar. The triallate granules were spread by hand and the triallate emulsion was incorporated by hand rake. The triallate granules were applied at four doses, 2.0, 1.3, 1.0 and 0.67 kg/ha/ai.

The layout was so designed that a control plot was adjacent to each treated plot.

The crops were sown on 20 May 1975 and the triallate (both granules and emulsion), flamprop-methyl, one ethofumesate treatment and terbutryne (treatments 1-5) were applied pre-emergence on 23 May. The remainder of the chemicals (treatments 6-15) were applied post emergence on 30 June 1975, when the Ryegrasses were at the 4-5 leaf stage and just starting to tiller.

Assessment was conducted on the basis of scoring 0-10 on a visual inspection of each plot on 5 August 1975. Each plot covered 4 doses of the herbicides, the initial heavy dose, one half of this, followed by one quarter and one eighth of it. The adjacent control plots were of great use in making these assessments being a continual eye reminder of score 10. A complete kill was scored as 0.

It was noted that the period after herbicide application was very dry and that effects could have been more severe if the weather had been wet. Sowing the seed had already been delayed because the wet spring weather had caused difficulties in seed bed preparations.

RESULTS

The results with treatment details are as shown in Table 1.

Several chemicals were very active on all cultivars, namely HOE 22870, HOE 23408 and cyanazine. Triallate emulsion damaged cv Maris Ledger and cv RvP considerably down to the quarter starting rate but this is below the lowest manufacturers recommended rate and even at one eighth of starting rate the population of completely killed individual plants was unacceptable. The two diploid perennials, however, tolerated the triallate emulsion quite well. Triallate granules appeared safe to all cultivars at commercial doses.

All the other chemicals used had little or no effect on any of the cultivars. It was noticeable that even terbutyrne which is supposed to control perennial ryegrass at 2.75 kg/ha had little effect at double this dose and its selective broad leaved weed control was remarkable even under the dry conditions experienced. Methabenzthiazuron was also conspicuous in its control of broad leaved weeds and its lack of crop effect.

DISCUSSION

The trial has yielded useful and positive pointers even though perforce the assessment method may be criticised as being subjective in nature. The information will be used in the conduct of replicated trials for the control of *Avena* spp and *Alopecurus myosuroides* as the opportunity arises. Forage grass seed crops show a remarkable ability to recover from damage and the senior author in his day to day duties with such crops has noted over a number of years remarkably high levels of seed yield from crops, the plant populations of which had been seriously reduced for one reason or another. It is suggested that a degree of damage is acceptable provided the crop has time to recover and to tiller well before inflorescence initiation takes place. The work also points to the variation in response to herbicides present in the two crop species.

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TABLE 1

Treatment	Starting rate ai kg/ha	S24				Ledger				Premo				RvP			
		Start	½	¼	⅛ dose	Start	½	¼	⅛ dose	Start	½	¼	⅛ dose	Start	½		⅛ dose
1. Tri-allate emulsion	4.2	1-5	5-6	7-8	8	0-1	2	3	6	1-6	9	9-10	9-10	1-3	3-5	5-6	6
2. Tri-allate granules	2.02-0.67	3-5	7-9	9-10	9-10	7	9	9	10	1-7	7-9	9-10	10	8-9	9	9	9
3. AC 92553	4.58	3-8	8-9	8-9	10	5	6-7	7-8	9	5-9	9-10	9-10	10	8-9	9	9	9
4. Ethofumesate	4.48	8-10	9-10	9-10	9-10	9	9-10	9-10	10	1-9	9-10	9-10	9-10	9	9	9	9
5. Terbutryne	8.4	3-5	6-9	9-10	10	5-6	8-9	9-10	10	0-6	6-9	9-10	10	1-5	5-6	6-7	8
6. Methabenzthiazuron	9.41	3-5	6-9	8-9	10	9-10	9-10	9-10	9-10	0-6	6-9	9	10	7-8	8-9	9	9
7. Cyanazine	4.03	3-5	6-9	8-9	10	5*	7*	8	10	3-5	5-9	8-9	10	4*	5*	5*	5*
8. Ethofumesate	4.48	8-9	8-9	9-10	10	8-9	9-10	10	10	9-10	9-10	9-10	9-10	9	9	9	9
9. Difenzoquat 330	4.00	8-9	9-10	9-10	10	7-8	8-9	9-10	10	6-9	9	9-10	9-10	8-9	9	9	9
10. Barban	1.01	7-9	8-9	9-10	10	9	9	9	10	9	9	9-10	10	9	9	9	9
11. HOE 22870	3.79	5-6⌿	5-6⌿	8⌿	9⌿	1	3	5	8-10	5-7	7-8	9-10	9	4*	6*	7-8	9
12. HOE 23408	3.79	0	0	0	0	0	0	0	0	0	2*	2-3*	3*	0	3*	3*	3*
13. Flamprop-isopropyl	3.37	9-10	9-10	9-10	9-10	9-10	9-10	9-10	9-10	9-10	9-10	9-10	9-10	9	9	9	9
14. Benzoylprop-ethyl	3.30	9-10	9-10	9-10	10	9-10	10	10	10	9-10	9-10	9-10	9-10	9	9	9	9
15. Flamprop-methyl	1.58	7-9	9-10	9-10	10	5-9	9-10	9-10	9-10	8-9	9-10	9-10	9-10	9	9	9	9

* Severe scorch

⌿ Damage: Ryegrass lacking vigour

Control of groundsel, redshank, field pansy, fat hen, fools parsley and knotgrass was almost complete on terbutryne plots - also ryegrass greener. Methabenzthiazuron controlled broad leaved weeds as listed except for fat hen.

THE CHEMICAL CONTROL OF AVENA SPP IN SEED CROPS OF PERENNIAL RYE-GRASS

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Summary Spring applications of herbicides were compared on two crops of Perennial Rye-grass both heavily infested with Avena spp. Good control of the weed is reported where chemical applications were made at crop growth stage 2-3 (Feekes - Large) of the Avena spp. but less satisfactory control was noted when applications were made at approximately the same dates but at later growth stages of the Avena spp.

INTRODUCTION

The work is a continuation of that started in 1973 (Mead et al 1974) in the eastern counties of England where herbage seed crops are grown as a break crop in a crop rotation mainly devoted to cereals and where Avena spp. are a serious weed hazard. The mandatory requirements of EEC regulations on the purity of grass seeds marketed in the community with particular reference to Avena spp constitute the main reason for the work. One of the difficulties of this type of work is in the finding of crops which have a sufficiently uniform distribution of the weed under investigation over a sufficiently large area on which to site an experiment. As a consequence the writers are very conscious of the fact that insufficient satisfactory sites may be available in one season.

METHOD AND MATERIALS

Herbicides were applied with a modified Van der Weij sprayer using Allman "00" jets at 2.21 bar in 225 l/ha of water. Plot size was 3m x 10m in three randomised blocks at two sites.

Site 1. Redbourn, Hertfordshire - a crop of cv Meltra tetraploid Perennial Rye-grass growing on a fine sandy loam with a heavy infestation of Avena fatua at crop growth stage 2-3 (50 plants m^2) and wheat (15 plants m^2) with a vigorous population of Poa annua at the base.

Site 2. Brettenham, Norfolk - a crop of cv Melle diploid Perennial Rye-grass on a very fine sandy loam with a heavy Avena spp. infestation at crop growth stage 5-6 (70 plants m^2).

Treatments were applied as shown in Table 1 and while assessments of Avena spp. populations at harvest are usually recorded in the department as panicle weight/m^2 there was so much early seed shedding during the dry summer of 1976 that panicle counts/m^2 were recorded as the basis of assessment.

All panicles of Avena spp. had reached their full scale of development in all plots except the isoproturon treatments where they were immature at harvest.

TABLE 1

Treatments	Dose kg/ha/ai	Application Date Site 1	Site 2
Control			
ethofumesate	1.96	19/3/76	26/3/76
difenzoquat (62% + 0.5% Agral)	1.00	30/4/76	28/4/76
benzoylprop-ethyl	1.12	30/4/76	28/4/76
flamprop-isopropyl	0.98	30/4/76	28/4/76
flamprop-methyl	0.53	30/4/76	28/4/76
isoproturon	1.20	19/3/76	26/3/76
dalapon	2.87	-	26/3/76
dalapon	1.43	-	26/3/76

RESULTS

The results are summarised in Table 2. Ethofumesate at Site 1 gave the most complete control of the *Avena* spp. coupled with elimination of the volunteer wheat and the *Poa annua*. However, at Site 2 where the *Avena* spp. were at a later growth stage the chemical was inferior to all except the low dose dalapon.

The difenzoquat was notable in the degree of control of *Avena* spp. without any apparent adverse crop effect but its effect was considerably less at the later growth stage application.

Isoproturon gave only moderate control at Site 1 but with considerable crop damage to the cv Meltra but its degree of damage on cv Melle at Site 2 was negligible with a high level of *Avena* spp. control compared with other chemicals. The different effects of this chemical on cv Melle to other Rye-grasses has been reported before (Mead et al 1974).

Benzoylprop-ethyl gave relatively poorer control of *Avena* spp. at both sites compared with the related chemicals flamprop-isopropyl and flamprop-methyl.

Dalapon was included because of its known selective effects in grasses but at the high dose at Site 2 although control of *Avena* spp. was high, the crop damage was unacceptable. At the lower dose, crop damage was acceptable but very noticeable.

TABLE 2

PERCENTAGE REDUCTION TREATMENT/CONTROL PANICLE NUMBERS AT HARVEST

Treatment	Site 1	Site 2	Grass Vigour (0 = complete kill)	
Control panicle nos/m^2	101	61	Site 1	Site 2
ethofumesate	99	34	10	10
difenzoquat	91	60	10	10
benzoylprop-ethyl	71	39	10	10
flamprop-isopropyl	88	56	10	10
flamprop-methyl	87	48	10	10
isoproturon	73	69	3	9
dalapon	-	80	-	2
dalapon	-	25	-	8

DISCUSSION

The results illustrate the necessity for close examination of the stage of growth of the Avena spp. before attempting control measures. Although the relative dates of chemical application were similar, far better control was obtained from applications at the earlier growth stages.

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HERBICIDE TOLERANCE STUDIES IN WHITE CLOVER

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Summary The effects of fifteen herbicide treatments are described on three commercial crops of White Clover (Trifolium repens L.), two crops of cv Kersey white and one of cv S100 white. The main weeds encountered were cultivated barley, Alopecurus myosuroides L, Avena spp, other grasses and broad-leaved weeds. The effect on the crop is also indicated on a basis of inflorescence numbers per unit area of crop.

INTRODUCTION

White Clover gives its highest seed yield when it is free from other plant competition. It is a crop which is readily invaded by weeds and other crop plants because of its lateness in growth in the spring and its poor competitive characteristics. Little work has been reported on weed control in White Clover seed crops.

The acreage of seed crops in UK has fallen considerably over the last decade, one of the main reasons being the low seed yield and consequent poor economic performance of the crop. In eastern England cereals and grasses most often form the most serious weed competition in arable rotations and the observations reported are an attempt to assess the most beneficial of the grass and broad-leaved weed suppressants available. Other investigations (Blood 1972, Soper and Hutchinson 1974, Mead and Finch 1973) have reported on the use of paraquat and carbetamide respectively for this purpose.

METHOD AND MATERIALS

All treatments were applied with a modified van der Weij sprayer employing "00" Allman jets. All treatments except the two wettable powders carbetamide and propyzamide were applied at 2.21 bars in 225 l/ha of water. The carbetamide and propyzamide were applied at 3.31 bars in 281 l/ha of water.

A randomised block design with three treatment replicates was used.

Weed populations before and after treatments were assessed and a count of White Clover inflorescences was made on 10 separate grids of 0.23 m^2 on each replicate immediately prior to harvest except at one site where the grower harvested without informing the writers.

There were three sites. At Goldhanger in Essex on a London clay the autumn treatments to the cv Kersey White were applied on 24 October and the spring treatments on 16 April 1975 and assessments were made on 29 July 1975.

At Stradbroke in Suffolk on a Beccles series sandy clay the autumn treatments to the crop of cv Kersey White were applied on 10 October 1974 and the spring treatments on 1 April 1975. Assessments were made on 24 July 1975.

At Histon, Cambridge, on a Hanslope series chalky boulder clay the autumn treatments were applied on 5 November 1974 and the spring treatments on 1 April. Weed assessments were made on 4 July 1975 after harvest at this site.

The harvesting of White Clover seed does not usually take place in eastern England before early August; 1975 being an "early" year.

Treatment rates and times of application are as shown in Table 1.

TABLE 1

Treatments and Times of Application

Treatment	Dose kg/ha ai	Time of Application	Goldhanger Clover Heads per m^2	Stradbroke Clover Heads per m^2
0 Control	-	-	306	733
1 Glyphosate	1.5	Autumn	199	733
2 Glyphosate	3.0	Autumn	9	640
3 Paraquat	0.56	Autumn	329	784
4 Paraquat	1.12	Autumn	368	743
5 Carbetamide	2.17	Autumn	389	823
6 Propyzamide	0.7	Autumn	372	647
7 Propyzamide	0.35	Autumn	310	798
8 Glyphosate	0.75	Spring	319	940
9 Isoproturon	2.5	Spring	271	812
10 Paraquat	0.56	Spring	349	731
11 Paraquat	1.12	Spring	457	799
12 Carbetamide	2.17	Spring	270	695
13 Propyzamide	0.7	Spring	290	782
14 Propyzamide	0.35	Spring	291	698
15 Carbetamide + dimefuron	1.47) 0.75)	Spring	329	727

The dominant weeds present on respective trials were

Histon - *Avena* spp, *Alopecurus myosuroides* and *Cirsium* spp

Goldhanger - *Anthemis arvensis*, *Cirsium* spp, *Rumex acetosa*

Stradbroke - *Avena* spp, *Alopecurus myosuroides*, *Sonchus* spp, barley

RESULTS

Results measured as influence on inflorescence population are as indicated in Table 1.

Both the autumn glyphosate treatments had an extremely drastic immediate effect on the crop but there was a recovery albeit patchy. Weed control was complete well into the winter but there was rapid weed regeneration in spring on all three sites. By harvest time on the Kersey White sites the clover had recolonised most of the plot area but the level of regeneration of barley, Wild-oat (*Avena fatua*), Black-grass (Alopecurus myosuroides L), and broad-leaved weeds was considerable. On the S100 site at Histon the clover was completely killed.

The spring glyphosate treatment reduced the White Clover ground cover by 40-50% at all sites and weed recovery by harvest was again considerable.

Both autumn paraquat treatments had little crop effect apart from some scorch but recovery by harvest was complete. Winter weed control was good but there was considerable weed infestation by harvest time.

The low dose paraquat in spring had no noticeable crop effect but there was considerable weed infestation at harvest time.

The heavy spring paraquat dose gave best weed control overall but there was no control of Docks (Rumex crispus and R. obtusifolius).

There was no crop effect from carbetamide or carbetamide and dimefuron at any time or rate of application. There were no site differences in weed control level which was of a high order on the grasses. Control of broad-leaved weeds except for members of the Compositae was also good.

No crop damage from any time or dose of propyzamide except a slight evanescent scorch from the spring treatments on S100. Broad-leaved weed control was only moderate but grass weed control was good.

The Isoproturon treatment in the spring had little noticeable effect on either cultivar but weed control of both grass and broad-leaved weed was poor.

Germination determinations were carried out at the Official Seed Testing Station, Cambridge but no effects from treatments were found.

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WEED CHANGES OVER 11 YEARS IN WRENCHES, AN ARABLE FIELD

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Summary Four detailed assessments made in April or May over 11 years on the weeds in an arable field show that considerable changes have taken place in the density of the principal species. Chrysanthemum segetum, Raphanus raphanistrum and to a lesser extent Stellaria media, Polygonum convolvulus and Viola arvensis have declined, while Poa annua, Polygonum aviculare and Capsella bursa-pastoris have increased. Several less frequent species maintained their density or declined slightly. The total weed density declined from $279/m^2$ to $97/m^2$ during the first five years, but then increased again to $137/m^2$ in the remaining 6 years. The number of species recorded varied between 25 and 28. Possible explanations of these changes are considered.

INTRODUCTION

Weeds in the arable fields of the Weed Research Organization's Begbroke Hill farm have been systematically assessed at various intervals for experimental and management purposes. The resulting data are of great interest for they give detailed information on the changes that are occurring in the weed populations, besides revealing characteristics of the weeds themselves. This paper reports on the changes that occurred in a long-term arable field over a period of eleven years and considers possible explanations of the changes.

METHOD AND MATERIALS

When Begbroke Hill farm was acquired in 1960 the field known as Wrenches (O.S. No. 42) had been in arable crops for several years. How long is not known exactly although an aerial photograph taken in July, 1949 shows it as pasture, but the absence of any weeds normally confined to grassland suggests it must have been arable for about a decade.

The field is 5.06 ha in area, is more or less flat and the soil is a sandy loam 30-60 cm deep overlying gravel.

Assessments of the weed flora were made in March 1961, May 1962, December 1964, May 1967, April 1969, January 1971 and April 1973, but only those in April and May are presented here, because those in other months give an unrepresentative picture, for they are outside the normal period of emergence of many of the species. Even so, April and May are outside the main germination period of Aphanes arvensis and April is early for Solanum nigrum (Fryer and Evans, 1968) so these may have been under-recorded. Each assessment was made by identifying and counting the weed seedlings in quadrats spaced regularly throughout the field. The field was marked out with a series of parallel and permanent transects located at 18.3 m intervals. Along each transect a 0.09 m^2 quadrat was placed at intervals of 20 paces (approximately 18 m). The field was thereby covered by 140 equally spaced quadrat positions. The spring assessments were made just before the application of herbicides to the crop when most seedlings had emerged and most were large enough to identify. The only difficulty lay in distinguishing between _Veronica arvensis_ and _V. persica_ which cannot be separated at the cotyledon stage. Perennial species, when present, were counted as the number of separate shoots in the quadrat.

The crops grown and other aspects of management are listed in Table 1. Fertilizers were added as appropriate. Crops were grown normally in all years with the exception of 1966 and 1968 when a number of small experiments on various crops with various treatments were laid down and the surrounding areas drilled with spring barley.

Table 1

Details of field management

Crop planted	Crop	Herbicides	Weed assessments
March 1962	spring barley under-sown with grass	dinoseb	May 1962
1963	grass		
1964	fallowed to control _Agropyron repens_		
Oct. 1964	winter wheat		
March 1966	expts drilled round with spring barley		
March 1967	spring barley	mecoprop	May 1967
March 1968	expts drilled round with spring barley	dinoseb	
March 1969	spring barley	dinoseb/MCPA	April 1969
March 1970	spring barley	dinoseb/MCPA/mecoprop	
Sept. 1970	winter oats	mecoprop	
April 1972	potatoes	paraquat/linuron	
1973	fallowed to control potatoes		April 1973

RESULTS AND DISCUSSION

The numbers of seedlings of each species counted in the 140 quadrats in each of the assessments are given in Table 2. The weed population in the field in 1962 was very largely a pre-herbicide arable weed flora, for the previous owner had apparently used no herbicides and only in 1961 had a herbicide been used, dinoseb in spring barley.

The most frequent species in the field

Chrysanthemum segetum was the most frequent species in 1962, forming just over 50% of the weed population. In 1967 it formed 11% of the weeds, in 1969 7% and 1973 only 1%. There are possibly several factors contributing to its decline. First, the herbicide dinoseb was used on four occasions to control this species. This combined

Table 2

Numbers of seedlings counted in 140 quadrats (= 13 m^2)

	1962	1967	1969	1973
Aethusa cynapium	116	83	116	93
Anagallis arvensis		6	2	1
Aphanes arvensis		2	6	5
Arabidopsis thaliana	1			
Arenaria leptoclados	1	1	1	4
Artemisia vulgaris	5			
Capsella bursa-pastoris	451	112	146	610
Chenopodium album	46		1	2
Chrysanthemum segetum	1,824	134	109	12
Cirsium arvense	7	2		
Convolvulus arvensis		3		
Epilobium sp.				1
Fumaria officinalis	212	148	100	182
Lamium amplexicaule	34	100	102	35
Legousia hybrida	5	2	1	2
Matricaria matricarioides				1
Matricaria recutita	4			12
Papaver argemone		2	1	1
Papaver rhoeas	12	13	7	20
Poa annua		6	12	342
Polygonum amphibium			3	
Polygonum aviculare	64	76	419	193
Polygonum convolvulus	90	20	60	25
Raphanus raphanistrum	194	92	72	13
Rumex crispus	1		3	
Senecio vulgaris		6	6	4
Silene alba	43	18	50	6
Solanum nigrum		3		
Sonchus asper	1	1	4	1
Spergula arvensis	69	17	28	2
Stellaria media	267	227	164	113
Trifolium repens		31	10	
Urtica urens				2
Veronica arvensis & V. persica	73	42	25	69
Veronica hederifolia	3	24	12	2
Vicia hirsuta	1	1		
Viola arvensis	99	86	76	24
Totals	3,623	1,258	1,536	1,777
Mean seedlings/m^2	279	97	118	137
Total No. of spp.	25	28	27	28

with the fallow in 1964 means that in five out of the eleven years little or no seed was produced by this weed. Second, there is some evidence (WRO unpublished data) that seeds of this species do not survive at least in dry storage for any length of time. Third, liming may also have contributed to its decline, for it is an indicator of calcium-deficient soils and absent from calcareous ones (Howarth and Williams, 1972). The field was limed in 1960 when the pH was raised from 6.0 to 6.8 by 5 t/ha of lime. These factors may also be responsible for a similar decline of

Raphanus raphanistrum from 5.4% to 0.7% of the weed population and of Spergula arvensis from 1.9% to 0.1%, both of which similarly prefer acid sandy soils. C. segetum and R. raphanistrum have been virtually eliminated from an adjacent field during a 15 year period, although S. arvensis has remained at a constant, but very low level (Chancellor, 1976).

The life-span of C. segetum seeds in soil is unknown although short in dry storage and little evidence is available for the other two species. R. raphanistrum retained its viability well in one test, dropping only from 100% to 92-3% after 2 years buried in soil (Hopp, 1957). S. arvensis has germinated after 5 years burial in soil (Chepil, 1946) and in another instance gave 10% germination after 10 years burial (Salzmann, 1954). It is suggested that a relatively short life-span of seed combined with effective herbicide usage are necessary to obtain rapid diminution of an annual weed. Liming was, however, a confounding factor in this field.

Capsella bursa-pastoris was the second most frequent species in 1962, forming over 12% of the weed population. Subsequently it declined, but increased once more in 1973 to become the most frequent weed, forming 34% of the population. The reason for this increase is uncertain, for herbicides were applied in each year between 1969 and the assessment in 1973 and it is susceptible to all those used. The only possible reasons for an increase are, either that the plant germinated, flowered and seeded during the autumn after the crop was harvested or that it was re-introduced as a contaminant of crop seed. It is more likely that the plant seeded during the autumn after harvest as reported from Russia (Kott, 1967) for it can germinate in most months in this country (Roberts, 1964). Furthermore, it was not among 90 species recorded as contaminants of cereal grain in one survey (Tonkin and Phillipson, 1973).

Stellaria media was the third most frequent weed in 1962, by 1973 it has declined by 58% and yet was still the fifth most frequent. Its susceptibility to dinoseb and mecoprop used in six of the eleven years probably accounts for its reduced density.

Aethusa cynapium and Fumaria officinalis whose mean density was 9 and 16/m^2 respectively in 1962 were very much the same in 1973, which may be due to their being less susceptible than Stellaria media to the herbicides used. However, the length of time their seeds survive in soil may have been a contributory factor, for A. cynapium can survive up to 22 years in soil (Peter, 1894) or possibly 53 years or even longer (Ødum, 1965), which is longer than many species. Several other species also maintained their density, i.e. Veronica arvensis and V. persica and Lamium amplexicaule. A notable feature of the data is the constancy of occurrence of some of the species present at very low densities, e.g. Papaver rhoeas, Veronica hederifolia and Legousia hybrida. Conversely, a few species present in 1962 at moderate (3-8/m^2) densities appear to be declining gradually e.g., Viola arvensis, Silene alba and possibly Polygonum convolvulus or have declined more rapidly e.g., Chenopodium album.

Only three weeds increased over the eleven year period. Capsella bursa-pastoris, as suggested earlier, has probably increased by seeding in the autumn after harvest. The other two, Poa annua and Polygonum aviculare, are different because they are much more resistant to the herbicides used in the field. Poa annua is resistant to dinoseb and mecoprop as is Polygonum aviculare too, although it is susceptible in the seedling stage to dinoseb. In an adjacent field, P. aviculare has built up even more strongly from 6/m^2 in 1961 to 100/m^2 in 1976 so that it now comprises 67% of all the weed seedlings in the field. It is suggested (Chancellor, 1976) that because it is a very early germinating weed it could arrive at the resistant stage by the time dinoseb was applied and so has been able to increase in density. In this field, P. aviculare built up rapidly from 6/m^2 in 1967 to a peak of 32/m^2 in 1969 and subsequently declined again to 15/m^2 in 1973. This subsequent decline is probably due to the change of cropping in 1970-2. The winter oats planted in September 1970 probably precluded any seeding by P. aviculare in 1971 for the weed germinates only in spring (Fryer and Evans, 1968). Similarly, the planting of potatoes in April, 1972 probably came after the main flush of emergence of this weed so that very little seeding was possible, expecially as a paraquat/linuron mixture was used, to which it is to some degree susceptible.

The sudden increase of Poa annua between 1969 and 1973 is a remarkable phenomenon which is hard to explain. It is certainly a very frequent weed of arable farms locally in Oxfordshire. Whether it has increased in recent years, due possibly to the increasing control of the dicotyledonous weeds with herbicides, or whether it is normally variable in occurrence, is not known. However, assessments of other fields on Begbroke Hill Farm have shown very large fluctuations in the density of Poa annua populations from year to year. This suggests that there may be some climatic or other factors regulating germination or establishment of the plant. Wells (1974a) has reported that viability of the seed seems to vary from year to year and from monthly plantings in the field he found that, when temperature was not limiting, it was moisture availability that determined seed germination (Wells, 1974b). Whether these factors were influential here is uncertain.

Other factors influencing weed populations

The effects of method of cultivation were also considered, for between 1963 and 1969 the field was ploughed in most years, while between 1969 and 1973 it was only cultivated except for ploughing in 1972. Ploughing would tend to bury newly-shed seeds and so might be expected to reduce the number of seedlings, yet the mean number of seedlings/m^2 was higher (165/m^2) in the years of ploughing than subsequently (137/m^2 in 1973). This suggests either that the method of cultivation is unimportant or that other factors were more so.

Farmyard manure was applied to the field in November 1971 and, although traditionally a spreader of weed seeds, there was no increase of Chenopodium album in 1973, which is the main species associated with manure. Similarly, other associated species such as C. rubrum and Atriplex patula remained absent.

The method of straw disposal can also be important in the dynamics of weed populations, particularly of tall weeds such as Wild Oats. Of the common species in the field, only Chenopodium album, Chrysanthemum segetum, Raphanus raphanistrum, Polygonum spp. and Silene alba are large enough to get included in straw. Of these, most would lose their seeds anyway during harvesting, with the possible exception of C. album and the Polygonum spp. The density of these species, however, did not fluctuate in relation to the removal or otherwise of straw from the field and so it is presumed that disposal method had little influence on the weed population.

Changes in weed population density

The mean number of weed seedlings per m^2 was 279 in 1962, and during the next five years, in which herbicides were only used once, it declined by 65%. This was probably largely due to the year under grass and the year when the field was summer-fallowed to control Agropyron repens. Apart from Poa annua and Agropyron repens, which was virtually eliminated in 1964, no other grasses were present. The weed density increased in both 1969 and 1973 due largely to increases in P. aviculare and Poa annua.

Changes in species and number of species

The major changes in the field have been the decline of Chrysanthemum segetum, Raphanus raphanistrum and to a limited extent Stellaria media, Polygonum convolvulus and Viola arvensis and the increase of Poa annua, Capsella bursa-pastoris and

Polygonum aviculare. The changes have been closely paralleled in a neighbouring field with much the same species (Chancellor, 1976).

The number of species recorded has remained relatively constant between 25 and 28. The small variation is due presumably to species which are recorded sporadically because of their very low densities.

Acknowledgements

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ASPECTS OF THE SEED POPULATION DYNAMICS OF DACTYLIS GLOMERATA L., HOLCUS LANATUS L., PLANTAGO LANCEOLATA L., AND POA ANNUA L.

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Summary Some aspects of the seed population dynamics of Dactylis glomerata, Holcus lanatus, Plantago lanceolata and Poa annua are presented in simple models describing the probabilities of a seed becoming buried, germinating and a seedling establishing. The variation in these probabilities is discussed in relation to husbandry practices.

INTRODUCTION

The acquisition of life historical data is increasingly being realised to be of importance in the understanding of the biology and control of weeds (Fryer, 1975). Sagar (1970) has suggested that the recognition of the factors regulating population size may be facilitated by the collection of actuarial data of the entire life cycle. Attempts at this approach have been made by a number of workers (e.g. Sarukhán, 1970, Sarukhán and Gadgil, 1974, Rauber and Koch, 1975) allowing the formulation of models to predict population size. Such models require a structuring of the life history of the species concerned, into phases or states through which there is the flux of individuals. This flux is described by a series of probabilities which express the chance of an individual moving from phase to phase. It is self evident that the 'transition' probabilities from phase to phase may be time (season) and space (environment) dependent and knowledge of the variation in transition probabilities is important if models predicting population size are to have generality.

This report summarizes some actuarial data of four species of agricultural importance in a range of artificially managed habitats and presents the conclusions of some simple models.

METHOD AND MATERIALS

Seeds of Dactylis glomerata L., Holcus lanatus L., Plantago lanceolata L. and Poa annua L. were introduced into field plots (0.5m. x 0.5m.) at Treborth Botanic Garden, U.C.N.W., Bangor, upon which twelve factorial combinations of different managements had been imposed (Table 1). Before introduction seeds of the grasses were marked with fluorescent paint (Colbry, 1968) to differentiate between introduced and indigenous populations and the viability of all seed populations determined using tetrazolium chloride (Isely, 1952). A factorial split plot experimental design with three randomised blocks and eight harvests was employed.

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Table 1

A summary of the managements of field plots

Habitat disturbance before seeding

1. Complete disturbance.
   Inversion of the sward and exposure of bare soil.

2. Surface disturbance.
   Removal of surface vegetation by hand, after kill with paraquat and diquat (dose, 1.12 kg./ha.)

3. Undisturbed.
   Closed sward cut initially to 7.5cm. in height, cuttings removed and left untouched.

Exclusion treatments

1. Exclusion of invertebrates by chemical means.
   a) Application of Metasystox 55 (Demeton-S-Methyl 54% w/v) at the rate 20ml./ha./14 days, and Draza (methiocarb) slug pellets, 100/plot/28 days.
   b) Control (Untreated).

2. Exclusion of small mammals and birds.
   a) Wire screening.
   b) Control (No screening).

At monthly intervals from the start in September, destructive harvests of the plots were made and a census of the number of buried seeds, ungerminated seeds, seedlings and established plants taken. Sown individuals were identified from markings on seed remains that fluoresced when illuminated with ultraviolet light from a portable lamp. All individuals of P. lanceolata were counted since no mature individuals were present in the plots and the indigenous buried seed population was very low. Buried seeds in the soil profile below the sown area were estimated by extracting the soil sample to a depth of 5cm. and observing it in the glass house over six months and counting the seedlings of marked individuals and of P. lanceolata that emerged. Introduced seeds that were buried and remained dormant over the six months were extracted by flotation.

At each harvest, ungerminated seeds from the field in enforced dormancy were assessed by a germination test under predetermined optimum conditions, and those seeds either in innate/induced dormancy or dead identified with tetrazolium chloride.

The data were analysed to give the probabilities of a seed becoming buried or germinating and a seedling establishing, for all of the management regimes.

RESULTS

Simple diagrammatic models summarize the seed population flux of the four species over one year post sowing in the site studied. The relative fates of species seed were very different and the models demonstrate the variability in the transition probabilities among phases in the life history from seeding to establishment, (Figure 1).

Figure 1. Seed population flux diagrams for *D. glomerata*, *H. lanatus*, *P. lanceolata* and *P. annua*. Small squares represent phases in the life cycle from seeding to establishment. Figures in arrows indicate the transition probabilities from phase to phase. On the assumption that seed populations come from one flowering plant, the relative sizes of the component populations are shown in the squares. Probabilities of death or predation are obtained by subtraction. In the surface seed bank the number of viable seeds are given. For simplicity seedlings may only arise from the surface seed bank. In the buried seed bank of the grasses the figure in brackets is the buried seed population of previous years estimated from data of Champness and Morris (1948). The buried seed bank data in brackets for *P. lanceolata* pertain to the experimental site. Data are individuals. 100/cm.^{2}/year[1].

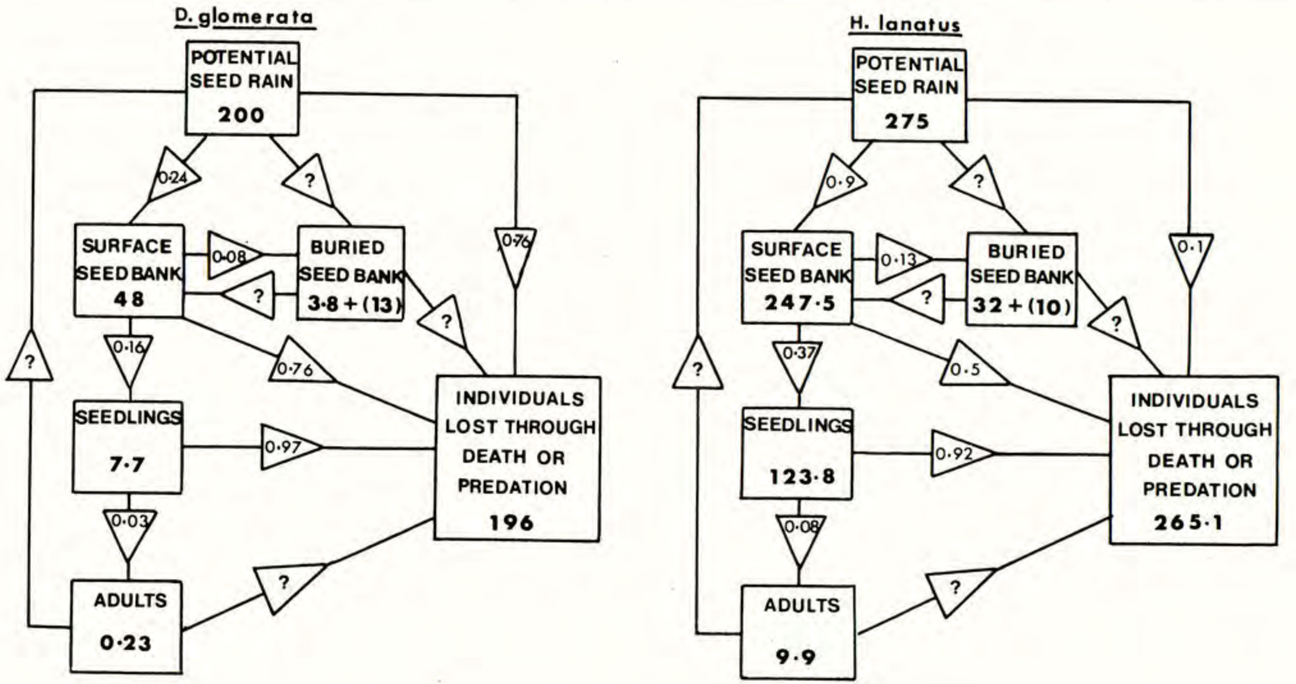
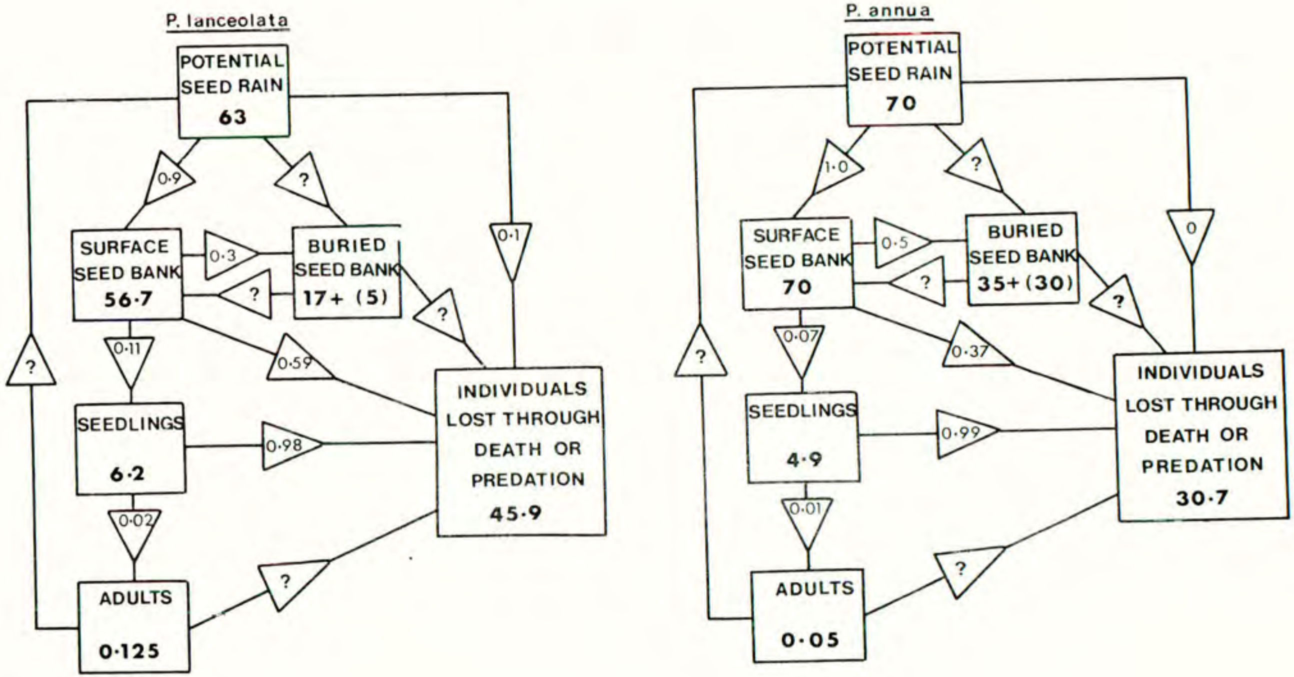


Figure 1. (continued)



Only a quarter of the potential seed rain of D. glomerata was viable in comparison to 90% or over for the other three species. Burial of seed of P. annua was most likely, 50% of seed raining on to the soil surface becoming incorporated into the soil profile. The larger seeds of the other three species were less likely to be buried, the lowest proportion being of D. glomerata. The probabilities of successful seed germination were also variable. Thirty-seven per cent of H. lanatus seed in the surface seed bank produced seedlings, in comparison to only 7% of P. annua, the other species being more intermediary. The chances of establishment of adults from seedlings were very low in the range of 1-8%. The models also indicate for the seed populations, the numbers of individuals ultimately lost through death or predation.

The data for two transition probabilities are presented in more detail in relation to the management regimes. Generally the probability of seed burial increased with an increase in habitat disturbance with the exception for P. annua seeds (Table 2). Where invertebrates were present the number of seeds buried was increased except for D. glomerata in the surface and completely disturbed habitat. The increased burial due to the presence and activities of invertebrates was 28% for D. glomerata, 25% for H. lanatus and P. annua and 35% for P. lanceolata.

Table 2

The mean probability of a seed from the surface seed bank becoming buried in 8 months, (September-May) in relation to invertebrate activity. -I, absence of invertebrates, +I, presence of invertebrates.

		Habitat disturbance		
		Complete	Surface	Undisturbed
D. glomerata	-I	0.176	0.114	0.033
	+I	0.209	0.134	0.092
H. lanatus	-I	0.239	0.114	0.046
	+I	0.289	0.169	0.105
P. lanceolata	-I	0.253	0.233	0.173
	+I	0.295	0.298	0.260
P. annua	-I	0.418	0.369	0.399
	+I	0.518	0.491	0.500

Least significant difference between two means ($P \leq 0.05$) = 0.037

The exclusion of invertebrates from plots, significantly increased the number of established plants present ($P \leq 0.001$). This was most marked in the undisturbed habitat for H. lanatus and P.lanceolata and for P. lanceolata in the surface disturbed habitat (Table 3). In all other habitats with the exception of P. lanceolata in the completely disturbed habitat, the probability of adult establishment from a seedling was increased by the exclusion of invertebrates but was not statistically significant.

Table 3

The mean probability of a seedling establishing an adult individual during 8 months, (September-May) in relation to invertebrate activity. -I, absence of invertebrates, +I, presence of invertebrates.

		Habitat disturbance		
		Complete	Surface	Undisturbed
D. glomerata	-I	0.031	0.024	0.069
	+I	0.026	0.017	0.065
H. lanatus	-I	0.125	0.037	0.154
	+I	0.095	0.017	0.076
P. lanceolata	-I	0.151	0.183	0.129
	+I	0.173	0.093	0.058
P. annua	-I	0.106	0.018	0.040
	+I	0.084	0.011	0.025

Least significant difference between two means ($P \leq 0.05$) = 0.029

Where exclusion of vertebrates was attempted, there was no statistically significant change in the probability of plant establishment of all four species in all habitats, except for P. lanceolata in the completely disturbed and surface disturbed habitats (Table 4).

Table 4

The mean probability of a seedling establishing an adult individual during 8 months, (September-May) in relation to vertebrate activity. -V, absence of vertebrates, +V, presence of vertebrates.

		Habitat disturbance		
		Complete	Surface	Undisturbed
D. glomerata	-V	0.039	0.024	0.070
	+V	0.018	0.016	0.064
H. lanatus	-V	0.120	0.030	0.119
	+V	0.099	0.024	0.111
P. lanceolata	-V	0.187	0.162	0.104
	+V	0.137	0.114	0.083
P. annua	-V	0.101	0.015	0.038
	+V	0.089	0.013	0.027

Least significant difference between two means ($P \leq 0.05$) = 0.027

Probabilities of establishment from seeds in the surface seed bank are given in Table 5 for two combinations of exclusion treatments. Establishment was more likely where both invertebrates and vertebrates were excluded and varied considerably between habitats, species differences being marked. Apart from P. lanceolata, establishment in the surface disturbed habitat was lower than in other habitats especially where no animal exclusion occurred. Establishment of P. lanceolata plants was proportional to habitat disturbance when animals were present whereas exclusion resulted in most establishment in the surface disturbed habitat. The highest probabilities of establishment were for D. glomerata and H. lanatus in the undisturbed habitat, in the surface disturbed for P. lanceolata and the completely disturbed for P. annua.

Table 5

The overall mean probability of a seed from the surface seed bank establishing an adult plant over 8 months, (September-May). -I, absence of invertebrates, +I, presence of invertebrates; -V, absence of vertebrates, +V, presence of vertebrates.

		Habitat disturbance		
		Complete	Surface	Undisturbed
D. glomerata	-I-V	0.0064	0.0044	0.0152
	+I+V	0.0029	0.0024	0.0096
H. lanatus	-I-V	0.0518	0.0148	0.0592
	+I+V	0.0329	0.0048	0.0333
P. lanceolata	-I-V	0.0187	0.0238	0.0167
	+I+V	0.0158	0.0087	0.0066
P. annua	-I-V	0.0077	0.0013	0.0034
	+I+V	0.0053	0.0006	0.0013

DISCUSSION

The levels of habitat disturbance employed in the study are analagous to the agricultural situations created by ploughing (equivalent to complete habitat disturbance), minimum tillage (surface disturbance) and a particular form of sward management (no disturbance). Control of animal activity in agroecosystems may be derived from a variety of pesticide regimes which the exclusion treatments in this study perhaps crudely simulate.

The chances of plant establishment from seed were predictably small and with high inputs of disseminated seed, common in the field, population maintenance and increase may be easily realised. It would appear that changes in husbandry involving gross alteration of habitat, for example minimum tillage in place of ploughing may radically alter both the composition and size of plant populations at least for the species in the present study. Husbandry resulting in the reduction of invertebrate and vertebrate activity generally increased the probability of establishment from seed. The means by which this was achieved may not necessarily be through a direct lowering of grazing pressures by molluscs, small rodents or birds but also a consequence of the reduction in the activities of seed burying agents such as earthworms. Earthworm kill was highly efficient with the chemicals used in the invertebrate exclusion treatment.

The models presented in Figure 1 emphasize the magnitude of loss from the surface seed population that may occur during the year subsequent to dissemination. The transition probabilities from state to state were very different for each species and were dependent upon the fauna within habitats, principally invertebrates. For P. annua and P. lanceolata the proportion of the surface seed bank becoming buried was relatively high. Seed shape and size may be functionally important in the burial of seed by abiotic means since invertebrate activity only accounted for up to 50% of the proportion of seed buried.

The models are deficient in that they do not take into account the return of individuals from the buried seed bank to the active plant population. Although there is considerable knowledge of the survival of buried seeds through the investigations of Roberts and his co-workers (e.g. Roberts, 1970) there is relatively little quantitative information on the numbers of seeds that germinate from the buried seed bank and contribute to the seedling and established plant populations. McRill (1974) has suggested that earthworms may be of importance in casting buried seeds to the surface and in producing favourable microsites for germination. It is probable that the transition probabilities from the buried seed bank to established plant may be very different from those of surface seed bank to established plant. Inclusion of individuals once dormant and buried, in the active plant population may have considerable genetic implications in the population structure of species that may be undergoing selection as a consequence of a change in husbandry.

Maximising the number of individuals lost through death or predation is a primary aim of weed control. The approach presented here illustrates parts in the life cycle where regulation is naturally occurring and the relative magnitudes of that regulation. It thus focusses attention on the transition probabilities that may be potentially reduced even further to allow effective control of population size. The models in Figure 1 are extremely simplistic since they do not portray the seasonal dynamics of the transition probabilities throughout the year nor do they contain information on density dependent regulation and vegetative reproduction. It remains for a more detailed analysis of the transition probabilities to be made and additional data to be collected concerning the influences of small mammals, birds and invertebrates on the dynamics of seed populations.

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