SESSION 3B

HERBICIDE—SOIL INTERACTIONS

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EFFECT OF SPRING WHEAT AND TEMPERATURE ON CHLORSULFURON PERSISTENCE IN SOIL

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Summary. Sealed pots of Begbroke sandy loam ± Highbury spring wheat were maintained close to field capacity in a controlled environment room with a day/night temperature of 16/10°C. When the wheat had four leaves chlorsulfuron at 1, 5 and 10 g a.i./ha was applied to the soil surface. One third of the pots remained in the 16/10°C room while the other two were transferred to 11/7 and 26/16°C rooms. After four weeks in the low temperature wheat treated with 10 g a.i./ha was reduced in weight, but by eight weeks all herbicide treatments were as controls. *Sinapis alba* bioassay of the soil showed that the presence of wheat reduced the persistence of chlorsulfuron. Metabolism of the herbicide in the wheat and stimulated microbial degradation in the rhizosphere and/or soil are proposed.

INTRODUCTION

Chlorsulfuron at between 5 and 25 g/ha controls broad leaved weeds and suppresses certain grasses in cereals (Palm *et al*, 1980). It is taken up by the foliage and roots and is translocated throughout the plant where it inhibits cell division in susceptible species and is inactivated in tolerant species such as wheat (Ray, 1980).

The residual action of chlorsulfuron is seen as an advantage where weed control in fallows is required (Nalewaja, 1980) but where sensitive crops follow its persistence could pose problems. Van Himme *et al* (1981) found residues which were toxic to a wide range of agricultural and horticultural crops, excluding wheat, five months after applying 25 g/ha of chlorsulfuron to uncropped land in October/November.

The aim of this preliminary study was to establish whether a tolerant crop, wheat, and temperature influence the persistence of chlorsulfuron in soil. At the same time observations were made on the response of spring wheat to this herbicide under three temperature regimes.

METHODS AND MATERIALS

A standard weight (416 g) of Begbroke sandy loam soil, supplemented with NPK and trace elements and of known moisture content, was placed in 10 cm diameter pots with their drainage holes sealed with plastic tape. The pots were divided into two groups and in one set a single seed of Highbury spring wheat was planted at a depth of 2 cm and the other set had no crop. The pots were weighed on an electronic balance and water added to bring the soil to approximate field capacity (21 ml water/100 g soil). The pots were subsequently weighed on a tared balance every 24-48 hours and water added to maintain approximately the same moisture content. The tare was adjusted weekly to compensate for plant growth. Water was applied from a syringe to the soil surface avoiding the foliage.

The plants were grown in a controlled environment room where the light intensity was 95 $W m^{-2}$ for 14 hours, the temperature 16 and 10°C and humidity 75 and 86% rh for day and night respectively.

When the plants reached growth stages 1.4, 2.1 (Zadoks et al, 1974), chlorsulfuron (75% dry flowable formulation) at concentrations of 5, 25 and 50 mg a.i./l of distilled water equivalent to 1, 5 and 10 g a.i. in 200 l/ha, was applied to the soil with a Burkard automatic syringe. Thirty 4 µl drops were evenly distributed over the soil surface avoiding the shoots in pots containing wheat.

Immediately after herbicide treatment the pots were divided into three groups; one remained in the same environment while the other two were transferred to rooms where the light and absolute humidity were the same as the previous environment, but the temperature regimes were 26/16 and 11/6°C day and night respectively.

After four and eight weeks in the three temperature regimes assessments were made of foliage and root (8 weeks only) fresh weights and the soil was bioassayed. It was removed from the pots, put in shallow dishes to dry and after 1-2 weeks the soil was sieved and thoroughly mixed, by shaking in a plastic bag, before being returned to the pots. Five seeds of Sinapis alba were sown and the pots were watered, but not weighed. The plants were raised in a glasshouse at 10 ± 7°C and a humidity of 65 ± 25% rh. The natural winter daylight was supplemented with sodium lamps to give a 14 hour daylength. After emergence the plants were thinned to four plants per pot. A proprietary liquid feed was applied to the plants growing in soil which had winter wheat as in an earlier experiment control fresh weights were less than half of those from the 'uncropped' soil. The fresh weight of S. alba foliage was determined 33 and 38 days after sowing for the four week and eight week assessments respectively.

Four replicates were used throughout and the pots were arranged in a randomised block design.

RESULTS

Wheat tolerance (Table 1). At the four week assessment the 10 g a.i./ha dose of chlorsulfuron significantly reduced the fresh weight and height of Highbury spring wheat in the 11/7 and 16/10°C regimes but not in the higher temperature regime. Eight weeks after herbicide treatment none of the herbicide treatments differed significantly from untreated controls. The mean fresh weight of roots for all herbicide treatments in each of the hot, medium and cool regimes was 5.7, 7.9 and 15.9 g respectively.

Table 1

Effect of temperature on Highbury spring wheat response to chlorsulfuron

	Time between herbicide treatment and assessment							
	4 weeks				8 weeks			
Chlorsulfuron (g)	0	1	5	10	0	1	5	10
	foliage fresh wt (g)							
26/16°C	4.41	4.97	4.77	4.51	11.96	11.21	11.20	11.88
16/10°C	5.37	5.88	5.61	4.15	17.91	18.16	17.51	16.49
11/7°C	3.92	3.27	3.57	2.13*	14.39	14.50	14.27	14.30
S.E. ±				0.304				0.605

* height of main shoot reduced

Chlorsulfuron persistence (Table 2). The foliage fresh weights of S. alba sown to assay residues in soil four weeks after treatment indicated that neither the temperature regime nor the wheat had a major influence on the phytotoxic residue in soil. There was substantial growth at the 1 g/ha dose under all regimes. At 26/16°C the presence of the crop was significantly reducing phytoxicity at the 5 g/ha dose. Eight weeks after herbicide treatment this trend had become significant at all temperatures.

Table 2

The effect of Highbury spring wheat and temperature on residues of chlorsulfuron in Begbroke sandy loam soil assessed with *Sinapis alba*

Temperature °C	chlorsulfuron g/a.i./ha	4 week assessment wheat	4 week assessment no wheat	8 week assessment wheat	8 week assessment no wheat	S.E.±
		Foliage fresh weight (g)				
26/16	0	9.69	9.34	7.54	9.68	0.805
	1	7.60	6.44	9.02	8.77	0.557
	5	5.00	2.94	7.44	3.61	0.446
	10	1.41	0.72	6.78	0.95	0.340
16/10	0	8.44	6.98	7.42	7.97	0.805
	1	7.18	5.51	6.80	7.90	0.557
	5	2.80	1.91	5.96	1.86	0.446
	10	0.89	0.84	2.60	0.85	0.340
11/7	0	8.14	8.48	8.24	8.97	0.805
	1	6.83	5.73	8.08	6.87	0.557
	5	1.90	1.95	4.08	1.52	0.446
	10	0.96	0.68	2.22	0.57	0.340

Between 4 and 8 weeks high temperature appears to have accelerated the inactivation of the herbicide in the presence of wheat. In uncropped soil there is a less marked trend for this to occur and the soil with wheat at 11/7°C sustains slightly more *S. alba* growth than the soil without wheat at 26/16°C with the 10 g/ha dose.

DISCUSSION

The aim of this work was to determine whether wheat and temperature influence the persistence of chlorsulfuron and the data in Table 2 clearly show that wheat increases inactivation of the herbicide during the 4 to 8 week period especially at higher temperatures. Factors that may contribute to this situation include the following:-

a) Sweetser *et al* (1982) found that 90% of chlorsulfuron entering wheat plants was metabolised to an inactive product within 24 h and this is probably the major mechanism of loss of active ingredient from the soil with wheat.

b) In order to maintain the soil at approximately field capacity, far more water was applied to pots containing plants than to those without and pots from the hot compared with the cooler regimes also required more water. The higher transpiration rate in the 26/16°C compared with the lower temperature regimes is likely to have led to a larger accumulation of herbicide in the hot grown plants. In addition the greater flux of water in the warmer environments may have resulted in a wider distribution of herbicide in the soil profile and exposure to more roots and/or sites where microbial, chemical and physical inactivation could occur.

c) Hsu and Bartha (1979) found diazinon and parathion are degraded rapidly in the rhizosphere and in the case of parathion enhanced breakdown was also induced by applying exudates to root free systems. From our results it is interesting to note that cool compared to hot grown plants had almost three times as much root, but soil from these had the larger herbicide residues. Thus if the rhizosphere is contributing to the removal of chlorsulfuron the nature of the exudates may be of key importance rather than quantity of root *per se*.

d) Temperature could influence the biosynthesis of substances in the plant associated with chlorsulfuron degradation there or in the rhizosphere. The weight of Highbury wheat shoots (Table 1) was reduced at the four week assessment by 10 g/ha of chlorsulfuron most markedly at the low temperature, which tends to support this proposal.

e) Degradation during the course of the bioassay could have been greater in the 'wheat soil' since the microbial population would be different to the 'no wheat' soil. Addition of nutrient to the 'wheat soil' may also have influenced the microbial population. However, in an earlier experiment, without additional nutrient, control fresh weights of S. alba were less than half those from 'uncropped soil', but the influence of the wheat on chlorsulfuron persistence showed the same trend.

This preliminary study suggests the need for several follow-up investigations. In this work the plants were in relatively small pots where contact of roots with the herbicide was probably higher than would occur in the field. Consequently the influence of tolerant crops and temperature on chlorsulfuron persistence in the field should be considered.

Finally, a physiological/biochemical/microbiological study could quantify the contribution of 'in plant' compared with rhizosphere and soil degradation and identification of plant and microbial substances associated with chlorsulfuron degradation could possibly provide leads on safeners for crops and soils.

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CROP RESPONSES TO LOW DOSES OF PENDIMETHALIN, NAPROPAMIDE, METAZACHLOR AND CHLORSULFURON IN THE SOIL

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Summary. The herbicides pendimethalin, napropamide, metazachlor and chlorsulfuron were incorporated into the surface 7-10 cm soil at a range of doses including several lower than those recommended commercially. Nine crops were sown in the treated plots and their responses measured after 6 to 8 weeks growth. Chlorsulfuron was highly active in the soil and growth of all crops except barley was affected at doses lower than 1 g/ha. Onion was the most sensitive; growth was affected severely at 0.25 g/ha. Lettuce, onion and carrot were the most sensitive to metazachlor residues and their growth was affected by doses less than 0.1 kg/ha. Pendimethalin at 0.2 kg/ha reduced fresh weight of beet by more than 20% but the other crops were relatively tolerant of the herbicide. Napropamide was particularly active against lettuce, barley, onion and carrot with doses of 0.15, 0.20, 0.30 and 0.30 kg/ha respectively reducing fresh weights by 20%. Persistence of the herbicides in the soil following application in the spring was also measured and the crop response data are discussed in terms of the following crops which may be at risk from residues in the soil.

INTRODUCTION

There are many reports in the literature of problems associated with herbicide residues in the soil. In most of these, the responses of crops sown at intervals following herbicide application were assessed but measurements of herbicide residues in the soil at the time of sowing or when phytotoxicity symptoms developed were not made (e.g. Lallukka et al., 1974; Burnside and Schultz, 1978). Such results are useful in identifying potential residue problems but they do not allow quantitative interpretation in terms of residue levels causing crop damage and are therefore of limited value for advisory purposes. In recent years, some attempts have been made to measure crop responses to defined soil concentrations of herbicides with the hope that such measurements will permit better interpretation of residue analyses. For example Walker and Brown (1980) incorporated seven herbicides into the soil at a range of concentrations and sowed seven crops in the herbicide-treated plots. When crop responses had stabilised, fresh weights were recorded and the concentrations of herbicide in the soil which gave a 20% reduction in fresh weight were tabulated for the different herbicide/crop combinations. Similar results for other herbicide/crop combinations have been reported by Caverley (1978), Eagle (1978) and Walker and Bond (1978). The present paper summarises results from experiments made at Wellesbourne to measure the responses of different crops to low doses of pendimethalin, napropamide, metazachlor and chlorsulfuron.

EXPERIMENTAL METHODS

The soil was a sandy loam with pH 6.5 containing approximately 2% organic matter, 18% clay and 70% sand. The herbicides used were commercial formulations of pendimethalin, napropamide, metazachlor and chlorsulfuron, and the crops examined were cabbage (cv. Winningstadt), lettuce (cv. Borough Wonder), carrot (cv. Chantenay), red beet (cv. Detroit), onion (cv. Rijnsburger Wijbo), dwarf French bean (cv. Processor), barley (cv. Georgie), turnip (cv. Golden Ball) and spinach (cv. Noorman).

Experiments in 1981

With the exception of chlorsulfuron, the herbicides were applied to separate small field plots (4 x 1.5 m) at 0.8, 0.6, 0.4, 0.2 and 0.1 kg a.i. in 1100 l/ha. Chlorsulfuron was applied at 20, 10, 5, 2.5 and 1.25 g/ha. The herbicides were incorporated with a single pass of a rotary power harrow at a working depth of approximately 10 cm. There were three plots for each rate, the first of which was drilled with single rows of barley, dwarf bean and red beet, the second with spinach, onion and cabbage, and the third with turnip, carrot and lettuce. There were five untreated control plots for each group of crops. The treatments were not replicated but the experiment was carried out twice (preparation dates, 12 May and 4 June). When the responses of the crops had stabilised (after about 8 weeks), fresh weights were measured by harvesting the central 2 m of the crop rows in each plot.

Experiments in 1982

Further experiments were made with chlorsulfuron and metazachlor in 1982 using an extended range of doses with each herbicide. The rates of chlorsulfuron examined were 16, 8, 4, 2, 1, 0.5 and 0.25 g a.i./ha, and of metazachlor were 1.6, 0.8, 0.4, 0.2, 0.1, 0.05 and 0.025 kg a.i./ha. The experimental procedure was the same as in 1981 and the experiment was carried out twice (preparation dates, 5 May and 9 June).

Measurement of herbicide persistence

Separate small field plots (6 x 1.5 m) were sprayed with napropamide, pendimethalin or metazachlor at 2.0 kg a.i./ha, or with chlorsulfuron at 30 g a.i./ha on April 23 1981. There were three replicates for each herbicide. Immediately after application, napropamide was incorporated to a depth of 4-5 cm with a rotary power harrow, but the other herbicides were not incorporated. On the day of herbicide application, 30 cores (2.5 cm diameter to a depth of 10 cm) were taken from each plot at random positions. The cores from each plot were bulked together, passed several times through a 2-mm mesh sieve and the total weights of sieved soil recorded. Further samples were taken in a similar way at intervals during the subsequent 20 weeks. Chlorsulfuron residues in the soil were measured using a bioassay based on the shoot growth of lettuce similar to that described by Bond and Roberts (1976). The minimum detectable concentration was 0.5 µg/kg soil. Pendimethalin, napropamide and metazachlor residues were measured by gas-liquid chromatography. The herbicides were extracted from duplicate subsamples of soil (50 g) by shaking for 1 h on a wrist-action shaker with methanol (50 ml; pendimethalin and metazachlor) or acetone + water (50 ml, 8 + 2 by volume; napropamide). The samples were allowed to stand until the soil had settled when 25 ml of the clear supernatant was removed. This was evaporated to a small volume and 5% sodium sulphate solution (50 ml) and hexane (10 ml) was added. After shaking and phase separation, herbicide concentrations in the hexane layer were determined using a Pye-Unicam series 104 gas liquid chromatograph fitted with a thermionic nitrogen detector. The column used was 5% SE30 on chromosorb-W High Performance and gas flow rates were nitrogen 50 ml/min, hydrogen 30 ml/min and air 450 ml/min. The detector temperature was 300°C and the column temperature was 215°C (pendimethalin), 225°C (metazachlor) or 235°C (napropamide). Duplicate 3 µl injections were made and the peak heights obtained were compared with those from similar injections of solutions containing known concentrations of the appropriate herbicide.

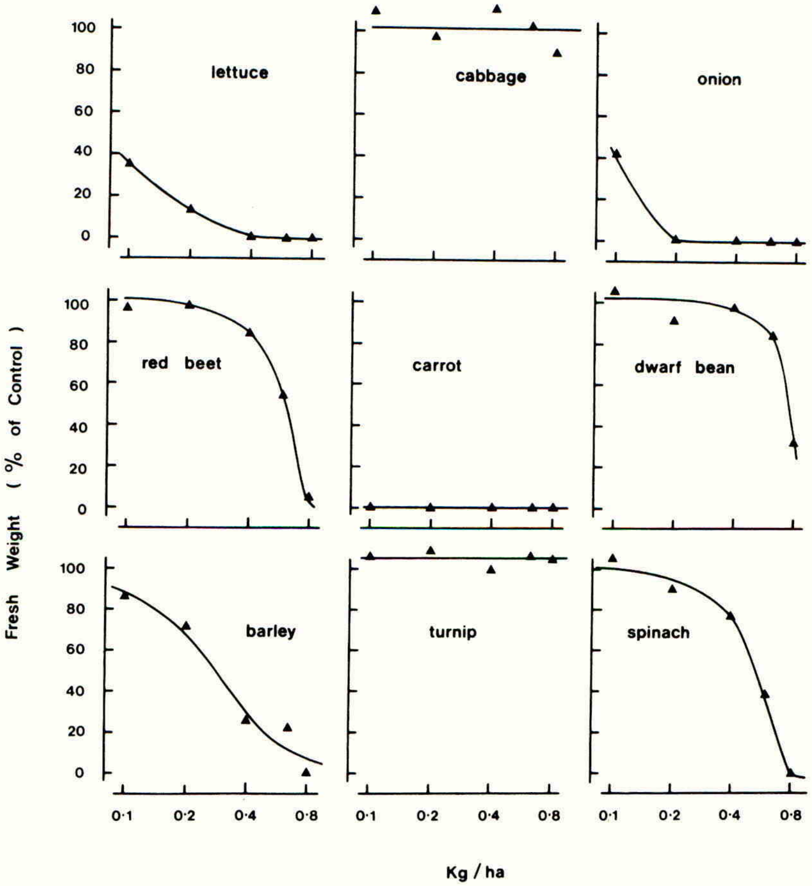
RESULTS AND DISCUSSION

Evaluation of crop responses

Examples of the dose response curves obtained in 1981 are shown in Figure 1. These data are from the experiment prepared on 4 June and show the fresh weights of the different crops (percentages of the untreated controls) as a function of the rate of metazachlor incorporated into the soil. There were marked differences between the crops in their sensitivity to the herbicide. Growth of cabbage and

Fig.1

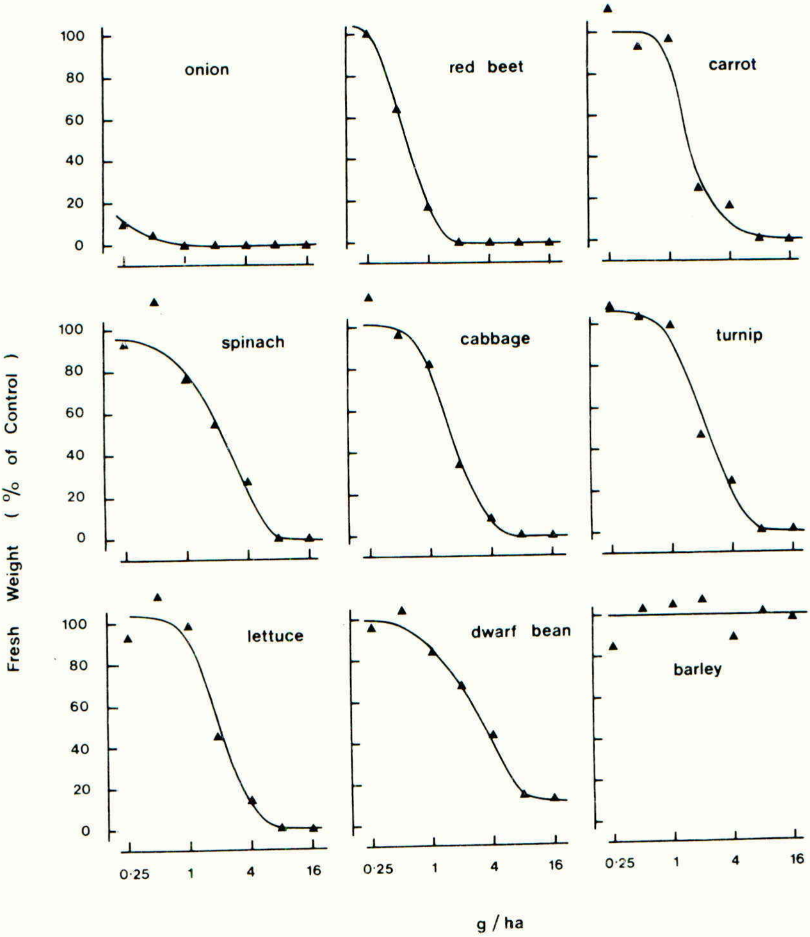
Response of nine crops to metazachlor incorporated into the soil



turnip was not affected at any of the rates examined, and the fresh weight of dwarf bean was reduced only at the highest rate (0.8 kg/ha). Red beet and spinach were intermediate in sensitivity and growth was reduced at doses above 0.3 kg/ha in the soil. Barley was somewhat more sensitive and doses above 0.2 kg/ha reduced fresh weight by more than 20%. Onion, lettuce and carrot were particularly sensitive and fresh weights were reduced by more than 60% at the lowest rate tested. The results from the experiments in 1981 also showed a wide range of crop responses to chlorsulfuron. Growth of barley was unaffected at the highest rate (20 g/ha) but growth of other crops (lettuce, onion, red beet) was severely affected even at the lowest rate (1.25 g/ha). For this reason, further experiments were made with metazachlor and chlorsulfuron in 1982 using extended dose ranges. Examples of the results obtained with chlorsulfuron in 1982 are shown in Figure 2. Growth of barley was not affected at 16 g/ha but all of the other crops were sensitive to the herbicide. The most sensitive crop was onion; fresh weight was reduced by more

Fig. 2

Response of nine crops to chlorsulfuron incorporated into the soil



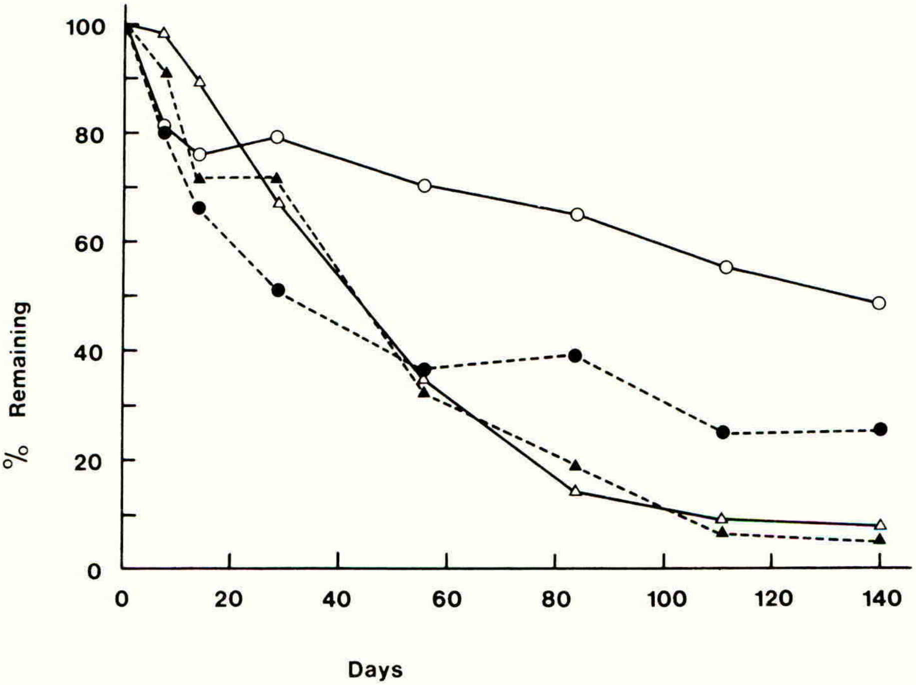
than 80% at 0.25 g/ha. The dose required to reduce fresh weights of the other crops by 50% compared with untreated controls was 0.63, 1.24, 1.51, 1.58, 1.78, 2.00 and 3.16 g/ha for red beet, carrot, spinach, cabbage, lettuce, turnip and dwarf bean respectively.

Summary of crop responses

The rates of herbicide which gave a reduction in crop fresh weight of 20% compared with untreated controls were derived from dose/response curves similar to those in Figures 1 and 2 for each herbicide/crop combination in each experiment. The average coefficient of variation in control fresh weights was about 10% and a reduction in fresh weight of 20% therefore represents the least significant difference at P = 0.05. A summary of the crop responses to the four herbicides averaged

Fig. 3

Persistence of napropamide (○), pendimethalin (●), metazachlor (△) and chlorsulfuron (▲) in soil following application on April 23 1981



across the different experiments is shown in Table 1. These data are expressed as kg/ha or g/ha and as concentrations in the top 10 cm soil. The concentrations were calculated from the appropriate rates (kg or g/ha), soil depth (10 cm) and soil bulk density (1.4 g cm^{-3}). These results further demonstrate the very high activity of chlorsulfuron in the soil with growth of all crops except barley affected at doses lower than 1 g/ha. Lettuce, onion and carrot were the most sensitive to metazachlor and their growth was reduced by doses less than 0.1 kg/ha. Pendimethalin at 0.2 kg/ha reduced fresh weight of beet by more than 20% but the other crops were relatively tolerant of the herbicide. Napropamide was particularly active against lettuce and barley with doses of 0.15 and 0.20 kg/ha respectively reducing fresh weights by 20%.

Persistence of the herbicides in soil

Results from the measurements of herbicide persistence are shown in Figure 3 in which the data are presented as percentages of the amounts recovered immediately after application as a function of time after application. Residues of metazachlor and chlorsulfuron declined relatively rapidly with the time for 50% loss between 40 and 50 days. After 20 weeks, only 5 to 8% of the amounts applied could be recovered from the soil. In contrast, napropamide was highly persistent; even after 20 weeks, over 50% of the amount applied could still be recovered. Pendimethalin residues declined rapidly during the first 3 to 4 weeks with about 50% remaining after 29 days. However, subsequent losses occurred more slowly and about 25% of the applied dose remained after 20 weeks.

Significance of residues to following crops

The crop response data in Table 1 together with the persistence results in Figure 3 permit some conclusions to be reached concerning the possible significance of soil residues of the herbicides to following crops. These conclusions must be treated with some caution since the data refer to only one soil type; further experiments are required on other soils before firm recommendations concerning the safety of rotational crops can be made.

Metazachlor is a new herbicide with clearance in 1982 for use in oilseed rape at a rate of 1.25 kg a.i./ha. With the exception of winter cereals which may be sown 12 to 15 months after application, no other crop is likely to be sown for at least 18 months. The results in Figure 3 suggest that metazachlor is of sufficiently short persistence for soil residues to be of little importance after this time. However, if the herbicide is developed for weed control in horticultural brassica crops which have a much shorter growing period than oilseed rape, the results suggest that some attention should be paid to rotational crops since carrot, lettuce and onion were sensitive to very low concentrations in the soil (Table 1).

Chlorsulfuron is also a new herbicide and is likely to be used for pre- or early post-emergence weed control in autumn-sown cereals at rates between 10 and 20 g a.i./ha. Somewhat lower rates may be recommended for weed control in spring-sown cereals. It was highly active against all the crops examined in the present experiments with the exception of barley (Table 1). However, it was also of relatively short persistence (Figure 3). When used in autumn-sown cereals, it is unlikely that crops other than cereals or oilseed rape will be sown within 12 months of application and soil residues should be sufficiently low to allow these crops to be sown safely. However, autumn-sown onions may also be grown in rotation with cereals and the very high susceptibility of onions to chlorsulfuron (Figure 2; Table 1) suggests that they may be at risk from soil residues. When used in spring-sown cereals, only a following cereal crop may be sown in the autumn and other crops are unlikely to be sown until at least 12 months after application. A possible exception again is onion which may be sown very early in the spring and the results suggest that this crop may be marginal in safety.

The main use of pendimethalin is for pre-emergence weed control in winter barley at rates from 1 to 2 kg a.i./ha. The only crop which showed marked sensitivity to soil residues was red beet (Table 1) and because of the long persistence of pendimethalin in the soil after an initial rapid loss by volatilisation (Walker and Bond, 1977; Figure 3), this crop together with sugar beet may be marginal in tolerance following use of the herbicide at the higher rate.

Napropamide is used as a soil-incorporated pre-sowing herbicide in oilseed rape at a rate of 0.8 kg a.i./ha. The very long persistence of this herbicide (Figure 3) together with the relative susceptibility of barley (Table 1) suggests that on some soils, autumn sown cereals may be at risk from residues in the soil. Current label recommendations state that the soil should be ploughed before a following cereal crop is sown and the present data strongly support this recommendation. It has been shown that deep ploughing can minimise the phytotoxicity of residues of a number of soil-applied herbicides (Eagle, 1978). If napropamide were to be developed for weed control in horticultural brassicas and hence used in a vegetable rotation, close attention must be paid to soil residue problems since lettuce, carrot and onion were sensitive to relatively low concentrations in the soil.

Table 1

Herbicide concentrations giving a 20% reduction in crop fresh weight

Amount which reduces fresh weight by 20%

	Metazachlor		Chlorsulfuron		Pendimethalin		Napropamide	
	kg/ha	µg/g	g/ha	µg/kg	kg/ha	µg/g	kg/ha	µg/g
Lettuce	0.03	0.021	0.80	0.57	>0.80	>0.57	0.15	0.11
Cabbage	>0.80	>0.57	0.75	0.54	>0.80	>0.57	>0.80	>0.57
Onion	0.08	0.057	< 0.25	<0.18	0.70	0.50	0.30	0.21
Red beet	0.40	0.29	0.35	0.25	0.20	0.14	>0.80	>0.57
Carrot	0.025	0.018	0.40	0.29	>0.80	>0.57	0.30	0.21
Dwarf bean	0.62	0.44	1.00	0.71	>0.80	>0.57	>0.80	>0.57
Barley	0.15	0.11	>16.0	>11.4	0.80	0.57	0.20	0.14
Turnip	>0.80	>0.57	0.85	0.61	>0.80	>0.57	>0.80	>0.57
Spinach	0.52	0.37	0.50	0.36	0.50	0.35	0.55	0.39

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EFFECT OF SOIL pH ON THE PHYTOTOXICITY OF ELEVEN SOIL-ACTING HERBICIDES

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Summary The effects of soil pHs from 4.7 to 7.4 were investigated on the phytotoxicity of chloroxuron, chlortoluron, diuron, isoproturon, methabenzthiazuron, metoxuron, linuron, terbacil, aziprotryne, terbuthylazine and metribuzin using cabbage seedlings grown in pots as test plants. It was found that as pH increased there was an increase in the rate of action of all herbicides.

INTRODUCTION

The activity of several herbicides has been shown to increase with soil pH. For example Ladlie et al (1976) demonstrated that the effectiveness of metribuzin increased as the pH increased from 4.6 to 6.7. Böttger et al (1977) reported that terbutryne activity increased with soil pH but the activities of methabenzthiazuron and chlortoluron were not affected by pH. In another study Banting et al (1976) found that the phytotoxicity of chlortoluron and metoxuron increased with increasing soil pH.

To obtain further information on the effect of soil pH on the activity of herbicides the phytotoxicity of eleven soil-acting herbicides was investigated using soils of four pHs. The objective was to determine whether slight to moderate acidity, which would have little direct effect on crop growth, affects the efficiency of the herbicides. Regular application of lime to maintain a soil pH of about 6.5 is recommended (Anon, 1979) for arable cropping on mineral soils since crop yield may be reduced by pHs below about 5.8. Between limings, however, soil pHs of 6 or below commonly occur, particularly in patches.

METHODS AND MATERIALS

The herbicides investigated were chloroxuron, chlortoluron, diuron, isoproturon, methabenzthiazuron, metoxuron, linuron, terbacil, aziprotryne, terbuthylazine and metribuzin. The rates applied for the former six herbicides were 0.25, 0.50, 0.75, 1.0, 1.5, 2.0, 3.0 and 4.0 mg/kg thoroughly mixed into the soil and treatments were not replicated except for the 1.0 mg/kg treatment with metoxuron which was in duplicate. For the latter five herbicides the treatment rates were 1.0, 1.5 and 2.0 mg/kg thoroughly mixed into the soil and replicated four times. The soils used to investigate the former nine herbicides were obtained from the liming experiment at Woburn Experimental Station situated on a coarse sandy loam soil. The liming treatments were O (no lime), L (low), M (medium) and H (high). Soil pHs were 4.7, 5.7, 6.4 and 7.1 respectively. Soil organic matter contents (Tinsley chromic acid oxidation method) were 1.2, 1.2, 1.4 and 1.3 per cent respectively. The soils used for the latter two herbicides were obtained from a similar experiment at Shardlow ADAS sub- centre. Soil pHs were 4.7, 5.6, 6.3 and 7.4 respectively. The soil was a sandy loam containing 2.7% organic matter. Before incorporating the former six herbicide treatments the soil was autoclaved for 1 hour (at 121°) in an Astell Horizontal autoclave. Substituted urea herbicides are subject to biological breakdown (Murray et al, 1969) and the object of the autoclaving was to minimise degradation during the experiment as the rate might be affected by soil pH. Autoclaving was shown by Jamet (1975) to almost prevent breakdown of chloridazon during 49 days incubation. The soil used for the other five herbicides was not autoclaved.

After incorporation of the herbicide treatments the soils were potted in 60 mm plastic pots with saucers. Each pot was sown with 10 cabbage seeds (variety Decema extra late) and after emergence thinned to 6 plants per pot.

The plants were grown in a glasshouse (temperature range 10 ± 6 °C) during the periods January to April and September to December, 1980. Supplementary lighting to give a day length of approximately 12 hours was given using 400 W high pressure mercury vapour lights.

Watering was with mains water for the herbicides diuron, chlortoluron, isoproturon, methabenzthiazuron and chloroxuron first tested and demineralised water for the other six herbicides. The experiments continued until the majority of the plants had died (27 - 43 days after sowing).

RESULTS AND DISCUSSION

At the end of the experiments in which mains water was used it was found that the pH of the soil from the 0, L, M and H liming treatments had risen to 5.2, 6.1, 7.2 and 8.0 respectively. In the subsequent experiments using de-mineralised water the final pHs were unchanged.

Table 1

Effect of herbicide rate on percentage of plant deaths at all rates of lime

Herbicide	Herbicide rate mg/kg							
	0.25	0.50	0.75	1.0	1.5	2.0	3.0	4.0
	Percentage of plant deaths*							
chloroxuron	0	0	0	0	29	58	58	79
chlortoluron	17	17	29	17	50	22	71	54
diuron	54	50	88	71	92	100	100	100
isoproturon	4	21	21	38	54	38	38	75
methabenzthiazuron	0	0	46	25	42	38	54	42
metoxuron	8	8	42	63	50	67	-	-
linuron	-	-	-	13	19	20	-	-
terbacil	-	-	-	23	27	29	-	-
aziprotryne	-	-	-	12	16	13	-	-
terbuthylazine	-	-	-	18	17	24	-	-
metribuzin	-	-	-	14	22	29	-	-

*when significant number of deaths first occurred (18 - 26 days after sowing)

Table 2

Effect of lime rate on mean percentage of plant deaths at all rates of herbicide

Herbicide	Lime rate							
	0	L	M	H	0	L	M	H
	% of plant deaths*				% of plant deaths Ø			
chloroxuron	13	10	44	46	31	52	52	54
chlortoluron	25	13	40	73	98	98	98	100
diuron	65	71	92	100	98	100	100	100
isoproturon	27	21	42	54	58	81	81	96
methabenzthiazuron	8	15	40	60	88	71	69	73
metoxuron	17	21	62	71	71	81	79	83
linuron	9	12	18	39	65	85	87	92
terbacil	12	17	24	51	83	76	94	96
aziprotryne	8	6	8	33	65	89	92	95
terbuthylazine	10	17	31	48	83	89	97	100
metribuzin	21	32	31	32	81	84	96	99

*when significant number of deaths first occurred (18 - 26 days after sowing).

Ø at termination of experiment (27 - 43 days after sowing.)

The effects of the herbicide treatments on the number of plant deaths are summarised in Table 1. Table 2 summarises the effect of liming treatment on the numbers of plant deaths caused by the herbicides. The data show that whether or not the soils were autoclaved the rate of action of all the herbicides tested increased with soil pH and for most of the herbicides increased with each increment of soil pH. When the initial soil pH was 5.6 or 5.7 (L) the occurrence of plant deaths due to all herbicides except metribuzin occurred considerably more slowly than when the initial soil pH was 6.3 - 7.4. Thus moderate acidity reduced the phytotoxicity of ten of the eleven herbicides investigated and severe acidity reduced the phytotoxicity of all the herbicides.

ACKNOWLEDGEMENTS

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THE EFFECT OF TILLAGE METHOD AND SOIL FACTORS ON THE PERFORMANCE OF CHLORTOLURON AND ISOPROTURON

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Summary. During autumn 1980 surface soil samples (0-2.5 cm) were collected from forty four fields. The degree of control of *Alopecurus myosuroides* by herbicides was subsequently recorded for each field. Soil adsorptive characteristics, determined as Kd values for chlortoluron, seemed to have more potential for predicting poor herbicide performance in the field than did organic matter analyses.

Direct drilled fields were associated with poor herbicide performance. There was no clear relationship between pH, soil textural class, nutrient status (P, K, Mg) and herbicide performance.

The possible use of soil Kd measurements as an advisory aid to identify fields where poor herbicide activity may occur is discussed.
Adsorption, burnt straw residues, organic matter, pH, soil texture, nutrients.

INTRODUCTION

The herbicides chlortoluron and isoproturon are widely used for controlling grass weeds in winter cereals. In most situations, they achieve excellent levels of control of *Alopecurus myosuroides*. However, occasional failures have been reported associated with minimum tillage systems. There has also been some experimental evidence to link poor herbicide performance with reduced cultivations (Moss, 1978, 1979). Many soil factors can be influenced by tillage, including surface organic matter, structure, pH and nutrient status, but none of these has been specifically linked with the problem.

As reduced cultivations and direct drilling systems are increasingly being adopted, better understanding of the processes involved is needed. As a first step, the work reported here was undertaken to try to identify the factors which might repay more detailed study.

METHOD AND MATERIALS

Soil sampling. Surface (approx 0-2.5 cm) soil samples were collected in autumn 1980 from forty four fields (forty two in winter cereals; two in oil seed rape) in central, eastern and north eastern England. Sampling was done after drilling but before any herbicides were applied. No attempt was made to conduct a random survey. Field staff were asked for soil from areas with both good and bad histories of soil herbicide performance but, in the event, the study was biased towards areas of poor or variable performance.

Although various sampling tools were used (soil corer, bulb planter, trowel) soil samples were taken at random and bulked together for each field.

Soil analyses. Determinations were made for Kd (chlortoluron), organic matter, pH, textural class and potassium, phosphorus and magnesium status.

Kd is a distribution co-efficient given by the ratio:

$$\frac{\text{quantity adsorbed/g soil}}{\text{concentration in equilibrium solution}}$$

It has no general physical significance but gives a useful indication of the capacity of the soil to adsorb herbicide. Strictly, it should not be used for comparative purposes unless the adsorption isotherms are known to be linear but for the purposes of this work the potential errors were not expected to be important. It was also expected that Kd values for chlorluron would be a reasonable indicator of the adsorption of isoproturon. This was because, although the values for the two herbicides differ, the proportionate increase on direct drilled plots compared to ploughed plots had been similar for the two herbicides in a detailed experiment (still in progress).

Kd values were determined by shaking overnight 1 g of air dried soil ground to pass a 52 mesh sieve with 10 mls of 10 mg/l chlortoluron. The slurry was then centrifuged and the chlortoluron concentration in the supernatant measured by high pressure liquid chromatography. The quantity adsorbed was then estimated from the difference between the initial and final solution concentrations and Kd was calculated as above.

The other analyses were made by standard ADAS methods (Ministry of Agriculture, Fisheries and Food,1973).

Field records. Details of cropping, cultivation, straw disposal and herbicide history were recorded for the period 1976 to 1981. Each farmer was also asked for comments on the control of *A. myosuroides* by herbicides for each year. The degree of weed control in the 1980/81 crop was visually assessed by the person who had done the soil sampling. Each field was then placed in a 'good', 'variable', or 'poor' category, based on the level of control achieved in the 1980/81 crop and the farmer's opinion of weed control in the preceding two cereal crops. Where non-urea herbicides had been used in 1980/81, as in the two oil seed rape crops, the decision was based on the past performance of urea herbicides.

RESULTS

Consistently 'poor' control of *A. myosuroides* by substituted urea herbicides occurred in sixteen fields and consistently 'good' control in seven fields. Twenty-one fields were identified where herbicide performance was 'variable' from year to year.

The results are presented in the form of summary tables. We were advised that the data were not in a suitable form for statistical analysis. Full details of the soil analyses and other data for each field can be obtained from the authors. The range and means of the soil analyses are shown in Table 1. In 1980 straw was burnt on 36 fields and baled on 8 fields - two in the 'good', one in the 'bad' and five in the 'variable' control categories.

Table 1

Results of analyses of surface soil samples

		Categories of field performance of urea herbicides		
		Poor	Variable	Good
Numbers of fields		16	21	7
Kd (chlortoluron)	Mean	7.1	4.1	3.1
	Range	2.8-13.6	1.5-6.4	2.1-4.3
% organic matter	Mean	5.4	4.3	3.9
	Range	2.7-11.0	2.9-7.5	2.7-5.6
pH	Mean	6.8	7.1	7.2
	Range	5.2-7.8	5.9-7.9	6.5-7.7
Phosphorus (mg/l)	Mean	50	34	37
	Range	26-105	15-86	29-50
Potassium (mg/l)	Mean	416	389	300
	Range	229-883	93-1138	174-607
Magnesium (mg/l)	Mean	193	220	120
	Range	44-399	60-751	53-278

Kd (chlortoluron). (Table 2) Where Kd values were above 6.0 black-grass control was poor on a high proportion of fields (91%). In contrast, where Kd values were under 3.0, poor weed control occurred on a smaller proportion of fields (17%). Good weed control was not achieved on any fields where Kd value was over 4.5. High Kd values were associated with a low proportion of fields with good weed control and a high proportion of fields with poor weed control.

Table 2

Kd values for chlortoluron : Number of fields in each performance category and % of fields in each Kd class

Kd	Poor		Variable		Good		Total No.
	No.	%	No.	%	No.	%	
< 3.0	2	17	6	50	4	33	12
3.0 to 4.5	2	17	7	58	3	25	12
4.5 to 6.0	2	22	7	78	0	0	9
> 6.0	10	91	1	9	0	0	11
	16	36	21	48	7	16	44

Soil organic matter. (Table 3) High organic matter levels were associated with a high proportion of fields giving poor weed control. However, poor control occurred on 25% of fields with less than 3.5% organic matter and on 57% of fields where organic matter levels were over 5.5%.

Table 3

Soil organic matter content : Number of fields in each performance category and % of fields in each organic matter class

	Poor		Variable		Good		Total No.
O.M. %	No.	%	No.	%	No.	%	
< 3.5	3	25	6	50	3	25	12
3.5 to 4.5	4	31	7	54	2	15	13
4.5 to 5.5	5	42	6	50	1	8	12
> 5.5	4	57	2	29	1	14	7
	16	36	21	48	7	16	44

Predictions of field herbicide performance based on organic matter levels appeared be poorer than those based on Kd values.

Figure 1 shows the relationship between Kd values and % organic matter for all fields. The higher the organic matter level, the higher the Kd value. However, the scatter of points shows that the relationship is not particularly close. Soil from direct drilled fields tended to have a higher Kd value than soil from cultivated fields. The mean ratio of Kd : % OM was 1.6 for direct drilled, 1.0 for shallow tined, 0.9 for deep tined and 0.9 for ploughed fields.

Cultivation system. (Table 4) Direct drilling was associated with poor herbicide activity. There was no clear relationship between the other cultivation systems and herbicide performance.

Table 4

Cultivation system : Numbers of fields in each performance category and % of fields in each cultivation class

	Poor		Variable		Good		Total
	No.	%	No.	%	No.	%	No.
Plough	2	25	5	63	1	12	8
Deep cultivated	0	0	8	80	2	20	10
Shallow cultivated	5	29	8	47	4	24	17
Direct Drill	9	100	0	0	0	0	9
Total	16		21		7		44

Soil pH. (Table 5) There was a slight trend for poor weed control to be associated with low soil pH. However, this was not a very clear relationship as there was a high incidence of poor results in the pH range 7.0-7.5.

Fig. 1

Relationship between Kd values (chlortoluron) and % organic matter in surface soil samples (0-2.5 cm)

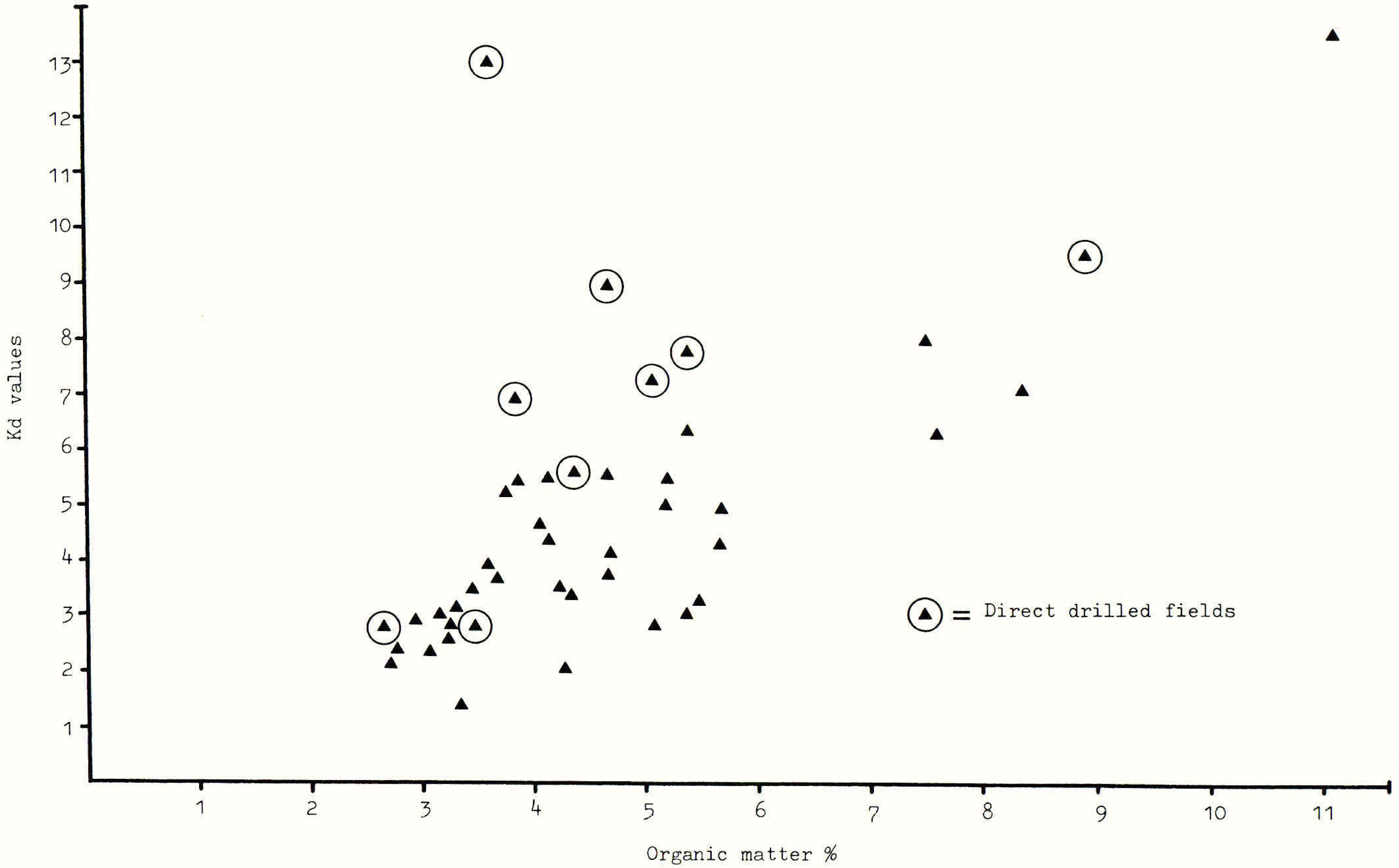

Table 5

Soil pH values : Number of fields in each performance category and % of fields in each pH class

pH	Poor		Variable		Good		Total
	No.	%	No.	%	No.	%	No.
< 6.5	5	62	3	38	0	0	8
6.5 to 7.0	3	25	7	58	2	17	12
7.0 to 7.5	7	58	3	25	2	17	12
> 7.5	1	8	8	67	3	25	12
	16	36	21	48	7	16	44

Soil textural class. (Table 6) and nutrient status (Table 1). There were no obvious relationships between any of these characters and herbicide activity.

Table 6

Soil textural class : Number of fields in each performance category

	Poor	Variable	Good	Total
Fine sandy loam	3	3	0	6
V. fine sandy loam	2	2	0	4
Loam	7	12	6	25
Silty loam	3	2	1	6
Clay loam	0	1	0	1
Silty clay loam	1	1	0	2
Total	16	21	7	44

DISCUSSION

The limitations of this study must be recognised. A relatively small number of fields, and a still smaller number of individual farms were sampled. The definition of the level of weed control was a subjective assessment, open to a variety of interpretations. It was also unfortunate that so many fields had to be included in the 'variable', category. This may reflect the many other factors, apart from soil characteristics, that can affect soil herbicide performance such as climate, application efficiency, state of seedbed.

However, even accepting these limitations the study has produced some interesting results and has identified aspects worthy of further research.

It appeared that poor field performance of both chlortoluron and isoproturon was more reliably indicated using Kd values for chlortoluron than using soil organic matter content. Only one field had an organic matter level above 10% which is the current maximum limit for the approved use of chlortoluron and isoproturon. However, poor herbicide performance occurred in many fields, where the soil organic matter levels were substantially less than 10%.

It is generally considered that organic matter is the most important soil property governing the relative extent of herbicide adsorption in different soils (Hartley and Graham-Bryce, 1980). This study indicated that the adsorptive character of the soil, as measured by Kd value, was sometimes much greater than soil organic matter figures would suggest. However, as already stated, Kd values give only an approximation of adsorption characteristics and can vary according to the herbicide concentration used. Also, Calvet (1980) has shown that the correlation between adsorption and soil organic matter is not always good, especially with soils containing less than 4% organic matter.

The presence of burnt straw residues has been shown to reduce the activity of chlortoluron and isoproturon (Nyffeler and Blair, 1978) probably because of adsorption of these herbicides. More recently, Embling, Cotterill and Hance (in preparation) have suggested that residues equivalent to 5 t/ha of straw, if heated at over 500°C for more than 1 minute, could increase the Freundlich K value of a 1 cm layer of soil by 5 units or more.

Therefore, although burnt straw residues may comprise only a small part of the total soil organic matter they may have a disproportionately greater influence on the adsorptive properties of the soil. It is also possible that the carbon present in burnt straw residues is only partially recorded in conventional organic matter determinations.

Poor herbicide performance was particularly associated with direct drilled fields. Direct drilled soil tended to have a higher Kd value and a higher Kd : % organic matter ratio than soil from other cultivation systems. This supports the view that burnt straw residues were the main cause of poor herbicide performance as, with direct drilling, such residues would be concentrated in the surface soil.

Although there was no clear relationship between pH, soil textural class, nutrient status and herbicide performance in this work, more critical research is needed before any such relationship can be ruled out. pH in particular may be important as previous work with metoxuron has shown that soil pH can affect the performance of this herbicide (Richardson and Banting, 1977).

This work suggests that Kd values could be used as advisory aids in identifying fields where poor activity of soil acting herbicides may arise due to the adsorptive character of the surface soil. Such fields are likely to be those where straw burning and minimum tillage systems are practiced resulting in a concentration of burnt straw residues in the surface soil. Regular Kd measurement might also be useful for monitoring the gradual increase in the adsorptive soil components in long term minimum tillage systems. The rate of such increases is not known but may be influenced by a variety of factors such as soil type, depth of cultivation, and efficiency of straw burn. If there are differences between fields, then routine sampling on a field by field basis would be desirable.

Although Kd values differ for each herbicide, it should be possible to use one compound to characterize a soil. This need not even be a herbicide and such a standard procedure was suggested by Hance et al (1968). In practice it is unlikely that all herbicides will suffer to the same degree on soils with a highly adsorptive character. Field activity is likely to depend on the rates of herbicide used, the intrinsic efficiency of the herbicide at controlling weeds, the effect of climate on herbicide performance and on any foliar action that the herbicide may have. Work is in progress with other herbicides to compare their activity on soil subjected to different cultivation systems.

It must be stressed that soil adsorption measurements are unlikely to predict accurately field herbicide performance as other factors, particularly climatic conditions, can have a large influence (Hance et al, 1968). However, such measurements may be useful in identifying the existence of a potential problem due to the presence of adsorptive burnt straw residues, even if the degree of the problem cannot be defined. Further work is needed on a wider range of fields before the value of an adsorption measurement as a practical advisory aid can be assessed.

Meanwhile, for the small but apparently growing minority of farmers with this problem the following suggestions have been made:

(a) Both chlortoluron and isoproturon achieve better performance from early post-emergence applications than when applied pre-emergence on marginally suitable soils. On very highly adsorptive soils, neither peformance may be satisafactory.

(b) Cussans and Moss (1982) have suggested that this problem increases with the length of time the land is cropped by minimum tillage. On the basis of a simple population model for A. myosuroides they suggest rotational ploughing, possibly on a 5-6 year cycle, to prevent build up of highly adsorptive top soil.

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INFLUENCE OF WEATHER ON HERBICIDE BEHAVIOUR IN SOILS

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Summary. The movement and degradation of propyzamide and chlortoluron were simulated for spring and autumn applications respectively, using weather data for the years 1974-1981. The results were compared with information from the Pesticide Residues sections of the MAFF-ADAS Regional Agricultural Science Service Annual Reports for these and other herbicides. Large differences in the amount of degradation, after spring applications, were simulated for different seasons but for moderately strongly adsorbed herbicides differences between the amount of movement between seasons seemed less important. The amount of degradation, after autumn applications, were similar for different years but the effect of movement was probably more significant. Prediction of risk of damage to following crops or failure to control weeds may be achieved by simulation of degradation alone for spring application but simulation of movement is necessary for autumn applications. In the future such simulations may provide a numerical basis for advice given to farmers where soil analyses are not available. Weather, simulation model, degradation by soil, herbicide leaching, chlortoluron, propyzamide, metribuzin, terbutryne.

INTRODUCTION

Weather affects the amount and distribution of herbicides in the soil, even so incidents of damage to crops or weed control failure are relatively few and usually result from accidental application of an incorrect dose, for example by overlapping the treatment at the ends of a spray boom. In some years weather may influence degradation and redistribution of the chemical such that high residues and damage to following crops occurs. When this risk is large farmers are advised to mouldboard plough before sowing the next crop but this is expensive so an accurate assessment of the risk would help them to decide if cheaper methods of cultivation are appropriate.

The most detailed studies of the influence of weather on herbicide behaviour in soil have been concerned with patterns of rainfall which occur shortly after application and were reviewed by Walker (1980a). The influence of temperature and soil type on degradation in soil were considered by Briggs (1980) who concluded that there will be little difference in degradation rate between different places in England and Wales. Walker (1980b) showed that differences in degradation for different application dates were greater than for different years for periods longer than four months. This paper compares, for different seasons, the effect of rainfall, evaporation and temperature on herbicide movement and degradation.

Recently simulation models have been developed to describe movement and degradation of pesticides in soil for example :Walker (1974), Leistra *et al* (1982), Nicholls *et al* (1982a,b). The model developed by Walker, which calculates degradation but not movement, is being used by ADAS to help to answer questions such as the safety on applying further treatments after the initial ones have failed to control weeds effectively.

The object of the present work is to discern in which seasons the distribution and persistence of herbicides was unsatisfactory, by simulating their movement and degradation, and to see if they correspond with those in which a greater than average number of reports of adverse behaviour were received by ADAS.
The work illustrates how simulations may, in the future, provide a numerical basis for advice given to farmers where soil analyses are not available.

SIMULATION

Simulations were made, using the model CALF described by Nicholls et al (1980a). The model simulates water and herbicide movement using the mobile and immobile water categories of Addiscott (1977). Herbicide degradation was calculated, as a function of soil temperature and water content (Nicholls et al. 1980a) using the equations of Walker (1976). Soil temperature was calculated from air temperatures by the method of Walker and Barnes (1981). The model requires the following data as input:

Weather (daily)	Rainfall Evaporation from an open water surface Maximum and minimum air temperature
Soil	Initial water contents Bulk densities Water content at field capacity and -2 bar pressure (-2x10^{5} Pa)
Herbicide	Initial distribution Adsorption coefficient Degradation rate constants

Weather data was measured at the Rothamsted weather station. Rothamsted soil (organic content 1.5%) was taken as representative of arable soils. Adsorption coefficients were calculated from octanol-water partition coefficients (Briggs, 1981).

Chlortoluron and propyzamide were chosen to represent typical autumn and spring applied treatments respectively and not because they give problems in use. They are sufficiently persistent to allow the influence of weather, for periods of many months, to be discerned and may give indications of the performance of compounds with similar behaviour such as metribuzin and terbutryne.

SUMMARY OF THE KNOWN EFFECTS OF WEATHER ON HERBICIDE BEHAVIOUR

Degradation rates increase with temperature and soil water content. Hence high temperature gives large degradation rates which might be opposed by soil being drier. Large rainfall produces downward movement, lowering herbicide concentration, and wet soil which favours degradation.

RESULTS AND DISCUSSION

Two seasons were considered spring-summer, March 1 - September 30 and autumn-winter, September 10 - February 28.

Table 1

Soil temperature at 10 cm depth (°C)[a]

Year	Mar 1 - Sept 30	April 1 - Sept 30	May 1 - Sept 30
75	12.5	14.0	15.4
76	13.3	14.9	16.4
77	11.2	12.2	13.5
78	11.4	12.5	13.9
79	11.4	12.8	14.1
80	11.5	12.8	13.9
81	12.0	13.0	14.1
Mean	11.9	13.2	14.5
Range	2.1	2.7	2.9

[a] Mean of readings taken daily at 0900 h, Rothamsted.

Table 2

Simulated recovery of propyzamide on September 30

Year	Total amount remaining (%)	Mean depth of penetration (cm)	Amount remaining in top 1 cm (%)
Applied March 1			
75	13	0.8	10
76	21	0.6	18
77	16	0.9	10
78	15	0.9	10
79	14	0.9	9
80	16	0.9	11
81	12	0.9	8
Applied April 1			
75	18	0.8	13
76	24	0.6	22
77	21	0.9	14
78	19	0.8	13
79	21	0.8	15
80	22	0.8	15
81	19	0.8	13
Applied May 1			
75	25	0.7	21
76	27	0.6	24
77	26	0.8	19
78	23	0.8	17
79	26	0.7	21
80	25	0.8	18
81	23	0.8	17

Table 3

Rainfall R, Evaporation E, Potential transpiration T (mm)

Year	Mar 1-Sept 30				April 1-Sept 30				May 1-Sept 30			
	R	E	T	(R-T)	R	E	T	(R-T)	R	E	T	(R-T)
75	372	571	492	-120	283	553	471	-188	230	512	419	-189
76	232	669	571	-339	215	629	534	-319	194	539	473	-279
77	354	459	458	-104	299	435	429	-130	268	386	374	-106
78	408	486	469	- 61	331	459	432	-101	274	420	386	-112
79	470	518	487	- 17	341	490	460	-119	248	443	406	-158
80	351	521	480	-129	272	493	454	-182	243	430	393	-150
81	414	490	431	- 17	363	466	406	- 43	312	409	354	- 42
Mean	372	530	484	-112	301	504	455	-155	252	448	401	-148
Range	238	210	140	322	148	194	128	-276	118	153	119	237

Table 4

Rainfall R, Evaporation E, Potential transpiration T (mm)

Year	Sept 1-Feb 28				Oct 1-Feb 28				Nov 1-Feb 28			
	R	E	T	(R-T)	R	E	T	(R-T)	R	E	T	R-T
74-75	514	136	74	440	411	83	36	375	308	54	26	288
75-76	260	157	88	172	157	82	41	116	139	45	25	114
76-77	581	132	72	509	457	73	34	441	352	48	15	337
77-78	353	143	105	248	330	71	54	276	281	40	33	248
78-79	329	147	102	227	299	66	43	256	294	25	20	274
79-80	356	154	97	259	338	78	40	298	258	39	23	235
80-81	266	148	101	165	242	79	50	192	145	41	30	115
Mean	380	145	91	288	322	76	43	279	254	42	25	230
Range	321	25	33	344	318	17	20	259	169	29	18	223

Spring - summer

i) Weather data

Mean soil temperatures, at 10 cm depth, for different herbicide application dates are given in Table 1. The temperature range over seven years was less than $3^{o}C$ which is not great enough to cause large differences in the amount of residue remaining in different years. Soil temperature range between years increases as the period decreases; that is the biggest differences between seasons, due to soil temperature, will be over short time periods and hence may be most apparent with less persistent compounds.

Degradation is also influenced by soil water content and the weather factors which influence it are given in Table 3. Evaporation from an open water surface exceeded rainfall in all years. As soil dries evaporation becomes much less than from an open water surface so a better estimate of the net water remaining is obtained from the difference between rainfall and potential transpiration (R-T). Again, water lost from soil always exceeded rainfall so downward movement of moderately strongly adsorbed herbicides is expected to be small. There were large differences in (R-T) between seasons which will have given differences in soil water content and in turn the amount of degradation.

ii) Simulations

The complex effects of weather factors in different years on movement and degradation may be compared using simulations.

The data in Table 2 show that the largest residues occurred in 1976, the warmest and driest season which indicates that in a hot summer dry soil enhances persistence despite high soil temperatures. There was least downward movement in 1976 hence concentrations near the soil surface, indicated by the amount in the top 1 cm, were also large. In the coldest season, 1977, a moderately high total residue was simulated. Relative differences between years of rainfall and simulated degradation are greatest for the earliest application date. In summer for moderately strongly adsorbed compounds downward movement is small and can be quite well simulated by a model such as that of Walker 1976 which ignores movement. This conclusion is favoured by the presence of a crop withdrawing water from soil, not included in the present simulations, which will further limit herbicide movement.

iii) ADAS Reports 1975-1980 (see references)

(a) Quotes:

1975 No general comments on the influence of weather on residues.

1976 The extended drought resulted in enhanced persistence of soil acting herbicides which caused damage to succeeding crops in some instances. A survey in late summer confirmed that residues were high. Ploughing was advised unless an analysis indicated that residues were small.

1977 There were many enquiries about the necessity for ploughing before winter wheat as the weather was wetter than in 1975 or 1976 which might have been expected to result in more complete degradation of propyzamide residues. Ploughing was advised as there were significant residues in several soil samples. The relatively high levels may have been due to the general low summer temperatures which would have resulted in slower degradation

1978-1980 No general comments

Table 5

Soil temperature at 10 cm depth (^{o}C)[a]

Year	Sept 1 - Feb 28	Oct 1 - Feb 28	Nov 1 - Feb 28
74-75	6.2	5.2	4.8
75-76	6.3	4.9	3.5
76-77	5.9	4.4	3.0
77-78	6.2	4.9	3.5
78-79	5.3	3.8	2.2
79-80	6.4	5.0	3.7
80-81	6.0	4.4	3.6
Mean	6.0	4.7	3.5
Range	1.1	1.4	2.6

[a] Mean of readings taken daily at 0900 h, Rothamsted

Table 6

Simulated recovery of chlortoluron on Feb 28

Year	Total amount remaining (%)	Mean depth of penetration (cm)	Amount remaining in top 3 cm (%)
Applied Sept 1			
74-75	43	2.1	33
75-76	49	1.3	46
76-77	43	3.7	16
77-78	47	2.7	29
78-79	54	2.6	35
79-80	48	2.3	34
80-81	49	2.1	38
Applied Oct 1			
74-75	50	1.9	41
75-76	59	1.2	57
76-77	51	3.5	22
77-78	51	2.7	32
78-79	60	2.6	39
79-80	52	2.3	35
80-81	55	2.0	43
Applied Nov 1			
74-75	58	1.7	50
75-76	66	1.1	63
76-77	64	2.8	37
77-78	61	2.5	41
78-79	66	2.5	44
79-80	60	2.2	45
80-81	64	1.8	54

(b) Comments

1976 was an exceptionally hot dry summer and ADAS reports correlate with simulations Table 2. Dry soil must have given small degradation rates despite high temperature. In contrast 1977, the coldest season, low soil temperatures probably caused small degradation rates and relatively large total residues. The influence of temperature on residues is greater in wet than in dry soil which may explain the observations for 76 and 77. The quote for 1977 emphasises the need for computer based advice.

Autumn - winter

i) Weather data

Soil temperature (Table 5) is obviously lower for autumn application and decreases for later application dates. Temperature range is smaller than summer so differences in residues, between years, due to temperature will be even smaller.

Soil water content will be at about field capacity for most of the winter so differences due to it will be small. Soils were probably drier than field capacity in autumn 1978 when only 55 mm of rain fell at Rothamsted. There were large differences in total rainfall between years, which after falling on soil already at field capacity will be effective in leaching reversibly adsorbed herbicides. Hence the biggest differences between years might be not the total residue but the amount of leaching and hence the residue concentration.

ii. Simulation

There are relatively small differences in total residue between years (Table 6) the greatest residue being for 78-79 the coldest winter and driest autumn, (Tables 4,5). High concentrations in soil are indicated by large amounts in the top 3cm. Greatest leaching and hence smallest concentration in soil was simulated for 76-77, the year of greatest rainfall, whilst least leaching and greatest concentrations were for 75-76, the year of least rainfall.

iii. ADAS Reports 1975-1980

(a) Quotes:

Blackgrass herbicides The mild winter (79-80) resulted in more rapid breakdown than usual of autumn applied blackgrass herbicides; a fact which was demonstrated by analysis of soil samples from fields where blackgrass control had been poor. There were many queries about the safety of applying further herbicides. Starting in 1981 it will in future be possible to answer such queries with the aid of computer predictions of herbicide persistence using the N.V.R.S. programme.

Chlortoluron

75-76 No chlortoluron damage reports. Some poor control of weeds
79-80 See above (blackgrass herbicides)

Terbutryne

74-75 A winter barley crop was damaged in the lighter parts of the field. The damage was attributable to leaching, by heavy rain, into the root zone.
76-77 Many crops of autumn sown barley on light land were damaged after application of terbutryne or isoproturon.

78-79 Many winter cereal crops particularly barley showed damage in the spring apparently because of less breakdown than usual during the previous very dry autumn and very cold winter. Similarly for one case of simazine damage.
79-80 In the autumn many winter barley crops were damaged in overlap areas or deeply drilled areas on light sandy soils. This was attributed mainly to rapid growth in warm moist weather before significant amounts of the applied herbicide had degraded.

Metribuzin

75-76 Numerous cases occurred in early spring of damage to winter wheat from residues applied to the 1975 potato crop. Damage was largely in fields where the manufacturers recommendation to plough had not been carried out. Because of late planting due to a wet winter post-emergence applications were very late and residues were more persistent than usual owing to the 1975 summer and autumn drought.
76-77 The widespread damage in wheat after potatoes seen in 1976 was not repeated in 1977 even though residues at the end of 1976 season were high. This in probably a result of the publicity given to the need to plough and rapid breakdown during the autumn of 1976 when the drought finally ended.
77-78 Residues of metribuzin applied to potatoes resulted in a number (12) of damage problems in succeeding crops.
78-79 No reports.
79-80 Damage confirmed in two cases of winter cereals.

(b) Comments:

Blackgrass herbicides Simulations do not indicate that total residues were especially small in 79-80 but they were significantly smaller than the preceeding year.

Chlortoluron It is remarkable that there are almost no reports of damage problems attributable to the weather but in 75-76 there was a report of poor weed control when simulations indicate herbicide concentration were greatest. It has been reported that in the dry autumn and winter of 75-76 preemergence applications of chlortoluron were very slow to act though after christmas the material did generally begin to take effect, Baldwin 1979.

Terbutryne 1974 was a very wet autumn. Greatest leaching was simulated for 76-77 so damage may have been caused by movement into the crop root zone. Greatest residues were simulated for 78-79 which correlate with the conclusions of ADAS.

Metribuzin Specific mention is made by ADAS of 75-76 when crop damage occurred in winter and 76-77 when it did not. Simulations indicate the presence of residues in high concentrations in 75-76 but not in 76-77.

Others In a large series of trials to monitor the performance of soil applied herbicides in Britain, Lutman and Thornton (1981) reported no damage from herbicides in 79-80. However in 80-81 bifenox/linuron, trifluralin/linuron and linuron/monolinuron adversely affected winter cereal crops. Simulations (Table 6) for the later spraying dates indicates less degradation and more leaching occurred in 79-80 than 80-81.

CONCLUSIONS

The degree of correlation between simulations and ADAS reports is summarised in Table 7 which indicates that some further experience in using models which simulate movement is required before they can be used to give reliable advice to farmers.

Table 7

Correlation between simulations and ADAS reports

Spring-summer		Autumn-winter					
Year		Year	BH[a]	C[b]	T[c]	M[d]	Others[e]
75	-[f]	74-75	-	-	fair	-	-
76	good	75-76	-	poor	-	good	-
77	fair	76-77	-	-	good	good	-
78	-	77-78	-	-	-	-	-
79	-	78-79	-	-	good	-	-
80	-	79-80	poor	-	fair	-	good
81	-	80-81	-	-	-	-	good

[a] Blackgrass herbicides
[b] Chlortoluron
[c] Terbutryne
[d] Metribuzin
[e] Lutman and Thornton (1981)
[f] - insufficient information

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EFFECTS OF SOIL MOISTURE ON THE ACTIVITY AND PERSISTENCE OF PROPACHLOR

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Summary. The activity of propachlor against the naturally occurring weed flora and against lettuce, a sensitive test crop, was assessed in four separate field experiments. The rate required for 50% weed kill varied from 1.1 to 3.8 kg/ha, and the rate which reduced lettuce fresh weight by 50% varied from 1.3 to 4.3 kg/ha. In all of the experiments, weed emergence began 10 to 14 days after preparation of the seedbeds but the period over which weeds continued to emerge varied considerably. Persistence of the herbicide in the soil also varied between experiments. When the soil was moist, propachlor concentrations declined to about 5% of the initial amounts after 40 to 50 days but dry soil conditions restricted degradation so that in an experiment prepared on 1 June, over 30% of the amount applied remained in the soil after 42 days. The results suggest that soil moisture content, herbicide concentration in the soil and the speed of weed seedling emergence interact to determine the activity of the herbicide.

INTRODUCTION

The activity of a herbicide following application to soil will be controlled by interactions between several soil and environmental factors which affect the amount of herbicide which is available to and taken up by weed seedlings. Two important factors which affect availability and uptake are the concentration of herbicide in the soil and soil moisture content. Soil moisture content is generally considered to be particularly important and there is considerable qualitative evidence to show that soil-applied herbicides do not perform well under dry soil conditions. One herbicide whose activity appears to be strongly influenced by soil moisture is propachlor (Walker and Roberts, 1974). This herbicide is also of very short persistence in the soil (Beestman and Deming, 1975; Roberts et al., 1981) and it seems probable that in order for it to give good weed control, both residual herbicide concentration and soil moisture content must be sufficiently high to optimise availability during the emergence period of the weeds. This paper summarises the results from a series of experiments made at Wellesbourne during summer 1981 to examine how soil moisture content, propachlor persistence and the timing of weed seedling emergence may interact to determine activity of the herbicide.

EXPERIMENTAL METHODS

Crop and weed responses

The experiments were of randomised block design with three replicates and the plot size was 3 x 1.5 m. The weathered furrow was ring-rolled and a single pass made with a rotary power harrow working to a depth of 10 cm. Two rows of lettuce, 45 cm apart, were sown in each plot, and the plots rolled with a cage roll to produce a relatively even soil surface. Propachlor was applied to separate plots at rates of 0, 0.5, 1.0, 2.0, 4.0 and 6.0 kg a.i./ha. Experiments were prepared on 23 April, 12 May, 1 June and 16 June 1981. The numbers of weed seedlings which emerged on the untreated control plots were counted in the area between the two crop rows at intervals of 2 or 3 days until the flush of seedling emergence appeared complete. The effects of propachlor on the naturally occurring weed flora were assessed by counting the surviving plants of each species on the whole plots about

8 weeks after herbicide application. Lettuce fresh weights were measured by harvesting the central 2 m of each crop row in each plot.

Propachlor persistence

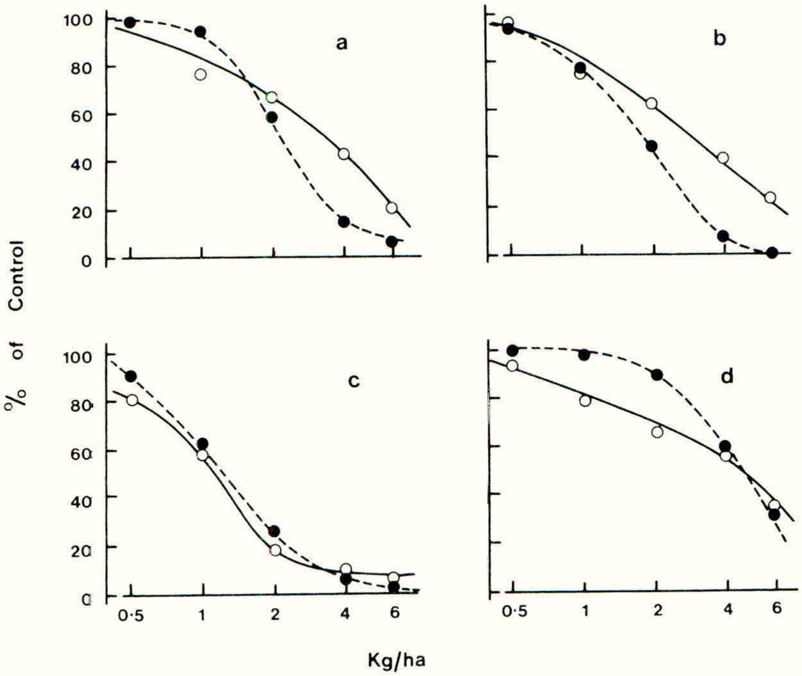
The soil of further replicate plots treated with propachlor at 6 kg a.i./ha was sampled immediately after herbicide application and at intervals during the subsequent 40 to 50 days. On each occasion 20 cores, 2.5 cm diameter to a depth of 10 cm, were taken and bulked separately for each plot. The samples were mixed by passing several times through a 2-mm mesh sieve and the total weights of sieved soil recorded. Propachlor concentrations in the soil were measured by GLC as described previously (Roberts et al., 1981).

RESULTS AND DISCUSSION

Dose response curves obtained in the different experiments are presented in Figure 1. The data show total weed numbers per plot and lettuce fresh weights, both expressed as percentages of the appropriate controls, as a function of propachlor application rate. There was considerable variability between experiments in activity of the herbicide. The rate required to give 50% reduction in weed number was 3.3, 2.7, 1.1 and 3.8 kg/ha in the four experiments respectively, and the rate which reduced lettuce fresh weight by 50% was 2.5, 1.8, 1.3 and 4.3 kg/ha in the different

Fig. 1

Lettuce fresh weight (●) and weed numbers (○) as a function of propachlor application rate in experiments prepared on (a) April 23, (b) May 12, (c) June 1 and (d) June 16 1981



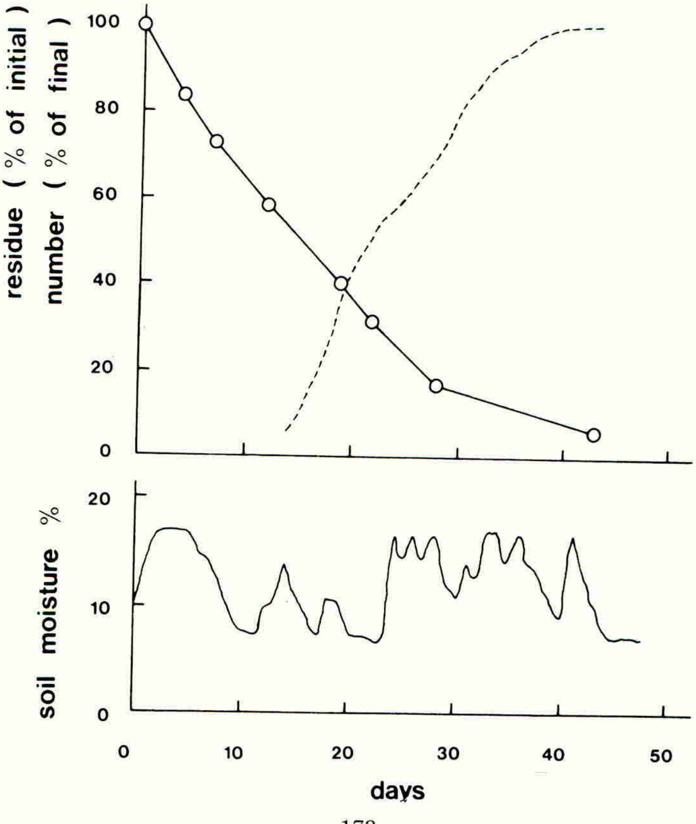
tests. There was little variation in the composition of the weed flora in the different experiments with Veronica spp., Stellaria media, Lamium spp., Poa annua and Capsella bursa-pastoris the dominant species. The variability in weed control can therefore be attributed to variations in soil and environmental factors affecting activity of the herbicide rather than to differences in the susceptibility of the naturally occurring weed flora. This conclusion is supported by the similarity between the variability in lettuce response and the variability in weed control (Figure 1).

The results from the measurements of propachlor residues in the soil and from the counts of the numbers of weed seedlings on the untreated control plots are summarised for experiments 1 to 4 in Figures 2, 3, 4 and 5 respectively. Also shown in these Figures are moisture contents of the surface 5 cm soil during the course of the experiments. These were calculated from the rainfall (mm day^{-1}), the daily maximum and minimum air temperatures (°C) and field capacity soil moisture content (17.1% w/w) using the computer model of Walker and Barnes (1981). The main features illustrated in Figures 2 to 5 are summarised:

(a) Experiment 1 (Figure 2) - Emergence of weed seedlings began 14 days after preparation of the plots and continued for a period of 24 days. The final density was 151 weeds m^{-2}. Soil moisture was high and close to field capacity throughout most of the experiment although there were some short dry spells between 10 and 20

Fig. 2

Propachlor residues in the soil (O), pattern of weed seedling emergence (----) and soil moisture content (——). Experiment prepared April 23 1981

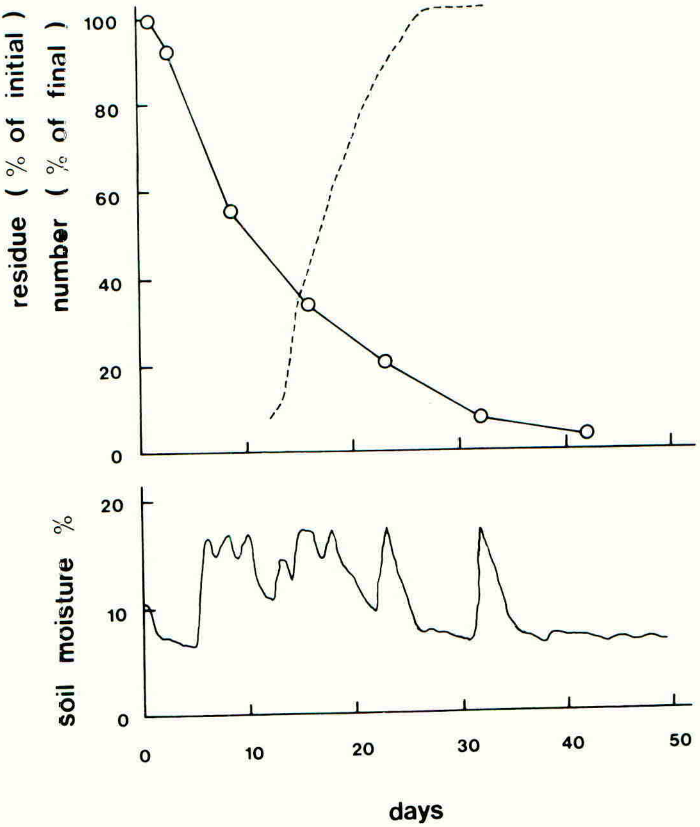


days, spanning the start of weed emergence. Propachlor concentration in the soil declined relatively rapidly and only 50% of the amount applied was recovered from the soil when weed seedling emergence began. When weed seedling emergence was complete, less than 10% of the applied dose remained in the soil.

(b) Experiment 2 (Figure 3) - The flush of weed seedling emergence started 12 days after plot preparation and was complete with 145 weeds m^{-2} by day 28. Propachlor was lost rapidly from the soil and, as in Experiment 1, about 50% of the applied herbicide remained in the soil when seedling emergence began and only 10% remained at the end of the emergence period. Soil moisture content was high immediately before and during the early period of weed seedling emergence.

Fig. 3

Propachlor residues in the soil (O), pattern of weed seedling emergence (----), and soil moisture content (——). Experiment prepared May 12 1981



(c) Experiment 3 (Figure 4) - Weed seedling emergence began 10 days after herbicide application and the initial flush was complete in 9 days (density, 85 weeds m^{-2}). There was rainfall shortly after plot preparation and at the time when weed seedlings first emerged and this gave short periods of moist soil conditions. However, for most of the experiment, soil moisture was below 50% of field capacity. The dry soil conditions had a marked effect on the rate of loss of propachlor. About 40% was lost during the first 4 days but subsequent losses occurred more slowly so that over 30% of the amount applied was present in the soil when weed seedling emergence was complete. There was little change in residual concentrations during the dry period between 19 and 42 days.

(d) Experiment 4 (Figure 5) - The experiment was prepared during a dry period and overhead irrigation of approximately 12.5 mm was given immediately after preparation of the plots. This was sufficient to stimulate weed seedling emergence which began on day 8. The period of emergence, however, was short and the final weed density (48 weeds m^{-2}) was lower than in the other experiments. There was no rain until 30 days after the start of the experiment which was reflected in low soil moisture during this period. The rate of propachlor loss from the soil was reduced considerably by the dry soil conditions. There was no apparent loss between day 8 and day 32, with about 60% of the initial dose remaining in the soil. This was followed by a period of rapid loss after the end of the dry spell and about 20% of the initial dose remained in the soil after 41 days.

Fig. 4

Propachlor residues in the soil (O), pattern of weed seedling emergence (----), and soil moisture content (——), Experiment prepared June 1 1981

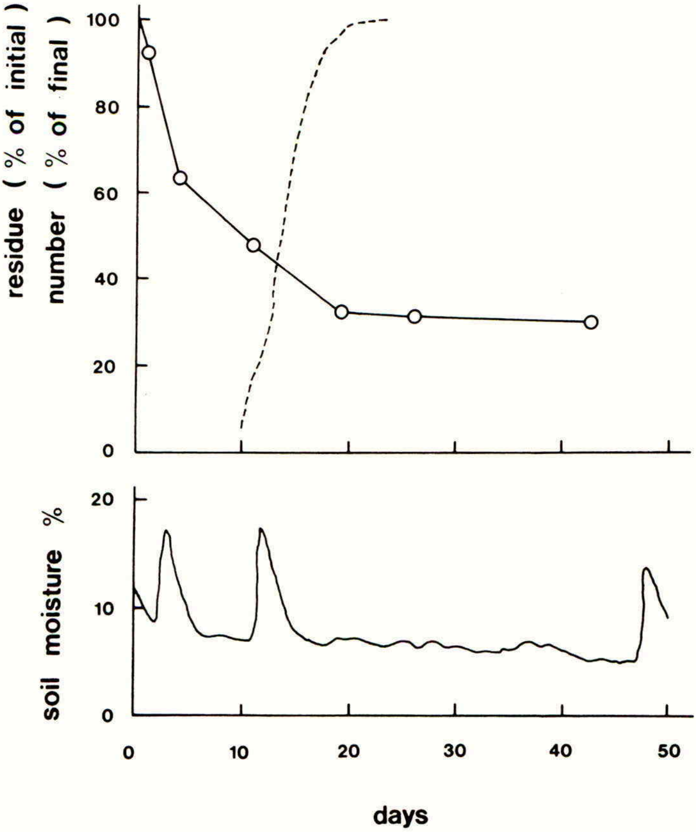
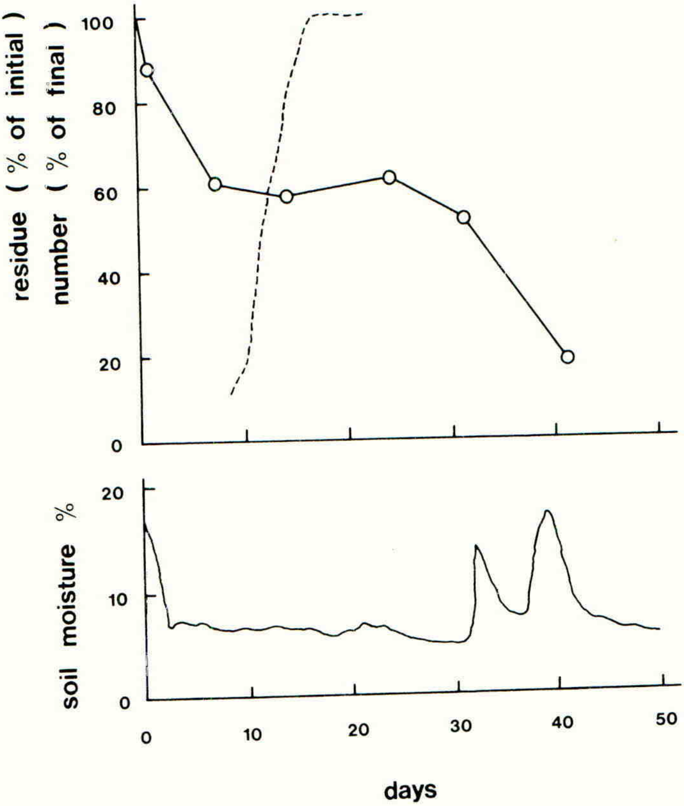


Fig. 5

Propachlor residues in the soil (O), pattern of weed seedling emergence (----), and soil moisture content (——). Experiment prepared June 16 1981



Detailed measurements of the patterns of lettuce emergence were not made in any of the experiments but this always began at approximately the same time as weed seedling emergence, between 8 and 12 days after sowing.

A comparison of the data in Figures 2 to 5 with the crop and weed response results in Figure 1 gives a qualitative indication of how the rate of weed seedling emergence, propachlor persistence in the soil and soil moisture content interact to determine the activity of the herbicide. The herbicide was least active in Experiment 4 (ED50 weeds, 3.8 kg/ha; ED50 crop, 4.3 kg/ha) and the results in Figure 5 suggest that the main reason for this was the very dry soil conditions before, during and after the period of weed and crop emergence. Soil concentrations of propachlor remained relatively high and about 60% of the applied dose remained in the soil when weed and crop emergence were complete. The herbicide was most active in Experiment 3 (ED50 weeds, 1.1 kg/ha; ED50 crop, 1.3 kg/ha). Although the soil was dry during most of this experiment (Figure 4), there was a short period of wetter weather which coincided with the early stages of weed seedling emergence. Soil concentrations of propachlor were relatively high at the start of the period of weed seedling emergence and over 30% of the amount applied remained in the soil when emergence was complete. In the other two experiments, activity of the herbicide was intermediate. It was somewhat higher in Experiment 2(ED50 weeds, 2.7 kg/ha; ED50 crop, 1.8 kg/ha) than in Experiment 1 (ED50 weeds, 3.3 kg/ha; ED50 crop, 2.5 kg/ha). In both of these experiments, soil moisture was generally high although there were some drier periods. In Experiment 1 (Figure 2), these drier periods occurred immediately before and after the start of weed seedling emergence, whereas in Experiment 2 (Figure 3) they occurred towards the end of the emergence period. Together with the results from Experiment 3, these data further suggest that high soil moisture during the early period of weed seedling emergence is important for optimum activity of propachlor. In Experiment 1, the period over which weed seedlings emerged was relatively long and the flush was not complete until 40 days after the experiment was prepared. By this time, less than 10% of the propachlor applied initially could be recovered from the soil. Seedling emergence was more rapid in Experiment 2, and the initial flush was complete in 28 days. However, in this experiment also, propachlor degraded rapidly and less than 10% of the amount applied remained in the soil when seedling emergence was complete. It seems probable that the reduced activity of propachlor in Experiments 1 and 2 compared with Experiment 3 can be explained by its rapid degradation under moist soil conditions.

Soil moisture therefore appears to have two opposing effects on the activity of propachlor. Moist soil conditions at the time of seedling emergence are important to maximise availability of the herbicide. However, moist soil conditions also maximise degradation of the herbicide, so that under some conditions its persistence may be too short to give optimum weed control.

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