HGCA

PROJECT REPORT No. 27

VARIABILITY IN THE CONTROL OF BLACK-GRASS WITH HERBICIDES IN WINTER CEREALS - HARVEST YEARS 1987-1989

JANUARY 1991

PRICE £10.00

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Variability in the control of black-grass with herbicides in winter cereals - harvest years 1987-1989

by

J. H. ORSON

Final report of a five month project which commenced in April 1989. The work was co-ordinated by ADAS Cambridge and was supported by a grant of £14,985 from the Home-Grown Cereals Authority (Project No: 0045/1/89).

Contents

ABSTRACT

Relatively high incidences of poor control of black-grass (Alopecurus myosuroides) with soil-applied herbicides occurred in winter cereals during the harvest years 1987, 1988 and 1989. In 1987, the incidences of poor control were not associated with soil texture but in 1988 and 1989 there was an association with heavy soils.

A review of the literature on the factors affecting the activity of the major soil-applied black-grass herbicides of the substituted (phenyl) urea group along with specific studies was commissioned by the HGCA in 1989.

The pot studies indicated that waterlogging in autumn 1987 and enhanced degradation were not contributory factors. However, the common observation of the establishment of the weed root system at greater depths below the soil surface than normally occurs was proved to reduce the control achieved by soil-applied herbicides. This "deep-rooting" has been associated with specific seedbed conditions and cultivation practices.

This report explains some of the factors associated with poor control in the years in question. Lack of rainfall after application was predicted not to have given sufficient herbicide movement in the heavier and more absorptive soils for optimal activity in 1988 and 1989 whilst in 1987 the cause was largely due to excessive degradation and leaching associated with warm and wet conditions. However, the role of the mild weather during the winters of 1987/88 and 1988/89 remains unclear as does the impact of cultivation practices on the weed root system and the influence of herbicide resistance.

This report and review, completed in January 1991, was funded by the HOME-GROWN CEREALS AUTHORITY, Hamlyn House, Highgate Hill, London N19 5PR, from whom copies are available for £10.00 each (postage and packing included).

INTRODUCTION

Black-grass (Alopecurus myosuroides) is a major annual grass weed of winter cereals in Central and Eastern England. The area of cereals sprayed against it is approximately 1.0-1.4 million hectares.

The weed shares the same growth cycle as winter cereals and is favoured by shallow tillage. A high level of control is required annually to contain populations, because of the large number of seeds produced.

Discussions at recent annual reviews of weed control of the British Crop Protection Council (BCPC), resulted in agreement that there have been particular problems in its control, especially in Eastern England. Poor control was reported on a range of soils in 1986/87, in discrete geographical areas, particularly in Hertfordshire and Bedfordshire. Poor control in 1987/88 and 1988/89 was generally limited to the very heavy clay soils in which black-grass thrives. However, BCPC member organisations could not explain the relatively high incidences of poor control of black-grass. The herbicides are usually best applied early post-emergence of the crop and weed up to the end of December. However, applications during these three winters often tended to be most effective in mid-January to mid February. It was decided that a review of information was required along with some specific experimental work on some aspects of herbicide activity.

The urgency of the situation was not just due to the cost of control to the farmer but also because the two major soil-applied residual herbicides used for the control of black-grass were being found in water supplies in some areas, particularly in the Anglian Water Authority region. In addition, it was recognised that herbicide usage should be minimised to reduce the likelihood of the further development of herbicide resistance in black-grass.

The study involved four main areas:-

(i) A review of the literature on factors affecting the performance of substituted urea herbicides (also known as phenyl-ureas). Isoproturon and chlorotoluron are the major herbicides used for the control of black-grass in winter cereals. Most of the other herbicides used in cereals are also soil-applied residual herbicides.

(ii) A pot experiment on the effect of waterlogging at low temperatures on the response of black-grass to isoproturon. It was suggested that the poor control in the very wet autumn of 1987 was due to waterlogged conditions.

(iii) A pot experiment investigating the influence of root development on the response of black-grass to isoproturon. Field observations suggest that control can be poor with soil-applied herbicides where the root system of the weed is all below 25 mm.

(iv) A laboratory study on the persistence in the soil and the possibility of enhanced degradation of isoproturon. Much of the poor control was reported on soils where substituted urea herbicides had been used for many years.

In addition to these particular studies, Alister Blair and Tim Martin of Broom's Barn Experimental Station, prior to their review of the literature and pot experiments, visited farms where black-grass control was a problem. A brief summary of these visits is included in this report.

Finally, the results of the review and experiments are discussed in the context of the particular seasons in question and conclusions drawn.

My thanks go to the colleagues who carried out the review and the experimental work along with David Eagle (ADAS) George Cussans and Stephen Moss (IACR) who read and commented on the script.

BACKGROUND TO THE PROBLEM

To gain an overview of the problems with black-grass (Alopecurus myosuroides) control in the previous autumns, A Blair and T Martin (Brooms Barn Experimental Station) visited farms in Eastern England in the spring of 1989. Visits were made with technical advisers.

These were: an Agricultural Development and Advisory Service (ADAS) adviser (A), a Consultant (B), an ADAS Adviser contracted to a large farm co-operative (C) and a herbicide manufacturer (D). They were distributed over a large area of Eastern England (Table 1). Visits were made either at the end of February (A, B, C) or at the end of March (D).

The sample size was very limited and the views subjective if only because levels of black-grass control are difficult to assess retrospectively. Areas are rarely left unsprayed and large numbers of black-grass survivors may simply reflect the size of the initial population.

Table 1 A summary of the advisers and sites visited

A	Annette Winter (ADAS, Kings Lynn)	1.	Kings Lynn, Norfolk	(silt)
		2.	Kings Lynn, Norfolk	(silt)
		3.	Wisbech, Cambs	(silt)
B	Peter Evans (Consultant)	1.	St Ives a, Cambs	(clay)
		2.	St Ives b, Cambs	(clay)
		3.	St Ives c, Cambs	(clay)
C	Peter Riley (ADAS/West Essex farmers)	1.	Chingford, Essex	(London clay)
		2.	Huntingwood, Essex	(boulder clay)
		3.	Toppesfield, Essex	(boulder clay)

D	Jim Butchart (Ciba-Geigy)	1.	Holbeach St. James (marine alluvium)
		2.	Willoughby, Lincs (wide range of soil types)
		3.	Lough, Lincs (marine alluvium)

The Weed Problem

Most of the growers rated good black-grass control as very important. It was widely recognised that poor control led to greater problems in succeeding years. Large populations of black-grass were established in many fields. Typical conditions favouring such a build-up are early drilling of continuous winter wheat where straw burning and minimal cultivation are practised. Black grass is strongly favoured by both non-inversion tillage and early sowing. There is, therefore, a greater dependency on chemical control but this is rendered less effective as burnt straw residues and trash build up in the surface raising the soil's adsorptive capacity which in turn reduces the activity of soil-applied herbicides such as chlorotoluron and isoproturon. The resulting large black-grass population may then have to be more effectively controlled, in percentage terms, than previously required, just to contain the problem.

Performance

Since most of the growers ranked black-grass control to be a high priority, we were interested in their views on any changes in the performance of the substituted urea herbicides.

The conclusions were varied and ranged from no decline in performance, a fall off only in cases of high adsorption capacity (K_d) or dry cloddy seedbed, to greater quantities of black-grass emerging from deeper in the soil, to several views that there is now a need to get all the factors right to get good black-grass control where, previously, this had not been the case. No one suggested that low temperatures/water logging would result in loss of activity.

It was recognised that delaying applications so that seedbeds had a chance to 'weather' and have a greater chance of adequate moisture being present, were important, but on heavy soils this approach can be impractical. Certainly many of the failure sites we observed were sprayed at the end of October or the beginning of November which coincided with a very dry period (Fig. 18 on page 59).

Resistance

No one thought that herbicide resistance in black-grass was present on their farms but mentioned that there is a need to get all factors right to get some good black-grass control where, previously this had not been the case.

Enhanced Degradation

Rapid microbial degradation of the herbicide before it had the chance to act was not thought to be a problem.

Soil Cultivation

Ploughing, at least on a rotational basis, has become a feature of many growers' systems. It buries ash and trash in the surface layers, buries weed seeds and was considered essential where large amounts of straw are incorporated. Typically seedbeds are then prepared using a power harrow. The result is often a layer of small clods 2-3 cm deep which allows light and air to penetrate to a 'false surface' at which black-grass germinates (discussed further on pages 34-38, 54). When these clods 'weather' a new surface forms above the false surface and the black-grass roots become protected from herbicide by a layer of soil.

Weather Patterns

There were few comments on the importance of weather patterns, except in relation to Site A3, where the farmer was interested in the occurrence of frost and wet foliage, and their interaction with isoproturon activity.

Soil Types

The sites visited were all heavy clay or silt soils. Examples of good and poor control were to be seen on a range of types and even within the same field. However, black-grass distribution is often patchy making this sort of observation unreliable.

Conclusions

Large populations of black-grass exist in many fields, the legacy of earlier drilling, decreased herbicide efficacy through ash and trash accumulation associated with minimal tillage and poor control in previous years.

In any particular year reasons for poor control are varied, but include one or more of the following; high adsorptive capacity, dry or cloddy seed beds and black-grass plants with roots deeper than normal in the soil.

Ploughing improves herbicide activity, but seedbeds produced with a power harrow on heavy soils may be cloddy and encourage "deep rooted" black-grass which is difficult to kill.

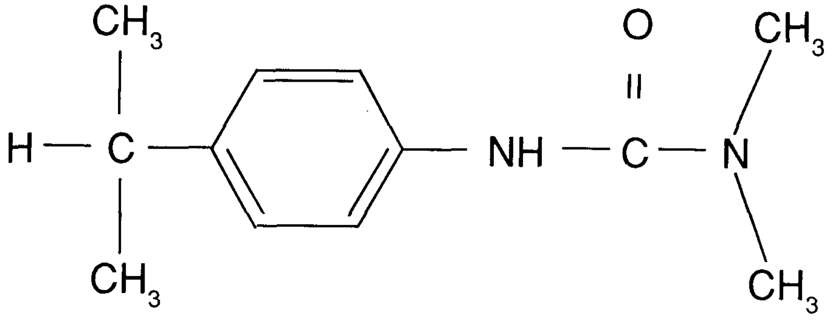
In 1988/89, instances of poor control resulted from applications at the end of October or beginning of November at a time when it was very dry.

A weathered, moist seedbed is important for good control but delaying application may be impractical for heavy land farmers.

A REVIEW OF THE LITERATURE ON SUBSTITUTED UREA HERBICIDES

The substituted urea herbicides, chlorotoluron and isoproturon (Figure 1), have been the major herbicides used to control black-grass (Alopecurus myosuroides) in winter cereals for about 20 years (Anon., 1989) and can be used on all soil types except where organic matter is greater than 10%. They are now also components of many of the commonly used herbicide mixtures.

isoproturon, N,N-dimethyl N^1-[4-(1-methylethyl)phenyl]urea (Trade names - Arelon, Chiltern IPU, Hytane 500 FW, Portman Isotop, Power Isoproturon, Power Swing, Sabre, Tolkan)



chlorotoluron, N^1-(3-chloro-4-methylphenyl)N,N-dimethylurea (Trade names - Dicurane, 500FW, Chiltern Chlortoluron, Chlortoluron 500, Hyvena S, Portman Chlortoluron, Power Chlortoluron, Talisman, Tripart Ludorum)

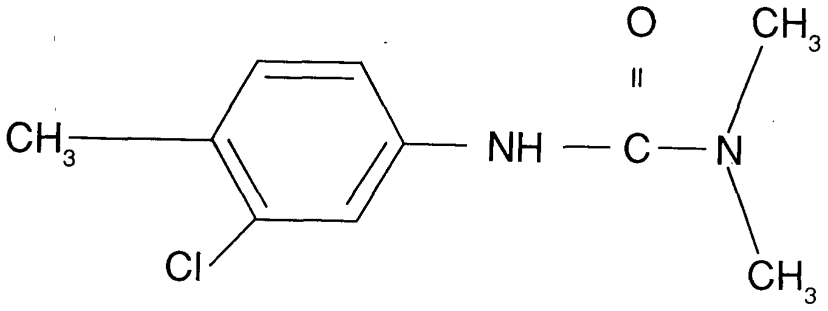


Figure 1. Common chemical names, full chemical name and structure, of chlortoluron and isoproturon.

This review deals separately with effects of herbicide on the plant and the soil and wherever possible isoproturon is used as the example compound.

The Plant

Site of entry

When applied pre-emergence, herbicides must enter plants from the soil but when sprayed after emergence entry from the soil, through the foliage, or both, is possible. Attempts to differentiate between foliage and soil entry have indicated that most activity of isoproturon on a range of grasses resulted from entry through the soil (Richardson, Dean & Parker, 1977). Foliage sprays of either isoproturon or chlorotoluron (Blair, 1978) on wheat, wild-oats (Avena fatua) and black-grass or of isoproturon on barren brome(Bromus sterilis) and Phalaris minor (Okereke, Blair & Caseley, 1981) showed little activity. Ingram & Kyndt (1981) also reported that isoproturon entry occurred primarily through root uptake. They claimed there could be some shoot uptake but presented no evidence for this. Blair (1978), using an activated charcoal layer at seed depth, concluded that both isoproturon and chlorotoluron were more damaging when placed below seed level of wheat, wild-oats and black-grass. Addala, Hance & Drennan (1985) also suggested some chlorotoluron entry occurred into the shoot below the soil surface layer and that this route of entry was relatively more important for plants such as perennial rye-grass (Lolium perenne) than for plants such as radish which develop roots quickly in the soil above the seed. Further evidence that root entry is more important than shoot entry was given by Blair & Martin (1987) who demonstrated that deeper planting in pots resulted in less damage to wheat and wild-oats from isoproturon. The effect was less pronounced with chlorotoluron or with either herbicide on black-grass. In more adsorptive soils the protection from isoproturon by planting wheat deeper was even more pronounced (Martin & Blair, unpublished). All these experiments were carried out in a glasshouse or controlled environment where the humidity is generally low or there is forced air movement, both of which would probably result in rapid movement of pesticides through the plant.

More recently, Blair & Martin (1990) have shown that more isoproturon can enter barley foliage, when it is wet and remains so for up to 24 hours. This sometimes resulted in crop injury and may in part, explain the extensive observations of cereal damage in the autumn of 1983, where for example, any overlaps in spraying occurred. The effect may also have been associated with plants drilled early in the autumn under warm conditions resulting in rapid growth and high evapo-transpiration. McIntosh, Robertson & Kirkwood (1981), Okereke, Blair & Caseley (1981), Achhireddy, Kirkwood & Fletcher (1985) and Achhireddy & Kirkwood (1986) have all studied isoproturon entry through the foliage of a range of species and concluded that efficiency of uptake was not a major influence on selectivity. In all these cases isoproturon was applied in discrete droplets or sprayed to run-off, both atypical methods of application for these compounds.

Mode of action/site of activity

Substituted urea herbicides isoproturon and chlorotoluron inhibit photosynthesis by interfering with electron transport in photosystem II and the reactions and components involved are believed to be distributed across the thylakoid membranes in the chloroplast (Moreland, 1980). Kirkwood, McIntosh & Robertson (1984) showed greater sensitivity to isoproturon of the Hill reaction (an indicator of photosynthesis) in isolated chloroplasts in wild-oats and black-grass than in those of wheat. This contrasted with results of de Felipe *et al*. (1986) who recorded no difference in the effect of isoproturon on the Hill reaction between the crop (wheat) and a weed (*Lolium rigidum*). Since Pfister, Radosevich & Arntzen (1979) suggested that the inhibiting activity of herbicides affecting photosystem II depended upon their ability to bind specifically to the chloroplast membrane, the fact that ^{14}C-isoproturon is less tightly bound to wheat chloroplasts than to wild-oats and black-grass may account in part for differences in response (McIntosh, Robertson & Kirkwood, 1981).

Movement to site of action

If the main route of entry to the plant is from the soil, the herbicide must be translocated to its site of action in the leaf chloroplast. The ability of a pesticide to be taken up by plant roots and translocated to shoots can be related to its logarithmic octanol-water partition coefficient (K_{ow}) (Briggs, 1984) and, on this basis, isoproturon is categorised as 'readily translocated'. Blair (1987) showed that photosynthesis in black-grass growing in nutrient culture was affected within 6 hours of treatment and that over the post-spraying 96 hours period, isoproturon entered the plant in similar proportions to water. Nine days after treatment of winter wheat with ^{14}C-isoproturon via the root system, 84.1% of the herbicide was found in the shoot (Muller et al. (1979). The same authors recorded that, when isoproturon was taken up through the leaves, distribution was largely acropetal with accumulation in the leaf tips and export from the treated leaf was very small (only 0.4% after 9 days). Kirkwood, McIntosh & Robertson (1984) made the general comment that there was no apparent relationship between uptake, translocation and the selectivity of isoproturon in wheat, wild-oat and black-grass. Achhireddy & Kirkwood (1986) however measured greater absorption of isoproturon by leaves of black-grass than by wheat with 55% and 32% remaining on the leaf surface of wheat and black-grass respectively 7 days after treatment. In black-grass, 25.5% of applied ^{14}C isoproturon was translocated in the xylem compared to 8.9% for wheat but this was 10 times that translocated through the phloem. As mentioned previously these authors applied the herbicide as droplets rather than as a spray which may affect entry into the leaf. Maas (1982) concluded that when combined with phosphilipids, a reduction of up to 50% of isoproturon dose gave equivalent activity on black-grass or loose silky-bent (Apera spica-venti). He concluded that this resulted from more rapid and efficient absorption of the herbicides.

Metabolism

There are more references to the metabolism of chlorotoluron than of isoproturon in plants. We do not propose to discuss these in detail since Owen (1987) reviewed herbicide detoxification and selectivity and included chlorotoluron in his discussion. He concluded, from experiments using leaf discs, that detoxification by ring methyl oxidation was the major metabolic pathway for tolerant plants (Fig. 2) whereas it represents only a minor pathway in susceptible cultivars and in graminaceous weed species. In these N-demethylation was the main metabolic route (Ryan et al., 1981; Ryan & Owen, 1983). This distinction was less apparent in a similar study using intact plants (Cabanne, Gaillardon & Scalla, 1985) though different cultivars were used.

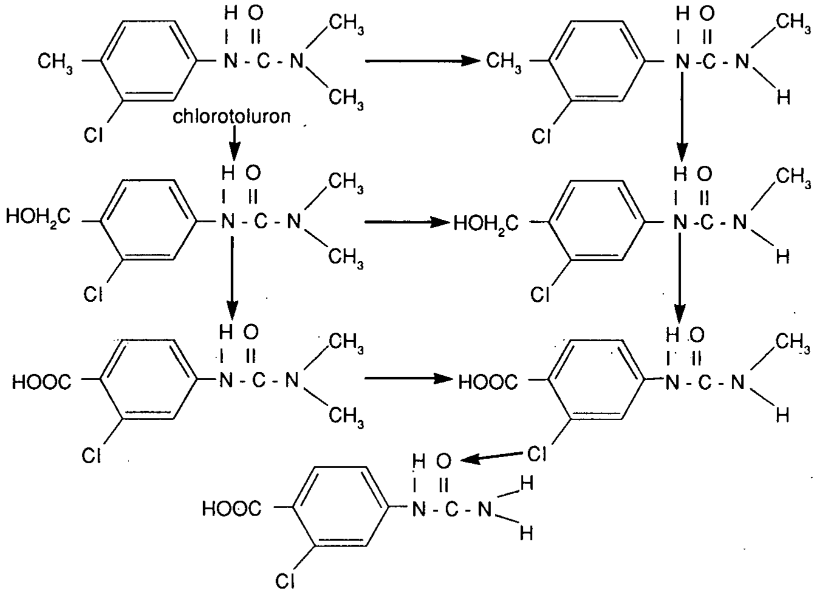


Figure 2. Pathways of chlortoluron degradation in wheat (after Ryan et al., 1981).

Kirkwood, McIntosh & Robertson (1984) also reported that isoproturon was degraded more quickly in wheat than in black-grass although no attempt was made to identify the major metabolites. In contrast to chlorotoluron, Muller et al. (1979) did not find any difference in rate and route of degradation of isoproturon in different wheat cultivars.

The involvement of cytochrome P-450 in the metabolism of chlorotoluron has recently been discussed by Jones & Caseley (1989) and will not be considered in any further detail in this review.

The Soil

Degradation

Chlorotoluron degradation pathways have already been outlined (Fig. 2) and microorganisms play a major role in this process (Smith & Briggs, 1978; Banting, Richardson & Holroyd, 1976).

Mudd, Hance & Wright (1983) suggested the pathway for isoproturon degradation in soil and identified all the intermediate metabolites shown in Fig. 3.

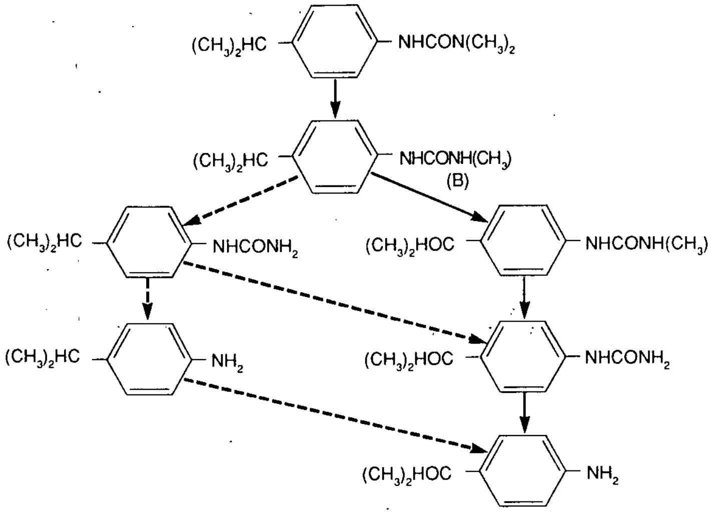


Figure 3. Proposed pathways of degradation of isoproturon in soil (after Mudd, Hance & Wright, 1983).

Fournier, Reudet & Soulas (1975) concluded that micro-organisms were important in degrading isoproturon by comparing sterile and non-sterile soils but the only metabolite they identified was B (Fig. 3). Fournier, Massenot & Drogoul (1981) also found decreased isoproturon degradation in soil stored for 2 months compared to 2 weeks, further supporting the importance of microbiological breakdown. The same authors also showed that isoproturon degradation could be decreased in the presence of other pesticides, particularly fungicides and insecticides. Since Fournier, Reudet & Soulas (1975) concluded that isproturon was degraded principally by co-metabolism, they speculated that enhanced degradation by soils was unlikely to develop. Wheat plants had no effect on isoproturon decomposition in soil in pots with the same radioactive products being obtained in both cases. This indicated to Mudd, Hance & Wright (1983) that the organisms responsible were not affected by the rhizosphere or that different organisms decomposed isoproturon at the same speed. In contrast, Kulshreshtha (1982) measured considerable chemical hydrolysis of isoproturon in water and suggested that this could contribute the major degradation pathway in soil. There was no difference between isoproturon degradation in autoclaved and non autoclaved soils (Kulshreshtha, 1983). Metabolite B (Fig 3) and an unknown highly polar metabolite were detected.

Half lives of isoproturon were reported by many authors (Table 2) and range from 1½ hours where photochemically degraded in solution (Kulshreshtha & Mukerjee, 1986) to greater than 70 days at 4°C (Mudd, Hance & Wright, 1983).

Half-lives can be determined in different ways and interpretation will depend upon the method used. The phytotoxicity of herbicide metabolites is rarely mentioned and the degree to which metabolites can be identified will depend in some experiments upon which particular carbon is labelled. For example, Madhum & Freed (1987) assessed the half-life on the basis of CO_2 released from labelled chlorotoluron and estimated it to be between 266-2306 days depending upon soil type and temperature. This very long time is presumably a reflection of the complete breakdown of the herbicide. Where half-life is assessed on the basis of plant growth (bioassay), the relative contribution of the herbicide or its metabolities to such activity is ignored. In a field experiment Ayres (1982) measured residues of isoproturon in plots treated with successive ¼ recommended dose isoproturon on 4 dates and compared these with the full recommended dose applied on the first or the last of the 4 dates. He found residue levels on plots on the 4 x ¼ dose plot to be intermediate between the other 2 treatments. Considerable differences in persistence of isoproturon activity (in a bioassay) in two successive years were found by Luscombe (1983). In 1979/80 fresh weight reduction of 90% or more was maintained for 2 months after application whereas in 1980/81 high levels were maintained for 4 months. He concluded that persistence of activity over winter was dependent upon rainfall.

Isoproturon is unlikely to have a harmful effect on micro-organisms at doses used commercially (Mudd, Greaves & Wright, 1985).

Table 2 Half-lives of isoproturon

½ Life (days)	Temp (°C)	Moisture Status	Lab/GlassHouse/ Field	Authors
35.5	15	12%	Lab	Blair et al (1988)
11	30	Flooded	Lab	Kulshrestha (1983)
25	30	Moist	Lab	Kulshrestha (1983)
43	30	Air-dry	Lab	Kulshrestha (1983)
12.5-15			Field	Kulshrestha (1983)
14	30	Moist	GHouse	Mudd et al. (1983)
21	20	Dry	GHouse	Mudd et al. (1983)
40			Field	Mudd et al. (1983)
25-30			Field	Moss (1979)
30			Field	Guth et al. (1970)

Movement

Herbicide adsorption is proportional to its logarithmic octanol-water partition coefficients (K_{ow}) and on the basis of log. K_{ow} values of 2.5-3 (isoproturon) and 2-2.5 (chlorotoluron), Briggs (1984) categorised these herbicides as suitable for autumn use as soil-applied pesticides under autumn/winter leaching conditions. Subsequent studies suggested that chlortoluron has a higher log. K_{ow} value than isoproturon (Briggs, pers. comm). Compounds with low values (<1) were highly mobile and those with higher values, less mobile. Siriwardana, Blair & Bartlett (1981) showed that wheat seedlings did not affect isoproturon movement in soil columns. Intensity of watering was important with 360 ml water in 180 minutes resulting in greater isoproturon movement than approximately the same volume of natural rainfall or 10 ml/day for 36 days.

Covering the columns to prevent surface evaporation resulted in deeper movement. Isoproturon appeared more mobile in soil than was chlorotoluron at the same dose although the bioassay plant (perennial rye-grass) may not be equally sensitive to both herbicides. Van Dord (1980) also presented data for relative leaching depth showing that isoproturon appeared to move further than chlorotoluron. By increasing the soil bulk density by compaction, from 1.2 to 1.65 g cm^{-3}, before applying water at high intensity the mobility of both isoproturon and chlorotoluron was decreased (Nyffeler & Blair, 1978). Luscombe (1983) measured isoproturon movement in soil columns to a depth of 16 cm following '10 cm' rain over a short undefined period of time. Banting, Richardson & Holroyd (1976) reported a greater reduction in dry weights of seedlings growing in soil removed from 0-3.8 cm layer of pots treated with chlorotoluron than from deeper indicating that even in pots more herbicide had remained near the surface. Martin & Blair (unpublished) confirmed this for isoproturon in pots in which wheat plants were growing. Blair et al. (1988) compared model predictions with measured amounts of isoproturon in a low adsorption sandy loam soil. Rapid movement to 5 cm, and probably deeper, within 7 days was measured. After 42 days, isoproturon was found at 15 cm deep in small amounts. The model consistently predicted higher residues than were measured in any one layer but predicted the distribution down the profile reasonably well. Nicholls & Buxton (1982) did not find a good correlation between predictions of herbicide movement and persistence and ADAS reports of chlortoluron damage. Chlorotoluron has been detected in drinking water sources (Lees & McVeigh, 1988).

After application of chlortoluron to sub-irrigated drain-pipes, Addala, Hance & Drennan (1985) detected chlortoluron below 10 mm one week after treatment; after 2 weeks, measurable concentrations were recorded in the 16-18 mm layer but after 3 weeks, less than 5% of chlortoluron recovered was from below 10 mm depth. Under this system movement was presumably by diffusion.

Various authors from France (Deleur _et al_., 1980; Agneessens _et al_., 1981; Deleue _et al_., 1984; Dautrebande & Agneessens, 1984) have measured the activity in solutions collected from the base of soil columns after application of labelled chlorotoluron. Deleu _et al_. (1984) accounted for 70% of activity over an 11-month period, 39% in soil and 37% in water, the remainder being lost as volatile products (undefined). Deleur _et al_. (1980) showed that in soil columns, even after 7 months under natural rainfall most chlorotoluron remained in the upper 10 cm layer but there were measureable quantities in both 10-30 and 30-50 cm horizons.

Hurle, Kibrer & Kirchhoff (1982) examined the effect of some other pesticides on chlorotoluron movement in field soils and found that movement was unaffected.

Availability

Adsorption by soils in usually expressed as K_d, the ratio of chemical adsorbed by soil and the soils solution concentration determined in soil-water slurries. Briggs (1984) presented data showing the relationship between K_d, organic matter content and octanol-water partition coefficient. Gaillardon, Calvet & Gaudry (1980) reported that adsorption of isoproturon by humic acid increased as the pH diminished and Chassin, Calvet & Terce (1981) proposed that this might be due to an interaction between ionized carboxyl and H-H bonds. Isoproturon and chlorotoluron were not adsorbed by three different clays, montmorillinite, kaolinite or illite, at pH's ranging between 3 and 8 (Terce & Calvet, 1978). Van Dord (1980) measured sorption values (mg/kg soil) for chlortoluron and isoproturon in 4 different soils ranging from 1.4-5% organic matter and these increased from 0.1 in the low organic matter soil to 1.0 (isoproturon) and 1.5 (chlorotoluron) in the high organic matter soil. The relationship between the distribution - coefficient (K_d) for chlorotoluron and organic matter content was not particularly close and other factors such as burnt straw residues could have an overriding influence on adsorptive capacity of the soil (Cussans et al., 1982; Moss, 1985). In 15 winter cereal fields Moss and Cotterill (1985) measured much higher adsorption levels for chlorotoluron in soils containing ash as a result of straw burning. There was a better correlation between adsorption and organic matter content for ash-free soils than for soils containing ash. Cotterill (1988) showed that adsorption of chlorotoluron by straw ash was related to its carbon content, probably a reflection of the efficiency of burning. The high adsorptive capacity immediately following straw-burning rapidly declined, probably due to leaching of those constituents of the ash which strongly absorbed chlorotoluron.

Embling, Cotterill & Hance (1983) also measured an increase in chlorotoluron adsorption by straw ash with increasing temperatures of straw burning to 500-700°C. Chlorotoluron adsorption was similarly increased by heating soil to 250°C in 2 of the 3 soils used but the reason for this could not be determined from these experiments. The soil with low organic matter (1.3%) was unaffected. Blair et al. (1988) measured both the K_d for isoproturon, recording a value of 0.1 for a sandy loam soil, and desorption with time of residence on the soil and thus derived a factor by which K_d was increased with time. This was used in a computer model to predict pesticide degradation and movement in the soil profile. For a more adsorptive clay soil Blair, Martin & Walker (unpublished) subsequently measured the K_d for isoproturon to be 1.29. Fraselle et al (1985) presented adsorption and desorption isotherms for chlorotoluron on 2 Tunisian soils but it is difficult to quote figures from the graphed data.

Influences of 'environment' on activity

General commercial usage has suggested that black-grass control by isoproturon is not greatly affected by soil type, however, Hewson & Read (1985) stated that it tended to be better on very heavy than on lighter soils, contrary to the general view (Cussans et al., 1982). Liming had only a small effect on chlorotoluron activity in one of two sandy loam soils used by Banting, Richardson & Holroyd (1976). Eagle & Rahn (1982) however, demonstrated increased phytotoxicity of both chlorotoluron and isoproturon to cabbage plant in pots as soil pH increased from 4.7 to 7.4. These authors used autoclaved soil but how long the soil remained sterile is uncertain. Cultivation can have a marked effect on chlortoluron and isoproturon activity with Moss (1979) finding that both herbicides applied pre-emergence were more effective in controlling black-grass after ploughing than after direct-drilling. Post-emergence treatments performed well after any cultivation, implying some foliar uptake or a decrease in adsorptive capacity of soil which had been burned and direct-drilled. In an examination of samples from 44 fields, Cussans et al. (1982) found that direct drilling was associated with poor chlorotoluron and isoproturon performance but they did not differentiate between pre- and post-emergence applications. Addala, Hance & Drennan (1984b) and Moss (1985) similarly observed less activity following chlorotoluron application where seed-beds were prepared by minimum tillage following burning when compared to ploughing and cultivating. There seemed to be no clear relationship on mineral soils between organic matter content and performance (Moss 1979; Cussans et al., 1982). Large clods should be avoided in seed-bed preparation (Marks, 1982) since it is suggested that they shelter areas of soil allowing weeds to germinate and grow freely. If the clods shattered, fresh areas of soil could be exposed which were 'free' of herbicide, perhaps indicating little lateral movement. The influence of straw-ash seemed to override many other factors in influencing performance. Several authors have shown that this can markedly decrease the activity of both isoproturon and chlorotoluron (Nyffeler & Blair, 1978; Hurle, 1978; Kemmer & Hurle, 1981; Addala, Hance & Drennan, 1984b).

Planting depth also influenced isoproturon activity on wheat (Blair & Martin, 1987) with deeper planting leading to less activity. This effect was exaggerated by increasing the adsorptive capacity of the soil for chlorotoluron on barley (Fraselle et al., 1985) and for isoproturon on wheat (Martin & Blair, unpublished).

Climatic factors have also affected activity of these herbicides, moisture being particularly important. Blair (1985) demonstrated in pot trials that isoproturon activity on black-grass could be manipulated by the amount and the way water was applied. Isoproturon was more active both in wet than in dry soil and when overhead rather than sub-irrigated. Some activity could be lost if the herbicide was applied to dry soil which was kept dry for 7 days post-spraying or even when chlorotoluron was applied to dry soil and not wetted for only 10 hours (Addala, Hance & Drennan, 1984a). In pots, less intense application of water resulted in more damage to barley from isoproturon than the same volume of water applied at a higher intensity (Blair, Bhan & Caseley, 1986). The low intensity watering may allow the herbicides to desorb from the soil into solution and move further down the soil profile. Hewson & Read (1985) and Read & Hewson (1988), in surveying results of many trials gave examples of good control which they attributed to adequate moisture and poor control attributed to lack of soil moisture.

In shading experiments (Blair, 1986) isoproturon symptoms on black-grass developed more slowly under heavy shading in a greenhouse but the final damage was similar to that on unshaded plants, perhaps indicating that light influenced the rate of development of symptoms more than the final result.

Isoproturon activity on both barren brome and P.minor decreased as temperature regimes increased (Okereke, Blair & Caseley, 1981) whereas wheat tended to be more damaged by isoproturon and chloroturon at high temperatures (26/16°C day/night) particularly where this was imposed after spraying (Blair, 1984). Activity on black-grass was less affected by temperature.

It is often difficult to differentiate between growth stage and climatic factors when assessing performance but Read & Hewson (1988) suggested that good black-grass control could be obtained up to the early tillering stage (GS 21-23 from Zadoks, Chang & Konzak, 1974) but thereafter the mean level of control dropped.

Addala, Hance & Drennan (1984a, b) found that chlorotoluron activity was unaffected in both pot and field experiments by methods of herbicide application ranging from rotary atomiser to conventional spray or a dribble-bar. Ayres (1978) reported that early post-emergence, only the very low volume rate of 15 l/ha (CDA) resulted in poorer control than conventional applications of chlorotoluron and isoproturon on black-grass. Volume rates down to about 30 l/ha gave satisfactory control.

Analytical methods

Various methods of analysis have been described principally based on high performance liquid chromatography (eg. Smith & Lord, 1975; Byast, 1977; Byast, Cotterill & Hance, 1977; Kulshrestha & Khazanchi, 1985). Other references to bioassay methods have been made by, for example, Theide (1975) and Lefebvre-Drouet & Calvert (1978).

Resistance

Resistance is not considered in this review since it has recently been covered in detail by Moss & Orson (1988) and Clarke & Moss (1989).

Crop Safety

Chlorotoluron is recommended for use only on specific cultivars of wheat and barley whereas isoproturon can be used on all cultivars. Tottman et al., (1975) looked at a range of cultivars at three sites and demonstrated that under some conditions the safety margin to both chlorotoluron and isoproturon was not large. Crop damage can occur when these herbicides are used on stony or gravelly soils especially if heavy rain falls soon after application. There are numerous other references in the literature to general usage of these herbicides on a range of cultivars under different conditions but these are not considered in this review.

Conclusions

(a) Under most conditions, isoproturon and chlorotoluron activity results from entry into plants from the soil.

(b) Selectivity is based on the ability of one species to metabolise the herbicide more efficiently than another, and the rates of uptake and movement within the plant contribute little to selectivity.

(c) Soil factors have a marked influence on activity with the adsorptive capacity of the soil surface being the major one; straw ash can override most other influences.

(d) Soil moisture is probably the most important 'environmental' factor in determining activity and also markedly affects the persistence and movement of herbicides in soil.

Small contributions from several factors may combine to result in poor performance.

THE INFLUENCE OF WATERLOGGING AT LOW TEMPERATURES ON THE RESPONSE OF BLACK-GRASS (ALOPECURUS MYOSUROIDES) TO ISOPROTURON (EXPERIMENT 1)

Introduction

Black-grass control was variable and relatively poor in the UK in the autumn/winter of 1987. At that time soil conditions were very wet following approximately two and a half times the average rainfall during October (measured at Broom's Barn, Suffolk and Figure 17). Farmers had suggested that if soil conditions are very wet and temperatures low, black-grass (*Alopecurus myosuroides*) makes very little growth and may be able to survive isoproturon treatment because the herbicide is metabolised fast enough to prevent the development of damage symptoms.

This experiment was designed to test the hypothesis that the combined effects of waterlogged soil and low temperatures contribute to poor weed control.

Materials and Methods

Sandy loam soil with 2% organic matter and a pH of 7.5 was collected from Brome Pin field at Broom's Barn Experimental Station on 3rd April 1989. Fifty two intact cores were taken by driving sections of drainpipe, 15 cm in diameter by 20cm in length, into the soil surface using a sledgehammer. On removal, squares of polypropylene mesh were taped to the base of the cores to retain the soil and facilitate moving. The cores were then transferred to a glasshouse and watered periodically to prevent drying out.

Seeding the cores was delayed initially through poor germination of the black-grass stock. This was overcome by using 1988 seed from White Roding, Essex. On 9th May seed was sown directly onto the raked surface of the cores, covered with 10 mm sieved soil and tamped down. After germination the cores were protected by a polythene cover to prevent drying out as day temperatures reached 40°C.

When the seedlings had 1-2 leaves they were thinned to give approximately 12 plants per column and the cover removed to harden off the plants before transfer to a cooler environment. In order to prevent cross-contamination between treatments it was necessary to isolate and waterlog each core separately. Isolation was achieved by placing each column inside a 12 x 18 inch heavy duty polythene bag secured by a rubber band that encircled the top of the column (Plate 1).

On the 22nd May all columns were transferred to a controlled environment (CE) room (14 hour 15°C day, 10°C night) and allowed to equilibriate. The temperature was dropped slightly over five days to 10°C 12 hour day, 5°C night to simulate conditions prevalent in the autumn of 1987. As the seedlings continued to grow the temperature was dropped still further to a 5°C day, 3°C night in an attempt to arrest plant growth.

On 31st May herbicide treatments were applied to the soil surface of cores in 1 ml solution per core using a hypodermic syringe; this was followed within 30 mins by 5ml water. Then, in the next two hours, appropriate treatments were waterlogged by adding 1.5 litres water to the polythene bags. Water levels were subsequently topped up twice a week and unwaterlogged treatments were watered daily. At this time the majority of black-grass seedlings were at the 2-3 leaf stage, often with one tiller visible.

The sixteen treatments consisted of a combination of the following dose range: 0, 0.083, 0.167 and 0.33 kg a.i./ha isoproturon in conjunction with a waterlogging regime of either 0, 2, 4 or 6 week time period. All treatments were replicated three times to give a total of 48 columns plus four spares for destructive assessments.

During 'waterlogging' the cores remained within the autumn/winter environment. Drainage of cores at two week intervals was achieved by snipping one corner of the bags after placing on mesh supports to avoid cross-contamination of drainage water. A period of 4-5 days elapsed between draining and the transfer of batches of cores to a warmer CE room, set to simulate spring conditions (14 hour 15°C day, 10°C night). Each batch of cores remained in the warmer environment for three weeks and was then harvested.

At harvest plants were counted, then cut off just below the soil surface. Assessments of each plant were made and the following recorded: tiller number, number of leaves showing tip scorch and fresh shoot weight. Finally the total shoot biomass per treatment, dried at 80°C for 36 hours, was also recorded.

Results and Discussion

The experiment was designed to test the theory that black-grass growing in waterlogged soil at low temperatures might be less susceptible to isoproturon. However, the failure to arrest plant growth after waterlogging prevented a full test of this hypothesis.

In general most plants grew vigorously even at low temperatures despite waterlogging. Except at the highest dose of isoproturon tiller number as percent of untreated was not markedly affected by the duration of waterlogging (Fig. 4).

Waterlogging for up to four weeks increased mortality of plants that received the top herbicide dose. This increase was less marked when plants remained waterlogged for six weeks although still significant ($p<0.05$) (Fig. 5). Total plant weight increased with length of the experiment irrespective of waterlogging for both the untreated and low dose treated plants (Fig. 6). This increase in weight was less marked at the two higher doses of isoproturon. Although the main effects of both waterlogging and dose were highly significant ($p<0.001$) the interaction between the two factors was not ($p>0.05$). When expressed as a percentage of the respective untreated control weight, only the main dose effect was significant ($p<0.001$) but the interaction between dose and waterlogging was non-significant ($p>0.05$) (Fig. 7). Plant numbers decreased with increasing herbicide dose on all waterlogging treatments (Fig. 8) although the interaction between dose and waterlogging was not statistically significant ($p>0.05$)

One might expect waterlogging to increase herbicide activity by not only making the plant more susceptible to its action but also by evenly distributing the compound throughout the rhizosphere. Isoproturon is both readily soluble and poorly adsorbed by sandy-loam soils with low organic matter (Blair et al., 1988) such as the Brooms' Barn soil; therefore a high percentage of the herbicide would be expected to be available for uptake.

Mudd, Hance & Wright (1983) measured the half-life of isoproturon incubated in soil at 4°C at approximately field capacity to be more than 70 days. Under waterlogged conditions however, Kulshrestha (1983) reported quicker degradation than at field capacity although at a much higher temperature (30°C). Under waterlogged conditions isoproturon activity decreased after only 42 days, the maximum waterlogging period, perhaps indicating an increased rate of degradation.

This may have been further encouraged by two malfunctions of the growth rooms resulting in higher temperature for up to 24 hour periods. Black-grass does however have a high degree of genetic variability which could also account for survivors of the highest dose and which enables herbicide resistance to develop (Moss & Orson, 1988).

The waterlogging technique worked well; it was simple to set up, easy to maintain yet at the same time very efficient.

Unfortunately time limitations gave no opportunity to conduct a pilot experiment to find the optimum conditions necessary to arrest plant growth. However, the growth rooms were set to temperatures representative to those in 1987.

Hence plants continued growing and Blair (1985) has already demonstrated an increased effect of isoproturon on black-grass at 150% field capacity under warmer conditions. Very wet soil conditions in the field would probably be accompanied by cold spells with frost and calm or less windy conditions. In the growth rooms there is a continuous air-flow.

The technique could be modified to get closer to the conditions required and needs repeating before the hypothesis under test should be discounted.

Plate 1. Waterlogging technique

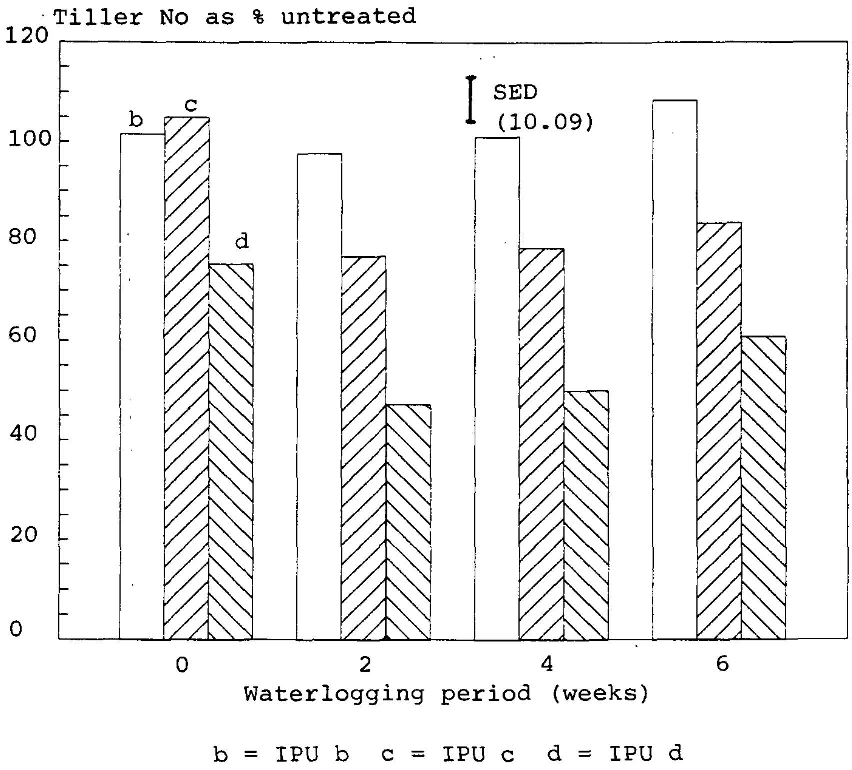
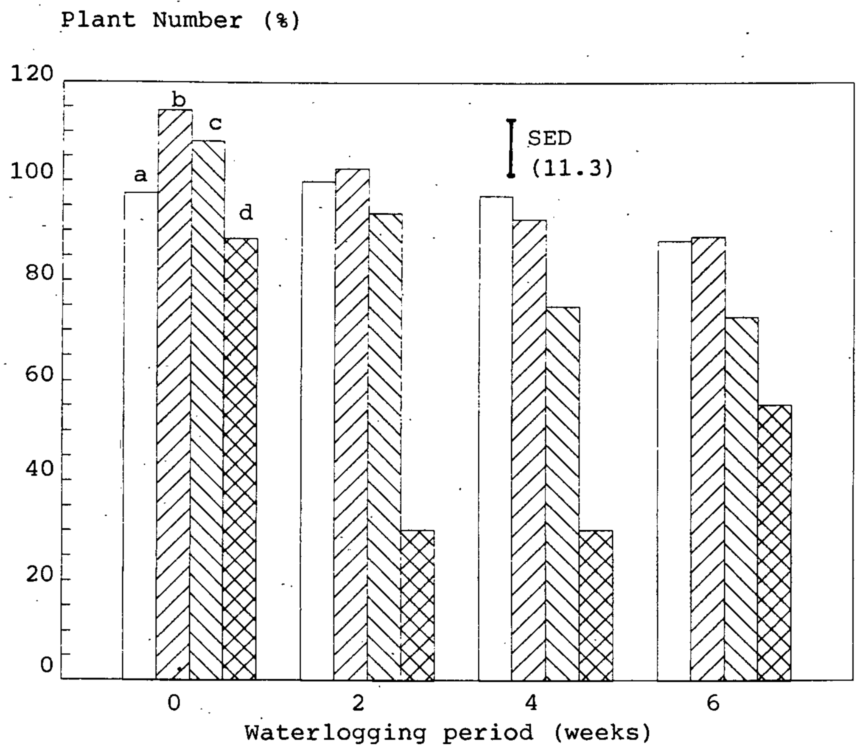
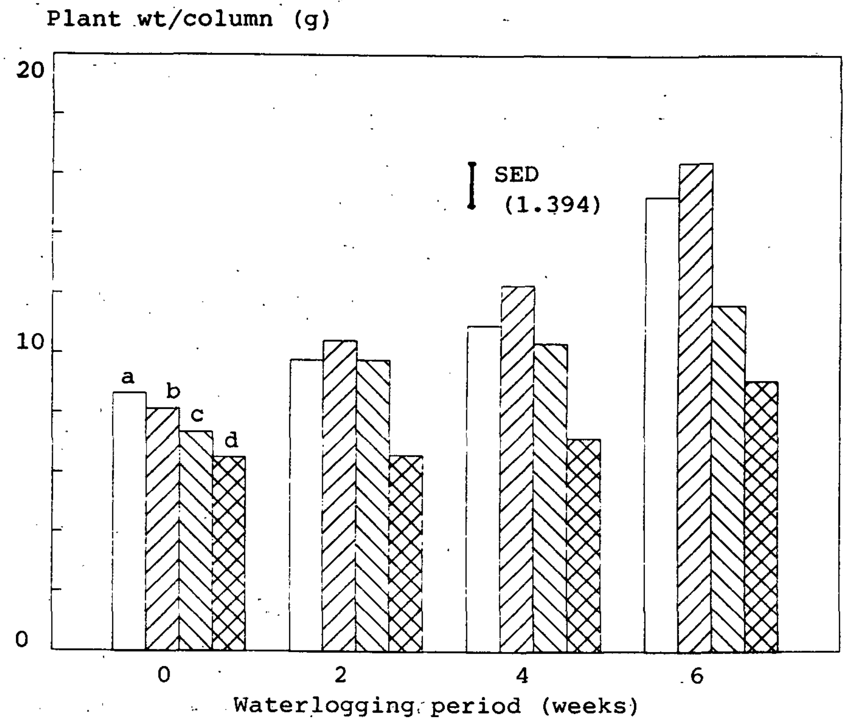


Figure 4. Tiller number of black-grass (% untreated) after treatment with isoproturon and waterlogging for various intervals.



a = control, b = IPU b, c= IPU c, d = IPU d

Figure 5. Black-grass plant number (% untreated at spraying) after treatment with isoproturon and waterlogging for various intervals.



a = control, b = IPU b, c= IPU c, d = IPU d

Figure 6. Total fresh weight of black-grass plants/column after treatment with isoproturon and waterlogging for various intervals.

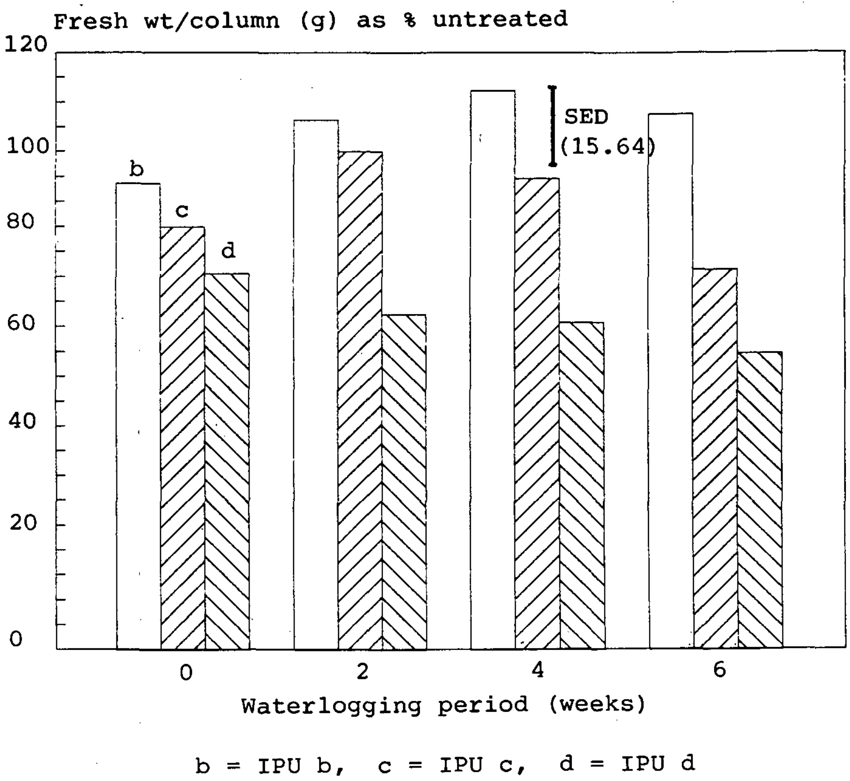


Figure 7. Total fresh weight of black-grass plants/column (as % untreated) after treatment with isoproturon and waterlogging for various intervals.

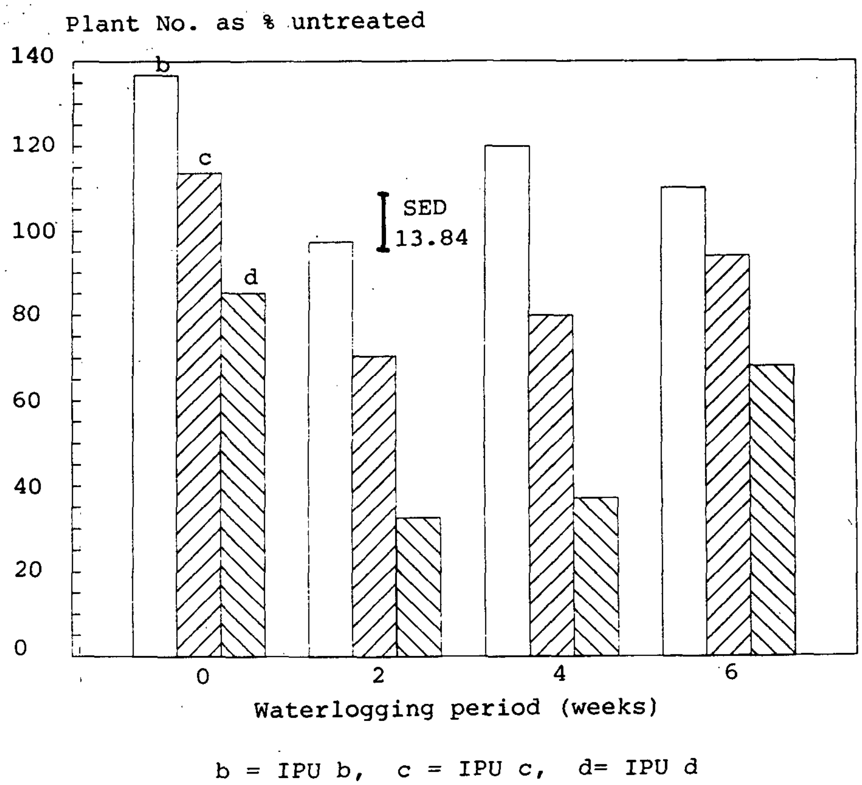


Figure 8. Black-grass plant number (% untreated) after treatment with isoproturon and waterlogging for various intervals.

THE INFLUENCE OF ROOT DEVELOPMENT ON THE RESPONSE OF BLACK-GRASS (ALOPECURUS MYOSUROIDES) TO ISOPROTURON (EXPERIMENT 2)

Introduction

As a consequence of discussions with farmers and advisers it appeared that depth of the root system of black-grass (*Alopecurus myosuroides*) might influence its response to isoproturon although this was not shown by Blair & Martin (1987) for either isoproturon or chlorotoluron. This experiment was therefore designed to manipulate the location of black-grass roots in relation to their depth below the soil surface, similar to that observed in fields where control proved difficult, and to see whether this influenced the response of the plant to isoproturon.

Materials and methods

Black-grass seeds (1988, White Roding, Essex) were pre-germinated on moist filter paper in the laboratory, and planted into soil collected from a field at Broom's Barn Experimental Station, Suffolk. The soil was a sandy loam which had been stored dry in a glasshouse for several weeks. In order to manipulate root development 4 seedlings were planted in each 10 cm diameter x 10 cm depth pot at either 2.5 or 5 cm depth on 21 May 1989. Two seedlings had their developing shoots covered with a plastic drinking straw (5 mm diameter and 3 or 5.5 cm long) before covering the seed with soil (Fig. 10). These straws prevented the herbicide coming into contact with any of the region above the seed (Addala, Hance & Drennan, 1985). Pots were carefully watered on the soil surface and kept in a glasshouse (14-42°C) throughout the experiment. The equivalent of 25 kg/ha N was applied in solution to pots on 2 June 1989.

Isoproturon was applied at a range of concentrations from 0.1 to 0.5 kg a.i./ha on 11 June 1989, 3 weeks after planting. The herbicide solution (0.5 ml/pot, equivalent to 600 l/ha) was applied to the moist soil surface using a syringe, followed by 5 ml water within 30 minutes. At treatment, plants had 2 fully emerged leaves, with 1-2 other leaves visible and 1 tiller. The deeper planted seedlings seldom had a tiller visible. Plants without straws had roots present from the node at 1-1.5 cm depth below the soil surface in addition to those from the seed.

After treatment plants were watered on the soil surface and dry weights of the above soil portion of each individual plant were measured on 26 June 1989.

Results and discussion

Necrosis of leaf tips was visible 7 days after treatment with isoproturon at 0.25 and 0.5 kg a.i./ha and occurred on plants from 2.5 cm depth both with and without straws. No necrosis occurred on plants sown at 5 cm depth. Damage was very variable between plants and replicates and remained so until completion of the experiment. At harvest the plants growing in the straws were significantly heavier than those without at all doses of less than 0.25 kg a.i./ha; the difference was not significant ($p<0.5$) at 0.5 kg a.i./ha (Fig. 9). Isoproturon can move quickly down the profile even in the field (Blair et al., 1988) and so may have penetrated below the base of the 3 cm straws in this experiment. Plants sown at 5 cm depth and grown in a straw were unaffected by isoproturon at the doses used (Fig. 10). Although there were not enough plants in the samples outside the straws (at 5 cm depth of sowing) to make any statistical comparison there was a clear indication of weight reductions at all doses. The degree of damage to black-grass without straws in this experiment was similar to that reported by Blair & Martin (1987).

At the final assessment there were rarely any roots within the straws from either depth of sowing. The crown nodes of plants from both depths of sowing without straws had developed about 1-1.5 cm below the soil surface (Fig. 11) and had produced a good root system from this point. It seems probable that the greater damage to plants without the straws resulted from isoproturon entry into these shallow roots although it is impossible to distinguish between root and shoot entry from this zone. This observation is similar to that made by Addala, Hance & Drennan (1985) for chlorotoluron. Blair (1978) used a charcoal layer at seed level to restrict herbicide availability and concluded that there was no significant difference in the effect on plant weight between placing equal amounts of isoproturon or chlorotoluron above or below black-grass seed. In that case the seed was planted much shallower (0.6 cm deep) than in the current experiment (2.5 or 5 cm).

Plants raised in straws emerged more rapidly as there was less resistance to growth in the straw than in the soil. Planting pre-germinated seedlings with enough shoot to cover with a straw meant that shoot was easily damaged unless protected by the straw when covering the seed with soil. This probably accounts for the very poor establishment of seedlings from the 5 cm depth outside the tube; Blair (1978) also reported decreased emergence from 5 cm depth. The technique could be refined to improve establishment. The method of application used probably resulted in an even more variable distribution of herbicide than a normal spray application but it was important to avoid any possible interaction from foliage entry. As weather conditions during this experiment were very hot and no temperature control was available in the glasshouse the experiment should be repeated under conditions more typical of those when black-grass establishes in the autumn.

The results from this one experiment support the hypothesis that black-grass might survive isoproturon treatment if the root system developed below a cloddy layer that may occur in the field. This is, however, only one of the many reasons which might contribute to the failure of isoproturon in the field.

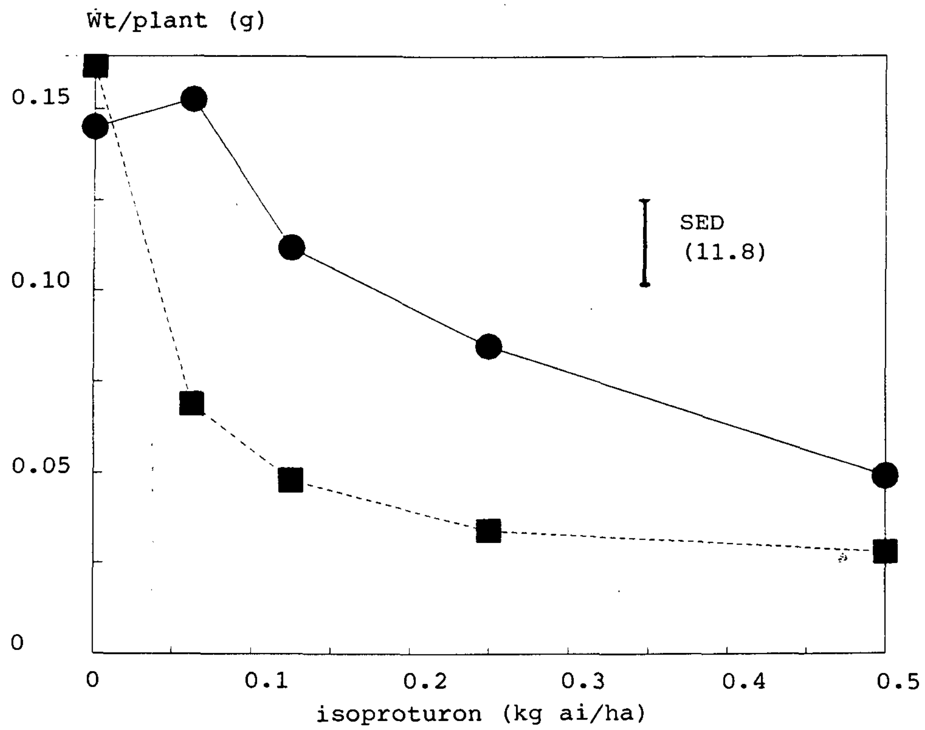


Figure 9. The effect of isoproturon on the plant weight of black-grass sown at 2.5 cm depth where the zone above the seed in the soil is protected (- ● -) or not protected (-- ■ --) from contact with the herbicides.

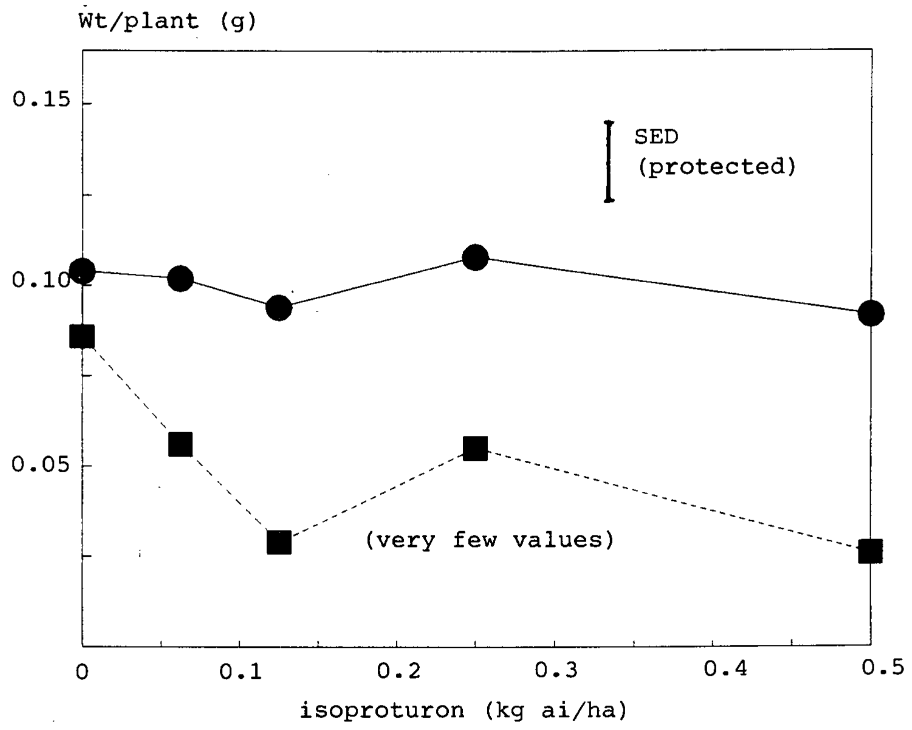


Figure 10. The effect of isoproturon on the plant weight of black-grass sown at 5 cm depth where the zone above the seed in the soil is protected (- ● -) or not protected (-- ■ --) from contact with the herbicides.

ISOPROTURON PERSISTENCE IN SOIL AND THE POSSIBILITY OF ENHANCED DEGRADATION (EXPERIMENT 3)

Introduction

Any successful soil-applied herbicide must have some degree of persistence in the soil in order to give an acceptable period of weed control. Isoproturon can degrade quite rapidly, and a half-life of 15-20 days under warm, moist laboratory incubation conditions has been reported (Mudd, Hance and Wright, 1983). When applied in autumn, the soil is usually moist but temperatures are low and, in common with most other herbicides, rates of degradation of isoproturon should be relatively slow during the winter months. Moss (1979) reported that between 2 and 8% of the isoproturon applied in autumn still remained in the soil the following spring. The herbicide is readily degraded by soil micro-organisms (Fournier, Soulas & Catroux, 1975; Mudd, Hance & Wright, 1983) and when used repeatedly at the same site, there is the possibility that micro-organisms capable of rapid degradation may build up, leading eventually to unusually short persistence. The phenomenon of 'enhanced' or 'accelerated' degradation is known to affect the soil persistence and biological performance of a number of herbicides (Roeth, 1986), insecticides (Suett & Walker, 1988) and fungicides (Walker, 1987). Since isoproturon has now been in continuous use in some fields for many years, there is the possibility that the reported poor performance in recent years may have resulted in part from enhanced degradation of its residues and the present experiments were made to examine this possibility.

Materials and Methods

Soil samples from five different sites were collected. The sites were selected on the basis that poor performance of isoproturon had been reported in the particular fields. Two soil samples were collected from four of the sites, one with a known history of heavy isoproturon pre-treatment, and the other from an adjacent field or garden with no known history of isoproturon use. At the fifth site, three soil samples were collected - the first with regular applications of isoproturon, the second with limited isoproturon use, and the third with no known previous applications of the herbicide. Soil properties are listed in Table 3. Organic matter was determined by loss on ignition, pH in a 1:1 soil:water suspension, particle size distribution by the pipette sedimentation procedure, and soil water holding properties by standard tensiometer and pressure membrane techniques. Separate quantities (50 g) of air dried soil were weighed into conical flasks and a suspension of isoproturon in water added to give a soil moisture content to the 33 kPa percentage (Table 3) and an initial herbicide concentration of 8.0 mg kg^{-1}. The flasks were loosely capped with aluminium foil. After 24 hours, the flasks were shaken vigorously to mix the herbicide into the soil and they were incubated at 20°C. At intervals during the subsequent 63 days, duplicate samples of each soil were removed and frozen until required for analysis. Isoproturon residues were measured by High Performance Liquid Chromatography (HPLC). The herbicide was extracted by shaking the soil samples with 50 ml methanol on a wrist-action shaker for 1 hour. The samples were centrifuged and sub-samples of the clear supernatant were injected into a Kontron Instruments Liquid Chromatograph. The mobile phase was methanol plus water (80:20 by volume) and the column used was a standard 25 cm C-18 reverse phase column. Detection was by UV absorbance at 240 nm. Retention time was approximately 4 minutes.

Results and discussion

The major properties of the soils used are listed in Table 3. As in other studies of the type described in this report there were some marked differences in characteristics between 'control' and 'pre-treated' soils from the same site. Organic matter content in particular was variable at at the Toppesfield, Benington and Peldon sites it was much higher in the soil from the control than from the sprayed areas. At the Poppylots site, organic content was higher in the sprayed than in the control soil. Factors such as pH and mineral content were generally more consistent at any one site, although the mechanical composition of the control soil from the Poppylots site was markedly different from that of the sprayed area. These differences in soil characteristics must be borne in mind when considering the results from the degradation experiments. The degradation data are summarised in Table 4 where the residual concentrations (% of the amount recovered at time 0) are listed as a function of time of incubation, and the data from the different sites are plotted in Figures 11 to 15. The results were also assessed on the assumption that degradation would follow first-order reaction kinetics and appropriate first-order rate constants and half-lives are listed in Table 5. These were derived from the slopes of the lines of best fit to plots of the logarithm of concentration against time of incubation calculated by linear regression analysis of the data.

Table 3. Soil Properties

Soil	Site and history	pH	O.M. %	Mineral Content (%)			Water Content (%) at:		
				Clay	Sand	Silt	5kPa	33kPa	200kPa
	Walpole								
A	Control	7.1	4.0	33	50	17	38.6	23.6	18.2
B	'Heavy'	8.3	4.1	39	39	22	35.8	26.6	21.3
C	'Light'	6.3	3.8	36	41	23	33.2	24.7	19.7
	Toppesfield								
D	Control	8.1	7.1	43	39	18	39.1	32.1	24.3
E	Sprayed	7.9	4.1	37	48	15	26.0	22.4	17.3
	Poppylots								
F	Control	8.4	5.7	28	52	20	42.2	32.3	23.3
G	Sprayed	7.6	8.4	46	21	33	49.4	41.5	32.9
	Bennington								
H	Control	6.3	6.4	28	60	12	45.3	37.8	30.2
I	Sprayed	6.4	3.2	21	70	9	19.2	15.5	11.4
	Peldon								
J	Control	7.6	8.4	50	29	21	63.8	50.9	40.1
K	Sprayed	7.7	6.6	45	35	20	46.8	34.1	26.7

Table 4. Residual concentrations of isoproturon

	Residue (% of initial) in soil:										
Days	A	B	C	D	E	F	G	H	I	J	K
0	100	100	100	100	100	100	100	100	100	100	100
7	61	63	78	41	71	60	77	62	54	46	56
14	58	58	72	17	50	49	68	43	35	22	36
21	32	49	57	6.9	47	42	58	20	23	8	26
28	37	36	43	2.4	33	38	53	14	16	3.4	21
42	22	26	45	1.6	15	33	39	7.5	10	0.7	8.9
56	16	18	29	-	7.1	29	33	5.7	8.5	-	4.6

Walpole Site

The pattern of degradation in soil from the 'heavy use' plot was almost identical with that in the control soil. Degradation in the 'light use' soil was somewhat slower (Fig. 11). The appropriate half-lives were 23.9, 22.3 and 33.7 days respectively (Table 4). The main differences in soil properties was somewhat lower pH in the 'light use' soil (Table 3).

Toppesfield Site

Degradation apparently proceeded more rapidly in the control soil than in the pre-treated soil (Fig 12., Table 5). Organic matter content was higher in the control. Extracts of the soil sample from the pre-treated area gave peaks which corresponded with isoproturon in the analytical method used. Appropriate corrections for these 'blank' recoveries were made to the measured residues.

Table 5. First order rate constants and half-lives.

Soil	Correlation Coefficient (r)	Rate constant (days $^{-1}$)	Half life (days)
A	0.968	0.0311	22.3
B	0.989	0.0290	23.9
C	0.968	0.0206	33.7
D	0.955	0.0838	8.3
E	0.993	0.0463	14.9
F	0.911	0.0193	35.9
G	0.990	0.0193	35.9
H	0.976	0.0534	13.0
I	0.962	0.0437	15.9
J	0.983	0.1011	6.9
K	0.996	0.034	13.0

Poppylots and Benington Sites

The pattern of dissipation of residues was similar in the control and pre-treated samples (Figs. 13 and 14, Table 5) although the rate of loss was much slower in the Poppylots soils (half-life about 36 days) than in the Benington soil (half-life 13 to 16 days).

Peldon Site

The data were similar to those from the Toppesfield site and indicated faster degradation in the control than in the previously-sprayed soil samples (Fig. 15, Table 5). Similar problems with high levels of co-extracted material from the pre-treated soil that chromatographed in an identical manner to isoproturon were encountered, and the data for this soil are corrected for these interferences.

The results summarised in Figs. 11 to 15 and Table 4 demonstrate large differences in degradation rate of isoproturon in different soils. The half-life at 20°C and soil moisture at the appropriate 33 kPa percentage (Table 1) varied from 7 to 36 days (Walker, 1989). There was no obvious relationship between the degradation rates and the major soil properties listed in Table 3. There was no evidence for enhanced biodegradation of the herbicide in any of the extensively pre-treated soil samples and the rate of loss in some of the control soils was more rapid than in their respective pre-treated samples. However, in general, the results indicate similar degradation rates in soils from the same site and do not suggest that changes in biological performance at any one site over a number of years will have resulted from major changes in degradation rate in the soil.

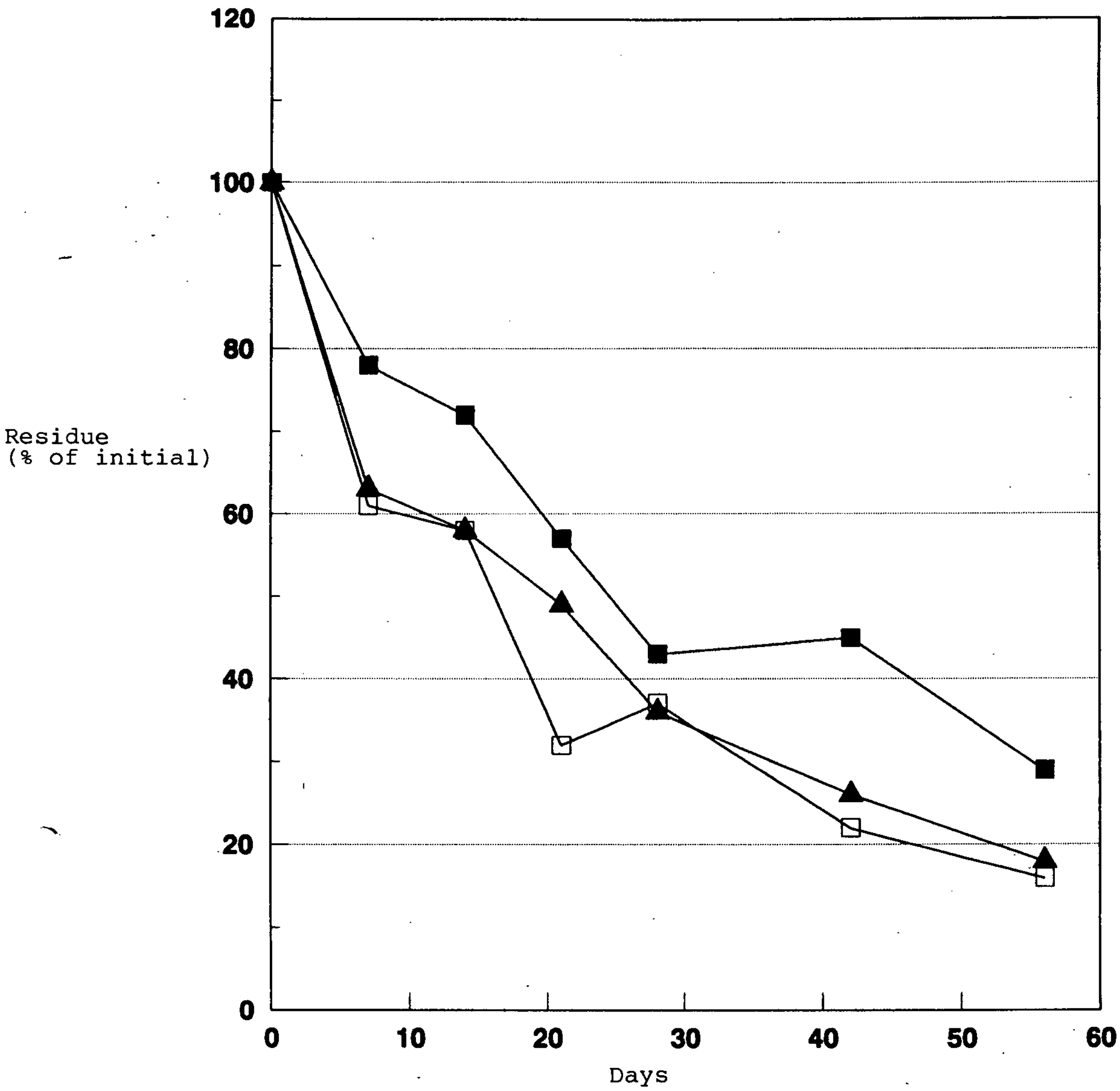


Figure 11. Degradation of isoproturon in soils from the Walpole site.
Soil A □ ; Soil B ▲ ; Soil C ■ .

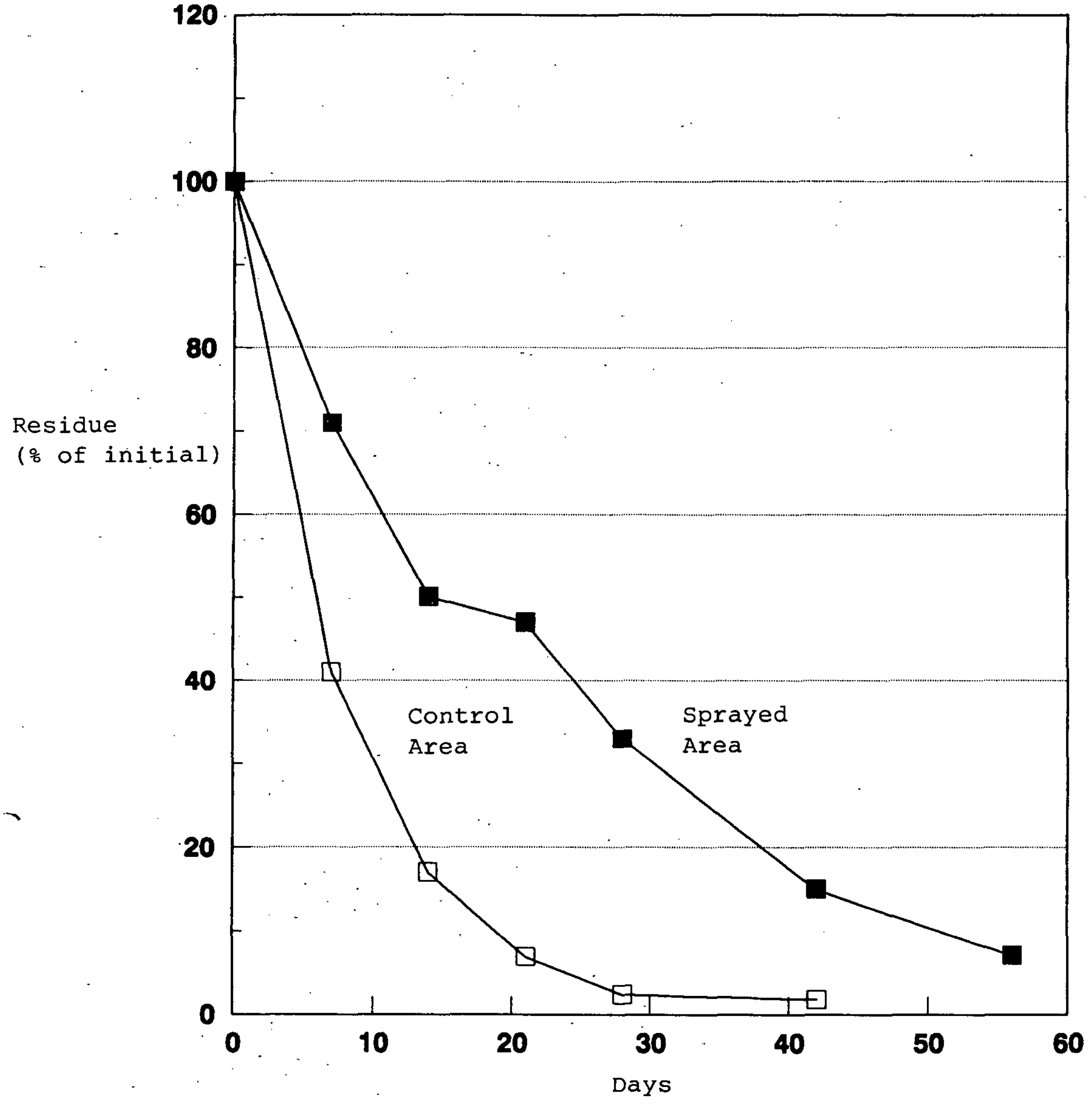


Figure 12. Degradation of isoproturon in soils from the Toppesfield site. Soil D □ ; Soil E ■ .

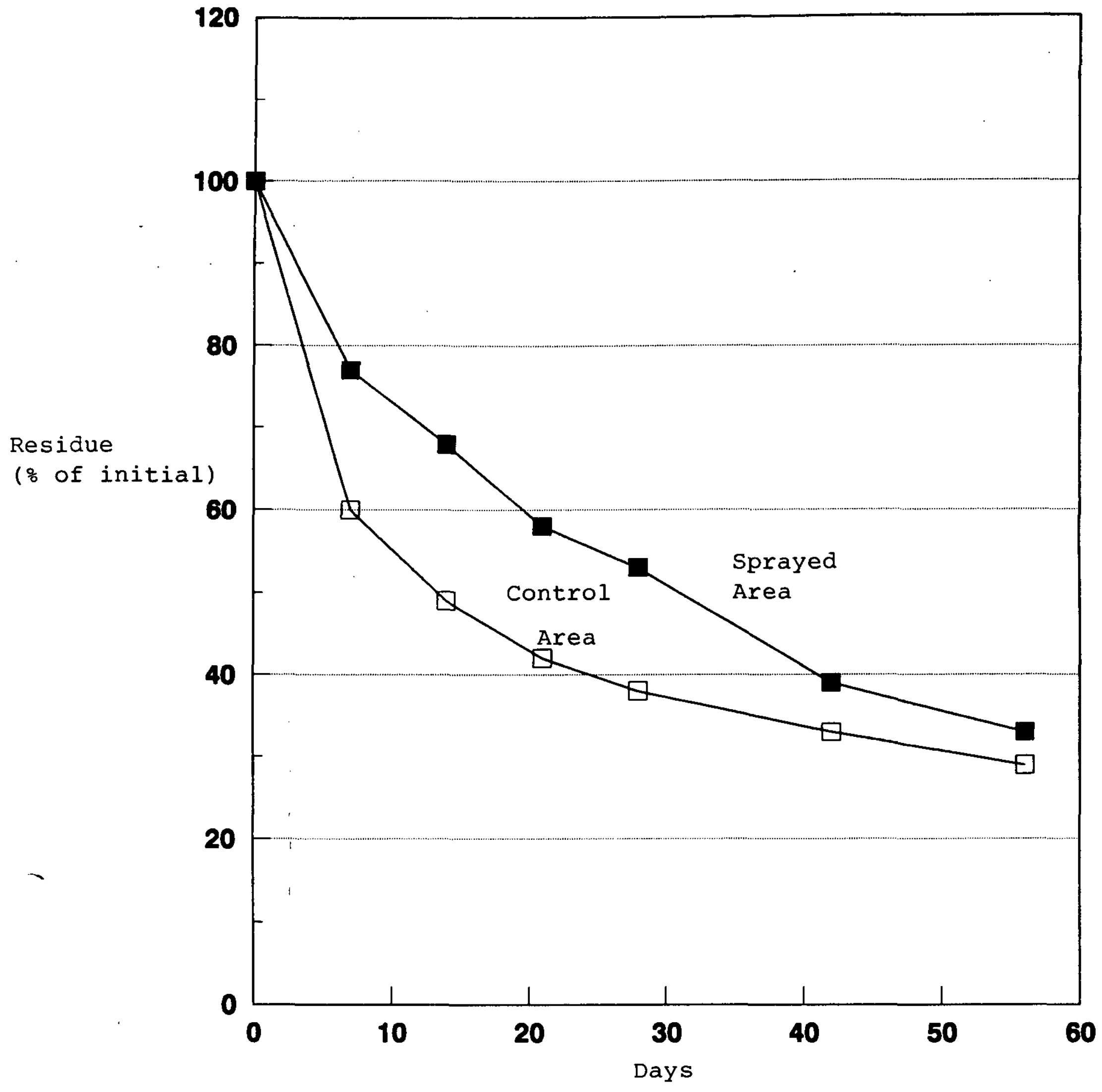


Figure 13. Degradation of isoproturon in soils from the Poppylots site. Soil F □ ; Soil G ■ .

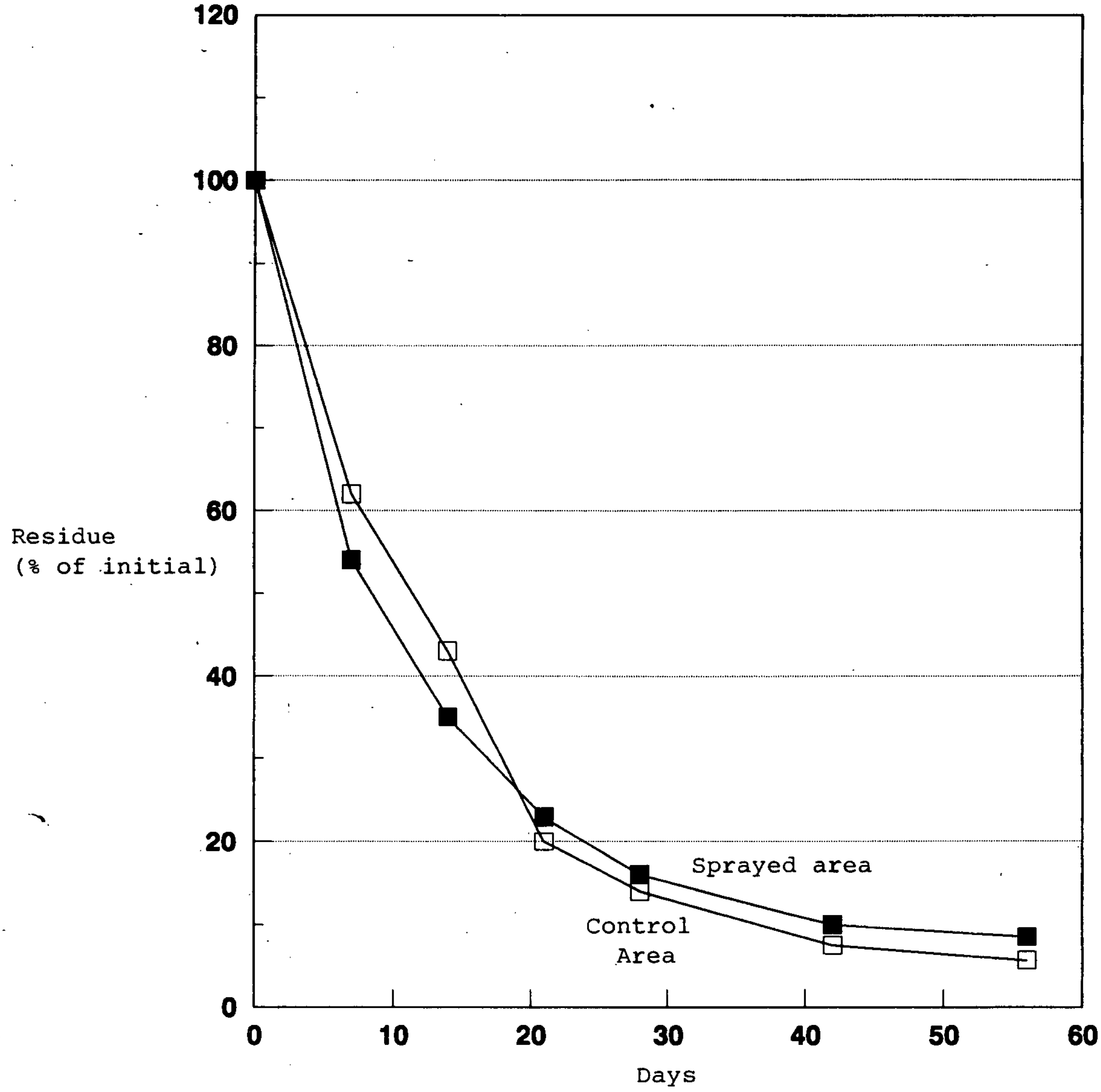


Figure 14. Degradation of isoproturon in soils from the Benington site
Soil H □ ; Soil I ■ .

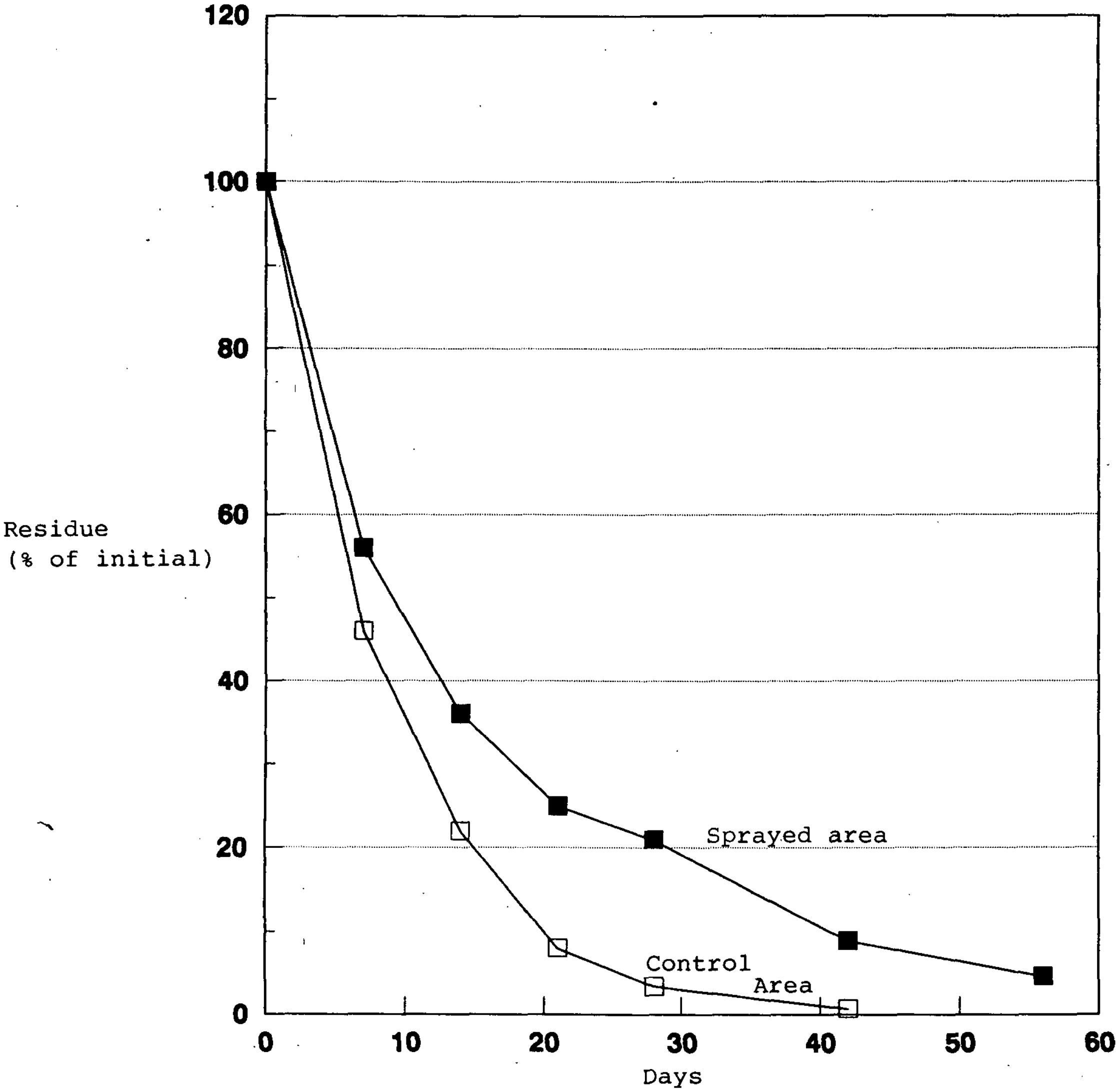


Figure 15. Degradation of isoproturon in soil from the Peldon site
Soil J □ ; Soil K ■ .

DISCUSSION

Seasonal factors that significantly affect substituted urea activity are:-

1. Rainfall

    (a) Affects adsorption onto soil organic matter and straw ash, thus reducing herbicide availability. Adsorption is stronger on dry soils and on very heavy soils where organic matter levels tend to be relatively high. Where minimal (non-ploughing) tillage is carried out, high levels of the residues of straw burning close to the soil surface can cause particular problems of herbicide availability due to high adsorption.

    (b) Affects availability, which is only maximised when the soil is moist.

    (c) Influences degree of leaching down the soil profile to the root zone of the weed.

2. Transpiration

    (a) The amount of herbicide taken up by the plant depends on transpiration, which is largely controlled by temperature, sunlight and wind speed.

Persistence of activity depends on:-

1. Soil moisture and temperature which controls degradation.

2. Amount of rain - high rainfall leads to loss of activity due to excessive leaching.

The review concludes that moisture availability is the most important 'environmental' factor with adsorptive capacity the most important soil factor. The experiments indicated that waterlogging and enhanced degradation were not causes of poor control with isoproturon and chlorotoluron. Field observations that black-grass plants with deeper crown roots than normal are more likely to survive the application of soil-applied herbicide, were confirmed.

Studies of the weather in the autumn of 1986 suggests that the warm and wet conditions alone may explain the poor control of black-grass in discrete areas of the country. This is confirmed by the fact that poor control was not related to soil type. In such localities rainfall caused excessive leaching. In Eastern England predictions by the ADAS Pesticide Residues Unit suggest that the time of application in question (October and early November 1986) had the greatest leaching and the highest degradation up to the end of December during the period 1979-1989.

Soil factors appeared to have been important in 1987/1988 and 1988/89. Poor control appeared to be limited to the heavier textured soils where adsorption, due to organic matter and in many cases straw ash, can be a significant cause of failure to control black-grass. The situation was compounded in the extremely dry autumn of 1988 (Fig. 19) by the fact that autumn and early winter applications were not predicted to have leached down to the main root zone of the weed on soils with moderate to high adsorption by the end of December (Eagle & Walker, 1989). Sufficient leaching had occurred by the end of March but by that time the early winter applications had degraded significantly due to the mild winter weather. Problems were encountered in the field of obtaining reliable samples for the assessment of herbicide adsorption and more information is required how this factor may change with time.

The problem encountered by mid-November to end of December applications in 1987 are more difficult to explain. In many situations the excessively wet October had resulted in crops being drilled in poor conditions. The cloddy seedbeds often resulted in a poor soil environment for the activity of soil applied herbicide. In addition, the open seedbeds, caused increased gaseous exchange and light penetration to the root zone of the weed and the soil surface. This resulted in the weed rooting at a deeper depth than normal (Austin & Jones, 1975) and even where conditions subsequently appeared satisfactory for control there were instances of poor control reported. Waterlogging was widely attributed to be the cause but this has been largely discounted by the study outlined on pages 24-33 and crops and weeds did not show symptoms typical of waterlogging. Indeed, studies (Fig. 17) show that once applications were possible in mid-November the soil had dried out significantly close to the surface which would have increased adsorption and decreased availability and the low rainfall between mid-November and end-December would have resulted in insufficient leaching on heavy soils for optimum activity. The following January was very wet and caused excessive leaching. The problem may have been further compounded by the fact that November and December 1987 had the lowest sunshine and transpiration for 20 years. This would have resulted in lower take up by the plants of the herbicides from the soil.

It has been suggested that the relative poor control in 1987/1988 and 1988/89 was due to a greater or lesser extent, to the mild winters experienced. Such conditions would assist rapid black-grass growth, improved overwinter survival and rapid degradation of soil-applied herbicides. The predicted degradation over the November-December period in both autumns 1987 and 1988 was close to the long term average. However, the mild winters did result in very large black-grass plants being retreated in the spring. There is no evidence to suggest that herbicide activity is decreased by warm winter weather but the relationship between temperature and rainfall and their effect on both the plant and soil-applied herbicide are not fully understood.

One other aspect that may have been significant, particularly on those farms practising intensive winter cereal growing with minimal tillage, is black-grass resistance to herbicides. HGCA sponsored surveys in 1988 and 1989 suggested that variability in susceptibility to the substituted urea herbicides may be the cause of poor control on a significant number of the fields with black-grass surviving in June/July on farms surveyed at random in an area within 50 miles of Peldon, East Essex. Certainly, several farmers and advisers consider that black-grass is now more difficult to control. However, it should be borne in mind that earlier drilling over recent years has increased significantly the control required from herbicides.

Earlier drilling of autumn cereals has implications, not only on black-grass numbers but also on their overwinter survival and the size of black-grass when farmers and advisers consider conditions are suitable for herbicide activity. Established black-grass plants are less likely to be killed by frost-lift in severe winters. In relatively dry autumns the black-grass in early drilled crops may be too advanced for optimal control by soil-applied herbicides by the time that the soil becomes moist enough for farmers to consider spraying. In autumns when the soil is moist, black-grass may reach the most susceptible stage of 1-2 leaves in early drilled crops when conditions are leading to rapid crop growth and herbicide degradation. Crop damage to rapidly growing crops can occur from applications of isoproturon, chlortoluron and other soil-applied herbicides used for black-grass control in winter cereals.

It appears that on soils with high herbicide adsorption the moisture status of the soil and the position of the soil-applied herbicide in the soil is of particular importance. This reliance on moisture and rainfall, before and after application is a significant drawback to reliable black-grass control with soil-applied herbicides on these soils. Ploughing will reduce adsorption where organic matter and the residues of straw burning have built up at the soil surface due to minimal tillage and reduce the control required from herbicides.

However, on very heavy soils, ploughing is expensive and can create difficulties and further expense in preparing a seedbed. The use of a foliage-applied herbicide would overcome many of the problems of associated with soil-applied herbicides. Until recently, the only foliage-applied herbicide that would give effective control of the weed was diclofop-methyl. Its use was restricted due to the fact that all of the black-grass had to be between the one to three leaf stage at application. The recently announced foliage-applied herbicide fenoxaprop-ethyl can selectively control emerged black-grass to very advanced growth stages and offers more reliable control on high adsorptive soils. However, the consequences of regular use of this herbicide, and others which share the same mode of action, in terms of herbicide resistance, are unknown.

Recommendations for further study:-

a) Implications of different seedbed preparation methods on the rooting habit of black-grass in relation to susceptibility to soil-applied herbicides.

b) Implications on herbicide resistance of regular usage of new products such as fenoxaprop-ethyl.

c) Continue to monitor black-grass resistance to herbicides.

d) To measure the effect of different temperatures and rainfall patterns on the growth of black-grass and its susceptibility to soil applied herbicides.

e) Develop strategies to improve reliability of weed control and to minimise both herbicide and cultivation costs. This subject area is of higher priority now that straw burning is to be banned.

f) Develop reliable field sampling techniques for the assessment of herbicide adsorption and to obtain more information on how this factor changes with time.

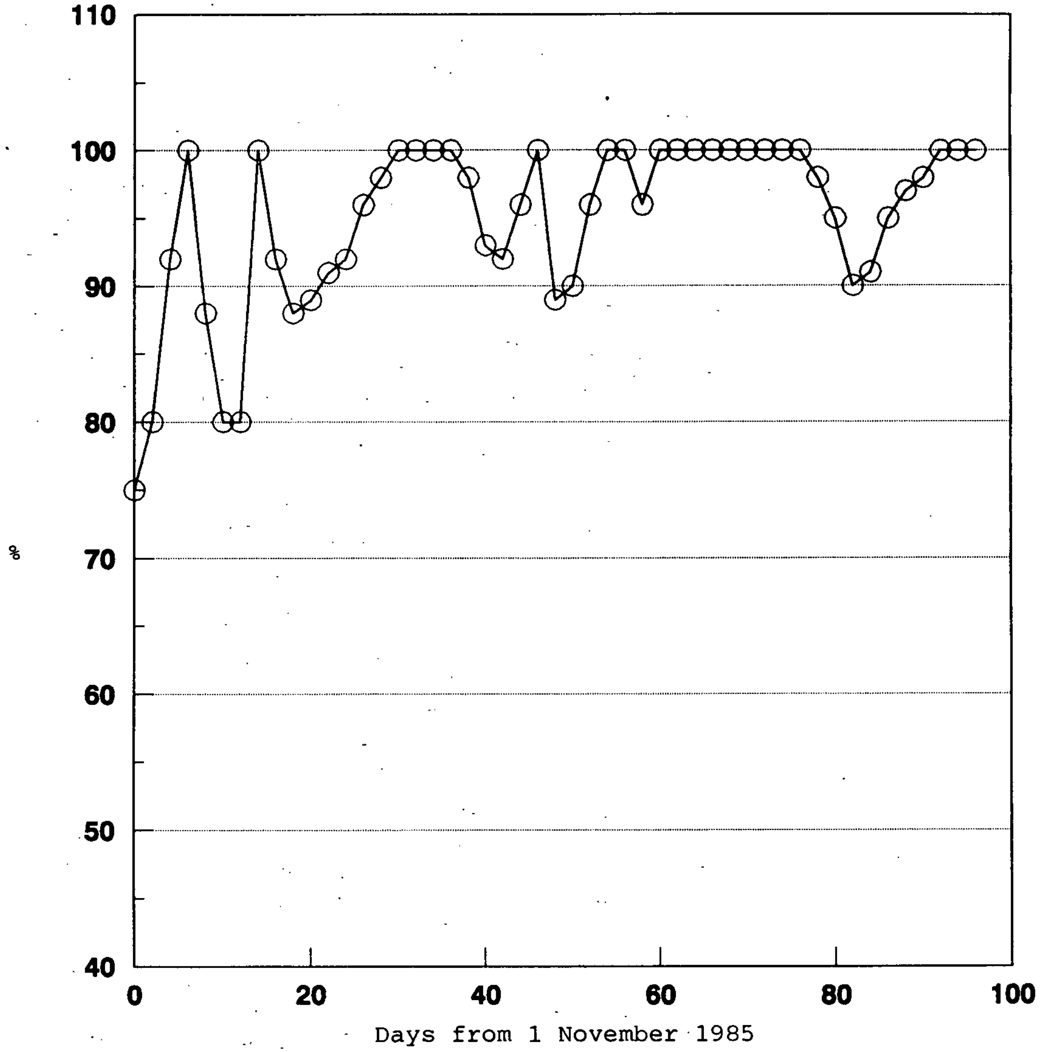


Figure 16. Percent of field capacity of top 2 cm of soil - 1985
(Wellesbourne, Warwickshire)

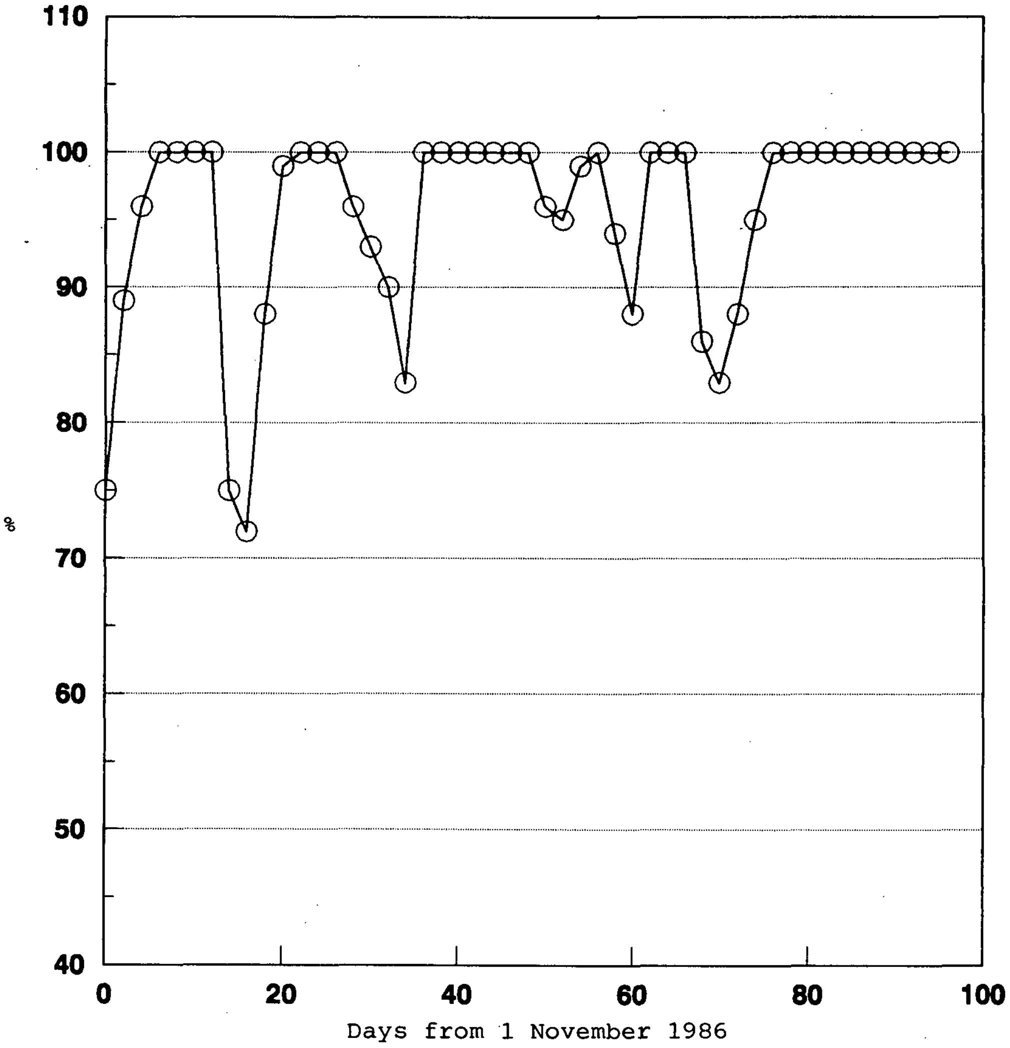


Figure 17. Percent of field capacity of top 2 cm of soil - 1986 (Wellesbourne, Warwickshire)

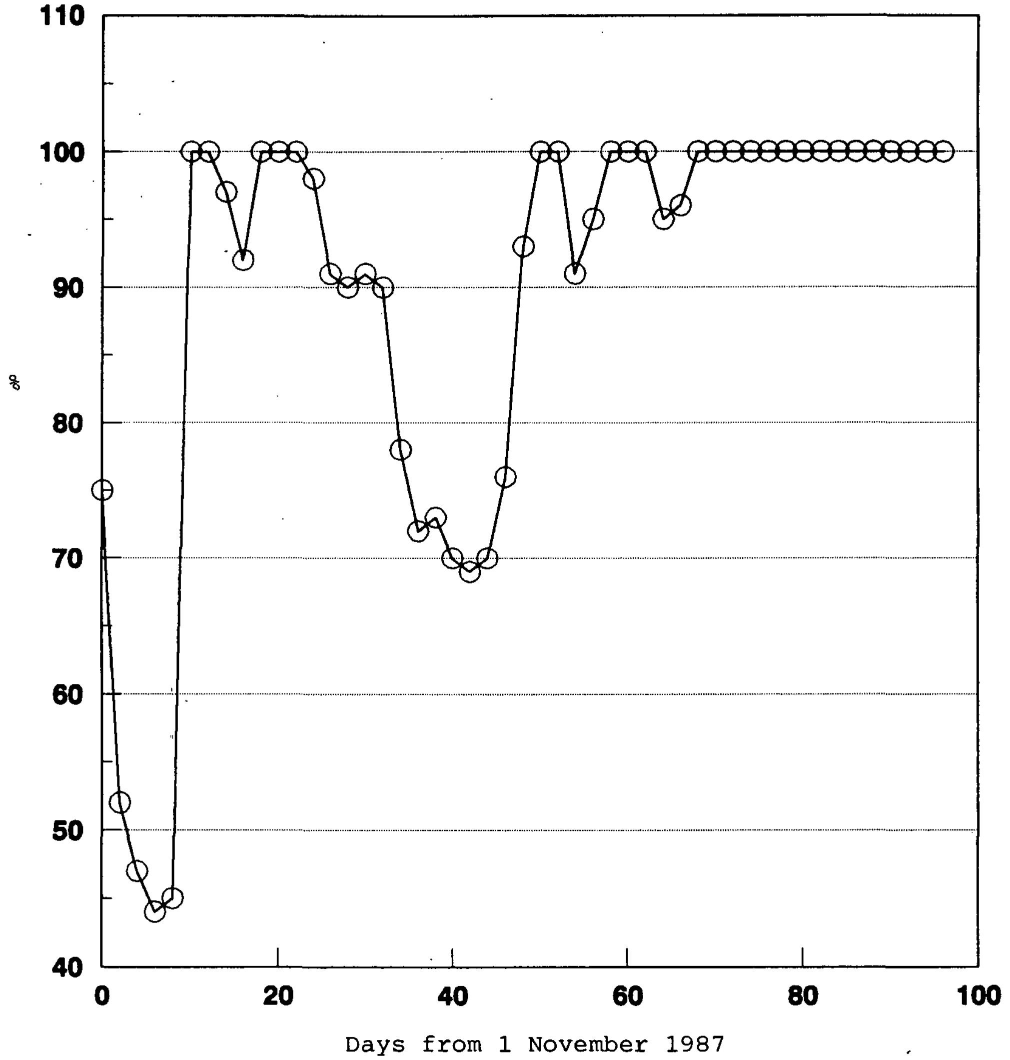


Figure 18. Percent of field capacity of top 2 cm of soil - 1987
(Wellesbourne, Warwickshire)

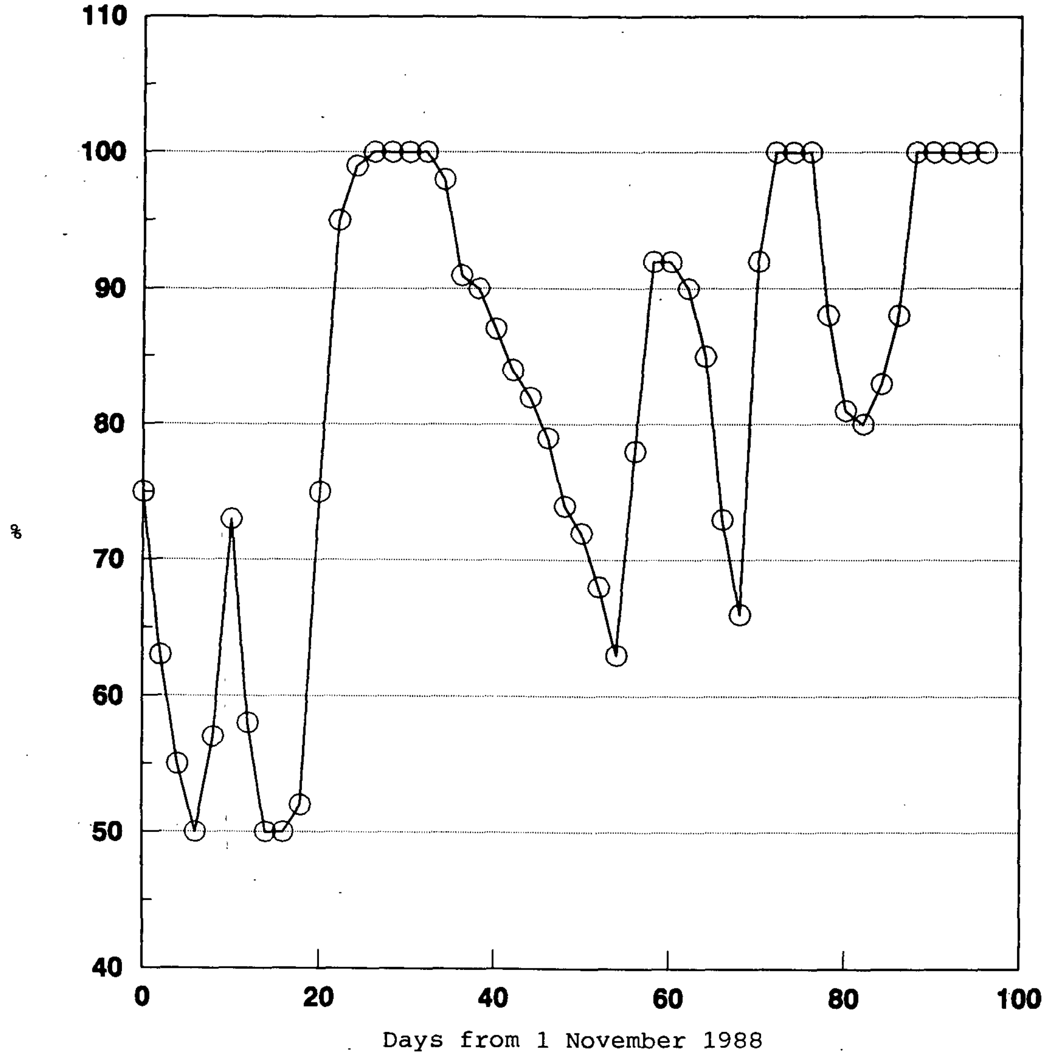


Figure 19. Percent of field capacity of top 2 cm of soil - 1988 (Wellesbourne, Warwickshire)

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