SESSION 8D

HABITAT MANAGEMENT: IMPACTS AND IMPLICATIONS FOR WEED CONTROL

SESSION
ORGANISER DR N. W. SOTHERTON

POSTERS 8D-1 to 8D-9

THE POTENTIAL OF QUINMERAC (BAS 518H) FOR THE SELECTIVE CONTROL OF CLEAVERS (*Galium aparine*) IN FIELD BOUNDARIES.

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ABSTRACT

During 1988/89 experiments were conducted in the field and under glasshouse conditions to test the effect of BAS 518H (quinmerac) on a range of hedgerow and rare weed species. Initial results suggested that quinmerac achieved excellent control of *Galium aparine* and had little effect on non-target species. Quinmerac may therefore be an appropriate means of reducing the threat of *G. aparine* seed ingress from field boundaries into crops, with minimal effects on the remaining field margin flora.

INTRODUCTION

Field boundaries are important wildlife habitats on farmland (Boatman, 1989) and their management is therefore a cause of concern to those interested in wildlife conservation in the wider countryside (Way & Greig-Smith, 1987). However, this habitat is often regarded by farmers as a source of arable weed infestation, in particular, of *Galium aparine* and *Bromus sterilis* (Marshall & Smith, 1987; Boatman & Wilson, 1988). Consequently a large proportion of farmers deliberately spray herbicides, often broad-spectrum, into hedgebottoms in an attempt to control the perceived problem (Marshall & Smith, 1987; Boatman, 1989), resulting in many cases in the impoverishment of this valuable habitat. Clearly the boundaries of arable fields are areas of potential conflict between agronomic (weed control) and conservation interests.

Work at The Game Conservancy has demonstrated the suitability of the herbicide quinmerac (BAS 518H) for the selective control of *G. aparine* in "conservation headlands" (Boatman, 1989). Quinmerac may also have a role to play in the control of *G. aparine* in field boundaries. *G. aparine* is one of the most frequently occurring herbaceous hedgerow species (Boatman & Wilson, 1988) and often dominates the flora at the expense of perennial, non-invasive species. Its selective removal may encourage the establishment and development of more desirable species, thus improving the habitat for wildlife whilst removing a threat to crop protection via reduced seed ingress to the field.

This research report presents the initial findings of a one year study to investigate the efficacy of quinmerac for *G. aparine* control in field boundaries and its effect (if any) on non-target species.

MATERIALS AND METHODS

Experiments conducted fell into two categories:

1. Field experiments in field boundaries
2. Pot screening for activity against hedgerow and rare weed species

Field experiments in field boundaries

Plots (3.6m long) were marked out in field boundary vegetation containing *G. aparine* at two sites near Basingstoke, Hampshire. Treatments were quinmerac at either 0.5 or 1.0 kg a.i./ha applied on 19 October (E) or 8 December (L) plus untreated control (U).

The experiments conformed to a randomized block design, with each treatment replicated four times. The herbicide was applied with a knapsack sprayer at a pressure of 2.5 bar and a volume rate of 218 l/ha.

G. aparine plant density and percentage cover of each species were recorded in six 0.25^2 fixed quadrats in each plot prior to spraying. Percentage cover and vigour scores for each species were recorded four and eight weeks post-spraying, in March, in May and in July. Vigour was assessed on a 0-6 scale as follows:

0. Dead
1. Moribund. A little green tissue but obviously dying.
2. Very severely stunted. Some green tissue but unlikely to make further growth.
3. Severely stunted but some growing points still active.
4. Stunted, but still growing.
5. Actively growing, but less vigorous than the healthiest plants.
6. Healthy and vigorous.

Only data for the May assessment are presented.

Pot screening for activity against hedgerow flora and rare arable weed species

Seedlings were grown from seed and transplanted into pots (4" x 4") containing a 1:1, sand:loam soil. Treatments were quinmerac at 1.0 and 2.0kg a.i./ha, fluroxypyr at 0.2 kg a.i./ha (toxic standard) and untreated control.

Four replicate pots each containing four plants per species were used per treatment where possible. Herbicides were applied with an Oxford Precision micro-sprayer at a pressure of 2.5 bar and a volume rate of 200 l/ha. Sprayed plants were watered from below. Plant growth stage was recorded prior to spraying. Plant vigour was recorded on a 0-7 scale (Richardson & Dean, 1974) two weeks after spraying. Plant vigour, shoot fresh weight and growth stage were recorded four weeks after spraying. The pot screen was carried out under glasshouse conditions at the University of Reading.

RESULTS

Field experiments in field boundaries

Pre-spraying assessments indicated that all species analysed statistically were, in general, evenly distributed between plots at both trial sites.

TABLE 1. Vigour of field boundary species affected following treatment with quinmerac at different times and doses, eight weeks after spraying.

Species	Site	U	0.5E	1.0E	U	0.5L	1.0L
		Application rate kg a.i./ha and timing					
Galium aparine	1.	5.9	2.6	1.9	6.0	2.0	2.2
	2.	6.0	1.1	0.8	6.0	2.7	2.5
Urtica dioica	1.	6.0	6.0	6.0	6.0	6.0	5.3
	2.	6.0	5.7	5.8	6.0	6.0	6.0
Chaerophyllum temulentum	2.	6.0	6.0	6.0	6.0	6.0	3.9
Lamium album	1.	6.0	6.0	6.0	6.0	1.6	4.8

TABLE 2. Percentage cover of field boundary species following treatment with quinmerac at different times and doses - May assessment. (Figures in parentheses are angular transformed data. Standard errors refer to transformed data.)

Species	Site	U	0.5E	1.0E	0.5L	1.0L	S.E.
		Application rate kg a.i./ha and timing					
G. aparine	1.	27.2 (30.1)	0.1 (1.2)	0 (0)	0.5 (2.5)	0 (0)	2.96
	2.	55.6 (48.8)	3.8 (5.7)	0.7 (2.9)	0 (0)	0 (0)	3.64
Grass spp.	1.	29.5 (32.7)	37.2 (37.3)	36.7 (35.8)	18.5 (25.3)	43.7 (41.3)	4.94
	2.	14.0 (20.8)	45.0 (42.1)	48.8 (44.3)	35.1 (36.3)	52.3 (46.5)	4.42
U. dioica	2.	12.7 (19.5)	32.5 (32.9)	33.5 (33.5)	43.8 (41.4)	22.4 (26.8)	4.90
C. temulentum	2.	4.6 (11.9)	2.5 (9.0)	0.6 (3.4)	3.1 (10.0)	2.5 (8.4)	1.42
G. hederacea	2.	0.6 (4.3)	4.5 (10.0)	3.7 (7.9)	1.1 (4.2)	4.3 (10.9)	3.01
H. helix	1.	9.8 (15.9)	26.9 (29.8)	30.0 (32.7)	31.0 (32.1)	24.9 (29.3)	5.24
	2.	2.1 (8.2)	0.7 (3.1)	0.6 (2.3)	3.2 (9.2)	2.1 (7.9)	1.67
A. sylvestris	1.	3.0 (9.5)	1.8 (6.5)	1.5 (6.0)	0.8 (3.6)	1.5 (5.8)	2.02
H. sphondylium	1.	13.8 (19.7)	20.4 (25.2)	12.8 (19.3)	19.2 (25.3)	9.4 (17.1)	4.12
G. urbanum	1.	1.4 (5.6)	3.0 (7.1)	1.2 (6.0)	1.2 (4.8)	2.8 (7.8)	2.63
L. album	1.	2.8 (8.7)	0.5 (3.4)	0.1 (1.3)	0.5 (3.2)	0 (0)	1.46
Bare earth	1.	1.6 (7.0)	7.2 (14.5)	4.8 (12.5)	4.2 (11.5)	5.3 (13.0)	1.93
	2.	9.1 (14.3)	3.5 (10.5)	2.7 (8.0)	6.9 (13.9)	8.6 (16.3)	3.72

Other species present at low levels in one or more plots treated with herbicide but showing no herbicide effects included *A. maculatum*, *R. obtusifolius*, *M. arvensis*, *L. communis*, *Artemisia vulgaris*, *G. luteum*, *C. vitalba*, *A. petiolata*, *Bryonia dioica*, *H. perforatum*, *G. rotundifolium*, *P. saxifraga*, *G. molle*, *H. hirsutum*, *S. alba*, *C. arvense* and *C. arvensis*.

Good control of *G. aparine* in the range 88-98% ($P<0.05$) was achieved at both sites with all treatments eight weeks post-spraying (data not presented). No other treatment effects in terms of percentage cover were recorded for other species. Early application of quinmerac reduced average vigour scores eight weeks after spraying slightly more than did late application (Table 1). Other species showing symptoms at this time included *Malva sylvestris*, *Galium mollugo*, *Lapsana communis*, *Arum maculatum*, *Glechoma hederacea* and *Galeobdolon luteum*. Of species affected only *L. album* failed to recover and this is reflected in a 90% reduction

(P<0.05) in cover in the May assessment (Table 2) with the higher rate of quinmerac. Other species present eight weeks after spraying but showing no symptoms included *Urtica dioica*, *Hedera helix*, *Chaerophyllum temulentum*, *Geum urbanum*, *Rosa canina*, *Silene alba*, *Cirsium arvense*, *Myosotis arvensis*, *Convolvulus arvensis*, *Fumaria officinalis*, *Anagalis arvensis*, *Aphanes arvensis*, *Clematis vitalba*, *Alliaria petiolata*, *Mercurialis perennis*, *Pimpinella saxifraga*, *Anthriscus sylvestris*, *Stellaria holostea*, *Geranium molle*, *Heracleum sphondylium*, *Hypericum perforatum*, *Geranium rotundifolium* and *Rumex obtusifolius*.

Excellent control of *G. aparine* was achieved by the following May with all treatments, ranging from 95% with early applications of the lower dose to total control (P<0.001) with late applications (Table 2). Where *G. aparine* was controlled, grass spp., *U. dioica*, *H. helix* and *G. hederacea* were able to colonise, the former becoming dominant in most cases with, for example, a 150%+ increase (P<0.05) in cover at site 2. No treatment effects were observed in May for any other species present.

TABLE 3. Effect of quinmerac (Q) and fluroxypyr (F) dose (kg a.i./ha) on growth stage and vigour for field boundary and rare weed species (U = untreated, - = growth stage indefinable).

Species	Growth stage* pre-spraying	28 days post-spraying: Growth stage U	Growth stage Q 1.0	Growth stage Q 2.0	Growth stage F 0.2	Vigour[1] Q 1.0	Vigour[1] Q 2.0	Vigour[1] F 0.2	S.E.
Field boundary spp.									
Vicia cracca	L5	L7	L6	L6	-	6.0	6.0	0	0
Achillea millefolium	W2,L4	W3,L14	W3,L14	W3,L14	-	7.0	6.0	2.0	0
Epilobium hirsutum	W3,L2	W5	W3	W3	-	4.0	2.0	0	0
Solanum dulcamara	L7	L9	L5	L5	-	4.0	3.0	0	0
Centaurea scabiosa	W3	W5	W3	W3	-	5.5	5.0	2.0	0.14
Plantago lanceolata	W3	W3,L7	W3,L5	W3,L5	-	3.3	3.0	2.0	0.24
Lathyrus pratensis	L5	L6	L6	L6	-	4.5	4.0	0	0.25
Artemisia vulgaris	L4	L10	L10	L8	-	6.0	5.3	1.0	0.13
Acer campestre	P7	P16	P15	P9	P7	7.0	7.0	5.0	0
Rosa canina	L17	L14	L16	L13	L8	7.0	7.0	0.0	0
Crataegus monogyna	L10	L20	L18	L18	L11	7.0	7.0	7.0	0
Prunus spinosa[2]	L18	L22	L26	L18	L11	7.0	7.0	3.0	
Rare weeds									
Misopates orontium	P2	P8	P4	P5	-	3.5	1.8	1.3	0.23
Petroselinum segetum	L5	L7	L3	L3	-	3.5	3.0	2.8	0.19
Valerianella rimosa	W3	W5	W4	W6	-	5.3	5.0	0	0.24

* = modified from Parsons (1983) as follows:
L = number of leaves
W = number of whorls
P = number of leaf pairs
[1] = control plants assigned vigour score of 7.0
[2] = one replicate only

The woody herbaceous species *Thelycrania sanguinea*, *Rosa canina*, *Prunus spinosa*, *Acer campestre*, *Crataegus monogyna*, *Ligustrum vulgare*, *Euonymus europeaeus*, *Viburnum lantana* and *Corylus avellana* were not affected by treatment with quinmerac.

Pot screen for activity against hedgerow flora and rare weed species

Results are presented for 15 species; 34 additional species are currently undergoing testing. Following treatment with the lower rate of quinmerac, plant vigour 28 days post-spraying (Table 3) was not reduced to a level at which recovery was unlikely for any species despite an observed reduction in fresh weight of 67-73% (P>0.01) for *M. orontium*, *P. segetum* and *L. pratensis* (Table 4). *C. scabiosa*, *A. vulgaris*, *S. dulcamara* and *A. millefolium* were not affected in terms of fresh weight reduction.

TABLE 4. Effect of quinmerac and fluroxypyr dose on fresh weight (g) for field boundary and rare weed species treated. (Figures in parentheses are log (x+1) transformed data. Standard errors refer to transformed data.)

Species	Treatment and application rate kg a.i./ha				
	U	Q 1.0	Q 2.0	F 0.2	S.E.
Field boundary spp.					
V. cracca	1.19 (0.78)	0.46 (0.38)	0.36 (0.30)	0.17 (0.16)	0.04
A. millefolium	3.81 (1.57)	3.33 (1.44)	2.65 (1.29)	1.81 (1.03)	0.07
E. hirsutum	3.10 (1.41)	1.45 (0.86)	1.27 (0.81)	0.25 (0.22)	0.08
S. dulcamara	5.48 (1.87)	4.78 (1.75)	3.44 (1.49)	0.47 (0.38)	0.05
C. scabiosa	5.03 (1.78)	4.67 (1.72)	3.35 (1.47)	0.91 (0.63)	0.09
P. lanceolata	7.90 (2.18)	3.19 (1.37)	3.33 (1.42)	1.70 (0.94)	0.17
L. pratensis	2.30 (1.19)	0.76 (0.55)	0.63 (0.49)	0.26 (0.22)	0.07
A. vulgaris	6.89 (2.06)	5.70 (1.89)	3.99 (1.60)	0.72 (0.53)	0.06
A. campestre	13.33 (2.66)	10.98 (2.48)	10.05 (2.39)	9.44 (2.34)	0.05
R. canina	8.84 (2.26)	7.89 (2.17)	6.27 (1.96)	1.79 (1.02)	0.11
C. monogyna	1.78 (1.02)	1.42 (0.84)	2.50 (1.17)	0.84 (0.60)	0.16
P. spinosa[1]	7.61	14.79	13.09	8.31	-
Rare weeds					
M. orontium	6.81 (2.05)	2.18 (1.12)	0.65 (0.49)	0.56 (0.43)	0.11
P. segetum	8.29 (2.23)	2.24 (1.17)	1.99 (1.09)	2.13 (1.11)	0.09
V. rimosa	6.14 (1.96)	4.34 (1.67)	3.07 (1.40)	0.23 (0.21)	0.06

[1] = one replicate only

At the higher rate only *M. orontium* and *E. hirsutum* were assigned vigour scores suggesting that recovery would be unlikely (P<0.001). Again, very large reductions in fresh weight of species with higher vigour scores was observed e.g. *L. pratensis* and *P. segetum* (73 and 76%, P<0.001, respectively). Of the remaining non-woody herbaceous species only *C. scabiosa* and *P. lanceolata* were unaffected in terms of fresh weight reduction (P<0.05). Of the woody herbaceous species only *A. campestre* was affected, treatment with quinmerac producing a 25% reduction (P<0.05) in fresh weight. Dose responses were recorded for *M. orontium*, *A. vulgaris* and *S. dulcamara* ($P<0.05$). In some cases growth stage was retarded following treatment with quinmerac e.g. *E. hirsutum*, *S. dulcamara*, *M. orontum*, *P. segetum*.

All non-woody herbaceous species were highly susceptible to treatment with fluroxypyr, which produced fresh weight reductions in the range 53-96% ($P<0.01$) and vigour scores in the range 0-2.8. Of the woody species only fresh weight of *R. canina* was significantly reduced ($P<0.05$).

DISCUSSION

Despite large reductions in plant fresh weight recorded in the pot screen following treatment with quinmerac, it must be stressed that the plants used were young and non-hardy and that the conditions for both herbicide application and subsequent activity were ideal. The degree of resistance, i.e. vigour and fresh weight considered in combination, shown by most plants to this very rigorous test indicates that under field conditions effects of quinmerac are likely to be small. However, further tests of the most sensitive species in the field would be justified.

Initial results from both pot trials and field boundary experiments suggest that since excellent control of *G. aparine* in the field boundary is achieved with 0.5kg a.i./ha quinmerac, and this lower rate would have a reduced effect on mature perennial plants of other species, the goal of selective removal of cleavers may be met by applications of this chemical. A further season's work is necessary to confirm this, especially in view of the mild winter in the 1988/89 season.

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REFERENCES

Boatman, N.D. (1989) Selective weed control in field margins. *British Crop Protection Conference - Weeds*. This volume.

Boatman, N.D.; Wilson, P.J. (1988) Field edge management for game and wildlife conservation. *Aspect of Applied Biology*, **16**, 53-61.

Marshall, E.J.P.; Smith, B.D. (1987) Field margin flora and fauna; interaction with agriculture. In: *Field Margins*, J.M. Way and P.W. Greig-Smith (Eds), *BCPC Monograph No. 35*, Thornton Heath: BCPC Publications, pp. 23-33.

Parsons, R.G. (1985) A simple growth stage key for broad-leaved weeds. *Aspects of Applied Biology*, **10**, 441-443.

Richardson, W.G.; Dean, M.L. (1974) The activity and post-emergence selectivity of some recently developed herbicides: oxadiazon, U-29, 722, U-27, 658, metflurazone, morflurazone, ACSO, 191, AC84, 777 and iprymidam. *Technical Report Agricultural Research Council Weed Research Organisation*, **32**, 74.

Way, M.J.; Greig-Smith, P.G. (Eds.) (1987). *Field Margins*. *BCPC Monograph No. 35*, Thornton Heath: BCPC Publications, 128pp.

SECONDARY SUCCESSION ON EXTENDED ARABLE FIELD MARGINS: ITS MANIPULATION FOR WILDLIFE BENEFIT AND WEED CONTROL

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ABSTRACT

The creation of diverse, perennial plant communities on arable field margins can offer low cost weed control and considerable benefits for wildlife. Large-scale experiments were established in 1987 to investigate the effects of timing and frequency of mowing on the development of both naturally regenerating and sown swards on newly-extended field margins. Although a high proportion of the species in neighbouring floras colonised these margins, the vegetation was dominated by a few species of pernicious weeds. Annual weeds declined after the first year but pernicious perennials continued to increase during the second year. In sown swards annuals declined more rapidly and the spread of perennials was restricted. For natural regeneration to be a successful option in the management of fallowed field margins, local floras must be relatively rich and management regimes must successfully select desirable from weedy perennials.

INTRODUCTION

Boundary strips and hedge bottoms around arable fields have presented increasingly difficult weed control problems in recent years. As the application of fertilisers by spinning discs has become a common practice, relatively diverse field-edge communities have been replaced by species-poor communities dominated by a few species of pernicious weeds. This is thought to result from the increase in the nutrient status of the boundary soils. This situation has been exacerbated by herbicide spraying, whether deliberate or by accidental drift, because the resulting gappy sward facilitates the establishment of annual crop weeds such as *Galium aparine* and *Bromus sterilis* (Froud-Williams *et al.*, 1980).

The impoverishment of the plant community, together with a progressive erosion in width by close cultivation, has made boundary strips very poor habitats for wildlife on many farms. However, these strips remain one of the major non-cropped farmland habitats and it is increasingly recognised that they have considerable potential value for wildlife (Hooper, 1987; Morris & Webb, 1987).

The establishment on the boundary strip of diverse, grassy, perennial swards that can be managed by mowing, offers a potential single solution to many weed control and wildlife management problems. In semi-natural grasslands it is well established both that annual species are normally unable to germinate and compete in perennial swards and that perennial weedy species can be controlled by manipulating the timing and frequency of mowing. Our experiments were designed to test the extent to which these principles can be applied within intensive arable systems. We are examining the feasibility of establishing, and maintaining by mowing, such grassland communities on fallowed strips around intensively farmed arable fields. We report here on the early successional development and on some of the effects of management on weed control and sward composition during the first two seasons of the experiment.

METHODS

We extended the width of the arable field margins at the University Farm at Wytham, Oxford, from around 0.5m to 2m by fallowing strips of cultivated land in autumn 1987. Fertiliser application was subsequently excluded from these strips by using a headland deflector-disc on the spinner, and spray drift was minimised by turning off the outer one or two jets on the spray boom. During 1988 ten management treatments were imposed on these strips, the original margin and the new extension being managed as a single unit. The treatments comprised controls and different combinations of timing and frequency of mowing and either removing or leaving the cut material. In six of the ten treatments the sward was allowed to develop by natural regeneration and in the remainder it was established by sowing a mixture of wild grasses and flowers that occur commonly in the Wytham area.

These ten treatments were replicated eight times. Where possible each block of ten was located around a single field such that variability in soil conditions and seed supply was minimised. Each treatment was imposed on a 50m length of field margin and the locations of the treatments were randomised around each field.

We recorded the relative frequency of the plant species, the height and density of the sward and demographic parameters of key weed species, five times a year in permanent quadrats. These were located in the original margin, its new extension (susequently referred to as the old and new margins respectively) and both 0.5m and 10m into the crop. Three banks of these four quadrats were located in each 50m length of margin. Soil samples were collected for seed bank analysis from the newly extended margin in autumn 1987.

RESULTS

Colonisation of the fallowed margins in 1988

Within six months of establishment 135 species had colonised the permanent quadrats in the newly extended margins. Fifty one per cent of these species were annuals. Perennials included 18 grasses and 14 woody species. The likely origins of this new flora could be assessed from the seed bank samples and the quadrats in the old margin and crop. A high proportion of the species in each of these "source" floras had colonised the new margins (Fig. 1). Only three of the 82 species in the seed bank in late autumn, had not yet appeared in the new margin and only one of these was absent from the extant flora on the farm. However, although the seed bank was likely to have made a critical contribution to the rates and frequency of colonisation of many species (maximum seed densities were 14 000 m^{-2}), it contributed little novelty to the new flora: only four species found in the seed bank were restricted to the new margin flora and were therefore likely to have been derived exclusively from this source. Of the 104 species that occurred in quadrats in the crop, only six rhizomatous perennials and 47 annuals could complete their life cycles in the crop: the remainder were perennials that established from the seed rain but were destroyed by cultivation before they could reproduce.

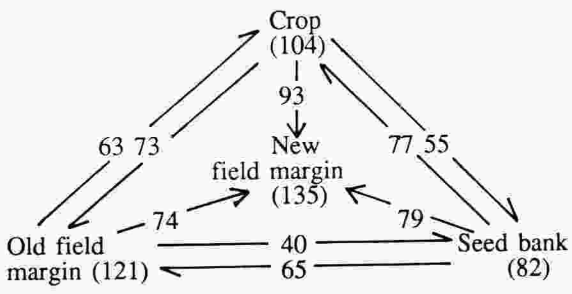

FIG.1 Relationship between new margin flora, neighbouring floras and the seed bank. Numbers on arrows are percentages of each flora represented in flora indicated by arrow. Numbers in parentheses are total species recorded in each flora.

All 53 of the species of the "true" crop flora occurred on the new margins during the first season. A smaller proportion of the old margin flora had colonised by this stage. Those species that failed to colonise in the first season were all perennials normally associated with long-established, semi-natural grasslands (e.g. *Viola hirta* and *Trisetum flavescens*) or shady habitats (e.g. *Arum maculatum* and *Mercurialis perennis*). Only three species that colonised the new margins were absent from the seed bank and near-by crop and boundary floras and must have colonised by dispersal from more distant sources.

Although a large number of species, constituting a high proportion of those in neighbouring floras, colonised the new margins in the first season, the majority of these occurred at very low frequencies (Fig.2a). This included most of the "desirable" perennials that might constitute a diverse grassland sward. The new sward was dominated by small numbers of very abundant species, most of which were annuals and almost all of which were pernicious weeds.

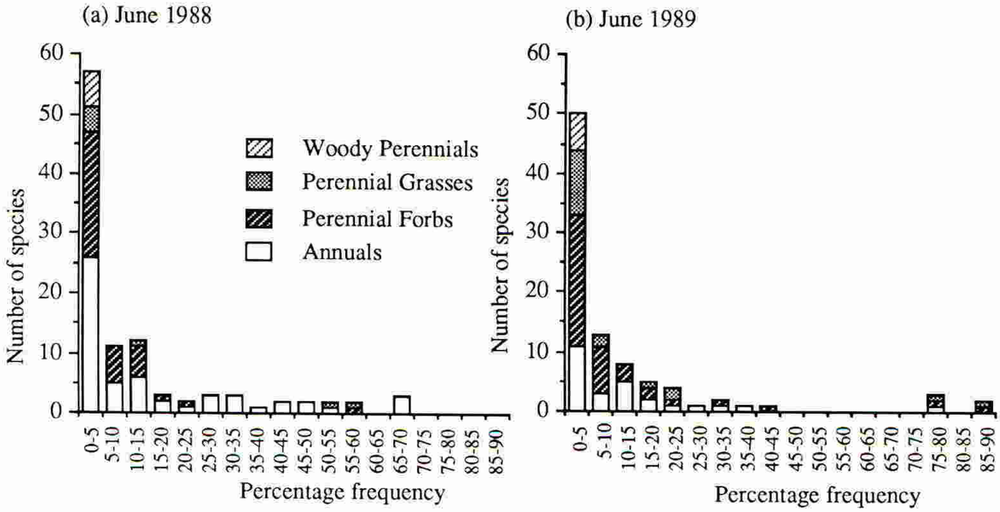

FIG.2 Relative frequencies of plant species colonising newly fallowed arable field margins

<u>Colonisation of the fallowed margins in 1989</u>

In the second season the new margin flora changed substantially, with a net decline of 18 species by June. The net number of annual species declined by 45%, while the number of perennials increased by 20% to include more species of semi-natural grassland and shady habitats. By June 1989 the new margin flora had less in common with the field weed flora and more in common with the flora of the field boundary. The relative frequencies of many of the remaining species also changed over the year. With the single exception of *B. sterilis*, the abundant annual weeds declined. In contrast, the few species of perennials that were abundant in the first season, had increased in frequency (Fig.2b). Most of these abundant perennials were pernicious agricultural weeds.

The decline in the number of annual species by the second season did not differ significantly between control plots and those managed by mowing. This suggests that it resulted from failure of the annuals to re-establish from seed in the increasingly dense perennial sward.

The effects of management

The magnitude of the decline in abundance of individual annual species varied between treatments. The most marked effects were between sown and naturally regenerating swards. Establishment of the seed mixture during the first season was very successful and resulted in a dense sward by late autumn. Figures 3a-c show the change in abundance of three common and pernicious annual grass weeds between June 1988 and June 1989, in the quadrats on both sown and naturally regenerating swards on the new margins, and in the old margins and the crop.

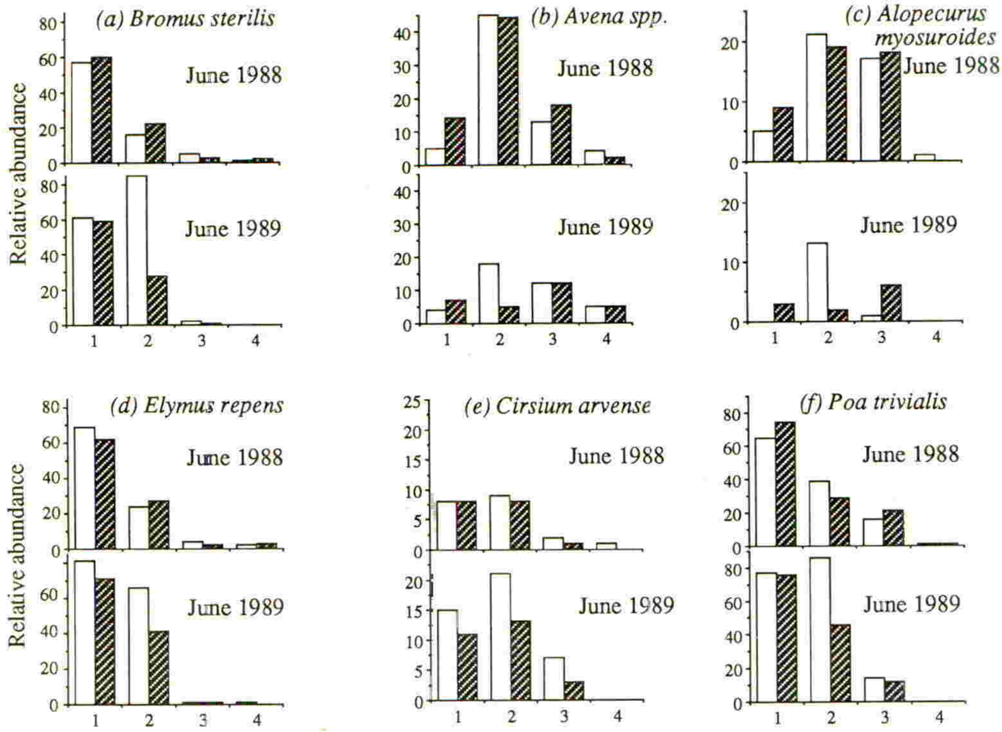

FIG.3 Relative abundance of three annual (a-c) and three perennial (d-f) weed species in permanent quadrats in (1) the old margin, (2) the new margin, (3) the crop edge and (4) the crop. Data are for strips with naturally regenerating ☐ and sown ▨ swards on the new margins.

Avena spp. and *Alopecurus myosuroides* were common on the new field margins in 1988 and were much more abundant there than in the old field margin or crop. These plants must have been derived from seed shed in the crop edge in previous seasons which could germinate easily in the open community when the edge was first fallowed. By 1989, however, both species had declined substantially on the new margins. This decline was much more extreme on the sown strips where, after one year, both species were at very low levels. *B. sterilis*, by contrast, increased in frequency on the new margins between 1988 and 1989. The contrast between its behaviour and that of the other two annual grass weeds may have resulted from its preference for germinating in shady conditions, such as prevailed under the new swards in the autumn of 1988. In common with the former species, however, its frequency in the sown swards was much lower than in those established by natural regeneration. Its frequency in sown swards was also substantially lower than that in the adjacent old margins, where it maintained its population in both years.

Equivalent data for three of the most abundant perennial weed species shows that they all increased in frequency on the new margins and, to a lesser extent on the old margins, between June 1988 and June 1989 (Figs. 3d-f). *Poa trivialis* was the most abundant perennial on the new margins but did not become a problem weed in the crop. When mown it formed a dense sward that could be effective in excluding annuals. *Cirsium arvense* and *Elymus repens* which could continue to invade the new margins from the old by rhizomatous extension, were considered more likely to cause crop weed problems. The increase in frequency of all of these species was reduced where they were competing in sown swards, but it remains to be seen whether these swards hold them in check in the medium term.

DISCUSSION

Succession on the fallowed arable field margins of our experiment has followed a very similar course to that recorded in abandoned fields in North America during periods of agricultural depression (e.g. Beckwith, 1954). Large numbers of species colonised at a very early stage with trees, shrubs, herbaceous perennials and annuals all establishing concurrently. By the second season a relatively dense perennial sward had established in which it was much more difficult for annuals to re-establish. Invasion by seed of new perennials continued, although at a much-reduced rate, because the seeds of many perennial species are better able than those of annuals to establish in small gaps in the sward and their seedlings are better able to compete in shady conditions (Fenner, 1978; King, 1975).

The majority of species that colonised the newly-fallowed margins were derived from floras in the immediate vicinity. More distant floras were increasingly unlikely to play a major role in sward development as opportunities for establishment decreased. The rate of early succession, leading to dense sward development, is likely to be rapid on all highly fertile arable soils. Our results suggested that the numbers of colonists were directly dependent on the richness of neighbouring floras and hence that there was little possibility of diverse perennial communities establishing in the absence of such sources. The seed bank was unlikely to introduce many novel species of the "desireable" longer-lived perennials that were required, because most such species have short-lived seeds (Roberts, 1970; Howe & Chancellor, 1983).

Although the species on the new margins included "desireable" perennials, most of these occurred at low frequencies in swards dominated by pernicious weedy species (see also Graham & Hutchings, 1988). The dominance of most annual weeds was restricted to the first season because of successional processes. However, it may be desirable both for farmer-acceptability and also, in temporary fallow, to prevent build-up of long-lived weed seeds (e.g. *Avena* spp.), to mow in the first season prior to seed maturation in the dominant problem annuals. The perennial weed problems, however, were much more substantial. The dominant perennials were those that were able to utilise most efficiently the high nutrient levels available in these former arable soils. In the absence of management the increase in frequency of these species will probably continue at the expense of the less common and slower-growing species.

The use of grass leys for sward establishment has evident advantages over natural regeneration. In one season they can effectively exclude annuals and, even in the absence of mowing, reduce substantially the rate of spread of rhizomatous perennials. Conventional farm grass leys can be used for this purpose (Peay, 1988) but their attractiveness and benefits for wildlife are low relative to those of wild grass and forb mixtures. Although natural regeneration is the only option that can potentially allow re-establishment of desirable and attractive elements of the local flora, our results suggest that where local seed souces are poor and perennial weeds or *B. sterilis* infestations are severe, then sowing is the only pragmatic method of establishing grassy swards. Our preliminary results suggest that even in these swards, rhizomatous perennial weeds can continue to spread in the absence of management. We hope to establish in subsequent seasons the extent to which management by differing mowing regimes can control the dominance of these perennials and allow a more diverse perennial sward, whether sown or derived from local seed sources, to persist on fallowed arable land.

ACKNOWLEDGEMENTS

This project is funded by the Nature Conservancy Council with additional support from the Ernest Cook Trust and the Co-Op Bank. We thank Chris Bond for invaluable help with computing and field work, Dr. Stephen Baillie for helpful comments on the manuscript, and the University of Oxford Farm for accomodating our experiments.

REFERENCES

Beckwith, S.L. (1954) Ecological Succession on abandoned farm lands and its relationship to wildlife management. *Ecological Monographs*, **24**, 349-376.

Fenner, M. (1978) Susceptibility to shade in seedlings of colonising and closed turf species. *New Phytologist*, **8**, 739-744.

Froud-Williams, R.J.; Pollard, F.; Richardson, W.G. (1980) Barren Brome: A threat to winter cereals? *Report of the Weed Research Organisation, 1978-1979*, 43-51.

Graham, D.J.; Hutchings, M.J. (1988) Estimation of the seed bank of a chalk grassland ley established on former arable land. *Journal of Applied Ecology*, **20**, 241-252.

Hooper, M.D. (1987) Conservation interest in plants of field margins. In: *Field Margins* J.M. Way & P.W. Greig-Smith (Eds), *BCPC Monograph No.35*, Thornton Heath: BCPC Publications, pp. 49-52.

Howe, C.D.; Chancellor, R.J. (1983) Factors affecting the viable seed content of soil beneath lowland pastures. *Journal of Applied Ecology*, **20**, 915-922.

King, T.J. (1975) Inhibition of seed germination under leaf canopies in *Arenaria serpyllifolia*, *Veronica arvensis* and *Cerastium holosteoides*. *New Phytologist*, **75**, 87-90.

Peay, S. (1988) Re-establishment of grass verges associated with hedges. *Unpublished report by Lincolnshire and South Humberside Farming and Wildlife Advisory Group*, 24 pp.

Morris, M.G.; Webb, N.R. (1987) The importance of field margins for the conservation of insects. In: *Field Margins* J.M.Way & P.W.Greig-Smith (Eds), *BCPC Monograph No.35*, Thornton Heath: BCPC Publications, pp. 53-65.

Roberts, H.A. (1970) Viable weed seeds in cultivated soils. *Report of the National Vegetable Research Station 1969*, 25-38.

THE EFFECTS OF BOUNDARY STRIPS ON THE FLORA OF CEREAL FIELDS

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INTRODUCTION

ABSTRACT

The effects of different treatments of the field boundaries of of winter wheat fields on the botanical composition of field margins were compared at three A.D.A.S. Experimental Husbandry Farms. The treatments were : (i) control - no boundary strip; (ii) 2m rotavated strips; (iii) 2m strips prepared using a residual herbicide and (v) 2m grass strips. No statistically significant effects of the treatments on botanical diversity were found. The distribution of three common agricultural weed species was influenced by the boundary strips, but in different ways. Further study is needed to fully assess the role of boundary strips in weed control and in the maintenance of high biological diversity in the margins of cereal fields.

INTRODUCTION

Loss of hedges, associated with post-war agricultural intensification in Britain, has been regarded as a serious loss of farmland habitat for wildlife (Pollard *et al.*,1974; Sotherton 1984; O'Connor & Shrubb, 1986; Rands & Sotherton, 1987; Baudry, 1988; Wratten, 1988). Hedge removal served several agricultural functions (Pollard *et al.*, 1974), one of which was to remove a potential source of weeds (Marshall & Smith, 1987; Roebuck, 1987). In 1987-8, the Agricultural Development and Advisory Service (A.D.A.S.) initiated a study designed to assess the effects of boundary strips (for terminology seeGreaves & Marshall, 1987) in minimising weed problems of cereal crops while maintaining a diverse field margin flora and insect fauna. This paper reports the preliminary botanical findings from three (of six) study sites from the first year of the investigation.

METHODS

In autumn 1987, study sites were prepared along winter wheat field boundaries adjacent to established hedges at Bridgets Experimental Husbandry Farm (E.H.F.), near Winchester, Boxworth E.H.F., Cambridge and Drayton E.H.F., Stratford-on-Avon. At each site, 20m long treatment plots were arranged in randomised blocks with four (Bridgets and Boxworth) or three (Drayton) replicates. The four treatments were: (i) no boundary strip, crop grown right up to field margin, (ii) 2m boundary strip prepared by rotavation in autumn 1987 and spring 1988, (iii) 2m boundary strip prepared chemically using a residual herbicide (propyzamide) in autumn 1987, and (iv) a 2m grass boundary strip sown with a ryegrass mix in autumn 1987 and mown in spring 1988, with the cuttings removed.

In each plot, three 5m transects running from the hedge centre Boxworth and Drayton) or from a protective fence (Bridgets) were established at right angles over the treatment and into the crop. Along the each transect, plant species were recorded in 10 cm^2 contiguous quadrats in July.

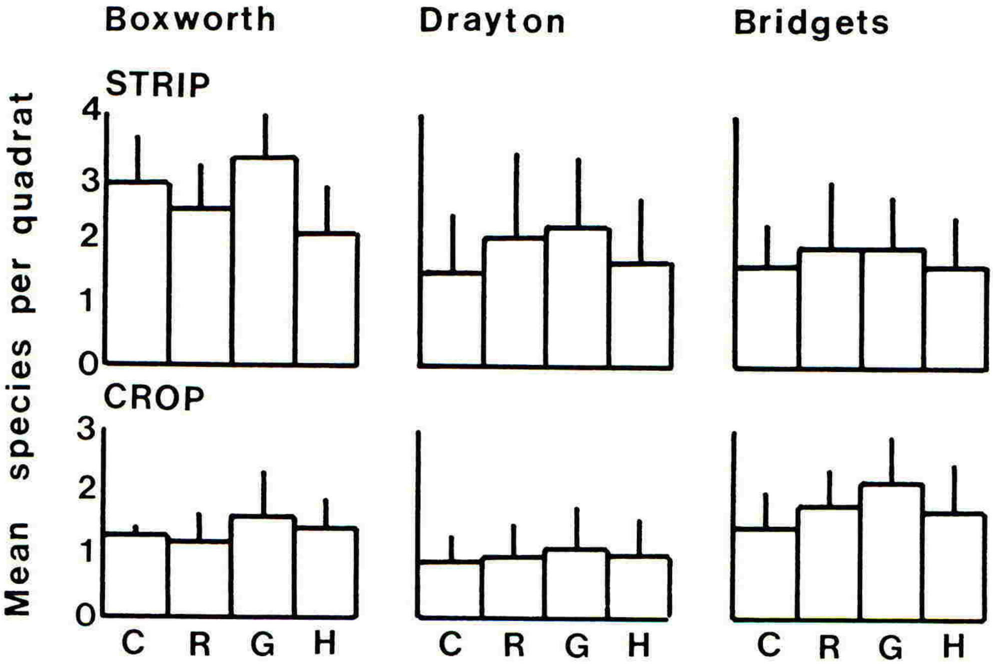
RESULTS

One hundred and eighteen species of plants were recorded on the transects at the three farms but 77 of these were unique to farms, only 41 species being recorded on two or more farms (Table 1). On each farm, the transects showed the greatest number of species per quadrat in the hedge and the smallest in the crop. There were no statistically significant differences between treatments in the mean number of species in the strip and crop (Figure 1), although in most cases the strip and crop floras were greatest where the strip had been sown with grass the previous autumn.

TABLE 1. Distribution of plant species in cereal field margins at Bridgets E.H.F., Boxworth E.H.F. and Drayton E.H.F.

No. of species recorded at:	Bridgets	Boxworth	Drayton	Total
1 farm	33	23	21	77
2 farms	9 (Bridgets–Boxworth)			
		3 (Boxworth–Drayton)		21
		9 (Bridgets–Drayton)		
3 farms		20 (Bridgets–Boxworth–Drayton)		20
Total	71	55	53	118

FIGURE 1. The mean number of plant species per quadrat (10cm^2) in the boundary strip and crop according to treatment. Within each treatment, quadrats 21-30 (strip and 41-50 (crop) were used for this anlysis, so that means are calculated from 120 quadrats at Boxworth and Bridgets (with four replicates) and from 90 quadrats at Drayton (three replicates). Vertical bar one standard error. Treatments: C- control (crop sown to margin), R- rotavated strip, G - grass strip, H - herbicide-treated strip.



Of the annual and perennial species regarded as agricultural weeds (Roebuck, 1987) 11 species occurred at Boxworth with two *Bromus* species at high densities, while fewer species, all at lower densities, were recorded at Bridgets and Drayton (Table 2). Thus while the margin at Bridgets E.H.F. had the highest species diversity, that at Boxworth had the highest proportion of weed species.

Analysis of the distribution of the commonest weed species at Boxworth suggested some influence of the boundary strip treatment on weed abundance in the strip, but not in the crop (Table 3). *Bromus commutatus* was more abundant in the grass strip than in the rotavated strip (t-test $p<0.05$) and in the herbicide-treated strip ($p<0.01$) but the difference between grass and the control strip was not significant. *Bromus sterilis* was less abundant in the herbicide-treated strip than in all other treatments ($p<0.01$ in all comparisons). At Drayton, *Poa trivialis* was more abundant in the rotavated strip than in the grass and herbicide-treated strips ($p<0.02$) but not significantly different from the control, while in the crop this species was more abundant in the rotavated and grass strips than in the control ($p<0.05$) but the difference between the control and herbicide-treated strip was not significant. No other significant relationships were found.

TABLE 2. The number of 10 cm^2 quadrats in which agricultural weed species were recorded in the field margins of ceral fields at three A.D.A.S. Experimental Husbandry Farms.

(No. of 10 cm^2 quadrats sampled)	Bridgets (1800)	Boxworth (1800)	Drayton (1800)
Annuals			
Alopecurus myosuroides		16	
Avena fatua		13	
Bromus mollis		13	
Bromus commutatus		1012	
Bromus sterilis	204	1419	
Galium aparine	92	9	28
Perennials			
Agrostis stolonifera	60	3	114
Arrhenatherum elatius	214	16	5
Cirsium arvense		67	2
Elymus repens	45	279	22
Poa trivialis	287	35	295

TABLE 3. Abundance (mean no. of quadrats/replicate containing the species ± one standard error) of the most commonly occurring weed species at Boxworth and Drayton EHF's in the boundary strip and adjacent crop in relation to the treatment of the strip.

Treatment	Boxworth *Bromus commutatus* Strip	Boxworth *Bromus commutatus* Crop	Boxworth *Bromus sterilis* Strip	Boxworth *Bromus sterilis* Crop	Drayton *Poa trivialis* Strip	Drayton *Poa trivialis* Crop
Control	54.0±13.1	6.5±2.9	92.2±3.2	11.2±2.9	14.0±4.0	2.0±1.1
Rotavated	48.2±11.6	9.2±2.2	86.5±2.1	12.0±2.0	30.7±5.6	12.3±2.7
Grass	81.2±5.8	10.7±4.3	87.0±4.9	11.0±2.3	5.0±2.0	21.0±1.7
Herbicide	35.7±4.4	7.2±2.6	41.5±2.5	13.5±0.6	1.7±1.2	16.0±7.6

DISCUSSION

The large differences between the plant species compositions of the three farms (Table 1) may have a geographical component due to variations in soils and climate, although age of the hedge and previous histories of the fields will have also influenced the botanical composition of the

field boundaries. In studies such as this, therefore, the results from each site must be considered independently. At none of the farms was there an influence of boundary strip treatment on the floral diversity of the strip or crop (Figure 1), although there was a trend for the grass strip to support the highest species density. In this study, the grass strips had been sown only 10-11 months before the species compositions were recorded in July 1988 and the sward was therefore not fully established, leaving bare patches available for colonization. This indicates that an assessment of the efficacy of grass strips in maximising the botantical diversity of field margins and in weed control should run over several years. However, the data do indicate that the timing and frequency of rotavation used in this experiment and the herbicide treatment failed to maintain those strips 'sterile' of vegetation.

Most of the species regarded as agricultural weeds occured at densities too low to permit meaningful analysis, but there were indications that the distributions of three species were influenced by the boundary strip treatments, but in different ways (Table 3). Residual herbicide appeared the most effective of the boundary strip treatments in reducing weed density, while rotavation appeared inefficient at the frequency employed here. The grass strips failed to discourage the annual weeds, but this may result from the relatively poor sward establishment to date of the young grass.

This study is continuing for a second year and its full implications will be revealed only when the botanical, entomological, crop yield and operational cost data are integrated. This will provide a background against which management decisions can be made, although clearly other forms of boundary strip management remain to be investigated in order to reconcile the desire for weed control combined with a rich floral and faunal diversity.

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REFERENCES

Baudry, J. (1988) Hedgerows and hedgerow networks as wildlife habitat in agricultural landscapes. In: *Environmental Management in Agriculture*, J.R. Park (Ed), London, Belhaven Press, pp 111-124.

Greaves, M.P.; Marshall, E.J.P. (1987) Field margins: definitions and statistics. In: *Field Margins*, J.M. Way and P.W. Greig-Smith (Eds) *BCPC Monograph No. 35*, Thornton Heath: BCPC Publications, pp 3-10.

Marshall, E.J.P.; Smith, B.D. (1987) Field margin flora and fauna : interaction with agriculture. In: *Field Margins*, J.M. Way and P. W. Greig-Smith (Eds), *BCPC Monograph No. 35*, Thornton Heath : BCPC Publications, pp 23-33.

O'Connor, R.J.; Shrubb, M. (1986) *Farming and Birds*, Cambridge : Cambridge University Press.

Pollard, E.; Hooper, M.D.; Moore, N.W. (1974) *Hedges*, London : Collins.

Rands, M.W.; Sotherton, N.W. (1987) The management of field margins for the conservation of gamebirds. In *Field Margins*, J.M. Way and P.W. Greig-Smith (Eds), *BCPC Monograph No. 35*, Thornton Heath : BCPC Publications, pp 95-104.

Roebuck, J.F. (1987) Agricultural problems of weeds on the crop headland. In: *Field Margins*, J.M. Way and P.W. Greig-Smith (Eds), *BCPC Monograph No. 35*, Thornton Heath : BCPC Publications, pp 11-22.

Sotherton, N.W. (1984) The distribution and abundance of predatory anthropods overwintering on farmland. *Annals of Applied Biology*, **105**, 423-429

Wratten, S.D. (1988) The role of field boundaries as reservoirs of beneficial insects. In: *Environmental Management in Agriculture*, J.R. Park (Ed), London : Belhaven Press, pp 144-150.

THE ACCESSIBILITY OF A FORMER PASTURE FOR NEW SPECIES: IMPLICATIONS FOR MANAGEMENT

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ABSTRACT

One conservation option for set-aside pastures is to transform them into more valuable species-rich hay meadows. Experience has shown the need for management by mowing and the removal of cuttings to lower the productivity thereby offering opportunities for new species introductions. However, in many cases re-establishment however has been very slow. A quantitative inventory of the seed bank, the seed rain and seedling germination of the vegetation in a former pasture has shown that the seed bank was the most important source of new species, but that this source was dominated by ruderals. Virtually no new species were present in the seed rain. Experimental species introductions both as seeds and seedlings, confirmed the existence of such a dispersal barrier. In order to achieve greater conservation value when managing former pastures active species introductions should be considered.

INTRODUCTION

Excess milk production in the Netherlands and the EC generally, has led to suggestions to set aside large areas of intensively managed grassland (De Wit, 1988). One option for these abandonned pastures is to manage them in ways such that former species-rich hay meadows with a greater conservation value will result. This implies that the few dominant grass cultivars in the sward have to be succeeded by a more varied assortment of species. Species replacement encompasses succession theory (Pickett et al., 1987). From such theory it can be deduced that the success of such operations depends on two factors: the reduction of the competitive ability of the resident species and access by the diaspores of new species.

The former objective can be realised by management aimed at reducing the nutrient status of soils, resulting in more open swards, with a greater species diversity (Grime, 1973). However, in practice the re-establishment of former less common hay meadow species, is less succesful (Oomes & Mooi, 1985; Bakker, 1987). It is hypothesised that plant dispersal limits their re-establishment, especially in cases where pastures are set aside in agricultural landscapes.

Before testing this hypothesis it must be realised that before re-establishment of a plant species could occur at least three barriers must be overcome, each of which may result in its exclusion. These barriers are dispersal, germination and establishment. Firstly a species might not arrive. This would depend on number and size of the sources of diaspores and their distance to the target area, influenced in turn by particular dispersal mechanisms. Secondly, the diaspore might not land in a suitable gap. Gap quality is species-specific and determined by its germination characteristics. When not germinating the diaspore might enter the seed bank from which it could later be released when according to its dormancy pattern conditions become more favourable. Finally after germination a species might suffer from the many risks encountered before establisment.

An inventory of the three barriers, from examining seed rain, seed bank and seedling establishment might allow one to discover which species could enter the vegetation. The next step would be to test potential barriers by sowing and transplant experiments (for a review see Bakker 1989). In this paper an inventory is presented together with some results of sowing and transplanting experiments. The results are evaluated against the ultimate goal of successful transformation.

MATERIAL AND METHODS

In a former pasture, not fertilized since 1978 and managed as a hay meadow since 1986, a 10x30m strip was selected perpendicular to the field margin (a ditch). Five transects were surveyed each 10m long at distance 0, 1, 3, 13 and 30m from the ditch. The inter-transect distance reflected the rate of change of species composition with increasing distance from the margin. All forbs were recorded in ten plots in each transect: adults (quadrat size = 20x20cm; presence/-absence), seedlings (15x15cm; all individuals recorded), seed bank (soil samples from eight soil cores per location; all individuals), seed rain (10cm diameter sticky traps; all individuals). The soil samples were treated using the methods of Post (1984), resulting in a germination response of 98.9%. Seeds were identified according to shape (Beyerinck, 1947) or by germination. To facilitate interpretation species have been categorised into four groups: hay meadow species, species indicative of disturbances in grassland, ruderals and others, mainly marsh or semi-aquatic species in the ditch.

Three dicots present as adults were selected for further experiments and compared with three dicots still absent but desired in such hay meadows. These species were introduced as seeds and seedlings at the field margin (3m) and in the field centre (30m) into small artificial gaps and under closed canopies. Each treatment consisted of six replicates. Per replicate, fifty seeds of known vitality were sown and four seedlings transplanted. The fate of all individuals was monitored during one growing season (spring/summer, 1989).

RESULTS AND DISCUSSION

There was a strong reduction in species diversity from the field margin towards the field centre, a gradient also found in the seed bank, seed rain and seedling flora (Figure 1a), with a tendency to change away from ruderals in favour of hay meadow species. This gradient resulted from species entering the field from the ditch bank and as a result of the greater disturbance from machinery concentrated along the field margin. Consideration of actual species abundance showed differences between the seed bank and seed rain with an emphasis on hay meadow species in the seed rain and on ruderals in the seed bank (Figure 1b).

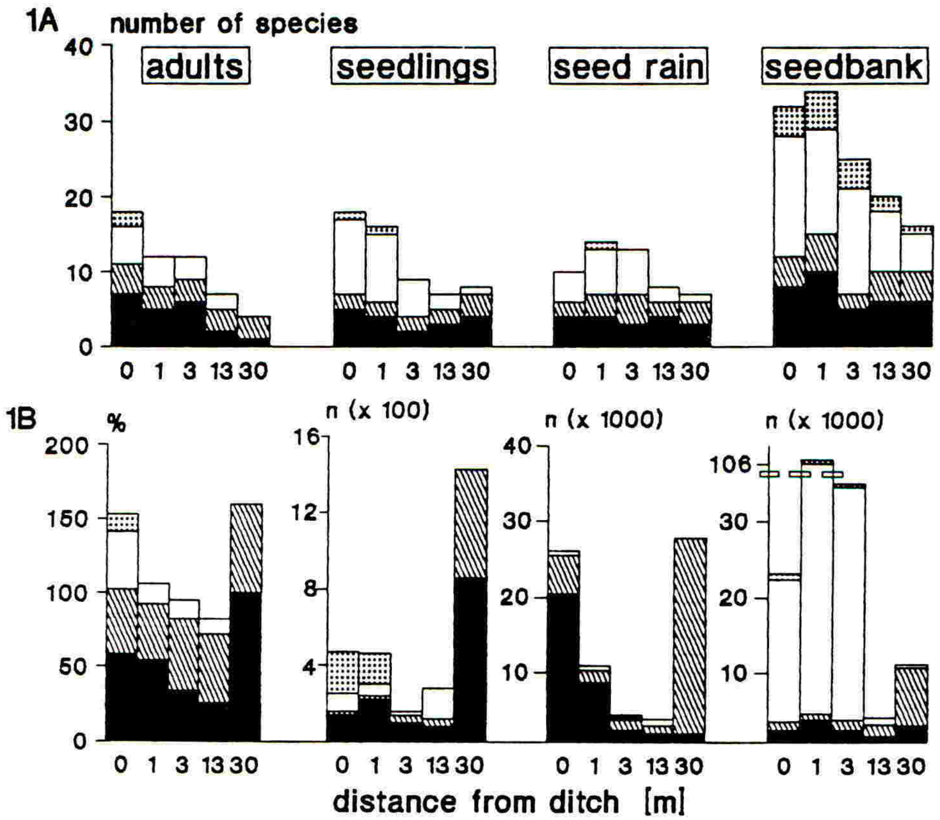

Figure 1a: Number of species per life cycle stage, at increasing distances away from the field edge. ■ hay meadow species; ▨ species indicative for disturbance in grassland; □ ruderals; ▦ others.
Figure 1b: Number of individuals per life cycle stage, at increasing distances from the field edge. The abundance of adult plants is presented as mean % frequency.

As a source of new species the seed bank was the most important (lowest similarity with the actual vegetation, Sørensen Similarity Index: Ø.55). The seed bank contained 22 species alien to the standing vegetation. The seed rain had an intermediate similarity (SSI: Ø.67). Five species were present in the seed rain that were absent in the actual vegetation, although only one species could be considered truly new (Glechoma hederacea) because the other four species were also present in the seed bank. The greatest similarity was found between seedlings and standing vegetation (SSI: Ø.76). Also five species were found as seedlings with no adult plant present in the vegetation, but all of these were present in the seed bank or in the seed rain. In all, 23 new species were found in the seed bank and seed rain together, five of which produced seedlings. The potential of these new species for altering the species composition in the desired direction is shown in Figure 2. Clearly there was very little potential for amelioration from the seed bank, a conclusion also reached in other situations (Graham & Hutchings, 1988; Bakker, 1989). As a source of new species the seed rain played a minor role, indicating the existence of a dispersal problem. Most new species were found in the margin, including many desirable species, but few germinated. In contrast in the field centre, there were less new species, fewer germinated but they were of the desired species.

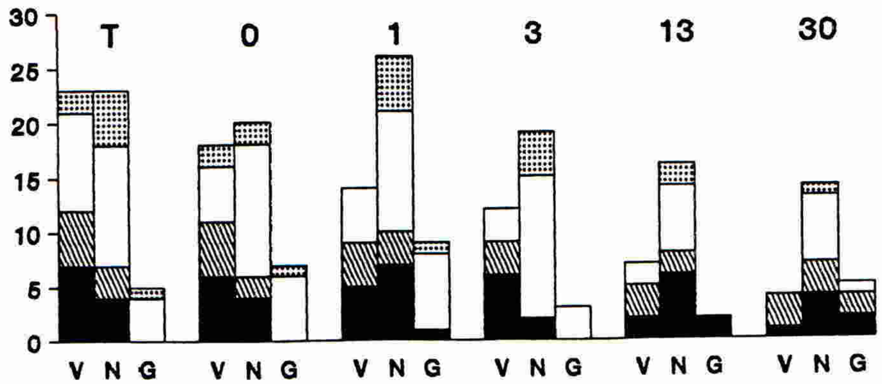

Figure 2: Number of species present in the vegetation (V); new species in seed bank and/or seed rain (N); new species actually germinating (G), at increasing distances from the field edge (Øm - 3Øm) and for the field as a whole (T).

To further test the hypothesis of limited access, species were sown and seedlings transplanted into the sward. The results showed that there were no clear differences in germination or in establishment between the two categories of species: those present and those expected to be present. Species specific differences in germination were found depending on the siting of the experimental sowings or transplantations both with the position in the field and within the vegetation structure. Some species preferred the field centre others the margin (Figures 3a & 3b). Species like Rumex acetosa preferred germinating in the field margin in open spots whereas Taraxacum spp. preferred open areas but more towards the field centre, the vegetation being most dense towards the margin and more open towards the field centre (Figure 3b). All species established best in open spots near the centre of the field and worst in closed spots near the margin except for R. acetosa which established well in closed spots near the margin. This is confirmed by the observation that under natural conditions more seedlings emerged and did so earlier near the margin but survival was better near the centre, resulting in a better net establishment.

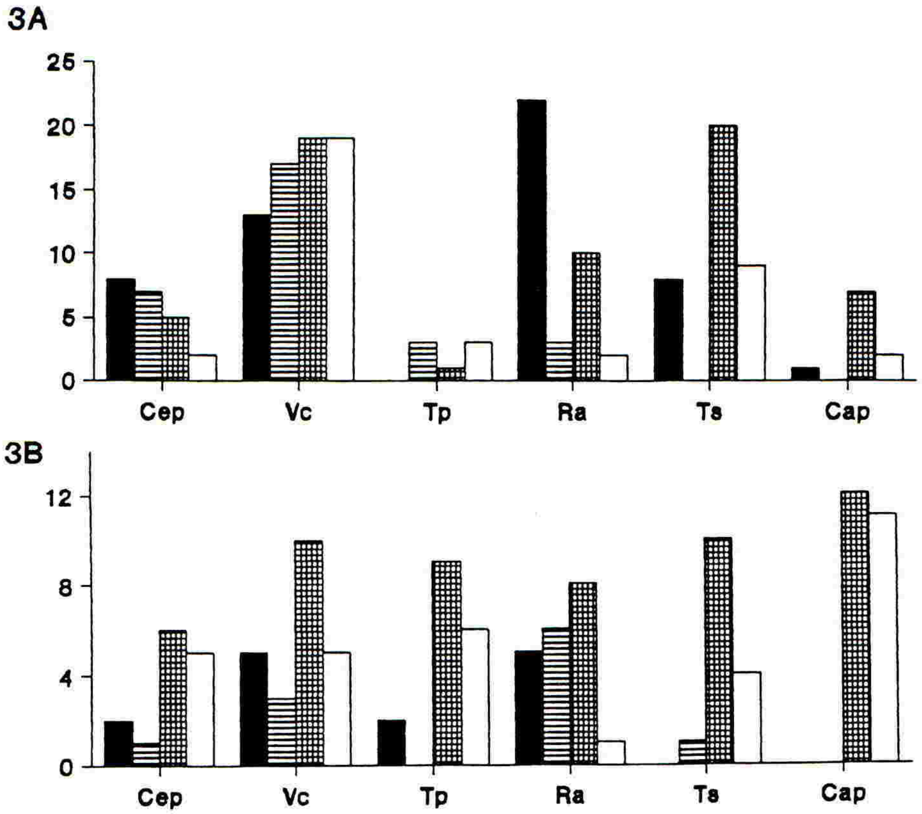

Figure 3a: Mean number of seedlings surviving out of 300 seeds seven weeks after sowing. ■ open spots near margin; ▤ closed spots near margin; ▦ open spots near centre; □ closed spots near centre. Species absent from the vegetation: Cep Centaurea pratensis; Vc Vicia cracca; Tp Trifolium pratensis. Species present in the vegetation: Ra Rumex acetosa; Ts Taraxacum spp.; Cap Cardamine pratensis.
Figure 3b: Mean number of seedlings surviving out of 24, 6 weeks after transplanting. Legend as in Figure 3a.

CONCLUSIONS

In this particular grassland there was a gradient from the field margin towards the field centre which was demonstrated in every experiment and for all life cycle stages studied.

Most species and also the greatest amount of propagules were found near the margin, among them also the greatest amount of propagules of new species, but mainly ruderals germinated.

The most abundant source of new species both in number of species and in number of propagules, was the seed bank.

Very few new species were carried into this grassland by means of seed dispersal, demonstrating a dispersal barrier. This was confirmed by sowing and transplanting experiments.

Few new species were found towards the centre of the field but their probability of successful establishment was greater. This was confirmed by results from the seedling transplant experiment where all species tested established better in open spots near the centre.

To realise a transformation from a former pasture into a species-rich hay meadow species introductions should be considered.

REFERENCES

Bakker, J.P. (1987) Restoration of species-rich grassland after a period of fertilizer application. In: Disturbance in grasslands, J.van Andel; J.P.Bakker and R.W.Snaydon (Eds), Dordrecht: Junk Publishers, 185-200.

Bakker, J.P. (1989) Nature Management by Grazing and Cutting, Dordrecht: Junk Publishers, 400 pp.

Beyerinck, W. (1947) Zadenatlas der Nederlandsche Flora, Wageningen: Veenman & Zonen, 316 pp.

Graham, D.J.; Hutchings, M.J. (1988) A field investigation of germination from the seed bank of a chalk grassland ley on former arable land. Journal of Applied Ecology, **25**, 253-265.

Grime, J.P. (1973) Control of species diversity in herbaceous vegetation. Journal of Environmental Management, **1**, 151-167.

Oomes, M.J.M.; Mooi, H. (1985) the effect of management on succession and production of formerly agricultural grassland after stopping fertilization. Münstersche Geografische Arbeiten, **20**, 59-67.

Pickett, S.T.A.; Collins, S.L.; Armesto, J.J. (1987) A hierarchical consideration of causes and mechanisms of succession. Vegetatio, **69**, 109-114.

Post , B.J. (1984) Physical and chemical treatments for assessing the seed bank in soil samples. In: VIIe Colloque International sur l'Ecologie, la Biologie et la Systematique des Mauvaises Herbes, G.Barralis and E.Robert (Eds), Paris: Columa EWRS, 71-79.

Wit de, C.T. (1988) Landbouw en milieu in het perspectief van de EG. Platform, **4**, 12-16.

THE DISTRIBUTION OF ARABLE WEED SEEDBANKS AND THE IMPLICATIONS FOR THE CONSERVATION OF ENDANGERED SPECIES AND COMMUNITIES.

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ABSTRACT

The within-field distribution of arable weed seed banks has been studied with particular emphasis being placed on species that are thought to have undergone a decline in recent years. Methods used were a survey of seedlings before herbicide application, and estimation of the soil seed bank from soil cores. Results indicated a concentration of most weed species within the outermost six metres of the field, with a few notable exceptions. These observed distributions have considerable implications for the conservation of endangered species.

INTRODUCTION

The future of arable farmland is currently the subject of much debate. It is possible that in future substantial areas of land will either be removed from arable production, or will be farmed in less intensive ways, and the first areas to be considered for alternative use are often field margins and corners (Anon, 1988). Casual observations have indicated that these are the areas of greatest botanical interest, and previous studies have supported this view (Marshall, 1985; Hald *et al.*, 1988).

The aim of this survey was to examine the relationship between the size and composition of arable field seedbanks and distance from the field margin, as part of a wider programme of research into the conservation of endangered arable weed species and communities.

METHODS

There are a number of problems inherent in estimating population sizes of arable weed species with annual life-cycles. In a normal farming situation, most weed seedlings will be eliminated by applications of herbicide, and so any survey must be conducted in the short time available between the germination of weed seedlings after the drilling of the crop, and the first herbicide application. A large resource of dormant seed can build up in the soil as a seedbank (Roberts, 1981), and an assessment of seedling emergence at one time in any one year would be measuring only a sample of this seed-bank. This sample will be strongly influenced by the interaction of cultivation timing with the germination periodicity of the individual species present, weather conditions and type and efficiency of cultivation (Roberts & Ricketts, 1979; Froud-Williams *et al.*, 1984). In order to obtain an accurate picture of weed populations therefore, the seedbank was sampled directly by means of soil coring, in addition to counting the emergence of seedlings in the field.

In early April 1988, seven fields were chosen that had been drilled with spring barley, but which had not yet received an application of herbicide. These fields were located on four farms in Hampshire, and were all known to contain populations of relatively uncommon weed species.

A grid of transects was laid out in a corner of each field, with sampling points on each transect at the following distances (in metres) from the crop edge; -0.5, 0, 1, 2, 4, 8, 16, 32, 64, and 128. At each sampling point, all weed seedlings in a $0.25m^2$ quadrat were identified and counted, and a soil core of cross-sectional area 3.85 X 10-3 m^2 was taken, to a depth of 20cm, the approximate depth of ploughing.

Each soil core was broken down into a separate tray in a greenhouse, and watered regularly. Each tray was stirred at regular intervals, and emerging seedlings counted. The trays were moved around occasionally to minimise the effects of any non-uniform conditions within the greenhouse.

Results were subjected to analysis of variance by multiple regression. The frequency of occurrence of individual species and pooled data for all species were analysed after adjustment for the position of each sampling point with respect to the two edges of the field corner. To illustrate and compare distributional trends, mean results over all seven fields for a predicted notional transect at -0.5m from the crop edge were calculated from the regression coefficients generated by the analysis, and were plotted against distance from the field edge. These trends were calculated for the total seedling population, total species number and some individual species (Figures 1 & 2).

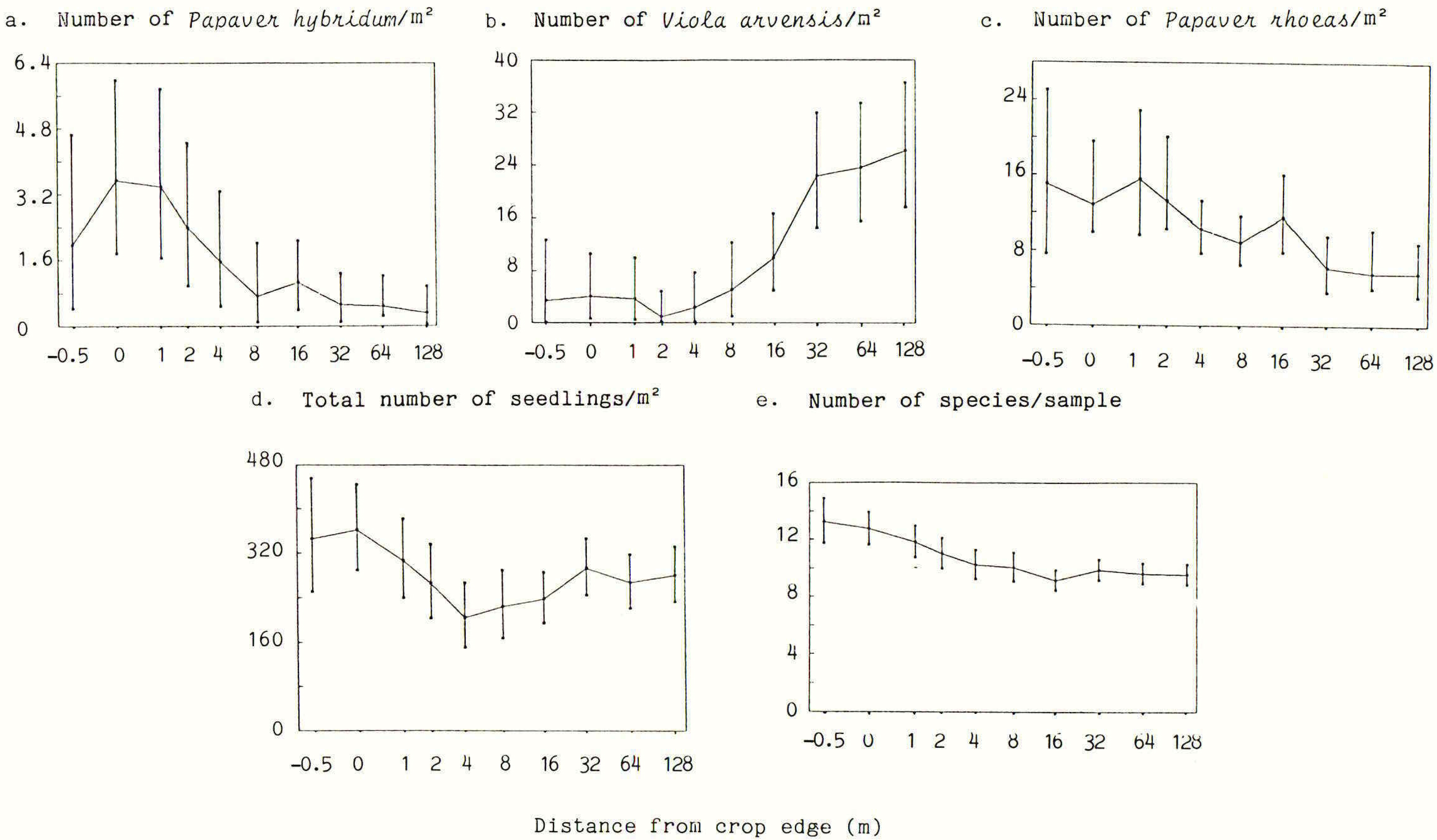
RESULTS

The variation between distribution patterns displayed by individual species may be illustrated by *Papaver hybridum*, *Papaver rhoeas* and *Viola arvensis* (Figures 1a-c). The frequency of *P. hybridum* (Figure 1a) was at a maximum of 3.6 per m^2 at 1 m from the crop edge, declining to 0.3 per m^2 at 128 m. The distribution of *V. arvensis* (Figure 1b) showed an opposite pattern, with a minimum of 0.9 per m^2 at 2 m from the crop edge, increasing to 26.4 per m^2 at 128 m. The other species examined, e.g. *P. rhoeas* (Figure 1c) showed a range of distributions between these two extremes, although almost all showed a decline with increasing distance from the field edge. For some species, e.g. *Valerianella dentata*, *Lapsana communis*, *Aethusa cynapium* and *Anthemis cotula*, these declines were of a similar order to that of *P. hybridum*.

The total seedling number (Figure 1d) decreased from 362.5 per m^2 at 0m to a minimum of 204.8 per m^2 at four metres from the crop edge, and then increased again to a secondary maximum of 293.7 per m^2 at 32m, as such abundant species as *V. arvensis* became more frequent towards the field centre. The number of species recorded per sample also became significantly smaller with increasing distance from the crop edge (Figure 1e), decreasing from 13.6 at -0.5m, to 9.1 at 16 metres.

Most of the species examined, seemed to show a secondary peak of abundance between 16m and 32m from the field edge. This was also shown in the data for total seedling number and species number. The secondary peak in the total seedling number graph could be greatly reduced by removing the data for very abundant species such *V. arvensis* and *Polygonum*

FIGURE 1. Distribution patterns of arable weed seedlings in relation to distance from the crop edge. Data with 95% confidence limits derived from field surveys of numbers of seedlings per 0.25m² in seven fields. Distance from the crop edge is plotted on a logarithmic scale.

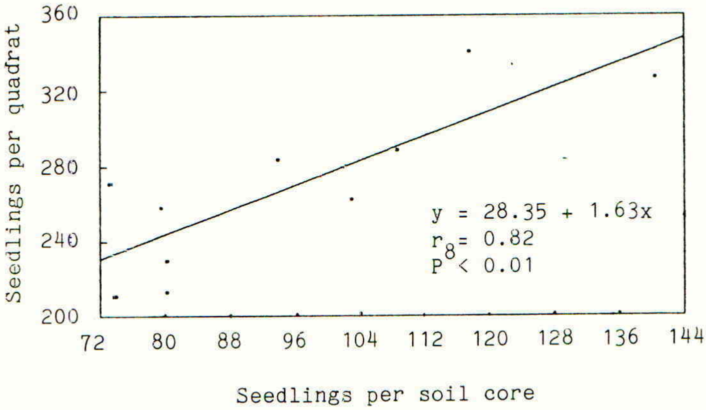


aviculare from the combined data set. Some of the individual species also showed a minimum at the -0.5m point, although this was not consistent between all of the species.

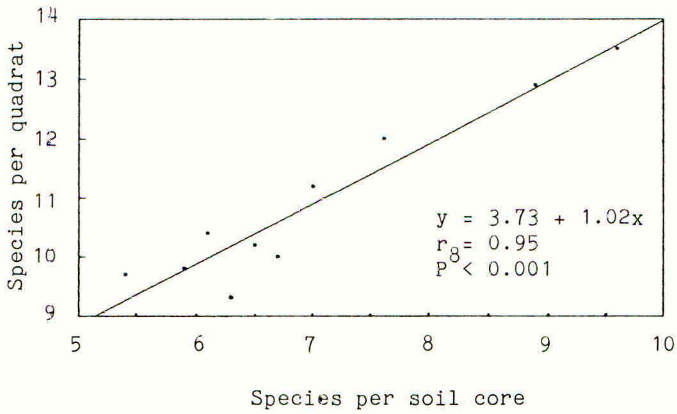
As the soil samples will be kept for at least two years to allow most seedlings to germinate (Roberts, 1958), the results from the seed-bank analysis are, as yet, incomplete. Initial comparisons of seed bank and seedling data however indicate that the data sets are closely correlated (Figure 2).

FIGURE 2. Relationship between number of seedlings per m^2 and number of seeds germinating from soil cores at ten distances from the field edge (data are mean of seven sites).

a. Mean number of seedlings per sample



b. Mean number of species per sample



DISCUSSION

Evidence indicates that crop yields are frequently lower near field edges (Boatman & Sotherton, 1988), and farming operations on the field headland often differ considerably from those practised on the rest of the field (Fielder, 1987). Field headlands are used for the turning of farm machinery, which causes considerable soil compaction and damage to the growing crop, thus potentially reducing crop competitive ability. In addition, the inner strip of the headland, and the outer strip of the main part of the field may frequently receive double applications of herbicide, fertiliser, and cereal seed.

Stubble burning, where practised, would have an additional effect on weed distributions, but as far as is known, it has not been carried out on the surveyed fields in recent years. Field headlands also receive increased grazing pressure from rabbits and deer.

It is possible that the effects of crop competition may thus increase across the field headland, allowing species present in the seed-bank to produce large numbers of seeds in proximity to the field edge, but fewer seeds with increasing distance. An area of poorest weed performance could occur at the inner edge of the headland, as a result of double applications of crop seed and chemicals. The accumulated effect of these processes over many years would be to create a gradient of seed abundance in the soil in relation to distance from the field edge.

It is to be predicted that less competitive species would show a greater decline in numbers with increasing distance from the crop edge. All of the less common species recorded in this survey (*P. hybridum*, *V. dentata*, *Lithospermum arvense*, *Scandix pecten-veneris* and *Adonis annua*) showed large decreases in numbers with respect to distance from the field edge. The species which showed the most striking increase with distance, *V. arvensis*, is among the most abundant dicotyledonous weeds of spring cereals in modern farming (Chancellor & Froud-Williams, 1984). This species is relatively resistant to several commonly used herbicides, and observations suggest that it may take advantage of the reduced competition from associated weed species after herbicides have been applied.

The relatively low abundance of some species at the -0.5m sampling point, may be due to the irregular cultivation of this extreme edge of the field, thereby creating an intermediate zone where the soil is disturbed only occasionally. In some fields, this area is also sprayed with a broad-spectrum, residual herbicide to prevent the possible ingress of invasive weed species from the field boundary thus preventing the growth of weeds in this area. Although several species were less abundant in the zone between the crop edge and the field boundary in this study, in certain circumstances this zone can be of immense importance for pauciennial species, and some rare annuals such as *Ajuga chamaepitys*, *Althaea hirsuta*, and *Teucrium botrys* (Silverside 1975).

These results are of particular importance when considering the management of arable field margins for their value in the conservation of traditional arable weed communities. It is possible that further changes in the status of some rare species may occur if conditions at field edges become unfavourable. If field margins are taken out of arable production, as part of a "Set-Aside" programme for example, the regular cultivation of the very narrow edge strip in which many of the rarer species seem to be confined will cease, removing all opportunities for these annual species to replenish the already small seed-bank.

Sympathetic management is therefore essential for field margins that are known or thought likely to possess a rich weed flora. At the very least, regular cultivation should be ensured, and ideally, active conservation measures should be taken, including the modification of herbicide and fertiliser inputs (Boatman & Sotherton, 1988; Boatman & Wilson, 1989).

ACKNOWLEDGEMENTS

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REFERENCES

Anon.(1988) Set Aside. SA1. MAFF.

Boatman, N.D.; Wilson, P.J. (1989) Cereal extensification, a vital tool for conservation. *Annual Review of the Game Conservancy*, **20**, 63-65

Boatman, N.D.; Sotherton, N.W. (1988) The agronomic consequences and costs of managing field margins for game and wildlife conservation. *Aspects of Applied Biology*, **17**, 47-56.

Chancellor, R.J.; Froud-Williams, R.J. (1984) A second survey of cereal weeds in central southern England. *Weed Research*, **24**, 29-36.

Fielder A. (1987) Management options for field margins, an agricultural advisor's view. In: *"Field margins"*. Eds. J.M. Way and P.G. Grieg-Smith, London: *B.C.P.C. monograph no. 35*, 85-95.

Froud-Williams, R.J.; Chancellor, R.J.; Drennan, D.S.H. (1983) Influence of cultivation regime upon buried weed seeds in arable cropping systems. *Journal of Applied Ecology*, **20**, 199-208.

Hald, A.B.; Nielsen, B.O.; Samsoe-Petersen, L.; Hansen, K.; Elmegard, N.; Kjolholt, J.(1988). Sprojtefri randzoner i kornmarker. *Milioprojekt*, **103**. Miljominiosteriet.

Marshall, E.J.P. (1989) Distribution patterns of plants associated with arable field edges. *Journal of Applied Ecology*, **26**, 247-257.

Roberts, H.A. (1958) Studies on the weeds of vegetable crops. 1. Initial effects of cropping on the weed seeds in the soil. *Journal of Ecology*, **46**, 759-768.

Roberts, H.A. (1981) Seed banks in soils. *Advances in Applied Biology*, **6**, 1-35.

Roberts, H.A.; Ricketts, M.E. (1979) Quantitative relationships between the weed flora after cultivation and the seed population in the soil. *Weed research*, **19**, 269-275.

Silverside, A. (1978) A phytosociological survey of arable weed and related communities in Britain. *Unpublished Phd. thesis*, University of Durham.

HABITAT DESIGN FOR RARE PLANTS IN ARABLE AGRICULTURE : A CASE STUDY

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ABSTRACT

Aspects of comparative population ecology in two closely related brome grasses currently differing in abundance in arable agriculture are reported. Failure in seed dispersal and interspecific competition are suggested as possible explanations for the extinction of *Bromus interruptus* in comparison to the abundance of*Bromus sterilis*. The implications for field margin management are considered.

INTRODUCTION

Underlying the practice of scientific conservation of rare plants is an understanding of the factors that determine the relative abundance of species. Reduction in the diversity of weed floras in arable agriculture has become increasingly evident in Europe (Eggers, 1984; Perring,1974) and a number of authors (eg Chancellor & Froud-Williams,1986) have pointed to reductions in habitat availability with changing agricultural practice as a major cause. The practice of annual arable cropping constitutes a powerful interspecific selective force on the natural vegetation of arable fields, the consequences of which are seen in the species assemblage in hedges, field margins and in the companion weeds of crops. Understanding the processes of interspecific selection at ecological and evolutionary levels can explain both the incorporation of species as weeds into a cropped flora and reasons for the exclusion of others. Whilst restricted habitat availability may be a major cause leading to rarity in a plant, other factors intrinsic to the species demography (particularly competition) may be equally important (Harper,1981). This paper reports on preliminary studies on the comparative population ecology of two brome grasses, *Bromus interruptus* defined as extinct in the U.K. (Lucas & Synge,1978) and *Bromus sterilis,* an abundant weed of winter cereals and assesses management approaches for the conservation of the former.

B. interruptus was first identified in 1895 (Druce,1987), being recorded in field edges in Cambridgeshire. An annual, its distribution is recorded as having peaked in the 1920's when it was found in 65 ten kilometre squares over 27 vice counties in southern England. In latitudinal range no locations have been recorded further north than southern Norfolk (Perring*et al.*, 1964). In contrast, *B. sterilis* has a wide distribution occuring throughout the U.K. occurring by roadsides, field margins and in waste places Changes in agricultural practice, in particular the increased usage of minimum tillage and the increasing acreage of winter cereals, have favoured its recent spread (Froud-Williams & Chancellor, 1981).

Field margins and headlands of arable land constitute a potential habitat refuge for annual species such as *B. interruptus*. Whilst varied in their characteristics (Greaves & Marshall,1987), major features of field margin habitats may be the virtual absence of the crop, reduced tillage and the effects of passage of agricultural traffic. Management of areas such as these to ensure the persistence of re-introduced *B. interruptus*, its containment to uncropped land and, at the same time, to prohibit the invasion of *B. sterilis* requires a clear understanding of the ecological differences between the species that have led one to become abundant and the other to become extinct. Three lines of investigation were employed a) autecological comparisons of seed and seedling ecology; b) introduction of populations into managed habitat 'types' in field trials; and c) studies of competitive interactions with winter wheat. The term 'seed' is used to describe the natural dispersal unit of both species.

MATERIALS AND METHODS

Seed of *B. interruptus* was obtained from the germplasm bank at the University of Liverpool Botanic Gardens and bulked up from pot grown plants in polythene tunnels. Seed stocks of *B. sterilis* were obtained from natural populations infesting winter cereals.

Autecological observations

Seed germination and seedling establishment

Freshly collected seed of both species was dry stored in the laboratory for two months and then sown in autumn into pots (30 seeds per pot) of John Innes seed compost at each of five planting depths - surface sown, 20,50,100 and 150 mm. Pots were set up in an unheated glasshouse in a randomised block design (three blocks), and watered to field capacity. Seedling emergence was monitored every day for one month, pots receiving aliquots of water every third day. At the conclusion of the experiment, pots were excavated and ungerminated seed tested for viability with tetrazolium chloride. Additional seed samples were germinated in distilled water on acid washed sand at 25^{o}C.

Seed dissemination

Twenty-five randomly chosen infructescences were monitored in 1987 in experimental populations of both species in wheat. Field counts of mature seeds remaining in panicles were made every week from mid July to early October.

Seed production in the field

A field trial was set up in October 1987 to measure per capita seed production in a range of habitat types that might be experienced in an arable field. Populations of both species were established over a range of densities in 2.25 m^2 plots in monoculture and in winter wheat cv Avalon (188 kg ha^{-1}). To mimic headland/field margin husbandry practices, a plot treatment included entire plot wheeling by tractor after seed sowing. These treatments were factorially arranged and replicated within two randomised blocks. Populations of each brome were sown to achieve densities of viable seed in the range 0.5 to 10000 seeds m^2. Cropped plots received fertiliser to a cumulative total of 160 kg N ha^{-1}. At harvest all plants in the central $1m^{-2}$ of each plot were counted, and all biomass removed, dried and threshed. After counting, seed population estimates were then corrected for seed viability on the basis of tetrazolium tests.

The model $\bar{c} = F(1 + aN)^{-s}$ was fitted to each data set where $\bar{c}$ is the mean per capita seed production, F is the fecundity of an isolated plant, N the population density at harvest and a and s are parameters describing the response to density. Parallel curve analysis (Ross,1987) was performed after fitting the model to independent data sets.

Competitive interactions with wheat

Response surface analysis was used to investigate the relative competitiveness of *B. interruptus* and *B. sterilis* in mixture with wheat (cv Bounty). Wheat was sown with either *B. sterilis* or *B. interruptus* in binary mixture at the rate per species of 0, 20, 40, 250, 2000 and 5000 seeds per m^2. All species were planted at 20 mm depth in 240 mm diameter pots of John Innes seed compost and plants raised in a heated and lit glasshouse. Pots were regularly watered over the next 88 days after which destructive harvests were made. The number of surviving plants and dry biomass per pot for each species was recorded.

Data were analysed using the following model for each species in binary mixture, $\bar{w}_x = w_{m,x}[1 + a(N_x + \alpha N_y)]^{-s}$ where $\bar{w}_x$ is the mean biomass of an individual plant of species x; $w_{m,x}$ is the biomass of an uncrowded individual plant of species x; N_x is the density of species x at harvest ; N_y is the density of species y at harvest; a and s are parameters describing the response of species x to density; α is a measure of the equivalence of species y relative to x.

RESULTS

Autecological observations

Seed germination and seedling emergence

Seed of both species germinated readily in the dark on sand (Table 1). Seedling emergence in *B. interruptus* was faster than *B. sterilis* on the soil surface and at planting depths down to 20mm. No seedlings of *B. interruptus* emerged from seeds planted below 100 mm whereas in *B. sterilis* reduced (23%) emergence was recorded. Upon excavation no dormant seed of either species was found except in *B.sterilis* from surface soil sowings.

Seed dissemination

Species differed noticeably in seed dissemination characteristics but mature seed was present in panicles of both by late July. Whereas disarticulation of seed was completed in approximately one month (mid August) in *B. sterilis*, culms of *B. interruptus* retained over 95% seed in late September and culm fracture was frequently observed before disarticulation.

TABLE 1. Comparative seedling emergence in relation to planting depth in *B. interruptus* and *B. sterilis*. Mean time to 50 % emergence is calculated from first watering and mean final emergence capacity corrected for seed viability. Surface(a) on sand in the dark at 25°C; Surface(b) on compost in an unheated glasshouse.

Species				Depth of planting (mm)			
		Surface(a)	Surface(b)	20	50	100	150
B.interruptus	Days to 50% emergence	2.4	6.1	6.0	9.6	-	-
	Emergence %	100.0	100.0	100.0	100.0	-	-
B.sterilis	Days to 50% emergence	4.8	8.0	8.5	9.8	13.6	-
	Emergence %	100.0	73.0	100.0	78.0	23.4	-

Seed production in the field

Seedling emergence in all three species was synchronous and was not influenced by plot treatment. Both brome species set viable seed under all treatments and per capita seed production declined predictably with density. Parallel curve analysis of data in showed that a) the fecundity of isolated plants (F, Table 2) of both brome species was significantly lowered by the presence of the wheat crop ($P<0.001$) and by the wheeling treatment ($P<0.01$), *B. interruptus* being reduced the most; and b) that species differed in their response to wheeling at high density ($P<0.05$). *B. interruptus* compensated more exactly for density (values of s approach unity) in wheeled plots whereas there was evident undercompensation in unwheeled plots. This effect was not detectable in *B. sterilis*.

TABLE 2. Parameter values of the yield density model (see text) relating fecundity per plant in *B. interrruptus* and *B. sterilis* to density.

	Wheeling	Seed / plant F	Parameters Response to density s	a	Coefficient of determination
B. interruptus					
Monoculture	-	1348	0.723	0.34	0.996
	+	830	0.903	0.04	0.997
In wheat	-	384	0.723	0.03	0.992
	+	263	0.901	0.01	0.995
B. sterilis					
Monoculture	-	1095	0.846	0.16	0.992
	+	864	0.887	0.10	0.998
In wheat	-	539	0.610	0.52	0.998
	+	738	0.760	0.19	0.993

Competitive interactions with wheat

On average the wheat emerged two days before either companion brome. No density dependent mortality was observed during the growth period. Above ground biomass accumulation by isolated plants over 88 days in the glasshouse was in the rank order *B.sterilis* > wheat > *B.interruptus*. Estimates of the comparative competitiveness of *B. interruptus* and *B. sterilis* in mixture in wheat are given in Table 3. *B.interruptus* was perceived by wheat as equivalent to only 0.15 (±0.042) of a wheat plant whereas *B. sterilis* appeared as a stronger competitor, equivalent to 0.42 (±0.13) wheat plants. Brome species also differed in their responses at high density within wheat,*B. interruptus* overcompensating for density (s > 1).

TABLE 3. The analysis of competitive interactions between wheat (cv Bounty) and *Bromus interruptus* and *B. sterilis.* Parameter values are as outlined in the text.

Mixture	Parameter				Coefficient of determination
	Biomass per plant (g)	Response to density		Equivalence coefficient	
	w_m	a	s	α	
Wheat in *B. interruptus*	4.15	0.023	0.795	0.15	0.92
B. interruptus in wheat	0.84	0.002	1.204	4.42	0.95
Wheat in *B. sterilis*	4.63	0.022	0.833	0.42	0.94
B. sterilis in wheat	10.52	0.055	0.845	1.92	0.83

DISCUSSION

An initial conclusion from this work is that *B.interruptus* does not possess a persistent seed bank in common with *B. sterilis.* Thus annual species abundance will be determined by seedling recruitment from a transient seed bank which is not naturally rained onto the soil surface until mid autumn. Modern crop combining techniques are likely to disseminate seed of *B.interruptus* at crop harvest within the chaff but the speed of seed germination once sufficient soil moisture occurs may result in loss of individuals prior to and during crop seed bed preparation as well as loss through burial at depth. Thus substantial mortality may occur in the post harvest phase of the life cycle. Figure 1 illustrates the relationship between loss in the post harvest phase and predicted equilibrium population size. Whilst little is known about yearly variation in parameter values, clearly substantial losses may be tolerated before extinction is likely. Annual seed production however is likely to be strongly influenced by competition from other species. Whilst not directly comparable, it is clear from the field and pot experiments that relative time of emergence and subsequent growth rates during the vegetative stage are important (and not surprising) determinants of yield in *B.interruptus.* Early gemination relative to both wheat and *B.sterilis* may place *B.interruptus* at a competitive advantage yet this may be offset by the apparent slower growth rate of *B.interruptus.* Tentative implications of these initial findings for *B.interruptus* in field margins of winter cereals are that a) that crop combining may lead to the presence of seedling populations in late summer and early autumn as seed dissemination is promoted ; b) interspecific competition may however severely reduce growth and yield and in the early stages at least the habitat should remain open and undisturbed by crop seed bed preparations. Whilst dicotyledenous species may be selectively and deliberately eliminated, there remains the possibility of ingression of injurious grass weeds, particularly *B. sterilis.* The absence of tillage coupled with light inhibition of germination in*B. sterilis* on the one hand and the rapidity of seedling establishment in *B. interruptus* , on the other, may however limit this occurrence. The hypothesis is currently being tested.

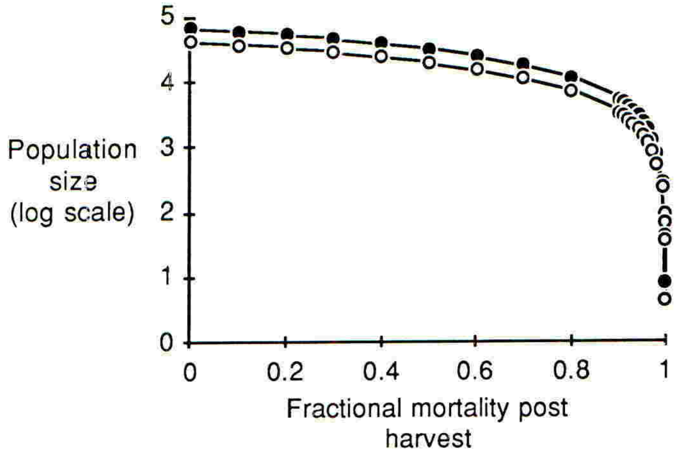

Fig.1. The relationship between predicted equilibrium population size in *B. interruptus* and density independent mortality in the post harvest phase of the life cycle. Populations in wheeled plots in monoculture (closed symbol) and in winter wheat (open symbol) . Population sizes calculated from data given in Table2.

REFERENCES

Chancellor, R.J. ; Froud-Williams, R.J. (1986) Weed problems of the next decade in Britain. *Crop Protection* , **5**, 66-72.

Druce, G.C. (1897) *The flora of Berkshire, being a topographical and historical account of the flowering plants and ferns found in the county.* Oxford.

Eggers, T. (1984) Some remarks on endangered weed species in Germany. *Proceedings of the 7th International Symposium on Weed Biology and Systematics, Paris.* 395 - 402.

Froud-Williams, R.J. ; Chancellor, R.J. (1981). A survey of grass weeds in cereals in central southern England. *Weed Research* , **22**, 163-171.

Greaves, M.P. ; Marshall, E.J.P. (1987) Field margins: definitions and statistics. In *Field Margins.* J.M. Way and P.W. Grieg-Smith (Eds). BCPC Monograph No 35, Thornton Heath; BCPC Publications, pp. 3 - 10.

Harper, J.L. (1981) The meanings of rarity. In *The Biological aspects of Rare Plant Conservation* . H. Synge (Ed) Wiley pp. 189 - 203.

Lucas, G. ; Synge, H. (1978)*The IUCN Plant Red Data Book*, IUCN Morges Switzerland.

Perring, F.H, Sell, P.D. ; Walters, S.M. (1964) *A flora of Cambridgeshire.* Cambridge University Press pp 365.

Perring, F.H. (1974) Changes in our native vascular plant flora. In *The Changing Flora and Fauna of Britain.* D.L. Hawksworth (Ed), Academic Press, pp.7 - 25.

Ross, G.J.S. (1987) *Maximum Likelyhood Program.* Rothamsted Experimental Station, Harpenden Herts.

THE CREATION OF WITHIN-FIELD OVERWINTERING SITES FOR NATURAL ENEMIES OF CEREAL APHIDS

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ABSTRACT

Narrow, raised earth banks were created by the careful ploughing up of ridges across the middle of a large spring barley field in order to increase the area of overwintering habitat for several key polyphagous arthropods that are important natural enemies of the bird cherry-oat aphid, *Rhopalosiphum padi*. The banks were sown with a mixture of common ley grasses or left unsown. Increased densities of predatory arthropods were found overwintering on these areas only one year after their establishment.

INTRODUCTION

Rhopalosiphum padi is the most important species of cereal aphid in Scandinavia (Wiktelius, 1982; Rautapää, 1976) and is a particular problem in spring-sown cereals (Wiktelius & Ekbom, 1985). Recent studies have shown that predation by spring-active polyphagous predatory arthropods can reduce the rate of increase of *R. padi* populations (Chiverton, 1986; 1987; Ekbom & Wiktelius, 1985). Several important predator species i.e. those that are relatively common, are active early in spring and feed on *R. padi* at low aphid densities, have been identified and include the carabid beetle *Bembidion lampros*, species of rove beetles of the genus *Tachyporus* and several species of linyphiid spiders (Chiverton, 1987).

These predators overwinter in field boundaries, particularly on raised grassy banks and under hedgerows (Sotherton, 1984; 1985). Many of these natural borders have been removed from Swedish farms during the last four decades, resulting in an increase in average field size (Ihse, 1989) and, consequently, a reduction in the field edge (overwintering site): field area ratio. Practices such as the removal of dry stone walls and hedges and the infilling of ditches still continues. Reductions of such non-crop habitats could dilute polyphagous predator densities within fields, and/or increase distances predators must disperse in spring in order to penetrate the centres of such large arable areas.

The aims of this project are therefore to reduce field size experimentally by creating within-field overwintering sites for the key aphid predators and to position predators in the right place at the right time to maximise their biocontrol potential.

MATERIALS AND METHODS

Field site

An 8.5ha rectangular study field (c. 450 x 190m) was used, situated 10km east of Uppsala, Sweden. The northern and eastern boundaries of the field consisted of grass covered banks, mixed woodland and shrubs. The southern boundary was a ditch, and the western boundary consisted of a grass verge and gravel track. Community structure of the predatory arthropod fauna in the field and its immediate surroundings has previously been described by Wallin *et al.* (1981).

Pre-treatment samples

During late winter, 1987 early spring, 1988, 60 random soil samples (20 x 20 x 15cm) were taken along the natural field boundaries (total 2.4m^2), and 30 taken from the middle of the stubble field (total 1.2m^2). Arthropods overwintering in the soil were extracted in modified Tullgren funnels.

Creation of the raised banks

The field was sown with spring barley (cv. Pernilla) on 12 April 1988. On 19 April two raised banks (0.3m high, 2.5m wide, and 150m long) were created by careful two-way directional ploughing across the field. A gap of approximately 18m was left between the ends of each bank and the natural field boundary to facilitate access between the two field areas to allow ease of farming operations. Each bank was then rotovated and rolled twice. The process was then repeated on 10 May whereupon half the length of each bank was drilled with a 1:1:1 mixture of *Dactylis glomerata*, *Festuca pratensis* and *Phleum pratense*. These are common ley grasses in Sweden and were selected for their good tussock formation (especially *D. glomerata*), winter hardiness and cover. Broad-leaved weeds emerging on the grass-sown sections of the banks were controlled with 'Certrol Tetra' (dichlorprop + MCPA + ioxynil + bromoxynil) and CMPP. Glyphosate was applied in an attempt to remove all vegetation on the un-sown sections.

In September 1988, a single tyne plough was used to create a sharply defined edge on both sides of the banks, thereby simulating the edge furrow of the natural field boundaries. Soil between the bank edges and the outer edges of the crop stubble (c. 1m) was then rotovated to remove weeds and any "ditch" effect caused by the ploughing.

Post-treatment samples

During the winter of 1988/89 15 soil samples, (20 x 20 x 15cm), were taken from each of the grass-sown and un-sown/bare soil banks and the middle of the field. An additional 30 soil samples were taken from the existing field edges. Overwintering arthropods were extracted as above.

RESULTS AND DISCUSSION

Pre-treatment soil sampling showed that the sun-exposed, grassy banks on the south and west facing edges of the field were favoured overwintering sites for *B. lampros* and *Tachyporus* spp. Linyphiid spiders overwintered in relatively large numbers in vegetation along all natural field edges. Very few predators were found overwintering in the central parts of the field (Table 1).

TABLE 1. Mean densities (± S.E.) of spring-active polyphagous arthropods in late winter, 1987/1988 overwintering at field edges and within the field prior to habitat manipulation.

		Predator density per sample (400 cm²)		
		Bembidion lampros	*Tachyporous* spp.	Linyphiids
Field edge	North	0.4 (0.16)	1.2 (0.44)	4.0 (1.35)
	East	0.15 (0.11)	1.0 (0.29)	1.4 (0.37)
	South	0.0	0.4 (0.38)	2.0 (0.87)
	West	0.1 (0.10)	0.1 (0.10)	1.1 (0.22)
Mid-field		0.03 (0.03)	0.0	0.03 (0.03)

Favourable growing conditions during the summer of 1988 ensured good establishment of the grass species used, giving between 80-90% cover during late summer/autumn.

TABLE 2. Mean densities (± S.E.) of spring-active predators in winter, 1988/89 overwintering in existing field edges and on newly created raised banks, sown with grasses or left bare, positioned across a spring barley field.

		Predator density per sample (400cm²)		
		Bembidion lampros	*Tachyporus* spp.	Linyphiids
Grass banks		0.53 (0.14)	0.23 (0.11)	0.57 (0.18)
Unsown banks		0.0	0.0	0.27 (0.13)
Mid-field		0.0	0.0	0.07 (0.06)
Field edge	North	0.4 (0.36)	1.0 (0.28)	2.2 (0.52)
	East	2.2 (0.81)	6.5 (1.58)	1.3 (0.80)
	South	0.0	0.6 (0.36)	1.4 (0.22)
	West	0.6 (0.38)	0.2 (0.13)	2.7 (0.60)

Individuals from the three predator groups overwintered on the grassy banks during the first year of establishment 1988/89. Densities of *B. lampros* were comparable with those found in existing favourable edge habitats (Table 2). Only relatively low densities of linyphiid spiders were found overwintering on the un-sown banks and in the central parts of the field compared to the newly created grassy bank (Table 2).

The densities of predatory arthropods found on newly created grass banks in Sweden were slightly lower than those found for carabids, staphylinids and spiders found in similar experiments in southern England (Thomas & Wratten, 1988), and were particularly encouraging in Sweden for the first year of the grass bank's establishment. Densities of the key predators overwintering in the banks are expected to increase in subsequent years as the grasses develop into a more tussock-like growth form. Current work is aimed at measuring potential increases in predation rate in the adjacent crop. However, it remains to be demonstrated whether availability of suitable overwintering sites is an important factor in determining the role of such predators in integrated control programmes.

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REFERENCES

Chiverton, P.A. (1986) Predator density manipulation and its effects on populations of *Rhopalosiphum padi* in spring barley. *Annals of Applied Biology*, **109**, 49-60.

Chiverton, P.A. (1987) Predation of *Rhopalosiphum padi* by polyphagous predatory arthropods during the aphids' pre-peak period in spring barley. *Annals of Applied Biology*, **111**, 257-269.

Ekbom, B.; Wiktelius, S. (1985) Polyphagous arthropod predators in cereal crops in central Sweden. *Journal of Applied Entomology*, **99**, 433-443.

Ihse, M. (1989) (Endangered habitats in arable land). In: *Växtodling 1989. Skanskalantmännen, Karlshamn*, 71 pp. (in Swedish).

Rautapää, J. (1976) Population dynamics of cereal aphids and method for predicting population trends. *Annales Agriculturae Fenniae*, **15**, 272-293.

Sotherton, N.W. (1984) The distribution and abundance of predatory arthropods overwintering on farmland. *Annals of Applied Biology*, **105**, 423-429.

Sotherton, N.W. (1985) The distribution and abundance of predatory Coleoptera overwintering in field boundaries. *Annals of Applied Biology*, **106**, 17-21.

Thomas, M.B.; Wratten, S.D. (1988) Manipulating the arable crop environment to enhance the activity of predatory insects. *Aspects of Applied Biology*, **17**, 57-66.

Wallin, H.; Wiktelius, S.; Ekbom, B. (1981) (Occurrence and distribution of beetles in a spring barley field). *Entomologisk Tidskrift*, **102**, 51-56. (English summary).

Wiktelius, S; Ekbom, B. (1985) Aphids in spring-sown cereals in central Sweden: abundance and distribution. *Journal of Applied Entomology*, **100**, 8-16.

THE CREATION OF ISLAND HABITATS TO ENHANCE POPULATIONS OF BENEFICIAL INSECTS

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ABSTRACT

As a mangement strategy to diversify the agro-ecosystem and provide improved overwintering opportunities for natural enemies, linear island habitats, were created across the centres of two cereal fields.

An investigation into the overwintering densities of polyphagous predators in the new habitats revealed densities of over 150 m^{-2} during the first year of establishment. Absolute sampling of the within-field habitats during the second winter (1988/89) showed that earth banks sown with certain grass species supported predator densities of over 1000 m^{-2}.

The effect on early season predation of artificial prey items resulting from the maintenance of a predator population within the field over the winter period was also investigated.

INTRODUCTION

Sotherton (1984; 1985) showed that field boundaries were of particular importance in providing overwintering refuges for many species of polyphagous arthropod predators in arable field systems. Habitats such as raised banks with rough, grassy cover supported high densities of Carabidae, Staphylinidae, and Araneae.

On modern U.K. arable farms, fields tend to be large and thus rapid spring colonisation of fields by the predators could be impaired (Wratten *et al.*, 1984; Coombes & Sotherton, 1986). The aim of this project therefore, is to create within-field overwintering habitats on farmland which favour the development of high populations of predators and reduce the field area: field boundary ratio.

MATERIALS AND METHODS

Creation of within-field habitats

The new within-field refuges took the form of raised earth banks (0.4m high, 1.5m wide, 350m long) that crossed the centres of two cereal fields (c. 10ha and c. 40ha) on an estate in Hampshire. The banks did not extend completely to link up with the existing field margins.

Six metre long sections of each new bank were sown (spring, 1987) with various grass species in a linearly randomised block design with six blocks per bank. Within each block the grasses chosen were *Dactylis glomerata*, *Lolium perenne*, *Agrostis stolonifera*, and *Holcus lanatus*. As well as sowing single-species treatments, mixtures of three (*A.*

stolonifera absent) and four species, and bare ground controls were also included making a total of seven treatments per block.

Assessment of predatory composition

During the winter of 1987/88 surface-searching was carried out and the numbers of polyphagous predators on the ridges and in their adjacent fields recorded. Six $0.1m^{-2}$ quadrats were used per replicate per treatment and 12 for each mid-field site; their being one mid-field recording for each block searched.

For the second winter (1988/89) surface-searching was again carried out. However, due to greater grass maturity at this time, surface-searching was no longer considered an efficient sampling method. Only one ridge, plus the accompanying field areas were sampled in this way. The remaining sampling was done destructively. Turfs of $0.04m^{-2}$ x 0.1m deep were removed, and the predatory arthropods extracted by hand sorting. Two destructive samples were taken from each of the single stand treatments on the ridge that had already been surface-searched. Four destructive samples were taken from the similar treatments on the second ridge. Twenty within-field samples were taken from each of the open-field sites.

Assessment of predation

To assess whether the within-field ridges and their predator populations influenced spring predation, predation rates on artificial prey were monitored from April to mid-May. In 1988, small dishes (5cm diameter) of soil were placed in the field and on the ridge. Each dish contained 20 freeze-killed third/fourth instar pea aphids (*Acyrthosiphon pisum*). Metal lids placed 5cm above each dish provided protection from rain.

For the second spring study (1989) similar experimental procedures were used. This time however, dishes of 25 *Drosophilia* pupae (*Drosophila melanogaster*) were used as artificial prey.

For both years, the numbers of prey remaining in each dish after 24h exposure on the various grassy treatments on the ridge and in the field were recorded. In 1988, 10 dishes were placed within each treatment of each of three blocks of only one ridge. Dishes of artificial prey were also placed out in seven transects running at right angles to each bank treatment at distances of 1m, 5m, and 15m into the adjacent field, one dish was placed at each distance. In 1989, dishes were placed in only two grass treatments (*D. glomerata* and *H. lanatus*) in each of six blocks. Associated with each of these 12 grassy parts of the bank were transects of dishes progressing into the crop at 3m, 10m, 30m and 60m from the bank. Once again only one ridge was used. Assessments of predation were made over one 24h period per week for seven weeks.

RESULTS

Data are presented for one ridge only.

Predator densities

Significantly higher densities of Carabidae, Staphylinidae, Araneae and the total predator fauna were found in the grass treatments than bare ground and open field in 1987/88 (Figure 1).

Surface-search data from the second winter showed a similar pattern, with however, slightly increased predator densities in all sown plots.

Destructive sampling revealed predator densities far in excess of those recorded by surface-searching. Certain grass species supported predator densities in the region of 1000-1500 m^{-2} (Figure 2). Analyses of variance showed *D. glomerata* and *H. lanatus* to support significantly higher densities of all the predatory groups ($F_{4,63} = 46.0$, $P < 0.05$).

Predation rate

The results of the 1988 predation study are presented in Figure 3. Although there were few significant differences between predation levels, a wave of apparently increased predatory activity appeared to moved away from the ridge into the field through time.

For the 1989 study some data are missing because of damage caused by small mammals to the prey. There were no detectable significant differences between predation levels along the transects into the field. No apparent wave of increased predatory activity appeared to penetrate the crop. In fact, the highest activity detected consistently occurred on the ridge itself (Figure 4).

DISCUSSION

The overwintering predator densities achieved during the first year were comparable to those found in typical hedges in Hampshire (Sotherton, 1985). Early maturity meant there were no consistent significant differences between grass treatments.

Surface-searching during the second winter, also failed to identify any distinct between-grassy treatment differences. It was considered therefore, that reduced sampling efficiency associated with the greater grass maturity, was responsible for masking such effects. This was verified by the destructive sampling, where *D. glomerata* and *H. lanatus* were shown to provide the most suitable overwintering habitats for all predatory groups. Greater resolution between grass species, and the role played by species mixtures, should be defined with increased sampling in the future.

For the 1988 predation study, it was originally considered that the change in activity into the crop through time, was associated with a wave of immigration of predators as recorded by Coombes & Sotherton (1986). In spring 1989, higher levels of predation were recorded on the ridge and its immediate environment. The findings of the 1987 study therefore, could be and artifact of the limited distance over which the investigation was carried out; the wave of immigration being no more than localised movements within the close proximity of the ridge. The new habitats however, do provide a nucleus population, which would otherwise be absent, from which dispersal can take place. Furthermore, artificial

FIGURE 1. Mean densities of groups of polyphagous predators sampled by surface-searching, winter 1987/88. Histographs within each group with the same letter do not differ significantly at the 5% level.

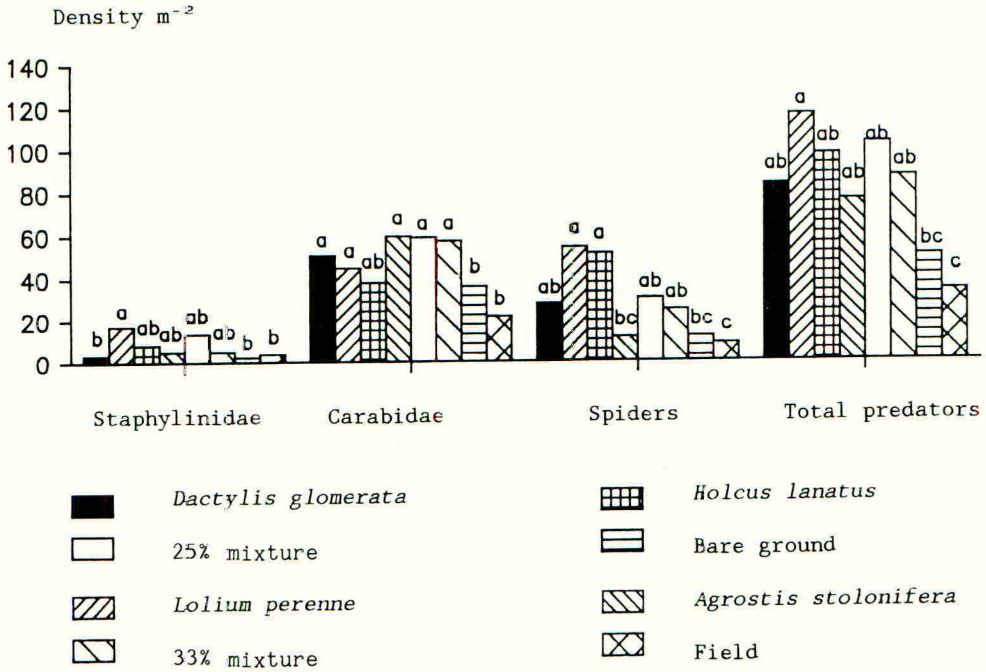


FIGURE 2. Mean densities of groups of polyphagous predators sampled by destructive sampling, winter 1988/89. (Levels of significance as Fig. 1).

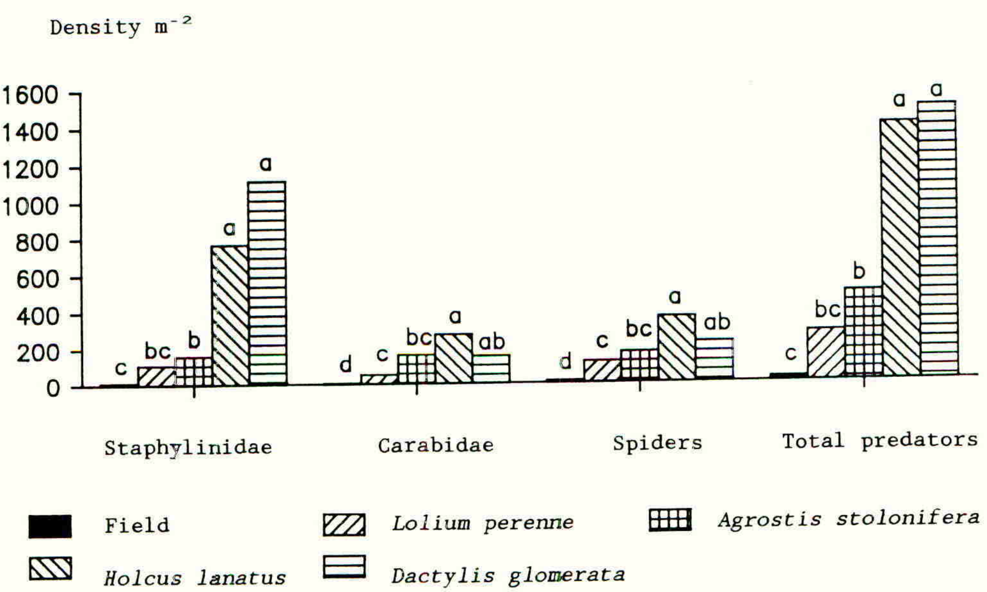


FIGURE 3. Mean number of artificial prey items removed from the earth ridge and from areas of the adjacent wheat field at 1, 5 and 15 metres into the crop, Spring 1988.

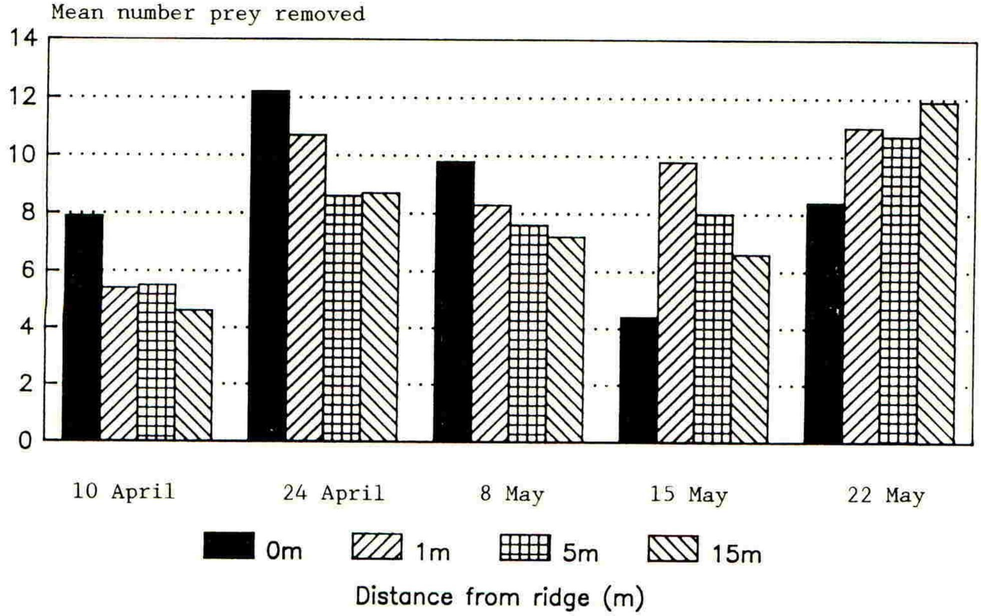
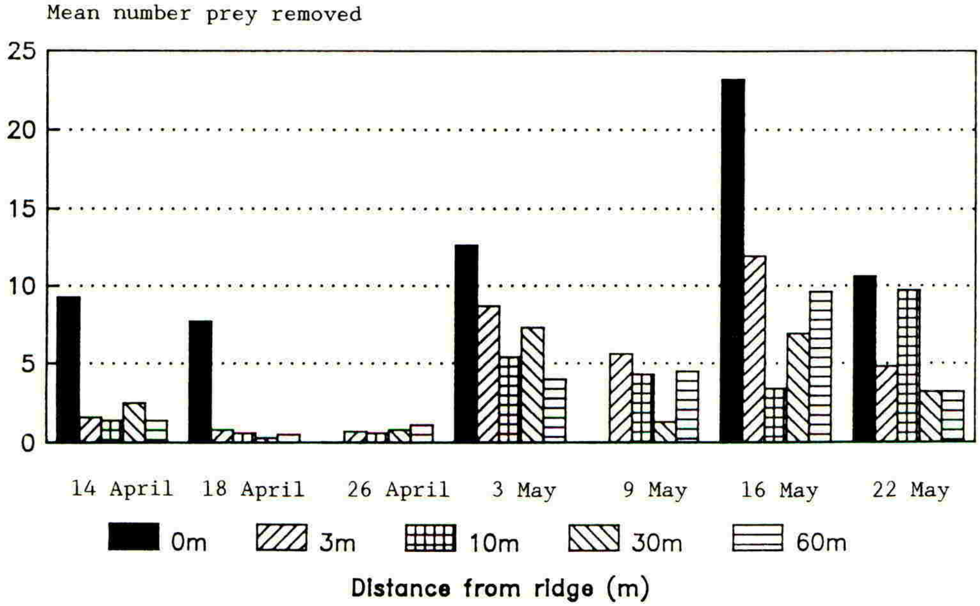


FIGURE 4. Mean number of artificial prey items removed from the earth ridge and from areas of the adjacent wheat field at 3, 10, 30 and 60 metres into the crop, Spring 1989.



prey of the type used exclude the activity of those predators, such as certain Araneae and Staphylinidae, which are fluid feeders, or those which only take live prey.

The system described here is not a working management strategy. It is not yet known for example, what role such habitats play in long term population enhancement. As a "goal-orientated" project however, this study has gone some way to showing the feasibility of beneficially manipulating the arable environment in an ecologically short period.

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REFERENCES

Coombes, D.S.; Sotherton, N.W. (1986) The dispersal and distribution of polyphagous predatory Coleoptera in cereals. *Annals of Applied Biology*, **108**, 461-474.

Sotherton, N.W. (1984) the distribution and abundance of predatory arthropods overwintering on farmland. *Annals of Applied Biology*, **105**, 423-429.

Sotherton, N.W. (1985) The distribution and abundance of predatory Coleoptera overwintering in field boundaries. *Annals of Applied Biology*, **106**, 17-21.

Wratten, S.D.; Bryan, K.; Coombes, D.S.; Sopp, P.I. (1984) Evaluation of polyphagous predators of aphids in arable crops. *1984 British Crop Protection Conference - Pests and Diseases*, **1**, 271-276.

THE ROLE OF NON-CROP HABITATS ON HOVERFLY (DIPTERA:SYRPHIDAE) FORAGING ON ARABLE LAND

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ABSTRACT

Observations were made of syrphid behaviour in two floristically different types of field-margins. In particular, the use made of arable weeds by adult hoverflies was studied to facilitate the development of selective weed control strategies for field-margins, to maximise the biocontrol potential of arthropod natural enemies.

The two field-margin types consisted of an established hedgerow and a boundary strip, left fallow and subsequently colonised by annual, arable weeds.

Ten commonly-occurring species of hoverfly were recorded at both sites. The relative contribution of individual syrphid species to the site totals varied with field-margin type.

Flowers were not visited according to their abundance; particular species of fly showed a "preference" for certain weeds. A "Forage Ratio" was used to quantify this preference, which varied with the species of hoverfly studied and according to the habitat composition. Implications for the management of non-cropped areas on farmland are discussed.

INTRODUCTION

A range of syrphid species occur as larvae in cereal crops and species composition varies according to geographical location and season. However, *Episyrphus balteatus* and *Metasyrphus corollae* are the most commonly recorded species on arable land in Great Britain (Dean, 1982; Chambers *et al.*, 1986) and their aphidophagous larvae have been identified as being economically important, having the potential to limit cereal aphid population growth. That is, qualitative studies have demonstrated an association between the presence of syrphid larvae and the cessation of aphid population growth (Rautapaa, 1976; Rabbinge *et al.*, 1979; Chambers & Sunderland, 1983; Holmes, 1984; Chambers *et al.*, 1986). Quantification of this relationship has shown that syrphid larvae do have the ability to halt aphid population increases (Chambers & Adams, 1986).

Adult flies feed upon pollen and nectar; females require the proteins and amino acids available from pollen for the maturation of their reproductive system (Schneider, 1948), This has implications for cereal aphid predation since the provision of appropriate floral resources has the potential to influence both the timing of oviposition and the number of eggs laid per fly.

MATERIALS AND METHODS

Field sites

Site one was an established hedgerow comprising *Crataegus monogyna*, *Rubus fruticosus*, *Sambucus nigra*, *Cornus sanguinea* and *Euonymus europaeus*. A variety of naturalised spring flowers gave way to grasses in the summer and autumn. By early summer grasses such as *Lolium perenne*, *Dactylis glomerata*, *Arrhenatherum elatius* and *Agrostis* spp. together with *Chaerophyllum temulentum* formed the dominant herb layer. In late summer, the few flowers available consisted of *Heracleum sphondylium*, *Rubus fruticosus* and *Rosa canina*.

Site two consisted of a 2m wide fallow strip running parallel to the field edge. In the spring the predominant weed species were *Lamium album*, *Silene vulgaris* and *Silene alba*. *Sinapsis arvensis*, *Lapsana communis*, *Sonchus* spp. and *Matricaria perforata* became abundant as the summer progressed.

Sampling methods

The total number of inflorescences of each weed species in a 50 x 2m block were recorded weekly at each site. Monthly estimates of vegetation frequency at each site were obtained using a 1m x 10cm comb quadrat.

A modified standard walk was used to study the behaviour of adult syrphids in the two field margins. Each block was censused at regular intervals throughout the day; individual syrphids were observed until they were either lost from view of flew out of the block. For each syrphid observed the category of behaviour (using criteria modified from Gilbert, 1981) and its duration were recorded verbally onto a micro-cassette. In addition, for each observation, the time of day, temperature, relative humidity, cloud cover and wind speed were also recorded. Census days were chosen irrespective of weather conditions so that the two sites were covered on adjacent days. Censuses usually began at 06.30 and ended between 16.00 and 16.30 B.S.T.

RESULTS

Syrphid distribution

From May until the end of August 1988 a total of 1491 observations of the ten most commonly occurring syrphids species were recorded from the two sites. *E. balteatus* was the most frequently observed individual from the boundary strip, accounting for 40% of all observations at that site. Other species had peaks of abundance during the study according to their phenology.

Melanostoma spp. were the most commonly observed species at the hedgerow site, representing 21% of all observations. However, *Eristalis* spp. and *Platycheirus peltatus* were also common during May and early June.

Flower visitation and the assessment of "preference"

Analysis of flower visitation by *E. balteatus* using a G-test showed that on each of the eight sampling dates between June and August the observed ratio of visits to individual flower species differed significantly from the expected ratio which was calculated according to the flower species' abundance within the habitat. This suggested that flies showed a "preference" for particular flower species.

A "Forage Ratio" was used to quantify this preference, by comparing the relative proportion of an item in the total number of visits with its relative abundance in the habitat. Preference was shown by ratios from one to infinity, while avoidance was measured from zero to one. Figure 1 shows the calculated preference ratios for *E. balteatus*, using observations of foraging behaviour from the boundary strip site. In general, certain yellow Compositae, particularly *Leontodon autumnalis*, *Taraxacum officinale* and *Sonchus* spp. were visited preferentially during July, whilst *Daucus carota* and *Sonchus* spp. were important during August.

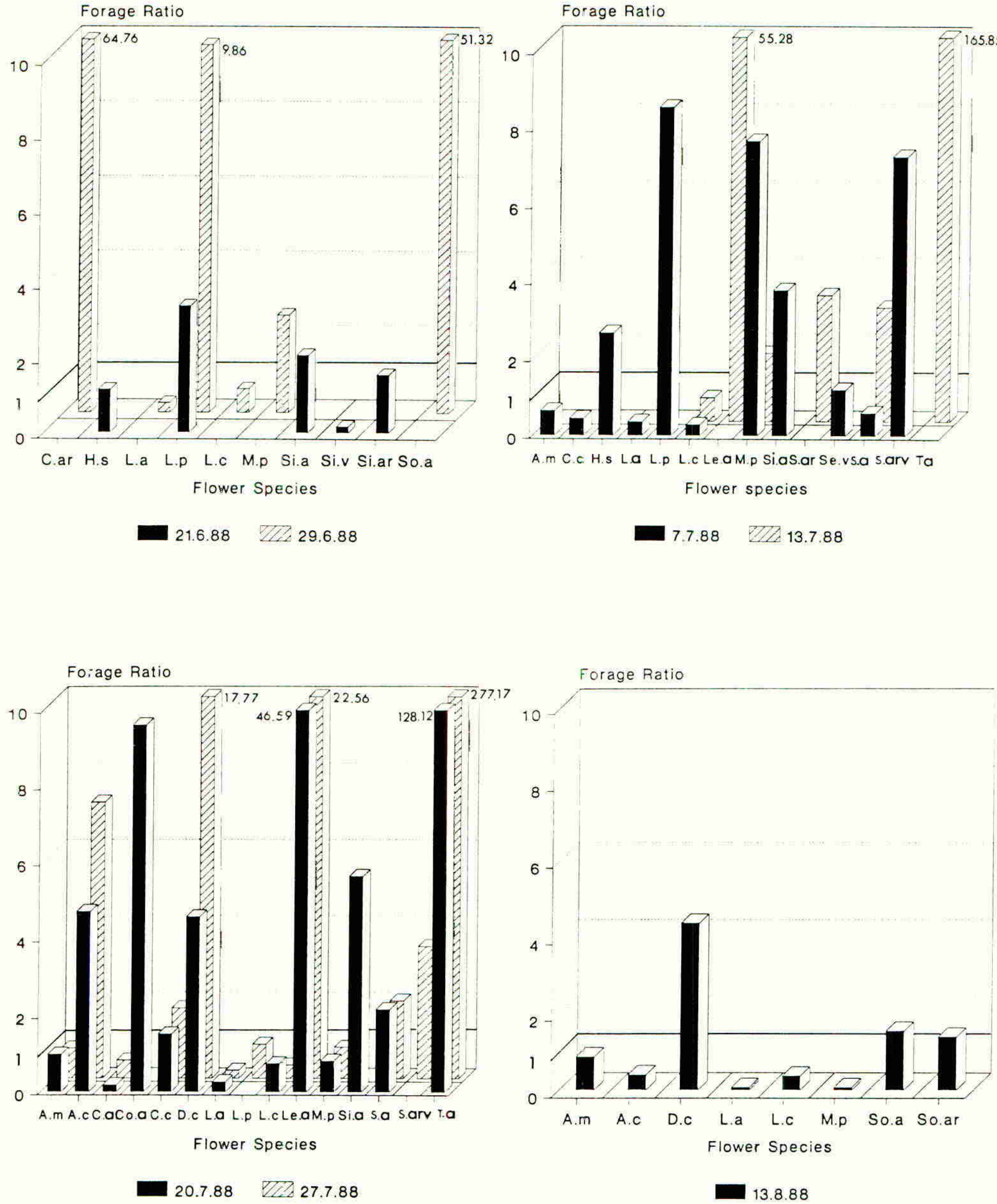
DISCUSSION

This work was consistent with results from previous studies of hoverfly flower visiting which concluded that flies had flower preferences which differed according to the species of fly (Barendregt, 1975; Gilbert, 1981). This study has identified the commonly occurring arable weeds which are "preferred" by an economically important species of syrphid.

The current agricultural situation in Great Britain, with the implementation of Set-Aside and diversification schemes, provides opportunities for the development of selective weed control strategies in field margins which favour beneficial insects. As a result, work currently being undertaken on this project is aimed at determining whether rich floras of preferred flowers have an effect on the number of syrphids within an area and whether field margin floral composition can influence syrphid oviposition. That is, are more eggs laid in cereal fields adjacent to weedy field boundaries? This will involve an examination of the use of The Game Conservancy's "Conservation Headlands" (Boatman & Sotherton, 1988) by syrphids, comparing the number of flies in floristically rich blocks of headland and adjacent sprayed blocks.

The relationship between syrphid oviposition and the availability of weeds outside the crop has been previously studies by several authors. Chandler (1969) concluded that the presence of flowers did not stimulate oviposition nearby. Similarly, Pollard (1971) was unable to correlate predation of *Brevicoryne brassicae* by syrphid larvae with habitat diversity in two contrasting areas. However, the high mobility of syrphids, especially species such as *E. balteatus*, which is thought to be a seasonal migrant, makes it difficult to show the impact of floral diversity on their distribution. As a result, it is likely that many experiments designed to assess the impact of field margin manipulation have resulted in unwarranted negative conclusions; effects, if any, are likely to operate at a larger scale than that of the vicinity of one field margin.

FIGURE 1. Foraging preferences of *Episyrphus balteatus*, calculated from observations made at the boundary strip site. A ratio greater than one indicated that *E. balteatus* foraged on that plant species more frequently than would have been expected from the plant's abundance relative to other plants in the block. Where indicated, forage ratios exceed the figure's maximum scale of 10.



Key to flower species:

A.m	*Achillea millefolium*	L.p	*Lamium purpureum*
L.c	*Lapsana communis*	A.c	*Aethusa cynapium*
C.ar	*Cirsium arvense*	Le.a	*Leontodon autumnalis*
Co.a	*Convolvulus arvensis*	M.p	*Matricaria perforata*
C.c	*Crepis capillaris*	Si.a	*Silene alba*
D.c	*Daucus carota*	S.ar	*Sinapsis arvensis*
H.s	*Heracleum sphondylium*	S.a	*Sonchus asper*
L.a	*Lamium album*	S.arv	*Sonchus arvensis*
T.a	*Taraxacum officinale*		

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REFERENCES

Barendregt, A. (1975) Bloemvoorkeur bij zweefliegen (Diptera:Syrphidae). *Entomologische Berichten*, **35**, 96-100.

Boatman, N.D.; Sotherton, N.W. (1988) The agronomic consequences and costs of managing field margins for game and wildlife conservation. *Aspects of Applied Biology*, **17**, 47-56.

Chambers, R.J.; Sunderland, K.D.; Stacey, D.L.; Wyatt, I.J. (1986) Control of cereal aphids in winter wheat by natural enemies: aphid specific predators, parasitoids and pathogenic fungi. *Annals of Applied Biology*, **108**, 219-231.

Chambers, R.J; Adams, T.H.L. (1986) Quantification of the impact of hoverflies (Diptera:Syrphidae) on cereal aphids in winter wheat - an analysis of field populations. *Journal of Applied Ecology*, **23**, 895-904.

Chandler, A.E.F. (1968) The relationship between aphid infestations and oviposition by aphidophagous syrphidae (Diptera). *Annals of Applied Biology*, **61**, 425-434.

Chew, F.S. (1975) Coevolution of pierid butterflies and their cruciferous foodplants. The relative quality of available resources. *Oecologia* (Berlin), **20**, 117-127.

Dean, G.J.W. (1982) Phenology of aphidophagous predators. *Annals of Applied Biology*, **101**, 182-184.

Holmes, P.R. (1983) A field study of the ecology of the grain aphid *Sitobion avenae* and its predators. PhD thesis, *Cranfield Institute of Technology*, U.K.

Gilbert, F.S. (1981) Foraging ecology of hoverflies: morphology of the mouthparts in relation to feeding on nectar and pollen in some common species. *Ecological Entomology*, **6**, 245-262.

Menge, B.A. (1972) Foraging strategy of a starfish in relation to actual prey availability and environmental predictability. *Ecological Monographs*, **42**, 25-50.

Pollard, E. (1971) Hedges, VI: habitat diversity and crop pests. A study of *Brevicoryne brassicae* and its syrphid predators. *Journal of Applied Ecology*, **8**, 751-780.

Rabbinge, R.; Ankersmith, G.W.; Pak, G.A. (1979) Epidemiology and simulation of population development of *Sitobion avenae* in winter wheat. *Netherlands Journal of Plant Pathology*, **85**, 197-220.

Rautapaa, J. (1976) Population dynamics of cereal aphids and methods for predicting population trends. *Annales Agriculturae Fenniae*, **15**, 272-293.

Schneider, F. (1984) Beitrag zur Kenntnis der Generationsverhaltnisse and Diapause rauberischer Schwebfliiegen. *Mitteilungen der Schweizerischen Entomologischen Gesellschaft*, **21**, 249-285.

SESSION 9A

HERBICIDE MOVEMENT AND PERSISTENCE IN SOILS: ASSESSMENT AND SIGNIFICANCE

CHAIRMAN	DR R. J. HANCE	
SESSION ORGANISER	DR A. WALKER	
INVITED PAPERS		9A-1 & 9A-2
RESEARCH REPORTS		9A-3 to 9A-9

PREDICTING THE FATE OF HERBICIDES IN THE SOIL ENVIRONMENT

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ABSTRACT

The fate of herbicides in soil depends upon the integrated effects of the processes of sorption, leaching, transformation, degradation, volatilization, erosion, and uptake by plants. These pathways are complex, often poorly understood and cannot be predicted with certainty. Knowledge of chemical fate pathways is usually applied in some form of predictive model. A successful model requires that we be able to identify important or dominant processes, describe them quantitatively at relevant spatial and temporal scales, and measure appropriate soil and chemical properties. Models should reflect the uncertainty introduced by simplified process descriptions, soil variability and the random nature of extrinsic factors such as climate, rainfall and chemical application patterns. Dynamic predictions such as the temporal and spatial variation of water and chemical flux densities are most difficult to perform accurately and require the greatest level of understanding and quantification.

INTRODUCTION

The environmental impact of agricultural practices is of increasing public and regulatory concern. The fate of agricultural chemicals is receiving much attention, in particular their persistence and movement to groundwater. Since the toxicity thresholds are very low for certain chemicals, only a small fraction of the chemical applied needs to reach the groundwater before a potentially hazardous situation exists. It is extremely expensive and difficult to remove chemicals from groundwater, thus management to minimize contamination is the cheapest and most effective method of protecting the environment. To achieve this goal we need to understand the factors which influence the dissipation and leaching of chemicals, and also the relative magnitude of the various dissipation pathways under specific conditions. There is a growing recognition that although agriculture operates in an environment that cannot always be controlled or predicted, practices can be devised that minimize the risk of contamination.

In this paper we present an overview of the processes which influence the fate of organic chemicals in soil. More detailed descriptions of the concepts presented here may be found in reviews by Addiscott and Wagenet (1985) and Wagenet and Rao (1989).

AN OVERVIEW OF HERBICIDE DISSIPATION IN SOIL

The relative importance of the various dissipation pathways of a herbicide is usually assessed from its solubility and vapour density, an index of sorption (usually a partition or distribution coefficient) and an index of persistence (usually a half-life value). Solubility and vapour density are chemical properties which can be measured easily and accurately, the others depend upon soil and enviornmental conditions and are more uncertain. The complex and interactive nature of herbicide reactions and movements in soil present soil scientists with the challenge of predicting potential environmental hazards using data which may be variable, estimated, or measured on an inappropriate scale. The following description of the various processes to which a chemical is subject after application to the soil surface outlines the major dissipation pathways.

Volatilization will be at a maximum immediately after application, especially if the chemical is applied to the soil or plant surfaces. Three factors determine how much will be lost: the vapour density, atmospheric conditions and time that elapses before incorporation into the profile by leaching or cultivation. At no subsequent time will the diffusion path length to the atmosphere be shorter or the vapour density gradients be higher. Once the bulk of the chemical is in the soil, volatilization slows dramatically.

The chemical may enter the soil by dissolving in rain or irrigation water. The concentration of the infiltrating water depends upon the solubility of the herbicide, its rate of dissolution and the water flow rate. Thus a very soluble herbicide subjected to a very low rainfall rate will enter the profile as a narrow band of concentrated solution. As the infiltration flux increases, and solubility or rate of dissolution decreases (both of which may be influenced by product formulation), the concentration in the infiltrating water may be lower. High rainfall intensities may give rise to macropore flow, causing some of the herbicide to be transported immediately to deeper depths through larger cracks and apertures. Several rain events may be required to leach all of the herbicide into the profile. Surface runoff and erosion may remove some of the herbicide from the field and cause contamination of surface waters. Leaching in macropores is less if the chemical is incorporated into the soil before water is applied.

Once in the soil the herbicide can react with organic or mineral surfaces, decreasing the concentration in solution. This is not necessarily an instantaneous process, since some of the sorption sites may not be easily accessible. The assumption that at equilibrium the ratio of the amount sorbed to that in solution equals the partition coefficient is not necessarily correct since it is doubtful whether equilibrium is ever attained. Soil water contents are changing continuously owing to infiltration and evapotranaspiration; cycles of wetting and drying are particularly extreme near the soil surface. The herbicide is thus subjected to corresponding cycles of adsoprtion and desorption. The nominal partition coefficient is a fairly good index of the relative sorption of different chemicals but cannot accurately describe the fluctuations in sorption with time and depth in field soils.

The herbicide is subject to transformation and degradation by bacteria. although chemical persistence is usually characterized by a half-life, bacteria do not degrade the chemical at a steady rate. There is an optimum temperature and water content range above and below which rates decrease. In addition, growth of a bacterial population capable of degrading a particular chemical may be slow. The distribution of bacteria vary with depth, fewer active cells being available in a dry surface soil or at deeper depths which have lower organic matter contents. There may be aggregates into which bacteria cannot penetrate but into which the chemical may diffuse. A parent compound may transform to a daughter product which may be more toxic and more mobile than the parent.

After each infiltration event there is some downward movement of water which may transport dissolved herbicide to deeper depths. In a field, soil water fluxes vary in rate and direction with time and depth, regardless of the scale at which they are measured. This tends to disperse what may initially have been a well-defined band of chemical; some moves in advance of the concentration peak and some is retarded. Although sorption attenuates the movement of the concentration peak relative to that of water it does not prevent it completely, and even low concentrations in moving water may present a potential environmental hazard. If water flows predominantly through larger pores it may not transport herbicide residing in stagnant regions and that in larger pores may move further than expected. Usually, convective transport exceeds that by diffusion, but diffusion in to and out of aggregates may be controlled by diffusion. A small proportion of the chemical in the gaseous phase can increase diffusive transport because gaseous phase diffusion coefficients are higher than those in solution. Some chemical may be absorbed by plants or adsorbed on to root surfaces.

The net result of these interacting processes is that the distribution of chemical in the profile becomes more diffuse and solution concentrations decrease with time. Sporadic high rainfall events or the cumulative effects of frequent smaller ones may leach chemical below the root zone after which degradation is much slower and sorption is less. The major mass balance components of herbicide fate are thus determined in the biologically and chemically active root zone, which fortunately is also the region most amenable to control by good management. Biodegradation of the parent chemical and of any toxic daughter products is the ideal way in which a pesticide is removed from soil. Less desirable pathways are leaching and volatilization.

To predict these processes fully requires a quantitative understanding of each process. Predictions of the behaviour of a chemical in the field may be obtained using a simulation model (e.g. Wagenet and Hutson, 1989; Carsel et al., 1984; Jury et al., 1983). The successful choice and application of a model requires an appreciation of their content, concepts and limitations.

THE MOVEMENT OF WATER IN SOILS

A knowledge of the spatial and temporal patterns of water flow in soil is necessary to predict chemical leaching. Two conditions are required for leaching, neither of which are easy to predict. Firstly, water must move out of the root zone and secondly, the chemical must be dissolved in that water.

The simplest way of envisaging (and modelling) leaching patterns with time is to employ the traditional concepts of field capacity, wilting coefficient and evaporation limits for each layer of soil in a profile. Infiltrating water increases the water content of the uppermost soil layer. Water in excess of field capacity drains to the next layer, from where drainage may again occur. Any excess water draining from the bottom of the profile represents drainage. Evapotranspiration, weighted according to water content, root distribution, and depth criteria, removes water from each layer. Thus a depletion is established before the next infiltration event.

Advantages of the capacity approach to water modelling are that few data are required, data are often available or easily estimated, and minimal computer time is required since the mathematics is simple and daily time steps are usually employed. Disadvantages are that the dynamic nature of soil water is simplified, leading to unrealistic estimations of water flux densities. Redistribution of water following the initial infiltration process is either not simulated or is simulated in an empirical manner.

The mechanistic or Darcian approach to simulating water flow assumes that water flux density is proportional to the hydraulic potential gradient, with the proportionality constant being the hydraulic conductivity (K). Relationships between water content (θ), matric potential (h) and hydraulic conductivity are required. The water content distribution in time and space is obtained by solving the Richard's equation

$$\frac{\partial \theta}{\partial t} = \frac{\partial}{\partial t} \left[K(\theta)\frac{\partial H}{\partial z}\right] + U\ (z,t) \tag{1}$$

where H is the hydraulic head (the sum of the pressure and gravitational components of the soil water potential), z is depth and U is absorption of water by plants. This approach provides a physically more realistic representation of the rates and direction of water flow in soils but requires data which are difficult to measure and involves more complicated computer programs.

During the past decade it has been recognized that preferential or macropore flow may lead to water moving rapidly to greater depths than expected. This has necessitated a change in traditional concepts of water and solute movement patterns in soils. When infiltration fluxes are high, and the soil is strongly structured or contains large cracks or pores open to the surface, Darcian water flow models may be inappropriate. Water flow can follow preferential pathways which constitute a small proportion of the water-filled pore space, and chemicals dissolved in this water will move downwards more rapidly than would otherwise be expected. Similarly, in soils having abrupt fine to coarse textural discontinuities, water can flow in narrow fingers. The quantitative prediction of this macropore, preferential or bypass flow and the elucidation of the conditions required to trigger these flows are presently the subject of much research.

On a large scale, macroscopic water fluxes in agricultural soils are primarily vertical. For this reason most transient root zone models are one-dimensional. However, on a small scale flow in real soils can be multi-dimensional. Surface micro-relief, drip or furrow irrigation systems, and crop root and leaf patterns can lead to non-uniform application distributions and leaching of water and chemical. In these situations two- or three-dimensional models would be more appropriate. However, increased complexity, data demands and computer processing time means that they usually cannot include much process detail. This leads to a familiar root zone modelling dilemma: a more detailed model requires more intensive data; detailed data is difficult to obtain and introduces more uncertainty. It is always important to examine a model in terms of major processes which are thought to operate in the field and ensure that all of these have been included. Wherever measurement and prediction disagree provides an opportunity to question our premises and assumptions of how the system works.

Regardless of the conceptual mechanism of water flow in soil, it is the balance between gains and losses of water that determine the leaching potential. Rain and irrigation are usually sporadic events, separated by longer periods of evapotranspiration. Redistribution of water in the profile after infiltration slows quickly, after which profile water distributions are determined largely by root extraction patterns. Small errors in estimating actual ET can have a relatively large impact on estimates of drainage, which in the long-term is the difference between infiltration and evapotranspiration.

THE MOVEMENT OF CHEMICALS IN SOIL

The movement of a chemical through soil can be accomplished by a combination of processes, listed here in their usual order of importance:

- convection (mass flow) of chemical dissolved in moving soil water,
- convection of volatile chemical in the vapour phase owing to barometric pressure fluctuations, wetting and drying cycles, and water table depth fluctuations,
- diffusion of volatile chemical in soil air in response to a gradients in vapour density,
- diffusion in the liquid phase in response to an aqueous concentration gradient.

This order may change under certain circumstances, for example when soil water flux densities are low or zero. Expressed mathematically, for steady state water flow conditions, the transport terms are:

$$J_S = J_{DL} + J_{CL} + J_{DG} + J_{CG} \qquad (2)$$

where J_S is total solute flux (mg m^{-2} day^{-1}), J_{DL} is the diffusion flux in the liquid phase, J_{CL} is the convection flux in the liquid phase, J_{DG} is the diffusion flux in the gas phase and J_{CG} is the convection flux in the gas phase.

Partitioning solute between sorbed, solution and gas phases

Movement of a chemical is attenuated if it is sorbed to minerals or organic matter. There are several mechanisms by which organic chemicals can bond to soil mineral or organic surfaces. If the herbicide is cationic (diquat, paraquat, some triazines) then ion exchange may predominate. Anionic herbicides may sorb on to positively charged sites in soil. The ion charge sometimes depends upon pH in which case soil pH may determine the extent of sorption. Ligand exchange is another common high-energy bonding mechanism. There are several low energy mechanisms such as hydrogen bonding, charge transfer and London-van der Waal's forces.

The complexity of the bonding mechanism means that the sorption isotherm (the equilibrium relationship between concentration in the sorbed phase to that in solution) is difficult to predict for a specific soil. It is also time-consuming to measure and is likely to vary with space and with depth. A further complication is that the rate at which equilibrium is approached may be slow, especially if the chemical has to diffuse through stagnant regions or into or out of aggregates having small pores. Because most non-ionic herbicides are sorbed onto soil organic matter, the organic carbon content of soils is used as an index of potential sorption. Also, for simplicity and mathematical tractability a linear sorption isotherm is used, which assumes that for each chemical there is a linear relationship between the amount of chemical sorbed per unit of organic carbon and solution concentration. In this case the proportionality constant is known as the organic carbon distribution coefficient. Considering the soil as a whole

$$c_S = K_d c_L \tag{3}$$

where c_S is the concentration of chemical in the sorbed phase (mg/kg), C_L is concentration in solution (mg/dm^3) and K_d (= $K_{oc}f_{oc}$) is a partition or distribution coefficient (dm^3/kg), calculated from the organic carbon partition coefficient K_{oc} and the organic carbon fraction (f_{oc}).

The main effects of sorption are, firstly, to decrease solution concentrations, which may decrease availability of the chemical to microorganisms and hence increase persistence, and secondly to decrease the rate of movement of the bulk of the chemical relative to that of water. The ratio of the rate of movement of the peak concentration to that of water can be expressed in terms of the retardation factor, R:

$$R = 1 + \rho K_d/\theta \tag{4}$$

where ρ is the soil bulk density, and θ is the fractional volumetric water

For volatile compounds it is necessary to relate solution (c_L) and gas phase (c_G) concentrations. Recognizing that the liquid-vapour partition can be represented by a modified Henry's Law, Jury et al. (1983) proposed that

$$c_G = K_H^* c_L \tag{5}$$

where K_H^* is the modified Henry's Law constant, defined as the ratio of the saturated vapour density (c_G^*) divided by the aqueous solubility (c_L^*), both in units of mass/volume.

At equilibrium the total amount of substance (c_T) contained in the solution, sorbed and gas phases in a soil volume of 1 dm^3 is

$$c_T = \rho c_s + \theta c_L + \epsilon c_G \tag{6}$$

where ϵ is the gas filled soil porosity ($\epsilon = \theta_s - \theta$, where θ_s is the saturated volumetric water content), and c_G is the gas phase pesticide concentration. For non-volatile substances K_H and c_G are zero. Substituting (3) and (4) in (6) enables c_T to be calculated from c_L,

$$c_T = c_L\ (\theta + \rho K_d + \epsilon K_H). \tag{7}$$

CONVECTIVE TRANSPORT

The movement of dissolved chemical by flowing water is the predominant form of chemical transport which leads to leaching. The convective flux of solute is usually represented as (Wagenet, 1984)

$$J_{CL} = -\theta D_M(q) \frac{dc_L}{dz} + qc_L \qquad (8)$$

where q is the macroscopic water flux, and $D_M(q)$ is the mechanical dispersion coefficient that describes mixing between large and small pores as the result of local variations in mean water flow velocity. The mechanical dispersion coefficient is similar in concept to a diffusion coefficient but increases in proportion to water flow velocity, far exceeding diffusion in magnitude during periods of water flow. What this means is that a narrow band of chemical at the soil surface will spread out as it moves downwards, some of the chemical moving in advance of the main concentration peak. This is of particular significance for toxic chemicals since small quantities of chemical can reach the groundwater relatively quickly. The process is similar in concept to that of macropore or preferential flow. The distinction between them is that (8) applies to dispersive flow but cannot describe macropore flow.

Gas convection can increase the mobility of volatile chemicals in soil. Changes in soil water content, barometric pressure and temperature may cause air flow through soil. The cyclical nature of these changes enables these effects to be simulated by increasing the effective diffusion in the gas phase (Wagenet and Hutson, 1989).

DIFFUSION

Diffusion in the soil solution and in soil air

Diffusion flux density in the aqueous and gas phases is described by Fick's law

$$J_L + J_G = -D_L \frac{dc_L}{dz} - D_G \frac{dc_G}{dz} \qquad (9)$$

where D is the effective molecular diffusion coefficient (mm^2/d) and c is the chemical concentration (mg/dm^3). Subscripts L and G refer to the aqueous and gaseous phases. Effective diffusion coefficients in soils are lower than those in water or in air owing to low water- or air-filled porosity and the tortuosity of diffusion pathways. Molecular diffusion rates are usually so low in comparison to other components of chemical flux that they are often ignored. But diffusion is usually the only means whereby chemical can move in and out of otherwise inaccessible areas of soil, such as inside aggregates. The large difference between diffusion and convective fluxes accounts for slow attainment of chemical equilibrium in some soils.

Diffusion in the gaseous phase is responsible for losses of chemical to the atmosphere during application, from the soil or plant surfaces or by diffusion through soil into the atmosphere. At the soil surface especially, both the diffusion coefficient and the vapour density gradient is likely to be high. Volatilization from the soil surface will be increased by wind and atmospheric turbulence. Losses of chemical from the surface will be accentuated if evaporative fluxes of water bring additional chemical to the soil surface. Incorporation of a chemical into the soil either by leaching or cultivation should drastically reduce volatilization losses to the atmosphere.

Effective aqueous diffusion coefficient

For the purposes of calculating the macroscopic flux of chemical, (8) and (9) can be combined to give an effective diffusion and convection flux in the liquid and gas phases, assuming equilibrium between them:

$$J_{DL} + J_{CL} + J_{DG} = -D_{\rho}(\theta)\,\frac{dc_L}{dz} - \theta D_M(q)\,\frac{dc_L}{dz} - D_{OG}K_H^{*}\,\frac{dc_L}{dz} + qc_L. \qquad (10)$$

The first three terms on the right-hand side are usually combined to give the general equation

$$J_{DL} + J_{CL} + J_{DG} = -\theta D(\theta,q)\,\frac{dc_L}{dz} + qc_L \qquad (11)$$

where $D(\theta,q)$ is the apparent diffusion coefficient (mm^2/d) that includes description of the effects upon solute movement of mechanical dispersion and both aqueous and gaseous phase chemical diffusion. Thus the diffusive behaviour of a chemical can be estimated from a knowledge of its saturated vapour density and solubility, organic carbon distribution coefficient and diffusion coefficients in the aqueous and gas phases, which are further adjusted according to soil porosity and water content.

THE CONVECTION -DISPERSION EQUATION

Almost all situations of chemical transport in the field occur under transient water flow conditions, in which water content (θ) and water flux (q) both vary with depth and time. Using (7) and (11) in conjunction with continuity realationships gives a general transport equation for solute movement:

$$\frac{\partial c}{\partial t}\,(\theta + \rho K_d + \epsilon K_H^{*}) = \frac{\partial}{\partial z}\,[\theta D(\theta,q)\frac{\partial c}{\partial z} - qc] \pm \phi \qquad (12)$$

where all concentrations c are solution concentrations, and ϕ indicates source and/or sink terms. There is currently much uncertainty as to the applicability of this equation in structured soils.

DEGRADATION

Degradation can occur chemically or biologically. For modelling purposes, degradation is usually described as a lumped first-order rate process

$$C = C_0\exp(-kt) \qquad (13)$$

where C is the concentration of substrate, initially C_0, remaining after time t.

Biodegradation is influenced by environmental conditions, microbial ecology and soil type. Values of k are usually obtained by fitting (16) to batch or field measurements of chemical disappearance. There is a danger in using such values to extrapolate to long time periods, but there is currently no more reliable way of estimating or predicting degradation. Other equations are sometimes used for describing the degradation process, some of which include microbial population growth (Simkins and Alexander, 1984).

DISCUSSION

Soil and environmental sciences, in common with others, expanded from qualitative and quantitative studies of small, isolated components to integrated and predictive descriptions of large scale, more complex, interactive systems. The widespread use of computer modelling techniques has enabled interactions between separate processes to be studied in a way that is not possible in any controlled laboratory or field experiment. This does not mean that experimental studies and measurement are no longer necessary; on the contrary they supply the starting data for computer simulations and the means for testing the assumptions and premises in models.

It is clear that to define the fate of a chemical at a scale useful for management purposes requires much scaling up or scaling down. In fact computer simulation models do just that. They integrate knowledge gained at a small scale to predict phenomena at a larger scale under conditions imposed at a still larger scale.

Modelling the field behaviour of chemicals, rather than small-scale, well-controlled experiments has made us acutely aware of the problems of spatially variable soil properties and the vast range of spatial and time scales at which we have traditionally described the various processes and boundary conditions of the soil-crop-atmosphere system. Coming to terms with this is probably the major problem in soil physics and chemistry today. Well-defined physical systems which can be described accurately using mathematical equations are most amenable to simulation. Soils, being part of a natural system in which chemical, biological and physical processes operate across a spectrum of scales while demonstrating considerable spatial variability, are difficult to model and characterize.

Two main categories of chemical fate and leaching models have been developed (Addiscott and Wagenet, 1985). In deterministic models, individual processes and their interaction are defined mathematically, each set of input data leading to a unique and reproducible prediction. The uncertain and variable nature of soil is accounted for by multiple executions of the model using a range of input values. Stochastic models, on the other hand, place less emphasis on process and more on predicting the statistical distribution or probability of results. Both approaches have merit and some combination of the two would be most desirable.

For all the uncertainty involved, we can still predict the likelihood of a chemical leaching especially if one or two factors dominate chemical fate. For example, if rainfall is low and well-distributed or the chemical is strongly sorbed, there is little chance of leaching, no matter what the chemical properties. If the chemical degrades rapidly then its chances of leaching is greatly reduced, unless it is leached shortly after application. Sparse input and validation data, or a spatially variable soil leads to uncertain results. Improvement of our modelling capabilities will depend on continued well-planned field experiments and monitoring programmes.

REFERENCES

Addiscott, T.M.; Wagenet, R.J. (1985) Concepts of solute leaching in soils: a review of modelling approaches. *Journal of Soil Science,* **36**, 411-424.

Carsel, R.F.; Smith, C,N.; Mulkey, L.A.; Dean, J.D.; Jowise, P. (1984) *User's manual for the pesticide root zone model (PRZM), Release 1.* US/EPA-600 /3-84-109. U.S. Environmental Protection Agency, Washington D.C. 216 pp.

Jury, W.A.; Grover, R.; Spencer, W.F.; Farmer, W.J. (1983) Behavior assessment model for trace organics in soil. I. Model description. *Journal of Environmental Quality*, **12**, 558-564.

Simkins, S.; Alexander, M. (1984) Models for mineralization kinetics with the variables of substrate concentration and population density. *Applied and Environmental Microbiology*, **47**, 1299-1306.

Wagenet, R.J.; Hutson, J. L. (1989) LEACHM - A process-based model of water and solute movement, transformations, plant uptake and chemical reactions in the unsaturated zone (version 2). *Continuum 2*, New York State Water Resources Institute, Cornell University, Ithaca, New York, 148 pp.

Wagenet, R.J.; Hutson, J.L. (1989) Simulating the fate of a volatile pesticide in unsaturated soil: a case study with DBCP. *Journal of Environmental Quality*, **18**, 78-83.

Wagenet, R.J.; Rao, P.S.C. (1989) Modeling pesticide fate in soils. In: *Pesticides in the Soil Environment: Processes, Impacts and Modeling*. H.H. Chang (ed). Soil Science Society of America. Madison, Wisconsin, (in press).

MEASUREMENT AND PREDICTION OF CHLORSULFURON PERSISTENCE IN SOIL FOLLOWING AUTUMN AND SPRING APPLICATION.

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ABSTRACT

Using sites with similar soil types chlorsulfuron at 30-32 g ai ha^{-1} was applied to uncropped plots in late November 1986 at Broom's Barn Experimental Station (BB) or early May 1987 at the Institute of Horticultural Research (IHR). Soil cores were taken either 13, 77 and 136 days (BB) or 63, 106 and 148 days (IHR) after treatment and divided into different horizons to a maximum depth of 50 cm for analysis by bioassay. The measured residues were compared with those predicted from a computer simulation of movement and persistence. The results indicated similar rates of breakdown at both sites but the computer model gave more accurate predictions following spring (IHR) than autumn (BB) treatment, both in terms of degradation and movement. At both sites more herbicide remained near the soil surface than was predicted by the computer model.

INTRODUCTION

Chlorsulfuron is a member of the sulfonylurea group of herbicides (Blair & Martin, 1988) and its main use in the UK was in a formulated mixture with metsulfuron-methyl (as 'Finesse'). Chlorsulfuron is highly active in soil and some rotational broad-leaved crops, sugar beet in particular, are highly sensitive to it (Breay *et al.*, 1986). Under certain circumstances chlorsulfuron may persist for long periods in the soil (Duffy, *et al.*, 1987) and because of the possibility of rotational crop problems, this product was withdrawn from the UK market in 1988.

Since there is little published information concerning movement of sulfonylurea herbicides in soil in the field, these experiments were made to measure chlorsulfuron movement and persistence in the soil profile under autumn (at Broom's Barn Experimental Station (BB)) and spring conditions (at Institute of Horticultural Research - Wellesbourne (IHR)). The measured values were compared with those predicted by a computer simulation model (Nicholls, *et al.*, 1982).

MATERIALS & METHODS

Field Experiments

Field experiments were conducted at BB (autumn application) and IHR (spring application) on sandy loam soils with characteristics as defined (Table 1; Walker et al., 1989). Chlorsulfuron was used as the water dispersible granule formulation (20% ai) and applied at either 30 (BB) or 32 (IHR) g ai ha^{-1}, approximately twice the quantity of chlorsulfuron (15 g ai ha^{-1}) used in recommended applications of 'Finesse'. At BB, on 28.11.86, an Oxford Precision sprayer fitted with 8002 'Teejet' nozzles delivering 210 l ha^{-1} at 210kNm^{-2} pressure was used to apply treatments to four replicate 3 x 24m fallow plots. At IHR two replicate plots 4 x 1.5m were treated on 5.5.87 with chlorsulfuron using a knapsack sprayer in a volume equivalent to 1100 l ha^{-1}. Soil samples were taken at BB on days 13, 77 and 136 after treatment and at IHR on days 63, 106 and 148 after treatment. At BB the samples were taken using a 4.75 cm diameter lined corer on day 13 and subsequently using a tractor mounted 7 cm diameter corer. Four cores per replicate were taken, each core was cut into 3 cm segments and soil samples were frozen until required. At IHR (Walker & Welch, in press) plots were sampled in successive 5 cm increments to a depth of 50 cm. The 0-5cm horizon was sampled with cylinders of 6 cm diameter and all other horizons with a stainless steel corer of 2.5 cm diameter. Twenty random cores were sampled at each date and bulked for each plot.

Bioassay

Since analytical techniques using HPLC are not sensitive enough to measure residues of chlorsulfuron which can damage crops such as sugar beet (Duffy et al., 1987), a bioassay technique was used at both sites. The assay used at IHR was based on that described previously by Walker & Brown (1983) and in detail by Walker & Welch (in press) using lettuce seeds (*Lactuca sativa* L. cv. Avon Defiance). The assay at BB which will be reported in detail elsewhere (Tottman *et al*., in preparation) involved extraction of chlorsulfuron from the soil in a calcium hydroxide solution as described by Morishita *et al*., (1985) and measurement of root lengths of seedling sugar beet growing under controlled conditions in the solution. Calcium hydroxide in ¼ strength Hoagland solution (1.15 g/l; 80 ml) was added to 40 g dry soil, shaken for 30 mins and placed in a cold room to settle. Thirty ml of solution was drawn off and added to a polythene bag containing fluted filter papers. Each filter paper comprised 25 flutes, each containing a sugar beet seed. After sealing, the bags were placed in an incubator for 72 h at 15°C to germinate, followed by 96 h at 22°C after which root lengths were measured. Standard treatments were included in the same way for comparison.

Laboratory experiments

Herbicide adsorption and degradation studies were carried out as described in detail by Walker *et al*. (1989).

TABLE 1. Soil properties, adsorption distribution coefficients (K_{ads}), degradation rate constants (K_{deg}) and half-lives (HL) of chlorsulfuron

Site	Depth (cm)	Organic matter (%)	pH	Moisture content at 33 k Pa % w/w	Microbial biomass (mgC $100g^{-1}$)	K_{ads}	K_{deg} (day^{-1})	HL (days)
BB	0-20	4.98	7.3	14.8	115	0.073	0.0094	74
	20-40	4.62	7.6	15.8	117	0.074	0.0096	72
	40-60	4.59	7.9	16.9	106	0.066	0.0082	85
IHR	0-20	2.17	6.5	8.5	148	0.163	0.0147	47
	20-40	2.17	6.6	10.5	25	0.107	0.0116	60
	40-60	2.36	7.0	10.8	18	0.047	0.0047	147

RESULTS AND DISCUSSION

Laboratory studies

Herbicide adsorption by the soils was characterised as distribution coefficients (K_{ads}) calculated from the amount adsorbed per unit weight of dry soil divided by the concentration in the equilibrium solution (Table 1). Walker *et al*. (1989) included these six soils (2 sites/3 horizons) in a group of 23 for which they compared K_{ads} with soil properties by linear regression analysis. For these 23 soils there was good correlation between soil pH and the distribution coefficients, transformed to their appropriate logarithmic values ($r = -0.751$, $p < 0.001$). Degradation was assessed on the assumption that first-order reaction kinetics would apply, and first-order rate constants (K_{deg}) and half-lives (HL) were derived from the slopes of the lines of best fit calculated by linear regression analysis of the logarithm of residual concentration against time of incubation. The results (Table 1) indicate that degradation rate at each site was slowest in soils from the deepest layers, particularly so in the 40-60 cm layer at IHR. This was accompanied by both an increase in pH and a lower microbial biomass with depth. Both these factors can decrease degradation (Walker *et al*., 1989).

Persistence and movement of residues in the field

Following autumn application at BB, chlorsulfuron residues were detected down to 36 cm, even after 13 days, although the peak concentration was still located near the soil surface (Fig 1). 77 and 136 days after treatment, the peak had moved down the profile and less herbicide was detected (~ 10% after 136 days). However, measurements were not made below 40 cm. At IHR, following application in spring, chlorsulfuron moved through the profile (Fig 2) and some had moved to a depth of about 40 cm during the first 63 days. The highest concentrations at this time were located in the top 25 cm.

Although little further movement was recorded at 106 and 148 days, degradation proceeded such that less than 10% of the initial amount was recovered after 148 days a similar proportion to that reported previously by Walker & Brown (1983). When total recovery was plotted against days after treatment for both sites (not presented) there was a good correlation ($r = -0.976$; $p < 0.01$) suggesting that the rate of breakdown was independent of site and season in these particular experiments. This contrasts with the view expressed by Duffy *et al.* (1987) that spring conditions would favour more rapid breakdown than in the autumn because soil temperatures would be more favourable for microbial activity. However, in the present experiments, recoveries were expressed as a percentage of applied doses and these were not actually measured at either site.

Prediction of movement and persistence

The data for adsorption and degradation of chlorsulfuron from the laboratory studies (Table 1) were used in the leaching model of Nicholls et al. (1982) as modified by Walker (1987). The model was further modified to permit different degradation rates and adsorption constants to be used for different depths in the soil (<20, 20-40, >40 cm). Constants to describe the moisture and temperature dependance of degradation were as described by Walker & Brown (1983).

At 13 days after autumn treatment (BB) the model predicted that residues would be present only in the top 18-21 cm soil whereas significant amounts were found down to 36 cm (Fig 1). In contrast, at 77 and 136 days, the model over predicted movement and the measured residues were located primarily in the top 30 cm. At 136 days, the model predicted that most of the residue would have leached below 40 cm but no residue measurements were made in these deeper layers so absolute confirmation is not possible. Checks for contamination were made by removing the outer layer of soil from the core and this gave similar results. Following spring application (IHR) the depth of penetration into the soil, the approximate position of the maximum concentration and total soil residues were predicted with reasonable accuracy (Fig 2). However, even at this time of year, the model overpredicted movement away from the surface soil layers. At all sampling times the model predicted relatively low residues of chlorsulfuron in the top layer of soil (except 13 days after treatment at BB), although measurements showed that significant amounts were retained near the soil surface. This could have important implications with respect to following crop safety, if significant residues remain within the plough layer to affect the developing roots of subsequent sensitive crops.

During the five month period following autumn treatment, total rainfall (213 mm) was greater than total potential evaporation (118 mm) whereas following the spring application, total rainfall (220 mm) was less than evaporation (392 mm). Hence in the autumn, net movement of water in the soil was downwards whereas in the spring it was upwards and therefore more extensive movement would be expected in winter than in spring. The measured values do not show this and do not suggest that large quantities of herbicide would have moved deeper than we sampled in the winter months.

The model, therefore, gives better predictions of herbicide movement during the spring and summer months when the soil is subject to alternate wetting and drying

Fig. 1 The movement and degradation of chlorsulfuron following application at Broom's Barn on 28.11.86 (observed; predicted)

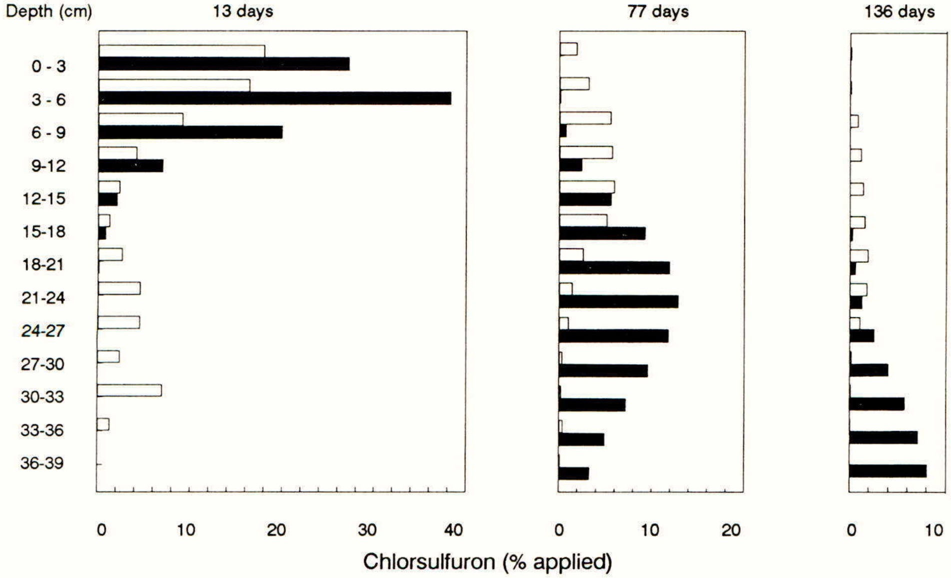
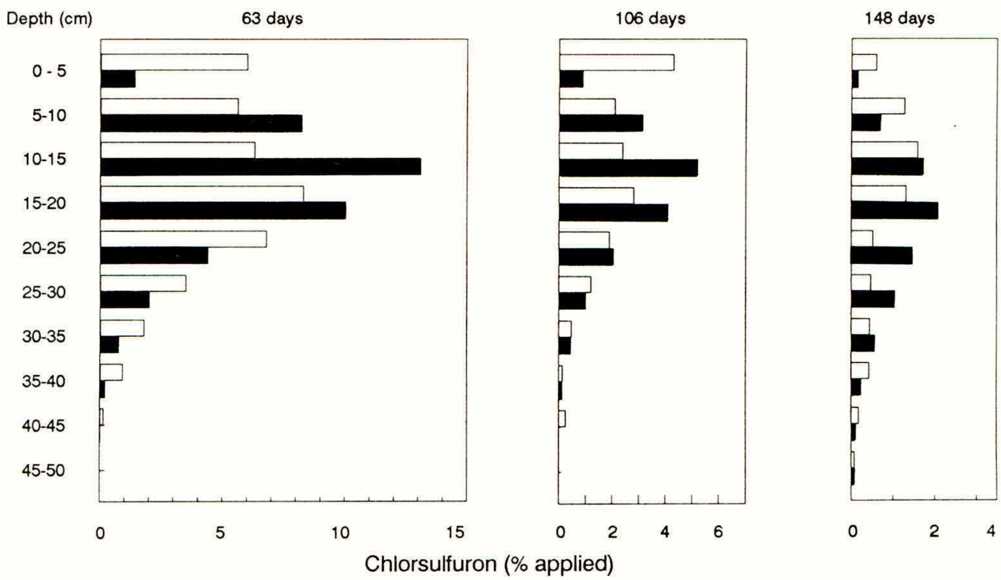


Fig. 2 The movement and degradation of chlorsulfuron following application at IHR on 5.5.87 (observed; predicted)



cycles, than in winter when the soil is predominantly wet. This suggests that the transport component of the model may be inaccurate when there is a large net influx of water into the soil. The data indicate that considerable caution will be required if the model is used to forecast rotational crop safety to sulfonylureas since overestimation of movement will underestimate the risk of crop damage.

ACKNOWLEDGEMENTS

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REFERENCES

Blair, A.M.; Martin, T.D. (1988) A review of the activity, fate and mode of action of sulfonylurea herbicides. *Pesticide Science,* **22**, 195-219.

Breay, T.; May, M.; Bray, W. (1986) Trifluralin and chlorsulfuron residues - how to recognise the symptoms; and where to look for clues. *Sugar Beet Review*, **54**, 21-24.

Duffy, M.J.; Hanafey, M.K.; Linn, D.M.; Russell, M.H.; Peter, C.J. (1987) Predicting sulfonylurea herbicide behaviour under field conditions. *Proceedings British Crop Protection Conference - Weeds*, 541-547.

Morishita, D.W.; Thill, D.C.; Flom, D.C.; Campbell, T.C.; Lee, G.A. (1985) Method for bioassaying chlorsulfuron in soil and water. *Weed Science*, **33**, 420-425.

Nicholls, P.H.; Walker, A.; Baker, R.J. (1982) Measurement and simulation of the movement and persistence of atrazine and metribuzin in a fallow soil. *Pesticide Science*, **13**, 484-494.

Walker, A. (1987) Evaluation of a simulation model for prediction of herbicide movement and persistence in soil. *Weed Research*, **27**, 143-152.

Walker, A.; Brown, P.A. (1983) Measurement and prediction of chlorsulfuron persistence in soil. *Bulletin of Environmental Contamination and Toxicology*, **30**, 365-372.

Walker, A.; Welch, S.J. The relative movement and persistence in soil of chlorsulfuron, metsulfuron-methyl and triasulfuron. *Weed Research*, (in press).

Walker, A.; Cotterill, E.G.; Welch, S.J. (1989) Adsorption and degradation of chlorsulfuron and metsulfuron-methyl in soils from different depths. *Weed Research*, **29**, 281-287.

FIELD OBSERVATION OF SOIL MOVEMENT AND RESIDUES OF SULFONYLUREAS IN SWEDEN

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ABSTRACT

Two approaches were used to assess the leaching potential and persistence of chlorsulfuron and metsulfuron methyl under Swedish conditions. The effects of different climatic conditions, soil textures and pH were studied in lysimeters and dissipation trials.

Field lysimeters with closed bottoms and undisturbed soil profiles or aged infilled soil profiles were treated in the spring. At recommended rates, metsulfuron-methyl was not detected in the leachate and chlorsulfuron was detected in only one sampling. At double rates the products were detected (0.013-0.033 ppb) on a few occasions. All detected concentrations were without biological activity.

Degradation was studied in separate field trials. Rates double those recommended were applied to cereals in the spring. Soil sampling was continued into the following season. The two compounds were primarily found in the top 10 cm of the soil. Most of the residues were degraded before October and by the following spring the residue levels were below detection and/or NOEC for sugarbeets.

INTRODUCTION

Chlorsulfuron and metsulfuron-methyl are the active ingredients in the sulfonylurea cereal herbicides, Glean and Ally. In Scandinavia, these compounds are marketed as 20 % dry flowable formulations. The label use rates in Sweden are 15-20 g/ha for Glean 20 DF and 15-30 g/ha for Ally 20 DF.

Due to extensive field testing, it was discovered early that some crops are extremely sensitive to very low concentrations of these sulfonylureas. In Scandinavia, both products are marketed with crop restrictions regarding growing certain sensitive crops the following season.

Pesticide movement in soils has received increasing attention during recent years because of its potential effects on surface and ground water quality. In Sweden, the persitence and movement of chlorsulfuron and metsulfuron-methyl has been studied in phytotoxicity trials with white mustard as the indicator plant. (Arvidsson, unpublished data, Nilsson 1983, 1984). The development and use of very low use rates has increased the need for extremely sensitive analytical methods. We are now able to detect concentrations, which used to be non-detectable or "0". It is therefore important to correctly evaluate the significance of measured levels of different pesticides in water and soil, both from a human toxicological and an environmental point of view, and to carry out a proper risk assessment.

METHODS

Lysimeter trials

Experimental design

The purpose of these trials was to study the leaching behaviour of chlorsulfuron and metsulfuron-methyl in different soils and under different climatic conditions. The lysimeter trials were located in Kjettlinge in central Sweden, north of Uppsala, and in Bulstofta in southern Sweden, east of Helsingborg. The trial locations were selected to ensure different soil types and climatic conditions. In total 20 lysimeters were used: 4 lysimeters with undisturbed soil profiles in Kjettslinge, and 16 lysimeters with aged disturbed soil profiles in Bulstofta.

The Kjettlinge lysimeters were polyvinyl chloride tubes with an inner diameter of 0.0295 m and a length of 1.18 m. The soil in the lysimeters had 2 layers: a topsoil of loam (pH 6.0-6.5, 3-6% organic matter) with a mean thickness of 0.27 m, and a subsoil of fine sand ranging 0.26-0.29 m. Below the undisturbed soil profile there was a filler (0.02-0.2 mm; 10 cm deep), drainage gravel (4-8 mm; 5 cm deep) and gravel (8-12 mm; 40 cm deep). The lysimeters in Kjettslinge are described in detail by Bergström (1987).

The lysimeters were cultivated and sown on May 8 with spring barley. The crop was harvested on September 8, and conventional ploughing was simulated through spading on October 16. Before treatment with the herbicides, the lysimeters were watered to ensure that the soil was at field capacity. Application of chlorsulfuron and metsulfuron-methyl was made with a small plot spayer at 2-4 leafstage (GS 12-14) of the cereal. Chlorsulfuron and metsulfuron-methyl were applied at 2 rates, 4 and 8 g a.i./ha, corresponding to label and double label rate in Sweden.

The Bulstofta lysimeters were polypropylene pipes with an inner diameter of 0.35 m and a length of 0.80 m. The lysimeters were filled with soil in 1972, keeping the topsoil separated from the subsoil. The aging of the soil for 16 years before used in this investigation, allowed for a pore system to develop in these soil profiles as well. Out of the 16 lysimeters, 8 lysimeters had topsoils of sand (pH 5.4- 6.3, <2% organic matter) and the remaining 8 had topsoils of clay (pH 7.8-8.2, 2-3% organic matter). The subsoil was identical in all lysimeters, a loamy moraine. The lysimeters in Bulstofta are described in detail by Bertilsson (1988).

Spring wheat was sown on 4 clay lysimeters and 4 sand lysimeters on April 21. On the remaining 4 clay lysimeters and 4 sand lysimeters spring barley was sown on May 5. The spring barley had to be resown on May 24 on the clay, due to establishment problem. The crops were harvested on August 18-24, and "ploughing" was made on September 20. Before treatment with the herbicides, the lysimeters were watered on May 10 and 13 with 10 mm on both occasions. Application of chlorulfuron and metsulfuron-methyl was made with equipment identical to that used in Kjettslinge. Because of the different sowing dates of the crops, the application date also varied in order to apply at the 2-4 leafstage (GS 12-14). Chlorsulfuron and metsulfuron-methyl were applied at 4 and 8 g a.i./ha.

Daily records of air temperature and precipitation were kept at Kjettslinge and Bulstofta. The cumulative rainfall was calculated at both locations and comparedon a biweekly basis with the average rainfall for the regions. Any calculated deficit was made up by watering of the lysimeters.

Water sampling and analysis

Water sampling was carried out every week if drainage was available. The water samples were deep frozen immediately after sampling or sent directly for analysis. The ELISA Microplate Immunoassay method was used to determine levels of chlorsulfuron and metsulfuron-methyl. The detection limits were 0.013 ppb for chlorsulfuron and 0.010 ppb for metsulfuron-methyl.

Dissipation trials

Experimental design

The purpose of the investigation was to study the degradation and mobility of chlorsulfuron and metsulfuron-methyl in the soil profile, from the time of application to the time of evaluation of sugarbeets the following season. The trials were carried out 1987-88 at 3 locations with various soil textures and pH in southern Sweden. The soil texture at Rinkaby was a loamy sand with 2.1% organic matter and pH 7.1. At Trolle-Ljungby the soil was a loamy sand with 2.5% organic matter and pH 5.9. At Trelleborg the soil was a clay loam with 1.9% organic matter and pH 7.4.

Applications of chlorsulfuron and metsulfuron-methyl at 8 g a.i./ha were made in winter wheat at 2-3 tillers-stage (GS 22-23). Evaluations of the sugarbeets the following season were made 21-22 June and 11-14 July.

Soil sampling and analysis

Soil samples were taken at 2 depths: 0-10 cm and 10-20 cm. Sampling was done once a month from the time of application to the time of ploughing in the fall of 1987. Another sampling was made in the end of June 1988 at the time of evaluation of the following crop sugarbeets. The soil samples were deep frozen immediately after sampling and then analyzed with the ELISA Micro-plate Immunoassay method with a detection level of 0.050 ppb for metsulfuron-methyl and 0.025 ppb for chlorsulfuron.

RESULTS AND DISCUSSION

Lysimeter trials

Precipitation and drainage

At both trial locations, precipitation typically occured during limited time periods. The highest drainage volumes were collected during October at Kjettslinge and during December at Bulstofta. The drainage volumes were similar in all lysimeters at Kjettslinge, while they varied greatly at Bulstofta. At Bulstofta, the sand lysimeters had a higher drainage volume than the clay lysimeters between June 1 and December 31. The clay lysimeters with resown barley had a very low drainage volume.

Chlorsulfuron and metsulfuron-methyl in the drainage water

At the label use rate, 20 g product/ha, neither chlorsulfuron nor metsulfuron-methyl was detected in any samples of leachate from lysimeters, except one sample from Kjettslinge which had a chlorsulfuron concentration just above the detection limit in November. In December, the residue level was again nondetectable.

At the double label rate, 40 g product/ha, 5 consecutive samples from Kjettslinge (0.014-0.021 ppb) and 3 consecutive samples from Bulstofta (0.024-0.043 ppb) contained chlorsulfuron. For metsulfuron-methyl, 3 samples from Kjettslinge (0.013-0.020 ppb) and 2 samples from Bulstofta (0.020-0.022 ppb) contained detectable residues. In the Kjettslinge samples the highest concentration of both compounds occurred on November 7, followed by a decline to non-detectable levels by December 9. At Bulstofta the detectable concentration of metsulfuron methyl came in October and November and then declined below detection, while the measurable concentrations of chlorsulfuron occurred in November and December. Chlorsulfuron was detected in the last sample in December, although at lower concentration than in earlier samples. All detected concentrations were below biological activity.

It is notable that residues were found in the Bulstofta clay lysimeters resown with barley at double label rate, while no residues were found at label or double label rate in the Bulstofta sand lysimeters. The explanation of this, could be that the rather high pH of the clay lysimeters (around 8 in the topsoil) probably reduced the dissipation rates. The sand lysimeters had a topsoil with pH around 6. Also, the resown clay lysimeters had very low drainage volumes compared to the other lysimeters. At Kjettslinge the pH in the topsoil was below 7, however the pH of the leachate ranged 7.8-7.9. This may have decreased the rate of dissipation of the compounds and increased the risk of leaching.

Dissipation trials

The sampling procedure used in this trial is likely to over-state the values for the 10-20 cm fraction, especially at the first sampling occasion. This study is not well suited for evaluating the mobility of the compound, but illustrates the degradation in the top 10 cm in different soil types. The results will focus on the residues in the top 10 cm fraction, where the largest portions of the compounds were found.

Rinkaby

The first soil sampling was made 1 month after application. The residue levels in the top 10 cm fraction were 3.13 ppb of chlorsulfuron and 4.54 ppb of metsulfuron-methyl. By September residues of chlorsulfuron were below 0.120 ppb, NOEC for sugarbeets the most sensitive known field crop. Residues of metsulfuron-methyl were below NOEC in August and below detection in October. Sugarbeets were grown without injury symptoms, which confirms that residues were below NOEC. In June there were no detectable residues for either product.

Trolle-Ljungby

The first soil sampling was made 5 days after application. The residue levels in the top 10 cm fraction was 1.72 ppb of chlorsulfuron and 2.05 ppb of metsulfuron-methyl. By September residues of chlorsulfuron were just below NOEC (0.119 ppb), while residues of metsulfuron-methyl were slightly above NOEC (0.230 ppb). The next season sugarbeets could be grown without injury symptoms and in June metsulfuron-methyl was not detected and residues of chlorsulfuron were well below NOEC.

Trelleborg

The first soil sampling was made 1 month after application. The residue levels in the top 10 cm fraction were 1.89 ppb of chlorsulfuron and 6.76 ppb of metsulfuron-methyl. By September residues of metsulfuron-methyl were below detection, and of chlorsulfuron below NOEC. A slight increase in the residues occured in October for both products. The next season sugarbeets could be grown without injury symptoms and in June no residues of either compound were detected.

There are several possible reasons for the variation in the amount of pesticide present at the first sampling. Although the crop stage at application was 2-4 tillers, crop coverage can vary a lot and have a great impact on the amount pesticide that reaches the soil. Also the difference in the time interval between the application and the first sampling would have some effect.

In summary, no pronounced differences in persistence could be observed between the tested soils. Even at double label rates, most of the residues were degraded before October and by the following season residues were below detection and/or NOEC for sugarbeets.

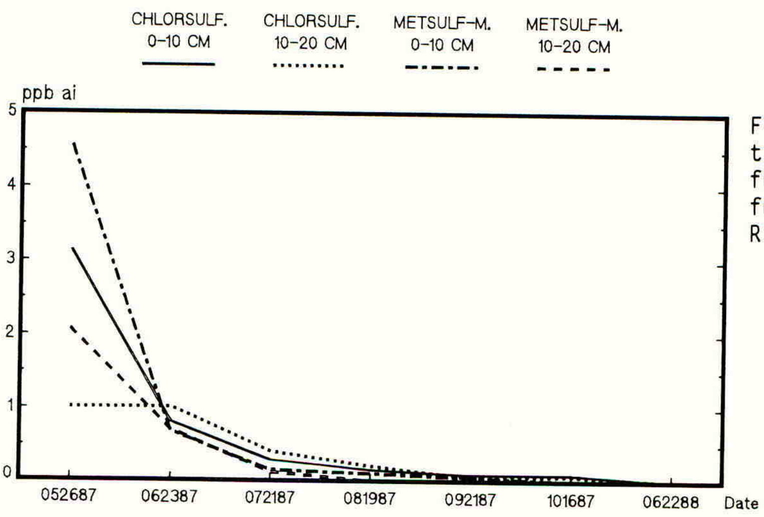

Figure 1. Dissipation of chlorsulfuron and metsulfuron-methyl at Rinkaby

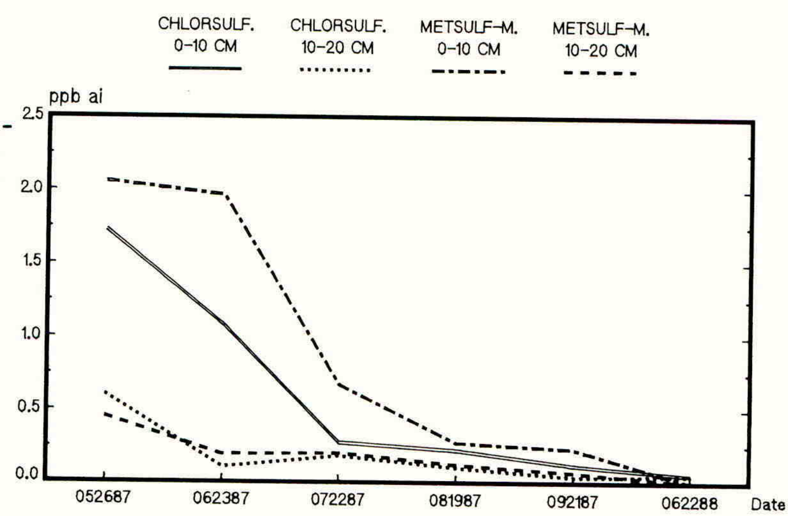

Figure 2. Dissipation of chlorsulfuron and metsulfuron-methyl at Trolle-Ljungby

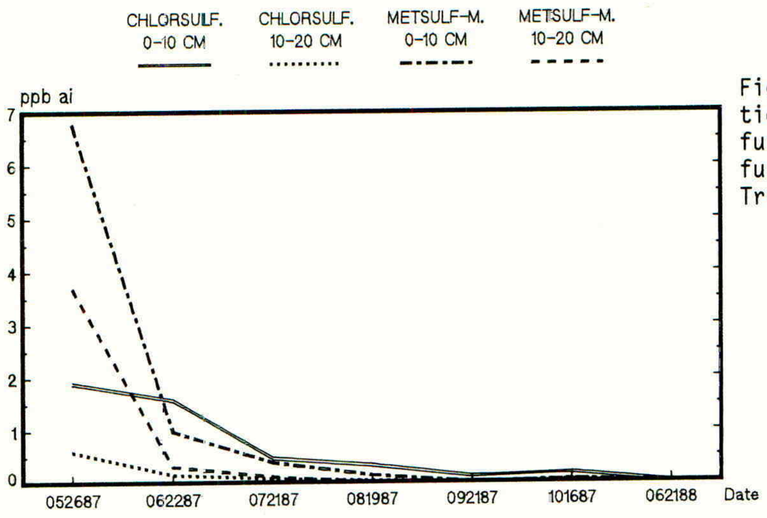

Figure 3. Dissipation of chlorsulfuron and metsulfuron-methyl at Trelleborg.

REFERENCES

Bergström, L. (1987) Nitrate leaching and drainage from annual and perennial crops in tile-drained plots and lysimeters. Journal of Environmnetal Quality **16**, 11-18.

Bertilsson, G. (1988) Lysimeter studies of nitrogen leaching and nitrogen balance as affected by agricultural practices. Acta Agriculturae Scandinavica **38**, 3-11.

Nilsson, H. (1983) Herbiciders persistens och rörlighet i åkerjord. Undersökningar 1980-81. Ogräs och ogräsbekämpning 24:e svenska ogräskonferansen, Uppsala 26-27 januari 1983, **1**, 308-316.

Nilsson, H. (1984) Herbiciders persistens och rörlighet i åkerjord. Undersökningar 1982-83. Ogräs och ogräsbekämpning 25:e svenska ogräskonferansen, Uppsala 2 februari 1984, **1**, 73-78.

A FIELD STUDY OF THE PERSISTENCE AND LEACHING OF CHLORSULFURON AND METSULFURON-METHYL.

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ABSTRACT

A field experiment investigated the persistence and leaching of sulfonylureas in cropped (spring barley) and fallow soil. Chlorsulfuron and metsulfuron-methyl were not detected in the upper 20 cm of soil 120 days after application. There was no evidence of substantial leaching, and degradation occurred in the warm, moist soil. Excellent weed control of the natural field population was achieved in the crop and the yield of barley was not reduced by any of the treatments.

INTRODUCTION

Chlorsulfuron, and metsulfuron-methyl are sulfonylurea herbicides characterised by their high activity at low application rates, and are used to control mainly broad-leaved weeds in cereal crops.

Chlorsulfuron residues in soil have caused damage to rotational crops, with sugar beet being particularly susceptible to very low concentrations (Brewster and Appleby, 1983; Peterson and Arnold, 1985).

Sulfonylureas degrade in soil by hydrolysis and microbial decomposition (Joshi et al, 1984). The rate of degradation varies with soil and environmental conditions. Degradation is generally more rapid in warm, moist, light-textured, acidic soils - and slower in cold, dry, heavy, alkaline soils (Beyer et al, 1987).

Soil mobility of sulfonylureas increases with pH and decreasing soil organic matter (Fredrickson and Shea, 1986; Beyer et al, 1987). Chlorsulfuron and metsulfuron-methyl are potentially very mobile in soil. Autumn applications are leached into the subsoil of a free-draining soil, whereas spring applications tend to remain in the topsoil (Nicholls et al, 1987).

This field experiment investigated the leaching and persistence of chlorsulfuron and metsulfuron-methyl applied at different dose rates in cropped and fallow soil. The natural field population of weeds was used to evaluate weed control, and the influence of the herbicides on barley yield was measured. The importance of weather conditions during the growing season was considered.

MATERIALS AND METHODS

The experimental area was at Sonning Farm, Reading. The soil is a sandy loam, with 73.4% sand, 11.0% silt, 15.6% clay, 2.9% organic matter and pH 5.8.

A randomised block design (5 replicates) was used for herbicide treatments, with each 8 X 6 m plot split into fallow and cropped sub-plots (8 X 3 m). Treatments were applied with an Oxford Precision Sprayer, and were:-

1	Control		
2	Chlorsulfuron	10g a.i. ha^{-1}	
3	Metsulfuron-methyl	6g a.i. ha^{-1}	Pre-em. 15.4.87.
4	Metsulfuron-methyl	12g a.i. ha^{-1}	

The area was ploughed and disced at the end of March 1987 and barley cultivar 'Kym' was drilled on 10.4.87. Nitrogen fertiliser was applied twice to give a total rate of 60 kg N ha^{-1}. Foliar disease was treated with propiconazole ('Radar'). Meteorological data was recorded daily at the Sonning Farm weather station (Fig.1).

Untreated soil samples were taken at planting from 0-5, 5-10 and 10-20 cm, to provide soil for bioassay standards. Following herbicide application, four each of 0-5, 5-10 and 10-20 cm depth times 7 cm diameter soil cores taken from each sub-plot were bulked together, then air-dried. Soil passed through a 3 mm sieve was bioassayed to estimate the starting soil concentration in soil of sub-plots treated with chlorsulfuron or metsulfuron-methyl.

Soil samples from depths 0-5, 5-10 and 10-20 cm were collected for herbicide bioassay on subsequent dates 15, 30, 45, 60 and 120 days after spraying.

A sweetcorn bioassay (Eleftherohorinos, 1985) to estimate chlorsulfuron concentrations was also suitable for metsulfuron-methyl. Bioassay standards (8 replicates) were used each time to compare with field samples (20 replicates per treatment).

RESULTS AND DISCUSSION

Persistence and leaching of chlorsulfuron

Chlorsulfuron was barely detectable in the field soil samples 120 days after application (Table 1). The very small concentrations detected in soil from below 10 cm indicate that degradation was more important than leaching.

Junnila (1983) and Nilsson (1984) reported that spring-applied chlorsulfuron remained in the surface soil, where it degraded under normal Swedish conditions. At cooler temperatures, they found that chlorsulfuron leached to 20-25 cm below the surface.

In spring and summer the direction of net water flow is often towards the soil surface, enabling the spring-applied compound to remain in the warmer surface soil where degradation would be faster (Duffy et al, 1987).

Chlorsulfuron degradation rate

The time to 50 % loss of chlorsulfuron found at Sonning was 34 days,

TABLE 1. Chlorsulfuron residues at 3 soil depths

		Estimated average chlorsulfuron concentration (ng g-1)		
Time (days)	System	0-5 cm	5-10 cm	10-20 cm
		Dose rate 10 g a.i. ha-1		
0	Cropped	9.36	-	-
	Fallow	9.36	-	-
15	Cropped	6.50	1.58	0.47
	Fallow	7.70	2.54	0.07
30	Cropped	5.88	0.13	0.50
	Fallow	5.24	0.11	0.02
45	Cropped	2.88	0.17	0.26
	Fallow	4.22	0.08	0.04
60	Cropped	0.71	0.04	0.04
	Fallow	0.80	0.03	0.02
120	Cropped	0.00	0.00	0.01
	Fallow	0.00	0.00	0.00

which agrees with other estimates (Walker and Brown, 1983; Beyer et al, 1987; Palm et al. 1980; Fredrickson and Shea, 1986).

The influence of cropping

The leaching and persistence of chlorsulfuron in cropped and fallow sub-plots was not significantly different. Additional chlorsulfuron inactivation in sandy loam soil has been reported in the presence of a wheat crop (Caseley, 1982).

Persistence and leaching of metsulfuron-methyl

As for chlorsulfuron, no metsulfuron-methyl was detected in soil sampled 120 days after application (Table 2). Leaching was not evident, degradation being predominant.

Metsulfuron-methyl degradation rate

The time to 50 % loss of metsulfuron-methyl at Sonning was 45 days; longer than that found for chlorsulfuron. Metsulfuron-methyl is reported to degrade at comparable, or slightly faster, rates than chlorsulfuron in the field (Anderson, 1985). However, Nicholls et al (1987) suggested that microbial breakdown was more important for metsulfuron-methyl than chlorsulfuron. Soil temperature at 10 cm was less than 10 °C until the start of May (Fig.1) - which could have inhibited microbial degradation until the temperature rose, along with a period of increasing rainfall, wetting the soil (Fig.1). By late May (day 60) the percentage of the initial dose of metsulfuron-methyl remaining was much reduced, compared with that at day 45 (Fig.2).

The influence of cropping

There was again no significant difference in residues between cropped and fallow plots. Anderson (1985) reported no effect from a wheat crop on metsulfuron-methyl activity in the soil.

The influence of metsulfuron-methyl application rate

There was no consistent effect of metsulfuron-methyl application rate upon its persistence in the soil.

TABLE 2. Metsulfuron-methyl residues at three soil depths.

Time (days)	System	Estimated average metsulfuron-methyl concentration (ng g-1) 0-5 cm	5-10 cm	10-20 cm
		Dose rate 6 g a.i. ha-1		
0	Cropped	3.55	-	-
	Fallow	3.55	-	-
15	Cropped	2.74	1.75	0.27
	Fallow	2.43	1.31	0.08
30	Cropped	2.63	0.16	0.20
	Fallow	2.92	0.36	0.16
45	Cropped	1.78	0.09	0.12
	Fallow	2.00	0.08	0.24
60	Cropped	0.09	0.01	0.04
	Fallow	0.08	0.02	0.04
120	Cropped	0.00	0.00	0.00
	Fallow	0.00	0.00	0.00
		Dose rate 12 g a.i. ha-1		
0	Cropped	7.64	-	-
	Fallow	7.64	-	-
15	Cropped	5.40	4.09	0.46
	Fallow	3.09	6.98	0.18
30	Cropped	4.03	0.60	0.45
	Fallow	6.12	0.92	0.43
45	Cropped	3.76	0.52	0.28
	Fallow	3.64	0.72	0.38
60	Cropped	0.99	0.10	0.07
	Fallow	0.58	0.05	0.07
120	Cropped	0.00	0.00	0.00
	Fallow	0.00	0.00	0.00

Safety to sugar beet

No injury to sugar beet plants was observed in a bioassay carried out on 3 kg soil samples collected from 0-20 cm in the chlorsulfuron and metsulfuron-methyl treated plots. Sugar beet grown for 12 weeks in a growth room at 15 °C, with a 14 hour day and a regular supply of nutrients and water. Controls with added herbicide (1 and 2 ppb chlorsulfuron) developed severe symptoms of toxicity.

Sulfonylureas have injured sensitive following crops under a variety of conditions (Brewster and Appleby, 1983; Peterson and Arnold, 1985). Sugar beet is 1000 times more susceptible to chlorsulfuron than wheat (Sweetser *et al*, 1982). Sugar beet root growth can be inhibited by chlorsulfuron or metsulfuron-methyl concentrations of less than 1 ppb, but no effects were detected in the Sonning soil at the end of the experiment. Metsulfuron-methyl allows more flexibility in crop rotations than chlorsulfuron (Warner *et al*, 1986).

Herbicide performance

Chlorsulfuron and metsulfuron-methyl gave excellent control of weeds within the barley sub-plots. Species controlled included *Chenopodium album* (Fat hen), *Erucastrum gallicum* (Hairy rocket), *Matricaria perforata*

(Scentless mayweed), Senecio vulgaris (Groundsel), Sinapis arvensis (Charlock) and Spergula arvensis (Corn spurrey).

Weed species controlled less successfully by chlorsulfuron and metsulfuron-methyl were Viola arvensis (Field pansy), Chamomilla recutita (Scented mayweed), Papaver rhoeas (Poppy) and Polygonum aviculare (Knotgrass). These species have been described as 'hard to kill' (Selley et al, 1985).

In all barley sub-plots, the yield of the crop was not significantly altered by these sulfonylureas at the dose rates applied.

REFERENCES

Anderson, R.L. (1985) Environmental effects on metsulfuron and chlorsulfuron bioactivity in soil. *Journal of Environmental Quality*, **14** (4), 517-521.

Beyer, E.M.; Brown, H.M.; Duffy, M.J. (1987) Sulfonylurea herbicide soil relations. *Proceedings British Crop Protection Conference - Weeds 1987*, **2**, 531-540.

Brewster, B.D.; Appleby, A.P. (1983) Response of wheat (Triticum aestivum) and rotation crops to chlorsulfuron. *Weed Science*, **31**, 861-865.

Caseley, J.C. (1982) Effect of spring wheat and temperature on chlorsulfuron persistence in soil. *Proceedings 1982 British Crop Protection Conference - Weeds*, **1**, 137-140.

Duffy, M.J.;Hanafey, M.K.; Linn, D.M.; Russell, M.H.; Peter, C.J. (1987) Predicting sulfonylurea herbicide behaviour under field conditions. *Proceedings British Crop Protection Conference - Weeds 1987*, **2**, 541-548.

Eleftherohorinos, I. (1985) Studies on the herbicidal activity of chlorsulfuron. *Reading University PhD Thesis*.

Fredrickson, D.R.; Shea, P.J. (1986) Effect of soil pH on degradation, movement and plant uptake of chlorsulfuron. *Weed Science*, **34**, 328-332.

Joshi, M.M; Brown, H.M.; Romesser, J.A. (1984) Degradation of chlorsulfuron by soil microbes. *Proceedings of the Western Society of Weed Science March 1984*, 63.

Junnila, S. (1983) Persistence and movement of chlorsulfuron in soil. *24th Swedish Weed Conference January 1983, Uppsalla*, 296-301.

Nicholls, P.H.; Evans, A.A.; Walker, A. (1987) The behaviour of chlorsulfuron and metsulfuron in soils in relation to incidents of injury to sugar beet. *Proceedings British Crop Protection Conference-Weeds 1987*, **2**, 549-556.

Nilsson, H. (1984) Persistence and mobility of chlorsulfuron in arable soils. Investigations 1982-1983. *25th Swedish Weed Conference February 1984, Uppsala*, 76-81.

Palm, H.L.; Riggleman, J.D.; Allison, D.A. (1980) Worldwide review of the new cereal herbicide - DPX 4189. *Proceedings 1980 British Crop Protection Conference - Weeds*, **1**, 1-14.

Peterson, M.A.; Arnold, W.E. (1985) Response of rotational crops to soil residues of chlorsulfuron. *Weed Science*, **34**, 131-136.

Selley, A.P.; Haney, P.J.; Austin, J.R. (1985) The use of metsulfuron-methyl alone and in mixture with chlorsulfuron for weed control in cereals in the United Kingdom. *Proceedings 1985 British Crop Protection Conference - Weeds*, **3**, 931-938.

Sweetser, P.B.; Schow, G.S.; Hutchinson, J.M. (1982) Metabolism of chlorsulfuron by plants: biological basis for selectivity of a new cereal herbicide for cereals. *Pesticide Biochemistry and Physiology*, **17**, 18-23.

Walker, A; Brown, P.A. (1983) Measurement and prediction of chlorsulfuron persistence in soil. *Bulletin of Environmental Contamination and Toxicology*, **30**, 365-372.

Warner, R.W.; Kral, C.W.; Henson, M.A.; Saladini, J.L. (1986) Metsulfuron-methyl - a new alternative for broadleaf weed control in cereals and reduced tillage fallow. *Proceedings of the Western Society of Weed Science 1986*, **39**, 129-133.

Figure 1 Rainfall and soil temperature (at 10 cm) at Sonning Farm

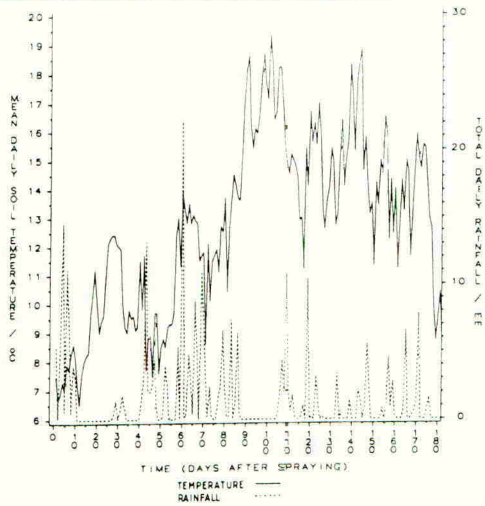
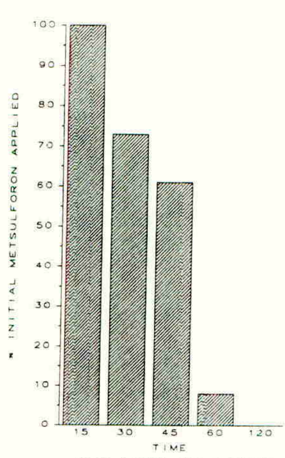


Figure 2 Metsulfuron-methyl persistence - total of three soil layers
Each value is a mean of 2 cropping treatments and 2 rates



ANALYTICAL METHODS FOR DETECTING CHLORSULFURON AND METSULFURON METHYL

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ABSTRACT

Du Pont has developed a wide range of technologies to detect chlorsulfuron and metsulfuron methyl in soil and water. Each of these technologies has its own advantages and disadvantages. Sample contamination and matrix effects are common problems with all the technologies in detecting low parts-per-trillion (ppt) concentrations of chlorsulfuron and metsulfuron methyl.

The methods developed allow Du Pont to meet the needs of customers and regulators worldwide. It is important for all parties to understand the significance of these trace concentrations which, until recently, would have been reported as not detected.

INTRODUCTION

In general, there are three reasons to develop residue methods for agricultural products. Those reasons being to: follow the behavior of the product in the environment, determine when following crops may be planted, and meet regulatory requirements.

The high level of herbicidal activity of chlorsulfuron and metsulfuron methyl requires that extremely sensitive detection methods must be developed. Du Pont has employed a number of different methods to meet these various needs. The methods and examples of their use are reviewed in this paper.

BIOASSAYS

Du Pont has developed several bioassays for sulfonylurea herbicides. One of the first was a corn root bioassay (Anonymous, 1980). Subsequently, the corn root bioassay was abandoned by Du Pont because it lacked adequate sensitivity and it was not well suited to a broad range of soils. However, several investigators (Anderson *et al.*, 1985; Groves *et al.*, 1985; Morishita *et al.*, 1985) have used this bioassay to study the behavior of chlorsulfuron in soil. Figure (1) shows the effect of chlorsulfuron on corn root growth (Groves *et al.*, 1985).

Du Pont has since developed the LRB$^{(sm)}$ (Laboratory Recrop Bioassay) which is more sensitive and reliable in determining the....

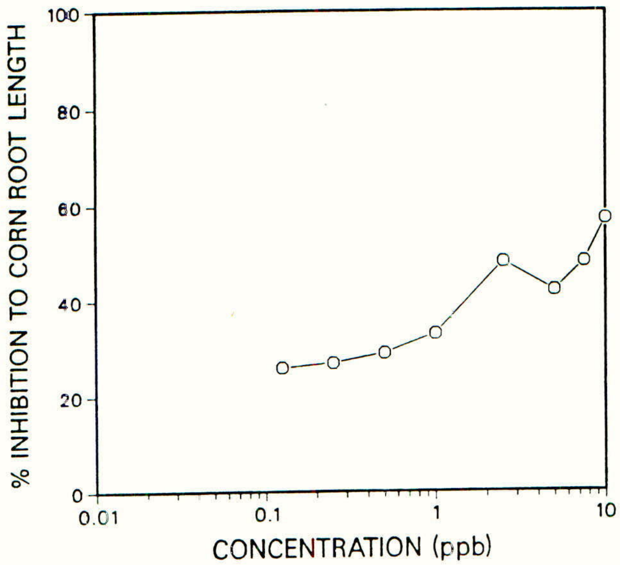

Figure 1. Inhibition of corn root growth as a function of chlorsulfuron concentration in Oxbow loam soil (Groves *et al.*, 1985).

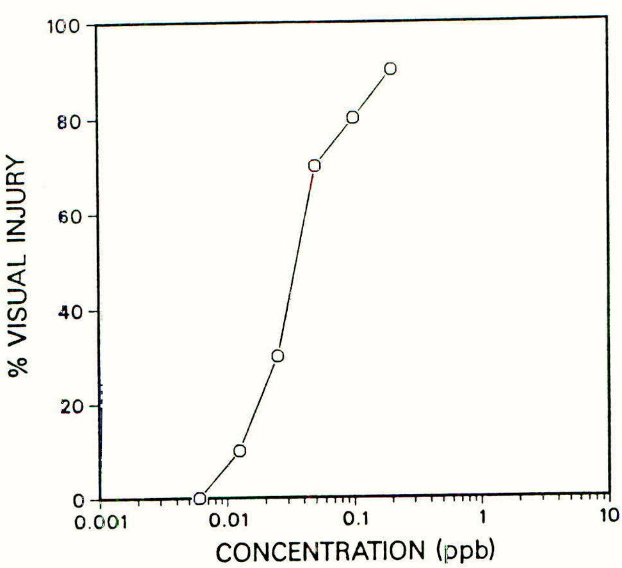

Figure 2. Inhibitions of lentil root growth as a function of chlorsulfuron concentration in Sassafras sandy loam soil.

...presence of chlorsulfuron and metsulfuron methyl (Peter *et al.*, 1988; Strek *et al.*, 1989). Figure (2) illustrates the inhibition of lentil root growth as a function of chlorsulfuron soil concentration. In the United States the LRB(sm) is used by farmers instead of a field bioassay to determine when certain sensitive rotational crops can be safely planted. The LRB(sm) has also been used in the U.K. to aid rotational crop investigations. A number of other herbicides as well as certain agronomic conditions can produce injury symptoms on crops similar to chlorsulfuron and metsulfuron methyl. The LRB(sm) has been instrumental in determining whether chlorsulfuron and metsulfuron methyl were the cause of injury.

While the LRB(sm) bioassay has certain advantages such as high sensitivity, measuring the biologically available fraction and low input costs, it also has disadvantages. These include: detection limit is soil dependent, analysis time is relatively long and the assay is not compound specific.

IMMUNOASSAY

Chlorsulfuron and metsulfuron methyl immunoassays utilize a standard competitive ELISA (Enzyme-Linked ImmunoSorbent Assay) which can be run in any suitably equipped analytical laboratory. (Kelley *et al.*, 1985; Sharp *et al.*, 1989; Strahan *et al.*, 1989) Both assays utilize rabbit-derived polyclonal antibodies against chlorsulfuron and metsulfuron methyl analogs. The assay format uses the antibodies to measure the concentration of chlorsulfuron in a series of steps which end up giving a colorimetric reading inversely proportional to the amount of the herbicide in the sample. All this is done in microwell plates which are small plastic plates with 96 wells and therefore capable of handling a large number of samples, controls and standards for analysis. Commercially available automated equipment uses these plates to measure the colorimetric reading in less than a minute. The assay format is such that the more color seen at the end of the assay, the less herbicide present in the sample.

There are a number of advantageous characteristics of the immunoassay. Recent assays which are extremely sensitive, measuring 10 ppt in water and 25-50 ppt in soil, depending upon the soil type, have been developed (Sharp *et al.*, 1989; Strahan *et al.*, 1989). These levels of detection are far below the lowest no-effect concentrations for non-target organisms. The assays are very compound specific, having no appreciable crossreactivity with related sulfonylureas or soil metabolites. The assay is done in less than a day's time. 25 soil or 50 or more water samples can be run per day per technician. This is an improvement over traditional analytical methodologies because the immunoassay requires no clean-up of water or of aqueous soil extracts prior to analysis.

Validation of the assay was accomplished by analysis of aged fortified soil samples and fortified water samples as well as comparison of analytical results of samples done by HPLC. These immunoassays have proven to be very useful in meeting regulatory and marketing needs.

GAS CHROMATOGRAPHY

Although sulfonylurea herbicides are thermally labile and can not generally be successfully analyzed using gas chromatography, Canadian researchers recently published a method alleged to be capable of detecting chlorsulfuron in water at 1-3 ppt (Ahmad *et al.*, 1987). This method is based on derivatization of the parent molecule with diazomethane to form the mono-methyl derivative (methylated on the sulfonamide hydrogen), which is thought to have adequate thermal stability for gas chromatographic analysis. From similar Du Pont work in the early 1980's (R. W. Reiser, unpublished work), it is not clear whether or not the mono-methyl derivative of the parent survives intact during GC analyses or thermally decomposes to the N-methyl sulfonamide. Furthermore, the derivatization procedure is somewhat dangerous, very slow and does not yield a single product.

Subsequent work by Du Pont (G. A. Sherwood, unpublished) and others using alternate derivatization chemistry has shown that stable derivatives can be formed that allow measurement of chlorsulfuron in water with extremely high sensitivity. Although the Du Pont work will be published in the near future, we feel that other analytical approaches such as LC/MS (Liquid Chromatograph/Mass Spectrometery) and ELISA are preferable.

LIQUID CHROMATOGRAPHY USING A PHOTOCONDUCTIVITY DETECTOR

Largely because sulfonylureas are thermally labile most of Du Pont's analytical effort has focused on methods employing liquid chromatography. Methods using liquid chromatography have been developed for chlorsulfuron in soil and water (Zahnow, 1982). A photoconductivity detector, much more sensitive than a UV detector, permits detection limits of 0.2 ppb in soil and 0.05 ppb in water. These methods have allowed Du Pont to follow the dissipation of chlorsulfuron and metsulfuron methyl in soil.

While these methods are highly sensitive, certain plants can be injured by chlorsulfuron and metsulfuron methyl at concentrations below 0.2 ppb. These procedures are lengthy which limits the number of samples that can be analyzed.

LIQUID CHROMATOGRAPHY USING A MASS SELECTIVE DETECTOR (LC/MS)

LC/MS has emerged as a sensitive and selective residue methodology for trace organic analysis of crop protection chemicals. Thermospray LC/MS has been extensively used for the study of sulfonylurea herbicides (Shalaby, 1987; Shalaby, 1989A; Shalaby, 1989B). This technology is especially applicable to the low use rate herbicides such as sulfonylureas. LC/MS requires minimal sample processing and clean up prior to chromatographic and spectroscopic quantitation. Thermospray LC/MS with selected ion monitoring is applicable to multiresidue sulfonylurea herbicide analysis in a fast and efficient way. This methodology also allows for structural confirmation.

Methods to detect chlorsulfuron and metsulfuron methyl in water matrices in the low ppt levels have been developed. Chlorsulfuron and metsulfuron methyl can be simultaneously extracted and detected using this method. Specific and selective detection offered by the mass spectrometer allow identification and quantitation at these low levels using single conventional LC column and without sample clean up. Similar sulfonylureas do not interfere with the detection of chlorsulfuron and metsulfuron methyl in the LC/MS analysis.

SUPER CRITICAL FLUID EXTRACTION (SFE) AND CHROMATOGRAPHY (SFC)

Supercritical fluid technology has been used to chromatograph and extract sulfonylureas from various matrices (McNally *et al.*, 1988; Wheeler *et al.*, 1987; Wheeler, 1989). There are a number of advantages supercritical fluid technology offers. Multiresidue applications are feasible. Several sulfonylureas have been simultaneously extracted with SFE. Extraction efficiencies, equivalent to or better than those obtained using conventional liquid extraction technology have been obtained. Extracted materials can be collected and analyzed on-line using reversed phase HPLC, GC or SFC.

Presently, the amount of sample which has been extracted precludes detecting chlorsulfuron and metsulfuron methyl at concentrations demonstrated by other methods.

REFERENCES

Ahmad, I. (1987) Capillary Column Gas Chromatography Determination of Trace Residues of the Herbicide Chlorsulfuron in Agricultural Runoff Water. *Journal of the Association of Official Analytical Chemists 1987*, **70**, 745-748.

Anderson, R. L.; Barrett, M. R. (1985) Residual Phytotoxicity of Chlorsulfuron in Two Soils. *Journal of Environmental Quality 1985*, **14**, 1, 111-114.

Anonymous (1980) DPX-4189 Corn Root Bioassay.

Groves, K. E. M.; Foster, R. K. (1985) A Corn (Zea mays L.) Bioassay Technique for Measuring Chlorsulfuron Levels in Three Saskatchewan Soils. *Weed Science 1985*, **33**, 825-828.

Kelly, M. M.; Zahnow, E. W., Peterson, W. C.; Toy, S. T. (1985) *Chlorsulfuron Determination in Soil Extracts. Journal of Agricultural and Food Chemistry 1985*, **33**, 962-965.

McNally, M. E. P.; Wheeler, J. R. (1988) Supercritical Fluid Extraction Coupled with Supercritical Fluid Chromatography for the Separation of Sulfonylurea Herbicides and Their Metabolites From Complex Matrices. *Journal of Chromatography 1988*, **435**, 63-71.

Morishita, D. W.; Thill, D. C.; Flom, D. G.; Campbell, T. C.; Lee, G. A. (1985) Method for Bioassaying Chlorsulfuron in Soil and Water. *Weed Science 1985*, **33**, 420-425.

Shalaby, L. M. (1987) On-line LC/MS as a Problem-Solving Tool for the Analysis of Thermally Labile Herbicides. In: *Applications of New Mass Spectrometry Techniques in Pesticide Chemistry*, J. B. Rosen (Ed.), New York: Wiley-Interscience, pp. 161.

Shalaby, L. M. (1989A) Methods For The Identification of Xenobiotic Metabolite Form Plants and Animals. In: *Mass Spectrometry of Biological Materials*, C. McEwen and B. Larsen, 1989 (Eds.): Marcel Dekker in press.

Shalaby, L. M. (1989B) Multi-Residue Determination of Sulfonylureas Herbicides and Metabolites in Soil and Water by LC/MS. To be presented at the FACSS XVI in Chicago, Illinois, October 4, 1989.

Sharp, J. K.; Lueng, F. S.; O'Brien, D. P.; Carski, T. H. (1989) An ELISA Method for the Detection of Chlorsulfuron in Soil and Water. *To be presented at the 198th ACS National Meeting in Miami Beach, Florida, Sept. 10-15, 1989.*

Strahan, J. C.; Charlton, R. R.; Hamill, P. A.; Carski, T. H.; Sharp, J. K. (1989) Detecting Herbicides Using Immunoassay Technology. *To be presented at the 103rd AOAC Meeting in St. Louis, MO, Sept. 25-28, 1989.*

Strek, H. J.; Burkhart, D. C.; Strachan, S. D.; Peter, C. J.; Ruggiero, M. (1989) Use of Bioassays to Characterize the Risk of Injury to Follow Crops by Sulfonylurea Herbicides. *The Brighton Crop Protection Conference - Weeds, 1989, In Press.*

Wheeler, J. R.; McNally, M. E. (1987) Comparison of Packed Column and Capillary Column Supercritical Fluid Chromatography and High Performance Liquid Chromatography Using Representative Herbicides and Pesticides as Typical Moderate Polarity and Molecular Weight Range Molecules. *Journal of Chromatography 1987*, **410**, 343-353.

Wheeler, J. R. (1989) Supercritical Fluid Technology: Residue Applications. *26th Annual Pesticide Residue Workshop 1989*, Daytona Beach, FL.

Zahnow, E. W. (1982) Analysis of the Herbicide Chlorsulfuron in Soil by Liquid Chromatography. *Journal of Agricultural and Food Chemistry 1982*, **30**, 854-857.

COMPARISON OF BIOASSAY AND CHEMICAL ANALYSIS FOR TRIASULFURON QUANTIFICATION IN SOIL SAMPLES

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ABSTRACT

Two trials were carried out in order to follow the degradation of triasulfuron in the field and to compare the determination of residues by bioassay and chemical analysis.

The laboratory bioassay uses two plant species of different sensitivity to triasulfuron. The response of the plants to unknown field samples is compared with standard calibration curves. With the bioassay the quantification of triasulfuron in soil samples is possible over the range of 10 to 0.1 g a.i./ha.

For chemical analysis triasulfuron was extracted by shaking with methanol/ phosphate buffer, followed by clean-up through ion-pair partition and column chromatography. Additional clean up and final determination were done by a three column HPLC switching system with UV-detection. The analytical method can detect triasulfuron down to a concentration of 0.04 µg/kg soil.

A good correlation between the results obtained with the bioassay and chemical analysis was observed. Both methods are valid to quantify triasulfuron residues in soil samples.

INTRODUCTION

Different methods for the determination of sulfonylurea residues in soil samples have been published, namely analytical methods (Zahnow 1982), an immunoassay method (Kelley *et al.*, 1985) and various bioassay methods (e.g. Hsiao and Smith, 1983; Walker and Brown, 1983). Since sulfonylureas can be active at very low concentrations in the soil any method has to fulfil rigorous requirements with respect to sensitivity.

A laboratory bioassay has been developed for the determination of triasulfuron in order to follow its degradation in the field (Iwanzik *et al.*, 1988). The bioassay method is sensitive enough to detect low concentrations of triasulfuron, which may cause injury to rotational crops. However the method is time and space consuming and non-specific.

A new chemical analytical method for the determination of triasulfuron in soil samples has been developed by CIBA-GEIGY and relevant details are presented in this paper.

The aim of the present investigation was to compare both methods with respect to quantification and sensitivity. For this purpose two field trials were carried out and soil samples were analysed by bioassay and chemical analysis.

METHODS

Application and soil sampling

In two field trials triasulfuron was applied at 15 g a.i./ha to bare ground. Application dates were April 20 (Lorsch) and 21, 1988 (Aspach), respectively. The characteristics of the soils are listed in Table 1.

Soil samples were taken at different time intervals after application down to 30 cm using a drilling system (Humax). For analysis the soil cores were cut into 0-10, 10-20 and 20-30 cm layers.

For comparison of sensitivity triasulfuron was incorporated into different soils and a bioassay was carried out. Plant fresh weight was taken and compared with that of plants grown in untreated soil. The soils were also used for analytical recovery experiments.

TABLE 1. Chemical and physical properties of soils used.

Soil	pH (H_2O)	O.M. %	clay %	silt %	sand %
Aspach	6.7	2.2	24.4	61.4	14.2
Lorsch	6.3	1.1	9.7	15.1	75.2
Combremont	6.3	11.2	17.0	15.0	58.0
Melfort	6.5	10.5	18.4	27.7	53.8
Les Barges	7.4	2.7	7.6	20.9	71.5

Bioassay method

The bioassay was carried out according to Iwanzik et al. (1988). The bioassay species used were *Lepidium sativum* with lower sensitivity and *Beta vulgaris* with higher sensitivity to triasulfuron. The response of the plants in field samples where triasulfuron had been applied was compared with calibration curves for both plant species.

Statistical evaluation was done using a Bayesian approach as described by Racine (1988).

Chemical analytical method

A 100 g subsample was extracted by shaking with 300 ml of a 2:1-mixture of methanol and aqueous phosphate buffer (pH 7, total phosphate concentration 0.07 mol/l). After filtration and acidification with phosphoric acid triasulfuron was re-extracted into dichloromethane. From this organic phase it was partitioned into aqueous sodium hydrogen carbonate solution (5%). After addition of tetrabutylammonium hydrogen carbonate (prepared by neutralization of tetrabutylammonium hydroxide solution with solid carbon dioxide), triasulfuron was re-extracted into dichloromethane-n-hexane (80:20). The organic phase was transferred onto a silica column (silica dried for 1 hour at 200°C, 3% of water added, column 2.4 x 30 cm, silica bed volume 35 ml) and the residue was eluted with dichloromethane-methanol (96:4). After evaporation and dissolution in methanol-water (1:3) the extract was cleaned up by a passage through a C_{18}-cartridge (6 ml bed volume, J.T. Baker Phillipsburg, USA), the residue was dissolved in mobile phase 1 (see below) up to 2 ml.

Additional cleanup and final determination was made on a 3-column-HPLC-system (Column 1; PRP 1, porous polymer, mobile phase 1; aqueous phosphate buffer 6.5 - acetonitrile (73:27), containing 5 g/l tetrabutylammonium bromide. Column 2; LiChrosorb RP 18, mobile phase 2; aqueous phosphate buffer pH 2-acetonitrile (69:31), containing 5 g/l tetrabutylammonium bromide. Column 3; Nucleosil Phenyl, mobile phase 3; aqueous phosphate buffer pH 2-acetonitrile (59:41), containing 5 g/l tetrabutylammonium bromide) and UV-detection (232 nm, 0.02 a.u. full scale). 1 ml of the final solution was injected, corresponding to a 50 g aliquot. The fraction of the mobile phase was switched through the three chromatographic columns by means of 6-port valves (Ramsteiner and Böhm, 1983).

The chromatographic system was standardized using standard solutions containing 2 to 50 ng/ml triasulfuron. Rectilinear standard curves were obtained and were used to calculate the residues. The limit of detection was 0.04 µg/kg soil. The performance of the method was regularly checked by analysing fortified check samples. The average recoveries were 91 $\pm$ 11% (n = 42).

For direct comparison reasons the concentrations determined as µg/kg soil were converted into g ai/ha values which are determined by the bioassay. A conversion factor of 1.4 (10.6 µg/kg = 15 g a.i./ha) was derived by weighing the top soil layers.

RESULTS

Comparison of measured concentrations

The concentrations for the two locations as determined by the bioassay and the analytical method are summarized in Tables 2 (Aspach) and 3 (Lorsch). Although the chemical method can detect triasulfuron concentrations down to 0.04 µg/kg soil, a detection limit of 0.1 µg/kg soil was considered sufficient for these investigations. With some deviations the values determined by bioassay and chemical analysis were in the same range. The correlation coefficients were 0.96 (Aspach) and 0.91 (Lorsch), respectively. The concentrations obtained with the bioassay were slightly higher for the Aspach location. No residues of triasulfuron were detected in the 10-20 cm and 20-30 cm layers. There was a good correlation between both methods for high and low concentrations. This indicates that the chemical method is sensitive enough to determine residue concentrations which are at the limit of detection with the bioassay (0.1g a.i./ha). However this limit of detection can be assumed to be around the lowest concentration where injury to susceptible rotational crops can be expected. The sensitivity of the analytical method (0.04 µg/kg) is clearly below this limit.

Comparison of sensitivity

In laboratory experiments, chemical analysis was able to detect triasulfuron in soil samples where plant growth was not affected (Table 4). Recovery by the chemical method varied between 83 and 100%. The soils in which triasulfuron showed low activity on beets had a high organic matter content (Table 1) indicating substantial adsorption of triasulfuron.

Degradation of triasulfuron

Triasulfuron was well degraded at both locations. For Aspach a half life of 30 days was calculated based on the concentration determined by bioassay on day 7 and for Lorsch a half life of 23 days based on the concentration determined on day 14.

At both locations triasulfuron was not detected in soil layers below 10 cm indicating that no downward movement had taken place. There was a considerable amount of rainfall, especially at Lorsch (Table 3).

TABLE 2. Comparison of triasulfuron concentrations as determined by bioassay and chemical analysis. Location Aspach. Application rate: 15 g a.i./ha. (n.a. = not analysed)

DAA	Soil depth	Bioassay	Chem. Analysis		Rainfall between
	[cm]	[g a.i./ha]	[µg/kg]	[g a.i./ha]	sampling [mm]
0	0-10	>10.0	8.2	11.5	
	10-20	0.1	0.1	0.1	
	20-30	<0.1	n.a.		5
7	0-10	9.1	5.6	7.8	
	10-20	<0.1	<0.1		
	20-30	<0.1	n.a.		-
14	0-10	7.9	4.3	6.0	
	10-20	0.2	<0.1		
	20-30	<0.1	n.a.		-
28	0-10	5.9	2.8	3.9	
	10-20	<0.1	<0.1		
	20-30	<0.1	n.a.		-
56	0-10	1.7	1.2	1.7	
	10-20	<0.1	0.1	0.1	
	20-30	<0.1	n.a.		81
84	0-10	0.4	0.7	0.9	
	10-20	<0.1	<0.1		
	20-30	<0.1	n.a.		94
112	0-10	0.4	0.2	0.3	
	10-20	<0.1	<0.1		
	20-30	<0.1	<0.1		71
140	0-10	0.3	0.2	0.3	
	10-20	<0.1	<0.1		
	20-30	<0.1	<0.1		

TABLE 3. Comparison of triasulfuron concentrations as determined by bioassay and chemical analysis. Location Lorsch. Application rate: 15 g a.i./ha. (n.a. = not analysed)

DAA	Soil depth [cm]	Bioassay [g a.i./ha]	Chem. Analysis [µg/kg]	Chem. Analysis [g a.i./ha]	Rainfall between sampling [mm]
0	0-10	6.6	7.8	10.9	
	10-20	n.a.	0.3	0.4	
	20-30	n.a.	n.a.		13
7	0-10	6.3	7.0	9.8	
	10-20	0.3	0.1	0.1	
	20-30	<0.1	n.a.		22
14	0-10	6.9	4.2	5.9	
	10-20	<0.1	<0.1		
	20-30	<0.1	n.a.		32
30	0-10	4.1	3.6	5.0	
	10-20	<0.1	0.2	0.3	
	20-30	<0.1	n.a.		82
58	0-10	1.7	2.1	2.9	
	10-20	<0.1	<0.1		
	20-30	<0.1	n.a.		79
89	0-10	1.0	2.0	2.8	
	10-20	<0.1	<0.1		
	20-30	<0.1	n.a.		50
124	0-10	1.0	1.9	2.6	
	10-20	<0.1	<0.1		
	20-30	<0.1	<0.1		54
152	0-10	0.2	0.9	1.2	
	10-20	<0.1	<0.1		
	20-30	<0.1	<0.1		

TABLE 4. Dose response of *Beta vulgaris* to triasulfuron in different soils. Percent weight reduction compared with untreated check plants.

Soil µg/kg	2	1	0.8	0.4	0.2
Les Barges	77	53	42	13	0
Combremont	20	17	0	0	0
Melfort	16	0	0	0	0
Aspach	74	62	39	6	5
Lorsch	75	70	67	45	10

DISCUSSION

The comparison of the triasulfuron concentrations determined by a bioassay method and a new chemical analytical method showed a good correlation. By using two plant species with different sensitivity to triasulfuron it was possible to determine triasulfuron over a wide range of concentrations with the bioassay. However, the method is time and space consuming, since standard calibration curves have to be carried out for each plant species and each soil layer.

The analytical method described here is of higher sensitivity (0.04 µg/kg) compared with that of Zahnow (1982) for chlorsulfuron determination in soil samples. A detection limit of 0.2 µg/kg was indicated by Zahnow (1982). The analytical method described here can detect triasulfuron at concentrations which do not affect the growth of very susceptible species such as beet, especially in soils with a high organic matter content where triasulfuron is less available due to adsorption.

In these investigations the parent compound was determined specifically with the chemical method. The bioassay is not specific but determines all biologically active compounds. The good correlation indicates that metabolites of triasulfuron are not biologically active.

Triasulfuron was well degraded at both locations and no downward movement was observed. This is in line with earlier experiments with spring applications of triasulfuron (Iwanzik and Amrein, 1988; Iwanzik *et al*., 1988).

REFERENCES

Hsiao, A.I.; Smith, A.E.; (1983) A root bioassay for the determination of chlorsulfuron, diclofop acid and sethoxydim residues. *Weed Research* **23**, 231-236.

Iwanzik, W.; Amrein, J. (1988) Triasulfuron - Behaviour in the soil. *Proceedings EWRS Symposium*. Factors affecting Herbicidal Activity and Selectivity, 307-312.

Iwanzik, W., Amrein, J.; Köller, R. (1988) Biotest zur Bestimmung von Triasulfuron im Boden. *Zeitschrift für Pflanzenkrankheiten und Pflanzenschutz, Sonderheft* **XI**, 301-310.

Kelley, M.M.; Zahnow, E.W.; Petersen, W.C., Toy, S.T. (1985) Chlorsulfuron determination in soil extracts by enzyme immunoassay. *Journal of Agricultural and Food Chemistry*. **33**, 962-965.

Racine, A. (1988) A bayesian approach to nonlinear calibration problems. *Journal of the American Statistical Association* **83**, 650-656.

Ramsteiner, K.A.; Böhm, J. (1983) A mechanical device for HPLC injection and multiple column switching. *Journal of Chromatography* **260**, 33-40.

Walker, A.; Brown, P.A. (1983) Measurement and prediction of chlorsulfuron persistence in soil. *Bulletin of Environmental Contamination and Toxicology* **30**, 365-372

Zahnow, E.W. (1982) Analysis of the herbicide chlorsulfuron in soil by liquid chromatography. *Journal of Agricultural and Food Chemistry* **30**, 854-857.

PREDICTING THE REDISTRIBUTION OF ISOPROTURON IN SOIL AND ITS SIGNIFICANCE TO PERFORMANCE OF THE HERBICIDE

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ABSTRACT

A computer model was developed to predict the depth of maximum concentration of isoproturon in soil due to leaching, and glasshouse experiments were made to evaluate the possible significance of this vertical redistribution to efficacy of the chemical. The glasshouse experiments indicated that when one quarter of the normal dose of isoproturon was present in the soil, efficacy of the herbicide was poor if it was located at depths greater than 4 cm. The efficacy of the full dose was poor when located more than 6 cm deep in the soil. The potential of the model as an advisory aid is discussed.

INTRODUCTION

Isoproturon is one of the most widely used herbicides on winter cereals in the UK particularly for the control of blackgrass (*Alopecurus myosuroides* Huds). However, in some recent seasons, performance has been disappointing, particularly in the wet autumn of 1986. Luscombe (1983) reported much longer persistence of isoproturon activity in the relatively dry winter of 1980/81 than in the wet winter of 1979/80. he attributed lack of persistence in the latter season to leaching rather than degradation in the soil. Rainfall in autumn 1986 was comparable with that in autumn 1979 supporting the theory that leaching was responsible for the poor performance in 1986.

The computer model of Nicholls *et al*, (1982), as modified by Walker (1987), has been shown to predict satisfactorily the movement of isoproturon in soil following autumn application, and to predict downward movement of a concentration peak through the soil (Blair *et al*., 1988). If excessive leaching is responsible for poor herbicide performance, then the model may have the potential to predict the situations when this is most likely to occur. In order to simplify the model for advisory use, it was modified to predict the depth of maximum concentration as a function of winter rainfall, with this parameter as the only input variable. Experiments were also made to assess the possible significance of herbicide movement in soil to its biological activity. This report describes the simplified computer model and summarises the results of the glasshouse experiments.

THE MODEL

The model used to make predictions of isoproturon redistribution in soil was based on that of Nicholls *et al*. (1982) as modified by Walker

(1987). For the present purposes, movement in soil was considered in isolation from herbicide breakdown, and the sub-routines dealing with degradation were removed from the original computer program. Soil properties required by the model were moisture contents at field capacity (-5kPa) and at a soil water stress of -200 kPa and these were taken as 25.0 and 15.0 (% by weight) respectively; equivalent to those that might be found in a medium textured clay loam soil. Bulk density was assumed to be 1.25 g cm^{-3}. The only herbicide property required was an adsorption distribution coefficient, and the model was run with this set at a range of values from 0.5 (weak adsorption) to 2.0 (moderate to strong adsorption). Daily values of rainfall (mm) and evaporation from an open water surface (mm) were also required. The main period of interest in terms of the calculations was from November to March inclusive and the weather data used were for the 150 days beginning on November 1 1979. Weather data from this particular winter were chosen because rainfall was relatively uniformly distributed over the full 5 month period.

Output from the model was printed at intervals of 10 days and the predicted depth in the soil at which the maximum residue concentration occurred was derived graphically. The results are shown in Figure 1 in which the depth of maximum concentration (mm) is plotted as a function of cumulative rainfall (mm) for different values of the adsorption distribution coefficient. In all instances, there was a highly significant linear relationship bewteen these two parameters (r 0.99). The slopes of the regression lines shown in Figure 1 were 0.93, 0.68, 0.52, 0.37 and 0.30 for adsorption distribution coefficients of 0.50, 0.75, 1.0,1.5 and 2.0 respectively. The respective intercepts were -7.04, -4.63, -2.40, -1.78 and -3.68. As would be expected, the model predicted less movement in the soil as the strength of isoproturon adsorption increased. With the largest adsorption distribution coefficient (2.0), the peak concentration of herbicide was predicted to be located within the top 5-6 cm soil, even after 150 days total and cumulative rainfall of 275 mm.

Walker (1987) provided evidence that herbicide adsorption by the soil increases as the residence time of the chemical in the soil is increased, suggesting that rainfall shortly after application may be more effective in moving chemical into the soil than the same amount of rainfall received later. The equation which best described this adsorption change was:

$$k_{ads} = k_1 + k_2 \sqrt{t} \quad \ldots\ldots\ldots\ldots\ldots \; 1$$

where k_{ads} is the adsorption distribution coefficient at time t, and k_1 and k_2 are constants. When equation 1 was incorporated into the computer model, it improved the predictions of propyzamide, linuron, isoxaben and fluorochloridone mobility in a sandy loam soil (Walker, 1987). In the present work, the model was re-run with the same weather data as before but with an initial adsorption distribution coefficient of 0.5 and an adsorption increment (k_2) of 0.05 (Walker, 1987), and with an initial adsorption distribution coefficient of 1.0 and an increment of 0.10. The predictions from this revised model were compared with those shown in Figure 1. Close examination of the data indicated that overall mobility could be predicted by a sequence of equations based on three of the straight line relationships shown in Figure 1. For the low adsorptive soils (k_1 = 0.5; k_2 = 0.05) the best relationship was :

$$Dmax = 0.93(RI) + 0.68(R2) + 0.52(R3) - 10 \quad \ldots\ldots\ldots\ldots 2$$

For the moderate adsorptive soils (k_1 = 1.0; k_2 = 0.10) the best relationship was : $Dmax = 0.52(R1) + 0.37(R2) + 0.30(R3) - 5$ 3

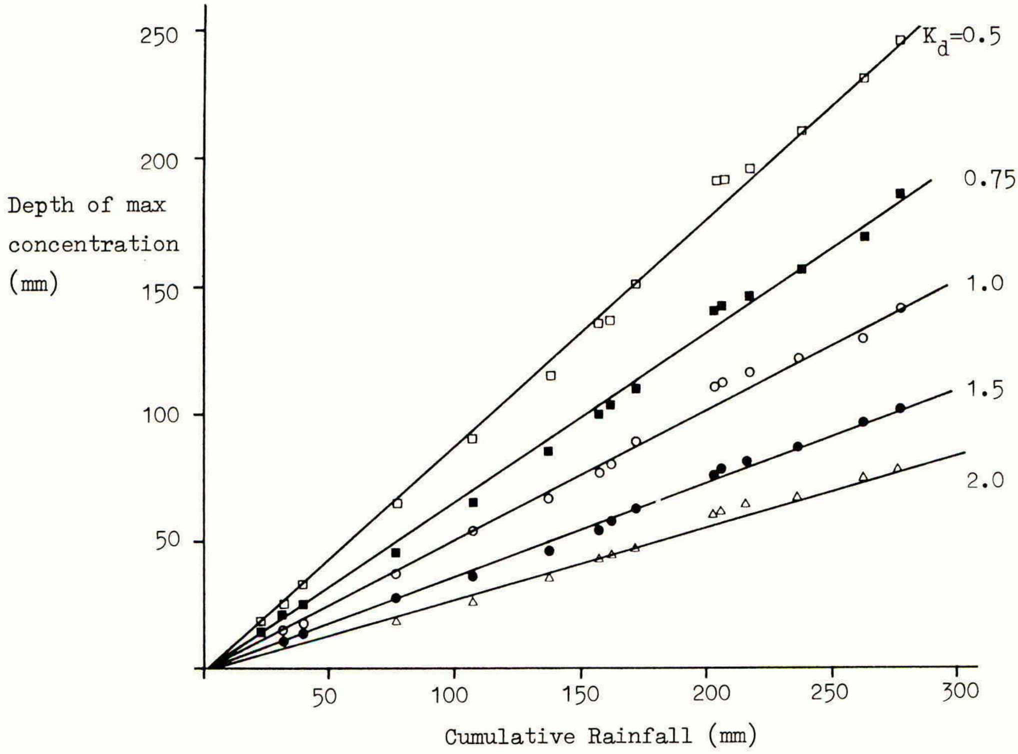

FIGURE 1. Relationship between winter rainfall and leaching depth of herbicides with different adsorption characteristics.

TABLE 1. Effect of isoproturon dose and placement depth on the growth of oilseed rape. (Sowing date, 16 March 1988; Sowing depth, 1 cm).

Placement depth (cm)	**% kill with dose (kg/ha)** 0.63	1.25	2.50
0-1	40	88	100
0-2	63	100	98
0-4	70	95	98
2-4	60	100	100
2-6	8	98	95
4-6	5	88	93

TABLE 2. Effect of isoproturon dose and placement depth on the growth of Italian ryegrass. (Sowing date, 7 April 1988; Sowing depth, 0.5 cm).

Placement depth (cm)	% kill with dose (kg/ha) 0.63	1.25	2.50
0-1	0	30	60
0-2	0	10	58
0-4	0	0	55
2-4	0	0	65
2-6	0	0	38
4-6	0	0	38

TABLE 3. Effect of isoproturon dose and placement depth on growth of blackgrass. (Sowing date, 13 February 1989; Sowing depth, 0.5 cm).

Placement depth (cm)	% kill with dose (kg/ha) 0.63	1.25	2.50
0-1	49	83	96
0-2	88	95	100
0-4	62	92	100
2-4	80	96	100
2-6	27	100	100
4-6	0	92	100

TABLE 4. Effect of isoproturon dose and placement depth on growth of blackgrass. (Sowing date, 2 May 1989; Sowing depth, 0.5 cm).

Placement depth (cm)	% kill with dose (kg/ha) 1.25	2.50
0-4	100	100
2-6	97	100
4-8	50	61
6-10	11	14

In these equations Dmax is the depth at which the maximum concentration is located in the soil (mm) and R1, R2 and R3 are rainfall recorded in 0-15, 15-60 and greater than 60 days respectively.

In order to make appropriate calculations for applications of isoproturon made at any time during the autumn and winter, the leaching model of Nicholls et al. (1982) and Walker (1987) could therefore be replaced by a simple BASIC program making use of equations 2 and 3 above and relevant input rainfall data.

GLASSHOUSE EXPERIMENTS

To obtain information on the possible significance of leaching depth to activity of the herbicide, effects on susceptible plants were measured following exposure of the test plants to isoproturon located at different depths in pots of soil. This was accomplished in a series of experiments with different concentrations of isoproturon uniformly mixed into a sandy loam soil placed at one of several depths **in 12.5 or 15 cm diameter pots of** soil. Twenty seeds of oilseed rape were sown in each pot in experiment 1 (Table 1), and 20 seeds of Italian ryegrass in experiment 2 (Table 2). There were 12 pre-germinated seed of blackgrass per pot in experiments 3 and 4 (Tables 3 and 4). After sowing, the pots were placed on saucers in a glasshouse maintained at 15°C. To minimise herbicide movement in the pots, water was applied mainly via the saucers, but the surface was also kept moist. The effects of the herbicide on plant growth were assessed by determining the percentage kill of the test plants. The treatments examined and the results obtained are summarised in Tables 1-4. There were two replicates in experiments 1-3, and three replicates in experiment 4.

RESULTS AND DISCUSSION

At the full dose of isoproturon (2.5 kg/ha), there was little effect of placement depth on phytotoxicity to oilseed rape (Table 1). At half normal dose, there was reduced efficacy when the herbicide was located above the seed (0-1 cm) or at a depth of 4-6 cm in the soil. At one quarter dose, there was little phytotoxicity from the herbicide when placed at depths greater than 2-4 cm in the soil.

In experiment 2 (Table 2), Italian ryegrass was grown after removal of the oilseed rape from the soil in experiment 1. Isoproturon concentrations would therefore have declined considerably from the initial amounts. Residual effects from the 2.5 kg/ha initial dose declined markedly when the herbicide was distributed other than in the top 4 cm soil. There was relatively little phytotoxicity from the half dose irrespective of position in the soil, and none from the quarter dose.

In experiment 3 (Table 3) effects on blackgrass were similar to those observed with oilseed rape. There was little effect of placement on activity of the full dose (2.5 kg/ha), but at half dose, efficacy declined slightly when the herbicide was incorporated into the top 1 cm soil. At the quarter dose, there was a marked reduction in efficacy when the herbicide was localised in the top layer of soil, and phytotoxicity declined sharply with placement depth greater than 4 cm in the soil. In the final experiment in which greater depths were examined (Table 4), phytotoxicity of both the full dose and the half dose was reduced considerably with placement depths greater than 6 cm in the soil.

The results indicate that when the amount of isoproturon in the soil is less than one quarter of the recommended dose (2.5 kg/ha), efficacy declines sharply if the herbicide is located at depths greater than about 4 cm. Under average weather conditions, residues of isoproturon at the end of January following application in November will normally be less than 25% of the intial amount (Walker & Eagle, 1983). On the basis of the present data, little residual weed control would be expected at this time if the herbicide was leached beyond a depth of 4 cm. During mild winters, residue decline will be more rapid, and hence loss of activity should occur sooner. The glasshouse tests indicate that in a very wet year, herbicide movement beyond 6 cm depth may result in some loss of activity even with the full dose of herbicide (Table 4). Using weather data from some recent years, leaching depths of more than 6 cm within 2 months of autumn application are predicted on many occasions for low adsorptive soils (Equation 2) and occasionally for moderate adsorptive soils (Equation 3). This suggests that leaching may influence performance in many situations.

The depth criteria for activity of isoproturon were relatively consistent between the different experiments and between the three test species examined which suggest that they are soundly based. If it is assumed that the depth criteria derived from these experiments will also apply in the field, then the leaching model described above, in combination with the persistence model described previously (Walker & Eagle, 1983), should help to identify those situations when rapid degradation or excessive movement limit activity of the herbicide. Such information would permit sound advice on the requirement for supplementary applications of herbicide to be given.

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REFERENCES

Blair, A.M.; Martin, T.D.; Eagle, D.J.; Walker, A. (1988). Measurement and prediction of isoproturon movement in soil following its application in winter. Proceedings 1988 EWRS Symposium, Factors Influencing Herbicidal Activity and Selectivity, 289-294.

Luscombe, B.M. (1983). The influence of rainfall and temperature on the persistence of autumn-applied tri-allate and isoproturon in 1979/80 and 1980/81 seasons. Aspects of Applied Biology, 4, 423-432.

Nicholls, P.H.; Walker, A.; Baker, R.J. (1982). Measurement and simulation of the movement and degradation of atrazine and metribuzin in a fallow soil. Pesticide Science, 13, 484-494.

Walker, A. (1987). Evaluation of a simulation model of herbicide movement and persistence in soil. Weed Research, 27, 143-152.

Walker, A.; Eagle, D.J. (1983). Prediction of herbicide residues in soil for advisory purposes. Aspects of Applied Biology, 4, 503-509.

THE USE OF SOIL SURVEY INFORMATION TO ASSESS THE RISK OF SURFACE AND GROUNDWATER POLLUTION FROM PESTICIDES

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ABSTRACT

Soil physical and chemical properties which are known to influence the behaviour of pesticides have been incorporated into a simple risk assessment model. A computerised spatial analysis system (SPANS) overlays the individual characteristics assigned to each soil series onto a digitised soil map. General or pesticide specific risk assessment maps at various scales can be derived.

INTRODUCTION

Increasing environmental concern in the U.K. has focussed attention on the spatial properties of soils and their influence on the fate and behaviour of pesticides. Since 1939 the Soil Survey and Land Research Centre (SSLRC) has produced soil maps at various scales, along with details of associated soil physical, hydrological and chemical characteristics. Four levels of soil differentiation are used, the most detailed being soil series whose narrowly defined range of diagnostic properties, many inherited from the soil parent material, ensure their consistent recognition in different parts of the country.

Over 700 different soil series have been identified in England and Wales (Avery 1980, Clayden and Hollis 1984) and they are labelled by names of places where they were first described. National coverage is provided by six 1:250,000 scale Regional maps where soil series are grouped into 296 associations. The maps have 67 colours representing those subgroups within which the dominant soil series characterising soil associations are classed. For example, orange colour shows the freely draining typical brown sands, purple the peat soils and yellow the brown rendzinas including shallow soils over chalk and limestone. More detailed surveys at 1:50,000 or 1:25,000 are only available for about 30% of the country. Survey at 1:10,000 scale (four inspection points per hectare) or less is suitable for farm maps, whereas experimental plots are usually surveyed on a 10 m grid basis.

Physical, hydrological and chemical properties of most soil series have been routinely analyzed and the results synthesized and stored in the SSLRC computerized Land Information System (LANDIS), along with digitized map boundaries and other relevant climatic and land use data. Using LANDIS, a wide range of applied data sets and interpretative maps have been derived. A relevant example is the production of a series of groundwater vulnerability maps at 1:100,000 scale for Severn Trent Water (Palmer 1987).

Pesticide risk assessments of trial areas are currently being developed and are based on the soil properties which are known to influence the behaviour of pesticides in the soil environment. The 1:25,000 soil map of Sleaford in Lincolnshire (George and Robson 1978) has been used to demonstrate the risk assessment procedure. The area straddles the Lincolnshire limestone, a major aquifer, and areas of Blisworth and Oxford clay provide contrasting soil and hydrological conditions. Small areas of humic and peaty soils also occur. Land use is largely arable and the vulnerability of the aquifer to contamination by nitrates and pesticides is a central issue.

SOIL PROPERTIES INFLUENCING PESTICIDE BEHAVIOUR

SPANS, a geographical information system was used to portray the individual soil properties influencing pesticide behaviour. Existing classifications for each soil property were applied to the digitised Sleaford soil subgroup map (Fig. 1a).

Chemical properties

Organic matter within soil physically adsorbs certain pesticides. MAFF (1984) describes three groups of soils with increasing organic matter content, mineral, organic mineral and peaty, defined by a combination of organic carbon and clay content. In mineral subsoils, where organic carbon content is typically less than 1%, clay content is a more important factor controlling adsorption. Cation exchange capacity can also be used as an indicator of the adsorption capacity of clay minerals, for example, kaolinite has a low capacity whereas smectite a high capacity.

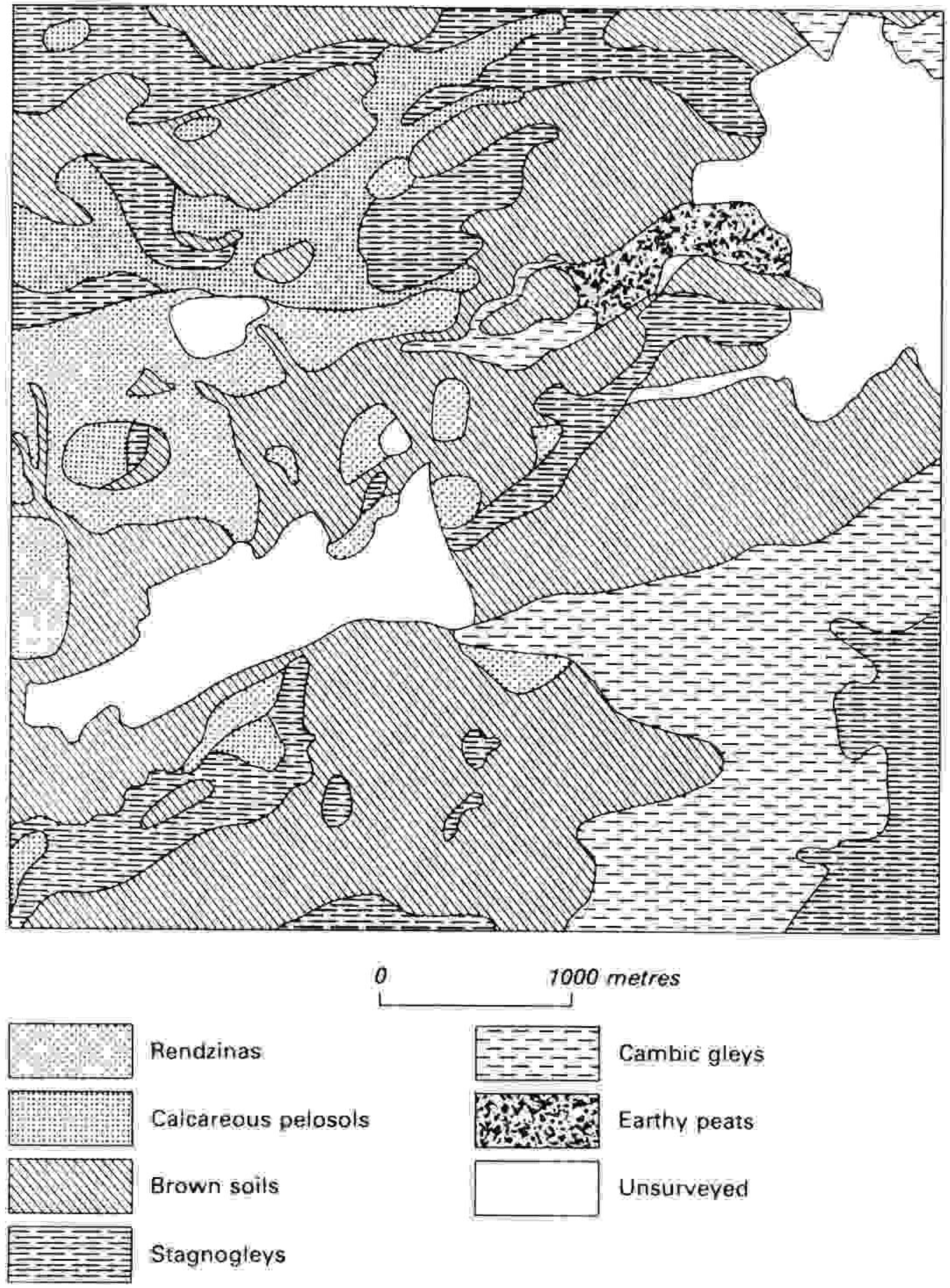
Soil reaction or pH is a property which can be easily modified by agricultural practice and therefore a simple division into calcareous and non-calcareous soils is made (Fig. 1b). A pesticide whose degradation is acid catalysed may persist in an alkaline soil.

Physical properties

Each soil type has a unique curve representing the relationship between the volume of water held and the soil suction (Reeve and Carter in press). At zero suction the soil is saturated, but as the soil drains suction increases and large pores empty of water. Progressive increases in suction will continue to empty narrower pores until only the finest pores contain water. The relationships between soil air, soil water and solid matter derived from water retention measurements can be presented diagrammatically so that changes in air/water/solid relationships can be seen at a glance. Figure 2 shows the properties of two contrasting soil types. The Cuckney series being a sandy freely draining soil and the Salop series a fine loamy over clayey soil with a slowly permeable subsoil. Less water, thus soluble pesticide, is retained by the sandy soil, whilst the clayey soil shows restricted air space in the subsoil where anaerobic conditions can develop.

Figure 1 Soil classification and risk assessment for the Sleaford area

1a Soil Group



1b Soil Reaction

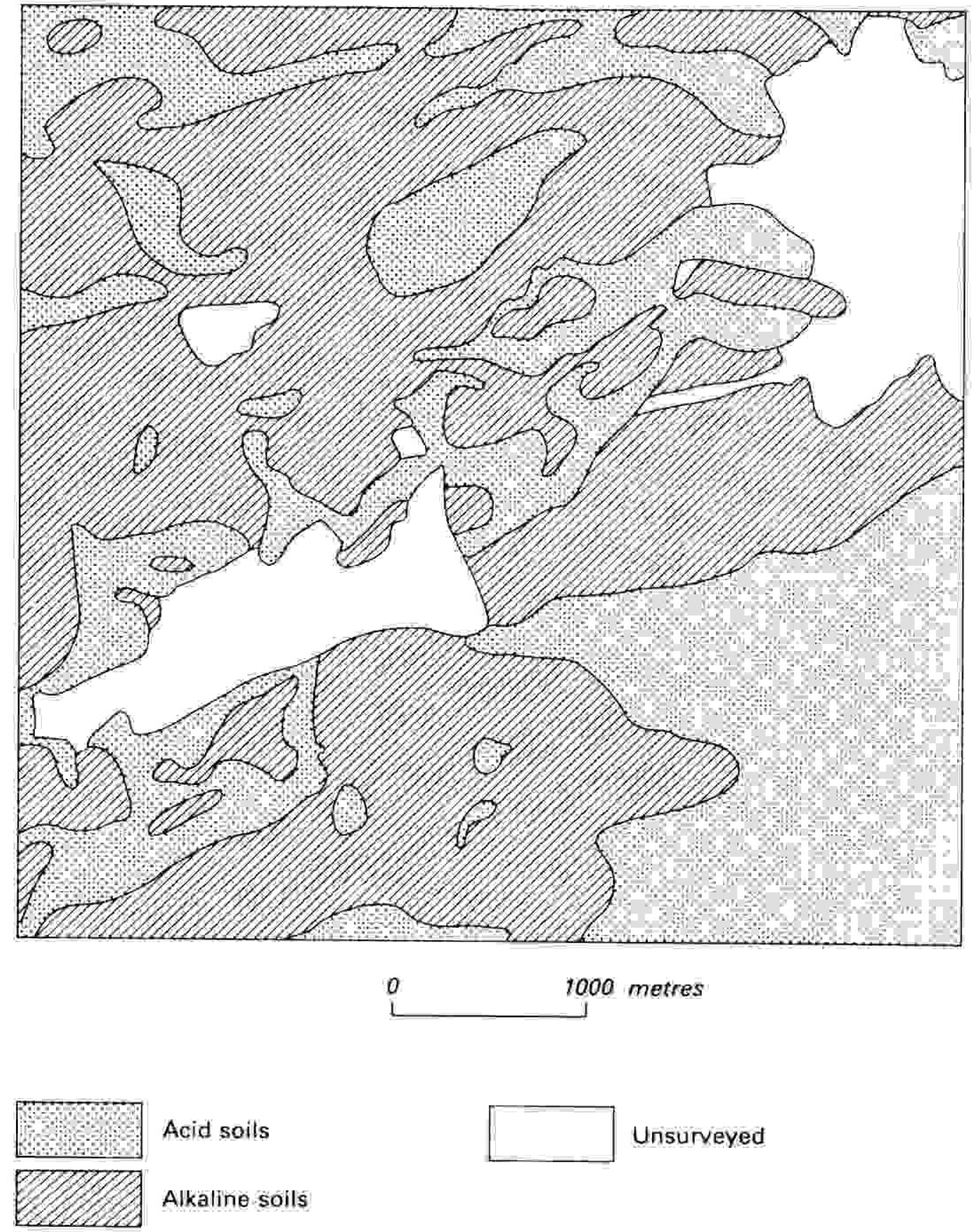
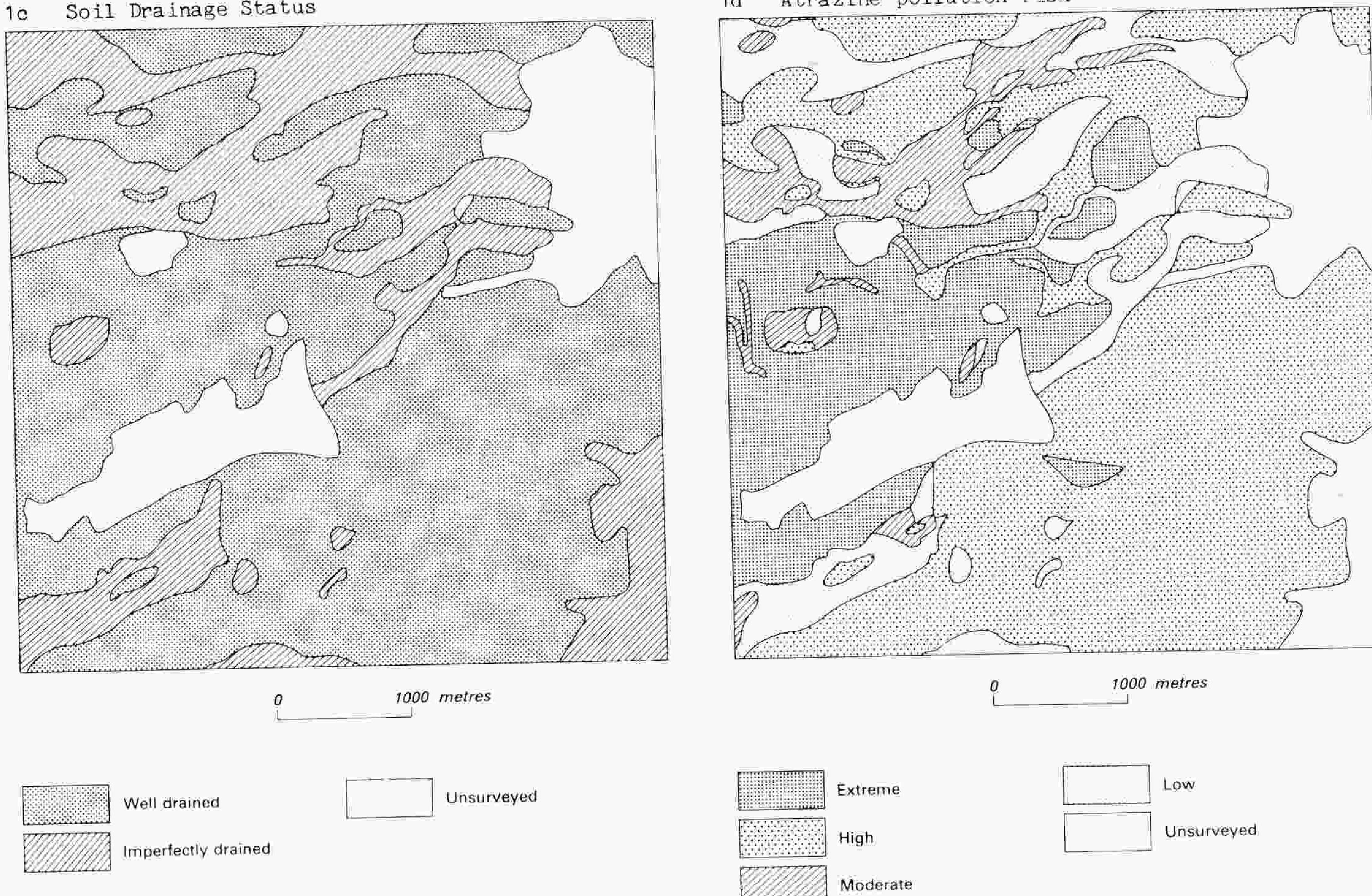


Figure 1 Continued

1c Soil Drainage Status

1d Atrazine pollution risk



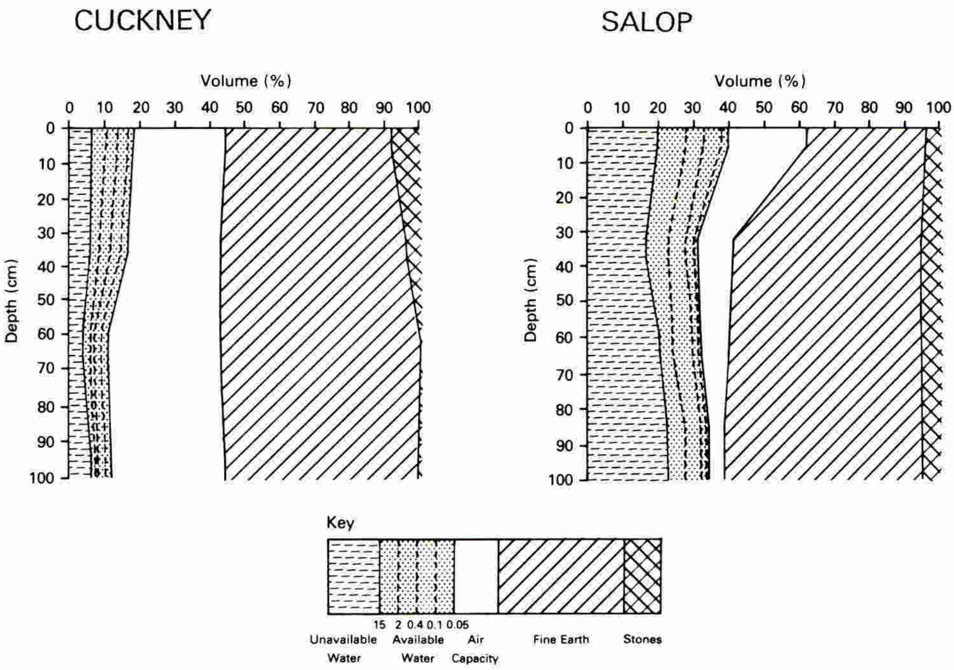


Figure 2 Water retention characteristics of soil profiles, Cuckney and Salop series

Hydraulic conductivity determines the rate at which a mobile pesticide moves through a soil profile. In a sandy soil, flow is rapid in the saturated state but rapidly diminishes as soil suction increases (Fig. 3). In a clayey soil matrix, flow is slow in both the saturated and unsaturated states, but can be complicated by large cracks which develop in shrinking clay soils and may connect with mole channels or drains. Cracks or macropores may account for by-pass flow and the rapid appearance of pesticides in drainage waters.

Water retention and hydraulic characteristics of a soil can be measured directly or inferred from basic data like texture and structure. Together they represent the leaching risk of a mobile pesticide, for example shallow permeable soils with a low water-holding capacity have an extreme risk (Carter et al. 1987).

Lateral or surface flow of soil water usually occurs above a slowly permeable soil horizon. Surface waters are more likely to receive such drainage. Pollution can be severe if the erosion risk of a topsoil is high since adsorbed pesticide may be concentrated in surface concavities or washed into surface waters. Whilst not strictly a soil property, slope is used as an index of erosion risk.

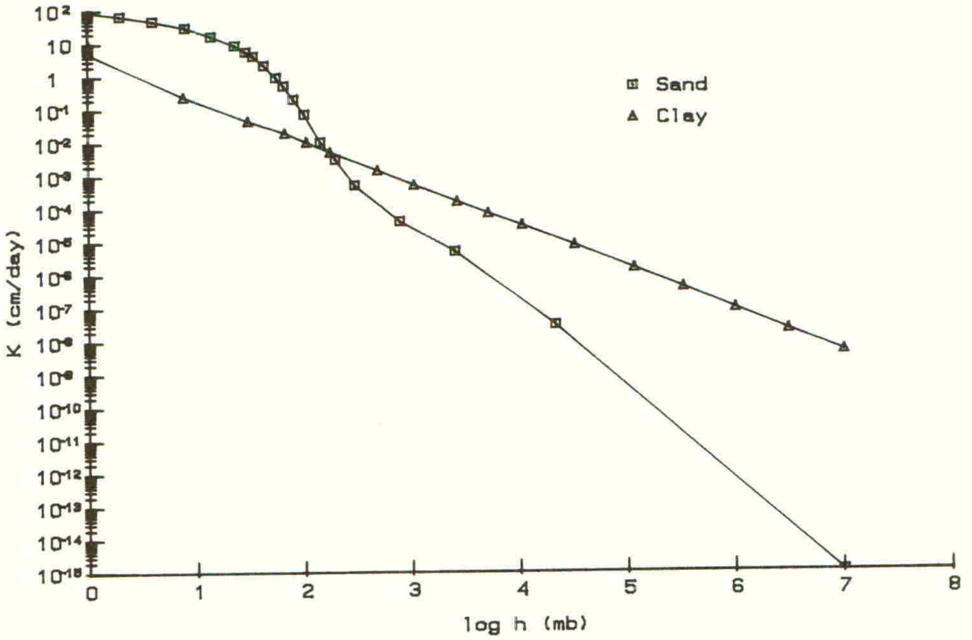


Figure 3 Hydraulic conductivity curves for two contrasting subsoil textures

The depth or duration of waterlogging of a soil series is described by a system of wetness classes from I (well-drained) to VI (almost permanently waterlogged within 40 cm depth). It has been suggested that persistent pesticides may return to the root zone in a fluctuating water-table, for example chlorsulfuron and sugar beet damage. The classes are grouped to give well, imperfectly and poorly drained soils and assume that drainage measures have been taken. Imperfectly drained soils are most likely to have fluctuating, seasonally impersistent, water-table levels within 70 cm of the soil surface and these soils cover a large area of the Sleaford map. No poorly drained soils are found in this area (Fig. 1c).

RISK ASSESSMENT

When a risk assessment for an individual pesticide is required, the SPANS system can merge the relevant soil classifications to produce a pesticide specific map. Atrazine is chosen as an example since it has been consistently located in surface and groundwaters in the U.K. Slope for erosion risk, organic carbon for adsorption and leaching risk are combined to represent the total risk assessment for this pesticide (Fig. 1d). The permeable shallow soils over limestone and chalk show extreme pollution risk whilst the clayey deeper soils have a lower aquifer pollution risk but a higher surface water pollution risk. Peaty and organic mineral soils show decreased risk categories due to adsorption effects. Only a small area of Sleaford has slopes greater than 3^{o} and therefore surface runoff or erosion risk is negligible.

Soil survey information is being used, together with land use data, to explain the high levels of dieldrin, the breakdown product of aldrin, in the river Newlyn in Cornwall. A source was traced to a daffodil farm where fields had been defoliated with a herbicide and bulbs planted upgradient. Compaction of the furrows caused by daffodil pickers enhanced surface runoff and aldrin was carried on soil particles into the river. Dual cropping and irrigation increase the amount of drainage water and likelihood of erosion from certain soils. The survey work for South West Water is now being extended to nearby catchments.

DISCUSSION

The risk assessment used on the Sleaford map is purely qualitative but does show the potential for future applications of soil survey data to pesticide studies. Small scale assessments provide national coverage and are useful for strategic planning, policy formulation and publicity exercises. Detailed surveys show more precise risk situations and would be essential in determining the location and management of surface and groundwater protection zones. Semi-quantitative regional and catchment based soil hydrological and erosion models (Hollis and Palmer pers. comm. and Morgan et al. 1986) are currently being developed so that a least risk scenario can be assessed for any pesticide. Continuing liaison with the pesticide and water industries, MAFF's pesticide registration unit and the Department of the Environment is necessary to evolve a multi-disciplinary approach to risk assessment.

A study of the behaviour of commonly used pesticides on a range of typical U.K. soils is necessary to validate any model used. Work has commenced on a freely draining sandy soil overlying a sandstone aquifer in north Nottinghamshire to test newly developed inert soil suction samplers which can extract soil water at 1.5 m depth in the soil profile.

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REFERENCES

Avery, B.W. (1980) Soil Classification for England and Wales. Technical Monograph No.14, Harpenden.

Carter, A.D.; Palmer, R.C.; Monkhouse, R.A. (1987) Mapping the vulnerability of groundwater to pollution from agricultural practice, particularly with respect to nitrate. In 'Vulnerability of Soil and Groundwater to Pollutants'. Ed. W. van Duijvenbooden, The Netherlands.

Clayden, B.; Hollis, J.M. (1984) Criteria for Differentiating Soil Series. Technical Monograph No.17, Harpenden.

George, H.; Robson, J.D. (1978) Soils in Lincolnshire II: Sheet TF04 Sleaford. Soil Survey Record No. 51, Harpenden.

Ministry of Agriculture, Fisheries and Food. (1984) Soil texture leaflet 895.

Morgan, R.C.P.; Morgan, D.D.V.; Finney, H.J. (1986) A simple model for assessing soil erosion on hill slopes. In: Agricultural non point source pollution: model selection and application. Ed. Giogrini A. Zingales, 147-159. Elsevier, London.

Palmer, R.C. (1987) Groundwater Vulnerability: Map 1 Stafford. Soil Survey of England and Wales, Silsoe, Beds.

Reeve, M.J.; Carter, A.D. (in press) Water release characteristics. In: Soil Analysis, Part III: Physical Methods. Eds. C. Mullins, K. Smith. Marcell Dekker, New York.

PESTICIDE CONTAMINATION OF WATER - REGULATORY CONSIDERATIONS

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ABSTRACT

Before a pesticide is approved for use, sufficient data must be generated to predict its fate in the environment and its potential to contaminate water. However this is an extremely difficult task; factors beyond those properties readily measured in laboratory studies may be responsible for pesticide transport and distribution within soil resulting in water contamination. Proposals are made to initiate discussion on the best assessment procedure to adopt for regulatory purposes and the best interpretation of data.

INTRODUCTION

From a regulatory point of view it is important to put the environmental fate and behaviour studies into perspective within the vast amount of data produced in support of an application for the registration of a pesticidal product. In the past most of the emphasis has been placed on the generation of data on the biological effects which comprise the mammalian and wildlife toxicology package. Whilst these data are essential, they provide only part of the information. Most regulatory scientists now distinguish between the hazard of a pesticide, which is the measured response from the laboratory toxicity studies and can be regarded as a property of the pesticide, and the risk from the use of a pesticide, which is the probability of the measured response occurring in practice following good agricultural practice. The risk, therefore, is a function of the exposure and toxicity. To extend this philosophy to environmental fate, the concern over water contamination must be related to human consumption, wildlife effects and crop damage such as phytotoxicity or growth regulating effects. It is essential, therefore, to obtain accurate "exposure" data in the form of quantifiable residues. The most important information consists of the rates and route of degradation, with characterisation and quantification of degradation products, and the vertical distribution of these residues in soil with time. The movement of pesticides in soil depends on the physico-chemical properties of the pesticide, the properties of the soil and weather. (Nicholls, 1988). In practice this means that there will be some areas of the UK which will be more vulnerable to the mobility of pesticide residues than others. Agricultural practice also plays an important part in influencing the transport of pesticides. For example, field drains facilitate the movement of water through the upper soil layers into ditches. This movement could transport some pesticides either in solution or associated with colloids or larger particles.

Greater attention has been focussed on the potential problems of water contamination recently because of the European Community "Drinking Water" Directive (80/778/EEC) stipulating that no more than 0.1 ug/l of a single pesticide, with no greater than 0.5 ug/l total pesticides, should be found in water if used for potable supply. Since these figures are the same for all pesticides regardless of the toxicity, they are entirely arbitrary. It has been emphasised in the previous paragraph that a risk evaluation needs both the exposure and the toxicity data. Therefore the EC Directive, if rigidly applied to the evaluation of the risk of pesticides, has for the first time taken away from the regulatory procedure important scientific steps in the evaluation.

It is not the intention of this paper to go into detail over the methods of the studies employed to generate basic data nor will it cover the behaviour of pesticides in soil. These subjects have been covered elsewhere (for example, methodology - Esser et al, 1988; behaviour - Hance, 1987; Khan, 1980; Nicholls, 1988; Plimmer, 1988). The main objective is to suggest a suitable regulatory procedure and decision making steps for the UK to adopt. It must be emphasised that this paper should be regarded as the initiation of discussion between interested parties and Government Departments responsible for pesticide registration. Before any procedure is finally adopted, agreement between such bodies will be necessary. Nevertheless, in the interim, the suggested procedure should begin to prepare pesticide manufacturers for the future policy.

CURRENT DATA GENERATION

Data are being provided from two main sources. Firstly the basic data generated to support a pesticide registration and secondly environmental residues data being provided by authorities responsible for monitoring the quality of water sources.

Generation of data by applicants

Pesticide manufacturers generate data to meet the demands of regulatory authorities world-wide. Currently the United States Environmental Protection Agency and some European states, notably the German authorities, have demanded extensive soil data. The main purposes of which are to determine the potential for adsorption, the rate of degradation in soil types and the characterisation of degradation products. Also an attempt at predicting the mobility is made. Some of these laboratory tests are extremely useful and more attention should be paid to extending the basic protocols to cover a wider range of soil conditions more relevant to UK agricultural practice. These studies are likely to form the core of the basic set required for European registration when the so called "Acceptance Directive" ("Amended proposal for a Council Directive concerning the placing of EEC-accepted plant protection products on the market"; OJ No C89/22, 32, 1989) is adopted.

Discussions on the final list of studies required for the "Acceptance Directive" are continuing at the time of writing this paper, however at present the main headings under which data must be provided are given in Table 1. In general terms the list could be regarded as covering the main areas of concern and harmonises the requirements of the member states of the European Community. But regulatory science is not about counting study reports or indeed weighing the data package. It is about interpreting data and predicting the probability of effects or contamination occurring.

TABLE 1. Data required by European Community to evaluate the fate in the environment of plant protection products

1.	Degradation in soil - at least three natural soil types
2.	Adsorption and desorption in soil - at least three natural soil types.
3.	Persistence in soil - at least three natural soil types
4.	Mobility in soil - at least three natural soil types
5.	Dissociation constant (pKa) - if appropriate.
6.	Degradation in the aquatic environment
7.	Laboratory tests on biodegradation, hydrolysis and photolysis
8.	Field testing for degradation

Survey data

At the other end of the scale authorities responsible for maintaining the quality of water have been finding some evidence of contamination by pesticides. Although there is a paucity of published data on this subject, what has been published gives the reassurance that residues are far below those likely to cause toxicological effects. Most of the published data refer to the environmental situations and the agricultural practice of the United States of America and therefore might not be directly applicable to all UK conditions. Published data from the UK refer mainly to organochlorine insecticide and herbicide contamination of surface waters. More recently Croll (1985) concluded that there was good evidence for widespread contamination of surface water in arable agricultural areas of eastern England with phenoxyalkanoic acid herbicides at levels up to 5 ug/l total. Contamination of ground water was less widespread or at levels below the limits of determination of the analytical method used at that time. For example atrazine was found in most surface waters up to 1.4 ug/l in eastern England.

EVALUATION OF DATA

Interpretation

Currently the data presented by applicants requesting a registration are interpreted in the UK in terms of the likely risk to consumers, operators and wildlife. If the contamination in water is likely to be below levels which would be regarded as contributing significantly to the daily intake of residues from the diet, the proposed uses would be recommended for approval. The data so far published confirm this view. The exceptions have been the use of some organochlorine insecticides and recently the remaining uses of aldrin have been banned in the UK because of high residue levels of dieldrin in some surface waters (Anon, 1989).

The maximum level of contamination of 0.1 ug/l imposed by the EC presents a difficulty which is not easily resolved because there is insufficient knowledge available to predict with such accuracy whether, for example, residues in ground water could exceed the limit. Field trial studies have been useful in determining the level of actual contamination but there still remains the need to conduct fundamental research to determine the mechanisms involved over a wide range of growing conditions. One thing is certain however that not all pesticides would be expected to contaminate water because of either the use patterns or physico-chemical properties. This fact is a useful starting point with any procedure adopted to evaluate such data.

If the current range of studies identified in Table 1 are to be useful in the risk evaluation process certain improvements will need to be made.

Adsorption coefficient

The adsorption coefficient K and possibly the coefficient Kom calculated as a function of the organic matter of the soil should be calculated. In addition it would be preferable to determine isotherms. The OECD have published good guidelines on the methods which can be used (OECD, 1981). Usually associated with adsorption data are desorption data. These, however, can be full of errors as the original starting concentration is often unknown. All of these tests should be conducted on a range of soils and one of them should be relevant to the type of soil that is likely to be treated in the UK.

Degradation

It is most important to select a relevant range of soil types likely to be found in the expected growing conditions in the UK. It has been suggested that three soil types would be sufficient; at least one should be relevant to the soil supporting the major crop to be treated and one should be a sandy soil. All three soils should be tested at two or preferably three moisture contents. It has been suggested that a range of between 50% and 90% of the moisture holding capacity should be chosen. Temperature is also an important factor and a suitable range should be chosen including a more typical UK value. A practical temperature of 10^{o}C would allow sufficient microbial action in the laboratory and reflect the soil temperatures of the UK. If appropriate the dissociation constant should be determined and the effect that pH would have on degradation.

Mobility

These studies are more a reflection of adsorption potential than presenting a true measurement of pesticide transport. The substrate is prepared in such an artificial manner as not to reflect the natural soil structure. In addition the conditions of the test does not reflect the natural movement of soil water.

Field studies

It will be important to select a site that is relevant to the soil supporting the treated crop. Either a small scale plot or lysimeter could be used. It will be preferable to include the treated crop. Also some thought should be given to pesticide regime employed on the crop and whether this will affect the breakdown rate of the pesticide being studied. The objective would be to determine the degradation and transport of the parent and important degradation products through the vertical profile of the soil. An assessment of the potential of the pesticide to be mobile through the topsoil horizon and into the subsoil and possibly an aquifer will be required. It will be necessary, therefore to demonstrate that contamination of ground water (or surface water if used for potable supply) does not exceed the EC maximum admissable level.

PROPOSED ASSESSMENT PROCEDURE

The following proposal is based on the utilisation of all the available data hopefully included with the data package submitted for registration. Esser et al (1988) have presented the best approach to this subject and much of the detail supporting the aims of this paper can be found there. The procedure is divided into two phases with decision making steps at the end of each of 3 sections. What it cannot do is to predict the likely contamination of water accurately for each region of the UK. Further research will be necessary to provide the fundamental data required for individual regional assessments.

Phase I

Section A

The following data will be required:

(i) physico-chemical properties of the active ingredient and the product,
(ii) application rates, frequency and timing,
(iii) methods of application
(iv) crop to be treated and purpose of treatment.

Using the available data on likely contamination from Lawrence and Foster (1987) a simple assessment could be made. For example, following 200mm/annum infiltration of water (rainfall over evapouration), up to 5% transport of the parent active ingredient through the soil into the subsoil without further degradation and up to 25% of a catchment receiving the treatment, a 20 g/ha application would contaminate ground water to 0.1 mg/l. As the values are likely to be worst case except for very water soluble chemicals, for the purposes of the regulatory assessment, products applied at such low application rates could be regarded as unlikely to contaminate water. Further tests would be needed only on degradation to determine the risk to wildlife and the crop.

Section B

The following data will be required:

(i) adsorption/desorption data (range of soil types),

(ii) degradation data (range of conditions and soil types),

(iii) dissociation constants (if appropriate).

If the degradation study shows a half-life of greater than six months, extensive field trials will be required to evaluate the potential for phytotoxicity and water contamination. Half-lives of less than this would need some field confirmatory data on degradation and vertical distribution. Adsorption data showing that $K > 10^4$ and the coefficient $P > 10^5$ would suggest that the chemical was unlikely to be mobile in most soils. Some confirmation would be necessary from field studies. However adsorption figures less than these values would need extensive field studies.

Phase II

This section relates to field studies which could be conducted either by lysimeters or in field plots.

FURTHER STUDIES

It is clear that continued use of pesticides in agriculture and in industrial situations will result in some contamination of water (surface and ground water). However, it is almost impossible to be able to predict with certainty from data presented for regulatory purposes, the likely contamination level. Agricultural practices and geographical and climatic conditions make such decision almost impossible. Research needs to be conducted to identify vulnerable areas of the UK in much the same way as for nitrate contamination. In addition greater understanding of the mechanisms involved in such vulnerable areas is needed so assessments can be made on good scientific principles. In such cases computer modelling could be developed with sufficient capability to take into consideration the many variables encountered. To validate the models, well designed field trials need to be conducted to provide sufficient information on which to base regulatory decisions. Such studies on field dissipation of pesticides are not common. One of the problems is to relate the movement of the pesticide with pulses of water movement following rainfull. This can be done successfully only if a complete catchment is being studied. A suitable site is currently being studied in the UK at Rosemaund Experimental Husbandry Farm (P. Matthiessen, pers. comm.) where all pesticide use in the catchment is being monitored. Certain herbicides have been found in a stream draining the farm in pulses following rainfall. It is hoped to conduct mass balance determinations at this site. Although this field dissipation study is not the only one currently being undertaken in the UK, insufficient resources are being made available for this important area of research.

CONCLUSIONS

Not all pesticides should be regarded as potential contaminants of water. However some, notable herbicides, will and indeed have already been found in ground water and surface waters. Agricultural use is not the only source of such contamination and before decisions are made on restricting use a careful examination of the uses most likely to result in contamination should be made. Certain areas in the UK are likely to be more vulnerable than others and should be identified with a view to controlling use perhaps on a regional basis.

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REFERENCES

Anon. (1989). Revocation of aldrin approvals. The Pesticides Register. MAFF.5;1

Croll, B.T. (198) The effects of the agricultural use of herbicides on fresh waters. Water Research Centre/WHO Conference - Effects of Land Use on Fresh Waters. Stirling. Paper 13. 201 - 209

Esser, J.O., Hemingway, R.J., Klein, W., Sharp, D.B., Vonk, J.W. and Holland, P.T.(1988) Recommended approach to the evaluation of the environmental behaviour of pesticides. Pure and Applied Chem 60. 6. 901 - 932.

Hance, R.J. (1987) Herbicide behaviour in the soil, with particular reference to the potential for ground water contamination. In Herbicides. D.H. Hutson and T.R. Roberts (Eds). Wiley and Sons Ltd. Chapter 7. 223 - 247.

Khan, S.U. (1980) Pesticides in the soil environment. Elsevier, Amsterdam.

Lawrence, A.R. and Foster, S.S.D.(1987). The polution threat from agricultural pesticides and industrial solvents - a comparative review in relation to British aquifers. British Geological Survey NERC, Hydrogeological Research Report 87/2.

Nicholls, P. H. (1988) Factors influencing entry of pesticides into soil water. Pestic Sci.22. 123 - 137

OECD (1981). Adsorption/Desorption Guidelines for testing of chemicals. 106.

Plimmer, J. R. (1988). Movement of pesticides from the site of application. Proc conf of International Atomic Energy Agency. IAEA-SM-297/35.61-77