FIELD EVALUATION OF CN-11-6180 FOR CONTROL OF *ABUTILON THEOPHRASTI* AND OTHER BROAD-LEAVED WEEDS IN CORN

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ABSTRACT

CN-11-6180 is a flowable formulated mixture of dicamba and atrazine developed by Sandoz Crop Protection Corporation for the control of annual and perennial broad-leaved weeds in corn. CN-11-6180 applied early post-emergence provided excellent, more consistent control of all broad-leaved weeds than atrazine or cyanazine applied pre-emergence . CN-11-6180 demonstrated good corn safety, and provided excellent, consistent control of particularly *Abutilon theophrasti* and *Ipomea* spp. The recommended label rate is from 0.89 to 1.57 kg/ha, applied from pre-emergence to the five-leaf stage of corn. CN-11-6180 gave satisfactory control of annual and perennial broad-leaved weed species when used in conventional, reduced, or no-till corn production systems.

INTRODUCTION

CN-11-6180 (dicamba + atrazine) was first investigated between 1978 and 1981 with field testing of different dicamba formulations. The dicamba potassium salt became a focus of research from 1982 to 1984, and grower Experimental Use Permits were conducted with the dicamba potassium salt version in 1984 and 1985, and commercial introduction was in 1986.

The active ingredients in CN-11-6180 are the potassium salt of dicamba plus atrazine, sold under the trade name Marksman Herbicide. This flowable formulation contains 358 g a.i./l in the ratio of 123 g of dicamba potassium salt plus 235 g of atrazine, and was the formulation used throughout the experiments described here.

MATERIALS AND METHODS

More than 130 trials were conducted in 1985 and 1986 by Sandoz Product Development to research CN-11-6180 in the following areas: the optimal application timing and rate, weed control in various tillage systems, tank mix combinations, competitive herbicide comparisons, hard to control annual broad-leaved weeds, and perennial broad-leaved weeds. University researchers have also included CN-11-6180 in their herbicide trials at more than 20 locations in 1985, and at more than 50 locations in 1986.

The data presented is from small plot replicated trials conducted by Sandoz during 1985 and 1986. Applications were made with backpack sprayers using flat fan nozzles and an average of 185 l/ha under a variety of weather conditions, soil types, and tillage systems. Trials were located entirely in the United States; locations included Illinois, Indiana, Iowa, Missouri, Ohio, Wisconsin, Minnesota, Michigan, New York, Pennsylvania, and North Carolina. Visual weed control ratings were taken from four to eight weeks after treatment. All data are from direct comparisons of CN-11-6180 applied early post-emergence to atrazine or cyanazine applied preemergence at recommended label rates according to soil type. The dosages tested of CN-11-6180 ranged from 0.89 to 1.79 kg/ha, cyanazine dosages ranged from 1.3 to 3.36 kg/ha, and atrazine dosages ranged from 1.12 to 2.24 kg/ha depending on soil texture and organic matter content. Yields were obtained using small-plot combines with an attached corn header.

Early post-emergence applications were made when corn (*Zea mais*) and broad-leaved weeds were from one to eight inches tall. Alachlor or metolachlor was used pre-emergence with all treatments. Data from triazine-resistant weed trials and perennial weed trials is not included in the summaries presented due to the lack of control from triazine herbicides of these species.

RESULTS AND DISCUSSION

Table 1 presents annual broad-leaved weed control from direct comparisons of CN-11-6180 applied early post-emergence to atrazine and cyanazine applied pre-emergence. Broad-leaved weed control ratings with direct comparisons from both years are summarized. The species tested included *Abutilon theophrasti*, *Xanthium pensylvanicum*, *Ipomoea* spp., *Chenopodium album*, and *Amaranthus* spp. CN-11-6180 averaged greater than 95% control, demonstrating its consistency over the range of weed species, weather conditions, and soil types in the trials. Broad-leaved weed control provided by CN-11-6180 ranged from 85 to 100% across locations and years. The atrazine and cyanazine treatments averaged less than 85%, due to a lack of consistency. Although both triazine herbicides provided excellent control in some of the trials, control fell to as low as 20% at some locations.

TABLE 1

Annual broad-leaved weed control provided by CN-11-6180 compared to atrazine or cyanazine in 1985 and 1986 [a]

Herbicide treatment	Method of application	Average Dose (kg/ha)	% Broad-leaved weed control [b]
CN-11-6180	Early post-emergence	1.57	97
Atrazine	Pre-emergence	1.57	81
Cyanazine	Pre-emergence	2.8	82

[a] 50 direct comparisons were made with CN-11-6180 and atrazine; 35 direct comparisons were made with CN-11-6180 and cyanazine.

[b] Weed species evaluated included *A. theophrasti*, *X. pensylvanicum*, *Ipomoea* spp., *C. album*, and *Amaranthus* spp.

Crop injury was not significant with any of the treatments tested, therefore no data is presented. However, where mild crop injury did occur, the symptoms consisted of temporary leaning and brace root injury with the CN-11-6180 treatment, and stunting with cyanazine treatments.

CN-11-6180 applied early post-emergence resulted in yields that were equal to or slightly greater than atrazine or cyanazine applied pre-emergence (Table 2).

TABLE 2

Average corn yields from 14 locations in plots treated with CN-11-6180, atrazine or cyanazine

Herbicide treatment	Method of application	Average dose (kg/ha)	Yield (t/ha)
CN-11-6180	Early post-emergence	1.57	8.78
Atrazine	Pre-emergence	1.57	8.41
Cyanazine	Pre-emergence	2.8	8.23

The control of *A. theophrasti* and *Ipomoea* spp. is presented in Table 3. CN-11-6180 applied early post-emergence gave greater than 95% control of these species, while atrazine and cyanazine applied pre-emergence resulted in average control of 85% or less.

TABLE 3

Average control of *A. theophrasti* and *Ipomoea* spp. provided by CN-11-6180 compared to atrazine or cyanazine

Herbicide treatment	Method of application	Average Dose (kg/ha)	% control of A. *theophrasti*	*Ipomoea* spp.
			(12)[a]	(9)
CN-11-6180	Early post-emergence	1.57	97	96
Atrazine	Pre-emergence	1.57	80	85
Cyanazine	Pre-emergence	2.8	82	83

[a] Numbers in parentheses indicate the number of trials

CONCLUSIONS

CN-11-6180 applied early post-emergence provided excellent, more consistent control of all broad-leaved weeds than atrazine or cyanazine applied pre-emergence. Use of CN-11-6180 resulted in yields that were equal to or greater than the triazine herbicide treatments. CN-11-6180 gave excellent, consistent control of the individual species *A. theophrasti* and *Ipomoea* spp.

NEW GRANULAR HERBICIDES FOR GRASS AND BROAD-LEAVED WEED CONTROL IN CEREALS

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ABSTRACT

Herbicides formulated as granules have several advantages over conventional liquid or powder formulations; increased work rate, reduced potential for environmental or operator contamination and the possibility of application under a wider range of environmental conditions. This paper describes the efficacy and crop safety of two granule formulations field tested during 1985-87. Chlortoluron/tri-allate and isoproturon/tri-allate at 25 kg formulated product/ha (2500/1875 and 1500/1875 g a.i./ha respectively), provided a high level of control of Avena fatua and Alopecurus myosuroides and broad-leaved weeds from pre-emergence or early post-emergence applications. This allows the farmer the application advantages associated with granules without the necessity for a sequential herbicide treatment.

INTRODUCTION

Chlortoluron and isoproturon have been used commercially for many years for the control of Alopecurus myosuroides and broad-leaved weeds. Chlortoluron and isoproturon will also provide good control of Avena fatua, although a follow-up treatment may be required (Barnes, 1981). Tri-allate either as a granule or liquid formulation is very effective for the control of A. fatua and provides some control of A. myosuroides (Hodkinson, 1972). This paper describes the efficacy and crop safety of two granule formulations, produced by a novel manufacturing process which ensures even loading and rapid release of the active ingredients, chlortoluron or isoproturon and tri-allate.

MATERIALS AND METHODS

Both experimental products were formulated as granules; chlortoluron/tri-allate as a 175 g a.i./kg delivering 2500/1875 g a.i./ha at 25 kg/ha formulated product, and isoproturon/tri-allate as a 135 g a.i./kg delivering 1500/1875 g a.i./ha at 25 kg/ha formulated product. The reference products employed in these trials were tri-allate as 'Avadex BW 10G' and isoproturon as 'Hytane 500FW'.

Trials were conducted throughout the UK both by Monsanto and Ciba-Geigy. All were of randomised complete block design with, for efficacy evaluations, four or three replicates, and plots 4 x 12 and 3 x 8 m respectively. For crop safety trials the plot size was 4 x 12 m with four replicates. Granules were applied using a 'Fischer Granulor' applicator calibrated to deliver 22.5 or 25 kg/ha. Spray applications were made using a precision plot sprayer with 6 Lurmark 02-F110 nozzles operating at a spray volume of 200 l/ha and pressure of 207 kPa.

The trials were carried out in commercially grown crops utilising areas of natural weed populations. Crop safety trials were placed in crops with low weed populations and applications were made at double the anticipated use rate. Two application timings were evaluated, pre-emergence or early post-emergence of the crop and the grass weeds at GS 11-21 (Tottman & Makepeace, 1979).

Weed control was evaluated throughout the season by plant counts or visual assessments. Crop safety was assessed visually as crop vigour or chlorosis at 4, 8 and 12 weeks after application, in addition eight trials were harvested to determine grain yields.

Although field testing has been carrried out since 1985, for consistency of comparison the results described here are drawn from the 1986/87 season.

RESULTS

Weed control

Results are presented for Ciba-Geigy trials (Tables 1, 3, 4 and 6) and for Monsanto trials (Tables 2 and 5).

TABLE 1

Percent control of *A. myosuroides* (based on headcounts in June)

Pre-emergence application

Trial number		01	02	03	05	06
Weeds/m^2		952	616	376	216	200
Date applied		26.09.86	01.10.86	08.10.86	14.10.86	22.10.86
	g a.i./ha					
isoproturon + tri-allate	1500 1875	100	98	95	99	100
chlortoluron + tri-allate	2500 1875	100	98	88	98	100
tri-allate	2250	99	92	81	95	79

Post-emergence application

Trial number		02	03	04	05	06	09
Weeds/m^2		616	376	816	216	200	668
Date applied		27.11.86	12.12.86	01.12.86	21.11.86	07.01.87	27.11.86
GS		11-21	13-22	12-21	11-12	12-13	11-12
isoproturon + tri-allate	1500 1875	97	84	92	97	100	89
chlortoluron + tri-allate	2500 1875	90	81	90	97	91	80
tri-allate	2250	88	71	68	75	34	61

TABLE 2

Percent control of A. myosuroides (based on head counts)

Trial number			10	11	12	13
Weeds/m^2			23	16	61	900
Date applied - Pre			13.10.86	09.10.86	29.10.86	29.10.86
- Post			07.11.86	12.11.86	12.12.86	03.02.87
	g a.i./ha	Crop Stage				
chlortoluron + tri-allate	2500 1875	Pre-em	94	94	100	96
chlortoluron + tri-allate	2500 1875	Post-em	100	100	97	100
tri-allate	2250	Post-em	91	86	52	88

Trial number			14	15	16	Mean
Weeds/m^2			280	62	26	172
Date applied - Pre			22.10.86	22.10.86	22.10.86	
- Post			20.11.86	09.12.86	20.11.86	
chlortoluron + tri-allate	2500 1875	Pre-em	98	96	100	97
chlortoluron + tri-allate	2500 1875	Post-em	95	91	86	95
tri-allate	2250	Post-em	9	58	21	59

The final level of control of A. myosuroides as determined by head counts are presented in Tables 1 and 2. Chlortoluron/tri-allate and isoproturon/tri-allate applied pre-emergence or post-emergence provided acceptable control of A. myosuroides. Both products achieved a level of control significantly greater than that from tri-allate alone, in particular from post-emergence applications. The mean control level from pre-crop emergence application both for chlortoluron/tri-allate and isoproturon/tri-allate was slightly higher than that obtained from post-emergence application. This difference appears to be due to the presence of large A. myosuroides plants (at early tillering) in four of the trials. In these four trials the mean control was 85% and 90% for the chlortoluron and isoproturon combinations, whereas in the two trials with a maximum GS of 13,the respective figures are 94% and 98%, very similar to the pre-emergence results (Table 1).

Although the speed of activity of pre-emergence applications of liquid or granular formulations were identical, there were differences following post-emergence applications (Table 3). In these trials the final level of control from granular applications was not reached until 112 days after application, in contrast to the liquid formulation treatment where 84 days following application were required. The chlortoluron and isoproturon combinations with tri-allate were similar, both appearing to be less active than the isoproturon liquid at 28, 56 and 84 days after application. This may be due to both the application rates employed and the formulation type.

TABLE 3

Speed of activity of post-emergence applications.

Mean percent control from visual assessments (four trials)

Days after application		28	56	84	112
	g a.i./ha				
isoproturon + tri-allate	1500 1875	69	78	87	96
chlortoluron + tri-allate	2500 1875	70	84	87	93
isoproturon	2500	88	92	98	99

Although these trials were designed to evaluate the control of *A. myosuroides*, other weed species did occasionally occur. The results for these species are presented in Tables 4 and 5. *A. fatua* was well controlled from both pre-emergence and post-emergence applications, as were *Matricaria* spp. Both granules gave superior control of *Stellaria media*, *Papaver rhoeas*, *Veronica hederifolia* and *Myosotis arvensis* compared with tri-allate alone.

TABLE 4

Mean percent control of broad-leaved weeds and *A. fatua* from visual assessments in the spring

Species		*A. fatua*	*Matricaria* spp.	*S. media*	*P. rhoeas*	*V. persica*
Number of trials		3	3	3	2	2
Pre-emergence applications	g a.i./ha					
isoproturon + tri-allate	1500 1875	98	100	95	23	66
chlortoluron + tri-allate	2500 1875	99	67	47	100	82
tri-allate	2250	96	0	47	0	79
Post-emergence applications						
isoproturon + tri-allate	1500 1875	93	100	95	93	93
chlortoluron + tri-allate	2500 1875	97	100	83	100	76
tri-allate	2250	65	17	35	33	86

TABLE 5

Percent control of broad-leaved weeds (based on plant counts in the spring)

Species	g a.i./ha	Crop Stage	*Myosotis arvensis*	*Matricaria inodora*	*Galium aparine*	*Stellaria media*	*Veronica hederifolia*	*Papaver rhoeas*
chlortoluron + tri-allate	2500 1875	Pre-em	96	100	42	100	92	100
chlortoluron + tri-allate	2500 1875	Post-em	78	100	44	99	63	100
tri-allate	2250	Post-em	57	14	63	22	12	34

TABLE 6

Crop safety - mean percent crop vigour (eight trials)

		Wheat Phytotoxicity				Barley Phytotoxicity			
		Pre-em		Post-em		Pre-em		Post-em	
Days after application	g a.i./ha	56	84	56	84	56	84	56	84
isoproturon + tri-allate	3000 3750	5	3	0	0	7	2	0	0
chlortoluron + tri-allate	5000 3750	7	4	0	0	2	0	0	0
tri-allate	4500	5	3	0	0	1	0	0	0

Crop safety

Under the conditions in these trials there was no significant crop phytotoxicity (Table 6) or effect on grain yield from double rate applications.

DISCUSSION

Chlortoluron/tri-allate and isoproturon/tri-allate formulated as granules provided excellent weed control from both pre-emergence and early post-emergence applications with a wide margin of safety to the crop. The combinations were more effective than tri-allate used alone for A. myosuroides and broad-leaved weed control, and at least as effective for A. fatua control. Chlortoluron and isoproturon have a complimentary weed control spectrum to tri-allate, enabling a reduction in the dosages of the individual herbicides of 29, 40 and 17% respectively when used in combination.

The chlortoluron and isoproturon combinations with tri-allate displayed significant broad-leaved weed activity. This was expected as both chlortoluron and isoproturon are commercially recommended at 1750 g a.i./ha and 1500 g a.i./ha respectively for the control of a range of broad-leaved weeds.

The final level of control of A. myosuroides was influenced by the growth stage at application. Applications to A. mysuroides which had reached early tillering were less successful than earlier treatments. Published reports (Blair, 1978; McIntosh et al, 1981) have shown that the full activity of isoproturon, when applied to established weed species, is a function of both root and foliar absorption. The absence of any foliar uptake from granular formulations probably explains the partial tolerance of large weeds to such formulations.

In the trials reported here, no significant crop phytotoxicity was noted, however, in these trials good husbandry techniques were employed. It is likely that applications to shallow drilled seed, or open seedbeds, or waterlogged or stressed crops would result in damage, as occurs from the application of chlortoluron, isoproturon or tri-allate in such circumstances.

It has been suggested that granules could be less reliable than liquid sprays due to a greater reliance on soil moisture for activity (Atkin & Turner, 1982). However, applications of granules in these trials made between September and December provided high levels of weed control. This may be associated with the ability of these combinations to control established weeds. Thus weeds which do germinate during a dry period, will be controlled subsequently when surface moisture is available.

Certain granular herbicides which were available during the early 1980's were criticised due to eratic weed control and the large quantities of dust associated with the formulation. Both the chlortoluron/tri-allate and isoproturon/tri-allate granules are produced by a novel manufacturing process which results in the even distribution of the active ingredients over the surface of the granule. This process also eliminates dust from the finished product.

Chlortoluron/tri-allate and isoproturon/tri-allate offer several advantages to the farmer, which are common to all granules: ease and speed of application, reduced operator and environmental contamination potential and application under a wide range of weather conditions. However, unlike previous granular herbicides, these two combinations open the potential for a single application of a granule to provide control of *A. fatua*, *A. myosuroides*, other annual grasses and broad-leaved weeds. Thus in certain situations a sequential liquid herbicide application would not be required, resulting in significant cost benefits associated with a reduced herbicide input and fewer and more convenient treatments.

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BROMOFENOXIM PLUS DICAMBA FOR WEED CONTROL IN FORAGE MAIZE AND SWEET CORN

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ABSTRACT

Under UK conditions maize is both comparatively slow to germinate and to establish; these factors combined with the cultural practices employed, render maize very susceptible to yield loss from weed competition. This paper describes the efficacy and crop safety from a single post-emergence application of a new herbicide field tested during the 1986 and 1987 seasons in the UK. Bromofenoxim/dicamba at 2.0 kg formulated product/ha (750/250 g a.i./ha respectively) applied early post-emergence at GS 12-14 gave excellent control of broad-leaved weeds including triazine resistant types, with good crop tolerance. This treatment provides farmers with the opportunity for the control of emerged broad-leaved weeds, independent of soil moisture, with residual activity and no carry-over effects on following crops.

INTRODUCTION

Pre-emergence applications of atrazine or simazine are traditionally the most commonly used herbicide in Europe for weed control in forage maize or sweet corn. Both herbicides provide good control of many annual weed species. However, their continuous use has led to the well documented emergence of triazine resistant weeds, (Bandeen & Maclaren, 1976; Ducruet & Gasquez, 1978). In addition these herbicides often impose restrictions on succeeding crops and their efficacy and subsequent degradation are greatly influenced by soil moisture. For these reasons complementary or alternative herbicides for use in maize are essential.

The herbicide strategy currently used is still dependent on atrazine or simazine applied pre-emergence to the soil surface or incorporated. This may be followed by an early post-emergence application at GS 13-15 with a contact herbicide, often in association with atrazine.

This paper describes the efficacy and crop safety of a wettable powder formulation of bromofenoxim and dicamba for the control of broad-leaved weeds. This mixture provides greater flexability and avoids the problems of weed resistance and soil persistence of the triazine herbicides.

MATERIALS AND METHODS

The experimental product was formulated as a wettable powder delivering 750 g a.i. bromofenoxim and 250 g a.i. dicamba at 2.0 kg/ha formulated product. The reference products employed in these trials were atrazine as 'Gesaprim 500FW' in the 1986 and 1987 trials, with pyridate as 'Lentagran' as an additional reference in 1987.

The 1986 trials were of a randomized complete block design with three replicates and plots of 3 x 8 m. In 1987 the trials were unreplicated with plots of 4 x 25 m. Treatments were made using a precision plot sprayer incorporating Lurmark 02-F110 nozzles delivering 200 l/ha at 203 kPa.

The trials conducted in the East and South-west of England were located in commercially grown crops utilising areas of natural weed populations.

Crop safety trials were placed in the same crops and applications were made at double the anticipated use rate of 4 kg product/ha. Application timings were governed solely by the growth stage of the crop targeted at between two to four leaves with the exception of atrazine in 1987 which was applied pre-emergence. Visual assessments of efficacy and crop safety were carried out at three week intervals, weed populations were determined by quadrat counts.

RESULTS

Efficacy

The final levels of control as determined by visual assessments are shown for the 1986 and 1987 trials in Tables 1 and 2 respectively.

The results from 1986 demonstrated that bromofenoxim/dicamba gave comparable levels of control to atrazine for 13 weed species, and higher levels of control for two weed species; *Aethusa cynapium* and *Convolvulus arvensis*. However, lower levels of control were observed for three weed species, *Anagallis arvensis*, *Viola arvensis* and *Veronica persica* although for this latter species an acceptable level of control was achieved.

At the time of application the weeds were generally large with up to four to six true leaves. There was little soil moisture for approximately four weeks after application resulting in very slow establishment of the maize. The dry soil conditions did not appear to affect greatly the final levels of weed control. The weed species not controlled by bromofenoxim/dicamba were stunted, as asssessed at three to six weeks after application, but did show significant regrowth at later assessments.

The 1987 trials were designed as a result of the field programme in 1986 which indicated that 2.0 kg/ha was the appropriate efficacy rate.

At the time of the 1987 applications the soil conditions were in contrast to 1986, very wet, although the weed sizes were comparable to those in 1986. The levels of control for all the weed species were higher than that given by atrazine or pyridate. The control of *Solanum nigrum* by atrazine was very poor compared to the 1986 results suggesting that at these sites it was probably atrazine resistant.

Crop safety

Crop safety was determined for double rate applications of bromofenoxim/dicamba (1500/500 g a.i./ha) in comparison to atrazine and pyridate over two years of field trials. Results are not presented in tabular form as no damage from any treatment at any assessment timing was noted during this period.

TABLE 1

Percent control of broad-leaved weeds in 1986 (mean of three sites)

	Number of leaves	bromofenoxim/ dicamba 750/250 g a.i./ha	atrazine 1700 g a.i./ha
Aethusa cynapium	4-5	95	42
Anagallis arvensis	6-8	69	99
Atriplex patula	4	100	100
Capsella bursa-pastoris	3-4	97	100
Chenopodium album	3-4	96	100
Convolvulus arvensis	3-4	85	50
Euphorbia helioscopia	2	94	98
Lamium purpureum	4	94	90
Matricaria spp.	2-3	89	92
Polygonum aviculare	2-6	85	85
Bilderdykia convolvulus	3-4	100	97
Polygonum persicaria	2	99	97
Senecio vulgaris	3-4	100	100
Sinapis arvensis	4	100	100
Solanum nigrum	1-4	97	99
Sonchus arvensis	4-5	95	98
Veronica persica	2-4	90	100
Viola arvensis	5	17	66

TABLE 2

Percent control of broad-leaved weeds in 1987 (mean of four sites)

	Number of leaves	atrazine 1700 g a.i./ha	pyridate 900 g a.i./ha	bromofenoxim/ dicamba 750/250 g a.i./ha
1. *Chenopodium album*	2-4	50	98	100
2. *Polygonum persicaria*	2-4	50	98	98
3. *Solanum nigrum*	4-6	10	80	90
4. *Thlaspi arvense*	4	70	100	98
5. *Trifolium repens*	4	100	80	100

DISCUSSION

The exploratory trials carried out during 1986 demonstrated that 2.0 kg/ha of bromofenoxim + dicamba 50WP controlled a wide spectrum of broad-leaved weeds. This was subsequently confirmed by further trials in 1987. The weed species controlled included those which are very competitive and therefore liable to reduce yield such as Polygonum spp. and species which in addition to affecting yield may also reduce the palatability of the harvested crop e.g. Matricaria spp. and S. nigrum.

Under conditions which favour rapid plant growth dicamba may act as quickly as a contact herbicide, however, more usually the weed control symptoms are typical of a growth regulator herbicide and require up to 20 days for full expression (Barlow & Hicks, 1985). The inclusion of bromofenoxim in combination with dicamba, not only provides a complimentary weed spectrum, but also ensures rapid activity under a wide range of environmental conditions. In the trials reported here neither the dry conditions of 1986 or wet soil conditions of 1987 adversely affected the performance of the herbicides. However, the weather conditions encountered during the 1987 season resulted in the late germination of a large number of weeds. This is reflected in the result achieved for atrazine applied pre-emergence where (excluding S. nigrum) the overall level of control was 50-70%. The later application of bromofenoxim + dicamba resulted in a mean control figure of 99%. The S. nigrum present in the 1987 trials appeared to be triazine resistant as repeated field applications of atrazine had little or no effect, the species was, however, highly susceptible to bromofenoxim + dicamba. This is of importance where atrazine is employed for grassweed control, and the control of broad-leaved weeds is also required. In these situations a tank-mix or sequential treatment of bromofenoxim/dicamba and atrazine would provide control of grass, broad-leaved and atrazine resistant weeds.

The use of triazine herbicides at the rates required for grass and broad-leaved weed control can restrict the range of subsequent crops that may be cultivated. Bromofenoxim/dicamba does not pose a hazard to subsequent crops. Where a tank-mix or sequential treatment to atrazine is required, the application rate of atrazine could be reduced from 1700 g a.i./ha to 1000 g a.i./ha so as to minimise re-cropping restrictions.

No crop phytotoxicity was noted under the varied environmental conditions encountered in these trials, indicating that this combination has a very wide safety margin.

The use of bromofenoxim/dicamba alone, sequentially or tank-mixed with other herbicides provides the UK farmer with a flexible option for weed control in forage maize and sweet corn.

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NEW FORMULATIONS OF PHENOXYPROPIONIC HERBICIDES CONTAINING ONLY THE HERBICIDALLY ACTIVE ISOMER FOR THE CONTROL OF BROAD-LEAVED WEEDS IN CEREALS

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ABSTRACT

Formulations of mecoprop or dichlorprop have contained a mixture of two optical isomers, but only one of the isomers has herbicidal activity. Using a novel proprietary separation process, it is now possible to commercially produce formulations of mecoprop and dichlorprop containing only the herbicidally active isomer. Results are presented from more than 30 replicated weed control efficacy and crop safety trials carried out over two seasons, which confirm that these herbicidally active isomer formulations are twice as active as conventional racemic mecoprop or dichlorprop, whilst also exhibiting increased crop safety. The new formulations can be recommended at the same growth stage timings but at half the appropriate application rate of current racemic products with consequent improvements to environmental and operator safety. Commercial development of the new formulations and of formulated mixtures with other active ingredients is now taking place.

INTRODUCTION

The herbicidal properties of mecoprop were first described more than 30 years ago (Leafe, 1956; Lush, 1956), while the growth regulating properties of dichlorprop were described even earlier (Zimmerman & Hitchcock, 1944), although dichlorprop was not introduced commercially as a herbicide until 1961. Both products have achieved widescale commercial usage, mecoprop having particular activity in cereals against *Galium aparine* and *Stellaria media*, while dichlorprop is particularly useful in controlling these same weeds plus polygonaceous weeds. The commercial products are composed of a mixture of two optical isomers $R^{(+)}$ and $S^{(-)}$ of which only the $R^{(+)}$ isomer is herbicidally active. Using a novel proprietary separation process it is now possible to produce $R^{(+)}$ technical acids of mecoprop and dichlorprop and, therefore, from these produce commercial formulations containing only the herbicidally active isomer.

This paper describes work carried out to prove the efficacy and crop safety of herbicidally active isomer formulations of mecoprop and dichlorprop under UK conditions.

MATERIALS AND METHODS

The following herbicidally active isomer formulations were compared with standard commercially available K salt formulations of mecoprop and dichlorprop:

$R^{(+)}$ mecoprop K salt 600 g a.i./litre	: Code No. AHM866 Trademark 'Marks Mecoprop-HI'
$R^{(+)}$ dichlorprop K salt 500 g a.i./litre	: Code No. AHM867

All trials were carried out on commercial farms in Yorkshire, Lincolnshire and Humberside. Winter cereal efficacy trials were carried out in winter wheat crops and crop safety trials in winter barley crops. All spring cereal trials were in spring barley except for one efficacy trial in spring oats. Rates of herbicide application were based around current label recommendations and all treatments were randomized in blocks replicated three times in efficacy trials and four times in crop safety trials. Plot sizes were 12m x 2m in efficacy trials and 12m x 3m in crop safety trials. All treatments were applied with an Oxford Precision Sprayer in 200 l/ha of water at a pressure of 210 kPa using Spraying Systems TeeJet 8002 brass flat fan nozzles.

Assessments of weed control were carried out six to eight weeks after spraying by scoring treated plots relative to untreated control plots. Crop tolerance trials were carried out on sites free of weeds and were assessed for scorch one week after spraying, for crop vigour three weeks after spraying and the number of grains per ear were counted on 20 ears per plot immediately prior to harvesting. A Hege small plot combine was used at harvest to determine grain yield.

RESULTS

Mecoprop

Herbicidal efficacy

Nine efficacy trials were carried out on winter wheat in spring 1986, which was notable for its very poor spraying conditions. Two trials were sprayed in March onto small weeds under low temperature conditions, while the spraying of the other seven trials was delayed until late May when the weeds were very large. Control of the main target weeds S.media and G.aparine was satisfactory with the standard racemic mecoprop (Table 1), which showed a small dose response. Although a dose response was still apparent, the control of other weeds was poorer and was not so consistent, hence the moderate overall level of weed control. AHM 866 was applied at half the dose of racemic mecoprop but gave equivalent weed control to the racemic. There was some variation between individual paired doses but the mean figures for all doses show that overall weed control and control of S.media and G.aparine did not differ between AHM 866 and racemic mecoprop, while the more difficult weeds were controlled slightly better by AHM 866.

Four efficacy trials were sprayed at the end of April 1987 when temperatures were warm and both crop and weeds were growing strongly. Good overall levels of weed control were achieved (Table 2) and high levels of control of S.media and G.aparine were obtained by both racemic mecoprop and AHM 866. Both formulations showed a slight dose response but did not differ in the rates of control achieved for paired doses. Control of other weeds was not so high and showed greater variation, however meaned over all doses there was no significant difference between the control given by racemic mecoprop and AHM 866.

Efficacy under autumn/winter conditions was tested in three trials with spraying taking place in January 1987 (Table 3). Control of S.media was excellent at all rates but control of G.aparine was only moderate under the cold winter conditions, however there was no significant difference between the levels of control achieved with racemic mecoprop or AHM 866. Other weeds showed poorer and inconsistent levels of control with AHM 866 slightly more variable than the racemic.

TABLE 1

Mean percentage control of weeds with mecoprop in winter wheat treated in spring 1986

Weed species	No. of sites	Rate of mecoprop g a.i./ha												Mean of all rates	
		1995 M	997 $R^{(+)}$	2195 M	1098 $R^{(+)}$	2395 M	1197 $R^{(+)}$	2595 M	1297 $R^{(+)}$	2795 M	1397 $R^{(+)}$	5586 M	2793 $R^{(+)}$	M	$R^{(+)}$
Overall	9	70	75	73	74	79	75	74	78	82	81	86	87	77	78
S. media	8	78	83	85	83	86	85	87	85	89	89	95	96	87	87
G. aparine	3	64	70	80	78	80	72	74	74	86	75	85	91	78	77
Matricaria spp.	4	9	10	9	8	14	12	9	12	17	18	33	26	15	14
Galeopsis tetrahit	2	24	34	35	25	28	30	26	43	38	40	55	56	34	38
Myosotis arvensis	1	44	37	25	32	29	31	25	34	34	46	50	48	35	38
Polygonum aviculare	1	27	30	42	23	40	33	40	50	38	50	53	65	40	42

M = racemic mecoprop, $R^{(+)}$ = $R^{(+)}$ isomer of mecoprop

TABLE 2

Mean percentage control of weeds with mecoprop in winter wheat treated in spring 1987

Weed species	No. of sites	Rate of mecoprop g a.i./ha								Mean of all rates	
		1995 M	997 $R^{(+)}$	2395 M	1197 $R^{(+)}$	2795 M	1397 $R^{(+)}$	5586 M	2793 $R^{(+)}$	M	$R^{(+)}$
Overall	4	81	81	84	83	90	83	93	92	87	85
S. media	3	86	86	87	88	93	87	94	95	90	89
G. aparine	1	90	82	93	88	93	93	95	95	93	90
Matricaria spp.	2	31	51	50	53	43	38	66	55	48	49
Veronica persica	1	52	35	46	20	53	60	72	82	56	49

M = racemic mecoprop, $R^{(+)}$ = $R^{(+)}$ isomer of mecoprop

TABLE 3

Mean percentage control of weeds with mecoprop in winter wheat treated in January 1987

Weed species	No. of sites	Rate of mecoprop g a.i./ha								Mean of all rates	
		1995 M	997 $R^{(+)}$	2395 M	1197 $R^{(+)}$	2795 M	1397 $R^{(+)}$	5586 M	2793 $R^{(+)}$	M	$R^{(+)}$
Overall	3	82	76	87	83	88	81	97	94	88	84
S. media	3	93	90	94	88	96	94	100	99	96	93
G. aparine	1	72	73	75	74	78	77	94	93	80	79
Matricaria spp.	1	50	27	50	53	43	40	87	88	57	52
V. persica	1	78	77	82	78	80	77	88	85	82	79
Lamium purpureum	1	55	33	54	55	50	40	77	83	59	53
Aphanes arvensis	1	77	80	80	77	80	77	85	84	80	80

M = racemic mecoprop, $R^{(+)}$ = $R^{(+)}$ isomer of mecoprop

Efficacy in spring cereals was tested in five trials in 1986 (Table 4) and three trials in 1987 (Table 5). Control of *S. media*, *Bilderdykia convolvulus* and *Chenopodium album* was excellent in all trials in both seasons, but the control of *Polygonum aviculare*, *Veronica persica*, *Matricaria* spp. and *Viola arvensis* varied from moderate to exceedingly poor and reduced the overall levels of control. In both seasons the level of weed control given by racemic mecoprop was matched by that given by half that dose of AHM 866.

TABLE 4

Mean percentage control of weeds with mecoprop in spring cereals treated in 1986

Weed species	No. of sites	Rate of mecoprop g a.i./ha								Mean of all rates	
		2186 M	1093 $R^{(+)}$	2394 M	1197 $R^{(+)}$	2622 M	1311 $R^{(+)}$	5244 M	2622 $R^{(+)}$	M	$R^{(+)}$
Overall	5	75	80	82	82	83	82	88	85	82	82
S. media	4	89	91	94	94	92	94	94	96	92	94
P. aviculare	3	59	62	65	61	64	62	62	67	63	63
V. persica	3	4	6	9	9	8	9	28	13	12	9
B. convolvulus	2	100	100	100	100	100	100	100	100	100	100
Matricaria spp.	2	5	6	2	5	1	2	15	7	6	5
C. album	1	98	98	83	83	82	100	100	99	91	95
Sinapsis arvensis	1	83	93	97	95	93	97	98	97	91	96
Capsella bursa-pastoris	1	82	91	95	93	93	92	92	94	91	93

M = racemic mecoprop, $R^{(+)}$ = $R^{(+)}$ isomer of mecoprop

TABLE 5

Mean percentage control of weeds with mecoprop in spring cereals treated in 1987

Weed species	No. of sites	Rate of mecoprop g a.i./ha								Mean of all rates	
		1995 M	998 $R^{(+)}$	2394 M	1197 $R^{(+)}$	2793 M	1397 $R^{(+)}$	5586 M	2791 $R^{(+)}$	M	$R^{(+)}$
Overall	3	70	75	69	71	73	72	81	78	73	74
S. media	3	100	99	100	98	99	100	100	100	100	99
P. aviculare	3	56	57	51	58	58	58	65	57	58	58
B. convolvulus	2	100	100	100	96	100	100	98	100	100	99
V. persica	1	85	90	85	87	85	87	88	90	86	89
V. arvensis	1	60	80	77	80	80	78	85	85	76	81
C. album	1	100	95	98	100	100	100	100	100	100	99
Urtica urens	1	95	93	98	98	100	99	100	100	98	97

M = racemic mecoprop, $R^{(+)}$ = $R^{(+)}$ isomer of mecoprop

Crop safety

Crop safety was assessed over two seasons using normal and double doses on weed-free sites. In 1986, spring treatment of winter barley resulted in slight post-spraying scorch with racemic mecoprop but less scorch with AHM 866. There was no significant effect on crop height, grains per ear or grain yield from any treatment. In 1987, treatments were applied to a winter barley crop at three timings during the winter months. Scorch was noted only from the first (December) treatment and then only on the racemic treatments. No other crop effects were noted for any treatment. When AHM 866 was tested in spring barley, any slight crop scorch was always less than with racemic mecoprop.

Crop safety was also tested in all winter and spring cereal efficacy trials with the inclusion of double doses. Any observed slight adverse crop scorch was always less from AHM 866 than from racemic mecoprop.

Dichlorprop

Efficacy and crop safety

Four trials were carried out in spring barley in 1986 using a range of doses and a double safety dose (Table 6). Control of S. media, S. arvensis, C. bursa-pastoris and B. convolvulus was excellent but other weeds were less well controlled. However, there was no difference between the level of control offered by racemic dichlorprop and half that rate of AHM 867. No adverse effects on the crop were noted from any treatment in any trial.

TABLE 6

Mean percentage control of weeds with dichlorprop in spring cereals treated in 1986

Weed species	No. of sites	Rate of dichlorprop g a.i./ha								Mean of all rates	
		2500	1250	2800	1400	3100	1550	6200	3100		
		D	$R^{(+)}$	D	$R^{(+)}$	D	$R^{(+)}$	D	$R^{(+)}$	D	$R^{(+)}$
Overall	4	78	78	81	79	79	78	85	84	81	80
S. media	3	85	88	91	89	91	92	94	97	90	92
P. aviculare	2	46	50	47	50	52	42	64	66	52	52
V. persica	2	26	43	36	48	44	48	52	60	40	50
Matricaria spp.	2	13	9	12	19	28	20	34	34	22	21
S. arvensis	1	88	94	86	95	95	96	100	95	92	95
C. bursa-pastoris	1	88	89	92	89	95	98	96	94	93	93
B. convolvulus	1	100	100	100	100	100	100	100	100	100	100

D = racemic dichlorprop, $R^{(+)}$ = $R^{(+)}$ isomer of dichlorprop

DISCUSSION

The results from both winter and spring cereal efficacy trials over two seasons confirmed that over a range of spraying conditions, AHM 866 mecoprop was herbicidally twice as active as standard racemic mecoprop, whilst a more limited range of trials pointed to AHM 867 dichlorprop being similarly twice as active as current dichlorprop formulations in spring cereals. Specific crop safety trials and the safety doses in the efficacy trials demonstrated that AHM 866 was somewhat safer to the crop than racemic mecoprop as shown by the reduction or elimination of the crop scorch in the few trials where this was recorded. Unreported trials in winter and spring cereal variety strips confirmed the safety of AHM 866 to all the usually sown varieties of wheat and barley. AHM 866 may therefore be confidently recommended for use at application rates half those of current product labels for racemic mecoprop and at the same crop growth stage timing. Typically, in winter cereals, the rate for control of S. media and G. aparine would be 2 l/ha of the 600 g a.i./l formulation.

With the reduced application rate, a reduction in pack size becomes feasible and desirable, from the current 20 l down to 10 l with corresponding increases in ease of use and, more importantly, safety for the sprayer operator. For the supplier, the benefits are reduced transport and storage costs due to the reduced volume of the more active formulation.

Toxicology reports showed that the toxicology of AHM 866 is similar to that of the equivalent racemic formulation. Hence the widespread use of AHM 866 would have considerable benefits to the environment, because the elimination of the inert isomer from the formulation results in a consequent halving of the organic material placed into the environment in the spraying process.

AHM 867 (dichlorprop) would appear to offer similar advantages over standard racemic dichlorprop, although it is at a less advanced stage of development, reflecting its lesser importance in the UK market.

As the weed spectrum for AHM 866 is similar to racemic mecoprop, in many field situations it will be necessary to provide a partner herbicide to give the full spectrum of weed control. Many potential partners have been checked in unreported biological compatibility trials so that a full range of broad-leaved weed and grass weed herbicide as well as fungicide and plant growth regulator tank mixture recommendations is available for commercial use. Formulated mixtures of R(+) mecoprop and R(+) dichlorprop with other active ingredients are under development.

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PHENMEDIPHAM CO-FORMULATIONS FOR BROAD-LEAVED WEED CONTROL IN SUGAR BEET

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ABSTRACT

In trials over the past three years a co-formulation of ethofumesate with phenmedipham showed better safety to small beet than the current ethofumesate + phenmedipham tank-mix recommendation, without loss of weed control. The co-formulation allowed greater flexibility in spray timing than the current tank-mix recommendation and was more convenient to use. Tank-mixes of the ethofumesate/phenmedipham co-formulation with metamitron proved safe and very effective; in many situations giving season-long weed control from a two-spray programme even in the absence of a pre-emergence herbicide treatment.

In the same trials a co-formulation of phenmedipham with desmedipham proved as safe and effective as phenmedipham, alone or in tank-mix with ethofumesate or metamitron.

INTRODUCTION

Phenmedipham has been widely used for broad-leaved weed control in sugar beet since the late 1960s. Initially phenmedipham was used alone, at 1140 g a.i./ha in 220 l/ha, as a post-emergence contact spray, usually following a pre-emergence herbicide treatment. Now it is used almost universally in low dose (194 - 400 g a.i./ha), low volume (80 - 100 l/ha) repeat spray programmes, often in mixture with a residual herbicide. Such mixtures can give improved control of weeds beyond the cotyledon stage and residual control of later germinating weeds, allowing the farmer to regularly achieve season-long weed control. The development of such mixtures is well summarised in a paper by Whitehead *et al*., 1986.

Ethofumesate is frequently tank-mixed with phenmedipham. The mixture gives better control of weeds beyond the cotyledon stage than phenmedipham alone, especially *Polygonum* spp., and has good residual activity. Unfortunately it has proved less selective to small beet than phenmedipham and can only be used at effective doses when beet are past the two true leaf stage. The delay until beet reach this stage allows weeds to grow and become more difficult to control and it would be beneficial to be able to use an ethofumesate + phenmedipham mixture sooner. With this in mind co-formulations of ethofumesate with phenmedipham, designed to improve crop selectivity, have been developed. One such formulation is now sold in Ireland as Betanal Tandem (1) and is presently in large scale development trials in the UK.

This paper reports results of extensive testing of this co-formulation in the UK over the past three years. Also reported are trials with a co-formulation of phenmedipham with desmedipham, a close analogue of phenmedipham, which has less potential to crystallize on dilution with water than current phenmedipham formulations.

MATERIALS AND METHODS

Herbicides used were:

ethofumesate 100g + phenmedipham 80g/l co-formulation EC (etho/pmp)

phenmedipham 129g + desmedipham 34 g/l co-formulation EC (pmp/dmp)

phenmedipham 114g/l EC as Betanal E (1) (pmp)

ethofumesate 200g/l EC as Nortron (2) (etho)

metamitron 700g/kg water dispersible grain as Goltix WG (3) (meta)

97% refined paraffinic oil as Actipron (4) (oil)

Treatment details and timings are shown in Tables 1-4.

Trials were conducted on farm crops of sugar beet. Approximately half of these crops had been treated with a pre-emergence residual herbicide, usually ethofumesate/chloridazon or chloridazon, by the farmer.

Treatments were applied using pressurised knapsack sprayers calibrated to deliver 100 l/ha through flat fan nozzles operating at a pressure of 280 - 300 kPa. Treatments were replicated three times in a complete randomised block design. Plots were 15 - 18 m long by four rows of beet wide and were divided into sub plots 5 - 6m long to permit the testing of up to three different timing regimes for each treatment eg T1 + T3, T2 + T3, T1 + T3.

T1 =	beet at cotyledon to cotyledon + bud stage (first true leaves just visible)
T2 =	7 to 10 days after T1, beet at 2-4 true leaf stage
T3 =	7 to 10 days after T2 or when appropriate according to weed growth, beet at 4-8 true leaf stage.

Crop stage and weed sizes were recorded before each spray application. Visual assessments of crop safety (untreated crop = 100% vigour) and weed control (untreated = 0% control) by biomass were made at intervals through the season.

RESULTS

Ethofumesate/phenmedipham co-formulation

1984 Trials (Table 1)

Etho/pmp at 3 l/ha gave good broad-leaved weed control, better than phenmedipham and similar to a phenmedipham + ethofumesate tank-mix (tm) in comparable spray programmes. Crop safety of etho/pmp at 3 l/ha was good in two or three spray programmes beginning when beet were at the cotyledon + bud stage; much better than the phenmedipham + ethofumesate tm and similar to phenmedipham alone. Reducing the dose of etho/pmp to 2 l/ha improved crop safety but reduced weed control unacceptably. Increasing the dose of etho/pmp to 4 or 5 l/ha gave little benefit in weed control over etho/pmp at 3 l/ha and reduced crop safety to small beet unacceptably.

Etho/pmp at 4 or 5 l/ha and phenmedipham + ethofumesate tm proved safe to beet in programmes beginning at T2 (beet at 2-4 true leaf stage).

1985 Trials (Table 2)

Three spray programmes beginning with etho/pmp at 2 l/ha when beet were at the cotyledon stage and continuing at 3 or 4 l/ha for subsequent sprays gave excellent broad-leaved weed control in the absence of a pre-emergence herbicide treatment. Doses of 4 l/ha offered no advantage in weed control over 3 l/ha etho/pmp at T2 or T3 spray timings. Two or three spray programmes of etho/pmp proved safer to beet in the absence of a pre-emergence treatment than the phenmedipham + ethofumesate tm or phenmedipham alone. Where ethofumesate/chloridazon was used pre-emergence two sprays of etho/pmp gave almost complete broad-leaved weed control but crop safety was no better than that of the phenmedipham + ethofumesate tm.

1987 Trials (Tables 3 and 4)

In the absence of a pre-emergence herbicide treatment three well-timed sprays of etho/pmp gave season-long weed control. Crop safety to cotyledon beet was good.

Addition of 1.25 kg/ha metamitron to 2 or 3 l/ha etho/pmp or to 3.5 l/ha phenmedipham resulted in almost complete weed control from two or three spray programmes beginning at T1. Etho/pmp at 3 l/ha ± metamitron at 1.25 kg/ha gave better control of *Polygonum aviculare* in spray programmes beginning at T2 than phenmedipham or the phenmedipham + metamitron tm.

Results of etho/pmp following pre-emergence treatments are not presented in tabular form due to lack of space. In these trials etho/pmp two-spray programmes gave essentially complete weed control. Crop safety was good and similar to phenmedipham or the phenmedipham + metamitron tm.

TABLE 1

Mean % weed control and mean % crop vigour 12-16 DAT, five trials, 1984

Treatment	Dose l or kg/ product ha	% Weed control T1 + T2	T2 + T3	T1 + T2 + T3	% Crop vigour T1 + T2	T2 + T3	T1 + T2 + T3
etho/pmp	2	75	74	82	83	87	78
etho/pmp	3	88	86	91	72	83	77
etho/pmp	4	89	87	93	66	82	71
etho/pmp	5	92	90	93	58	81	65
pmp + etho	2.5 + 1.5	86	89	93	67	81	73
pmp/dmp	2	84	72	82	79	86	82
pmp/dmp	2.5	87	79	88	74	83	80
pmp/dmp	3	87	82	88	66	83	73
pmp	3.5	87	73	87	71	82	72
meta + oil	1.7 + 1.7	87	83	94	88	87	83

T1 beet = cotyledon + bud, T2 beet = 2 - 4 true leaves, T3 beet = 4 - 8 true leaves

TABLE 2

Mean % weed control and mean % crop vigour 10-23 DAT, 1985

	l or kg/ product ha			No pre-emergence (three trials)				With pre-emergence * (three trials)	
				% Weed control			% Crop vigour	% Weed control	% Crop vigour
	T1	T2	T3	T1 + T2	T1 + T3	T1 + T2 + T3	T1 + T2 + T3	T1 + T2	T1 + T2
etho/pmp	2	3	3	92	83	96	94	99	93
etho/pmp	2	3	4	92	87	97	97	99	95
etho/pmp	2	4	4	94	82	97	97	98	90
pmp + etho	2.5 + 1.5**			95	93	98	88	99	93
pmp/dmp	2.5	2.5	2.5	82	78	92	96	97	96
pmp	3.5	3.5	3.5	85	80	92	92	95	98

T1 beet = cotyledon + bud, T2 beet = 2-4 true leaves, T3 beet = 4-8 true leaves

* ethofumesate/chloridazon as 3.5 l/ha Spectron. (2)

** AT T1, T2 and T3

TABLE 3

Mean % weed control and mean % crop vigour 12-17 DAT, three sites, no pre-emergence treatment, 1987

	l or kg/ product ha			% Weed control					% Crop vigour		
	T1	T2	T3	T1 + T3		T2 + T3		T1 + T2 + T3	T1 + T3	T2 + T3	T1 + T2 + T3
				O'll	P.avic	O'll	P.avic	O'll			
etho/pmp	2	2	2	90	88	82	69	96	94	99	91
etho/pmp	2	3	3	90	88	92	94	96	96	96	92
etho/pmp + meta	2 + 1.25	2 + 1.25	2 + 1.25	96	99	92	84	99	96	96	90
etho/pmp + meta	2 + 1.25	3 + 1.25	3 + 1.25	97	95	96	94	99	92	97	88
pmp	3.5	3.5	3.5	91	92	89	70	97	98	98	95
pmp + meta	2.5 + 1.25	2.5 + 1.25	2.5 + 1.25	94	86	95	75	99	99	99	96

O'll = Overall   P.avic = *P. aviculare*
T1 beet = cotyledon + bud, T2 beet = 2-4 true leaves, T3 beet = 4-8 true leaves
T1 P. aviculare = cotyledon, T2 P. aviculare = 2 true leaves

TABLE 4

Mean % weed control and mean crop vigour 15-20 DAT, 1987

		No pre-emergence (three trials)		With pre-emergence* (two trials)	
	l or kg/ product ha	% Weed control T1 + T2 + T3	% Crop vigour T1 + T2 + T3	% Weed control T1 + T2	% Crop vigour T1 + T2
pmp/dmp	2	91	96	92	79
pmp/dmp	2.5	94	96	96	75
pmp/dmp + meta	2 + 1.25	100	97	98	82
pmp/dmp + etho	2 + 1.5	99	94	98	75
pmp	3.5	93	99	96	80
pmp + meta	2.5 + 1.25	100	98	98	87
pmp + etho	2.5 + 1.5	99	95	98	78

T1 beet = cotyledon + bud, T2 beet = 2-4 true leaves, T3 beet = 4-8 true leaves

* ethofumesate/chloridazon as Spectron or chloridazon as Trojan SC (2)

Phenmedipham/desmedipham co-formulation

Pmp/dmp at 2.5 l/ha gave weed control and crop safety similar to 3.5 l/ha phenmedipham in two or three spray programmes, with or without a pre-emergence herbicide treatment. In mixtures with 1.25 kg/ha metamitron or 1.5 l/ha ethofumesate, 2 l/ha pmp/dmp proved as effective and safe as phenmedipham + metamitron or phenmedipham + ethofumesate tank-mixes.

DISCUSSION

Trials in the past three years showed 3 l/ha etho/pmp (phenmedipham 240 g a.i. + ethofumesate 300 g a.i./ha) to be safer to the crop, more convenient to use than the present tank-mix recommendation (phenmedipham 285 g a.i. + ethofumesate 300 g a.i./ha) and just as effective. The improvement in crop safety was not sufficient for 3 l/ha etho/pmp to be used on cotyledon beet. However, 2 l/ha etho/pmp proved safe at this timing and spray programmes beginning with 2 l/ha etho/pmp on cotyledon beet, progressing to 3 l/ha etho/pmp for later sprays gave safe and very effective weed control.

The addition of 1.25 kg/ha metamitron, a second residual herbicide, to etho/pmp gave further improvement in broad-leaved weed control such that, in 1987, a two spray programme of etho/pmp + metamitron gave season-long weed control with or without a pre-emergence treatment. This approach requires confirmation in other conditions and in other seasons but is an interesting possibility.

The co-formulation of phenmedipham with desmedipham is under consideration as an alternative to our phenmedipham formulation. Pmp/dmp at 2.5 l/ha gave broad-leaved weed control similar to phenmedipham 3.5 l/ha and had similar crop-safety. Tank-mixes of 2 l/ha pmp/dmp with 1.25 kg/ha metamitron or 1.5 l/ha ethofumesate are possible and have proved as safe and effective as current recommendations for 2.5 l/ha phenmedipham with metamitron or ethofumesate.

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THE CONTROL OF VOLUNTEER POTATOES WITH FLUROXYPYR IN UK CEREALS

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ABSTRACT

The elimination of volunteer potatoes in following cereal crops has many advantages for the crop rotation. Field experiments with fluroxypyr in unreplicated, replicated and grower trials were conducted in 1984, 1986 and 1987. Doses ranging from 200 to 400 g ai/ha were evaluated at various timings with respect to cereal crop growth stage and size of potato haulm. The effect on daughter tubers at harvest, their capacity for sprouting following storage, and the field levels of 2nd year regrowth were recorded. The differential effect of fluroxypyr on different potato cultivars was shown by variety screens in the absence of crop competition. Results show that fluroxypyr can be recommended for the control of volunteer potatoes in winter cereals up to GS39 at a dose rate of 400 g ai/ha.

INTRODUCTION

Volunteer potatoes (*Solanum tuberosum*) are an increasingly serious national weed problem, particularly in following cereal crops. Potato volunteers lead to the carry over of potato cyst nematode (Lumkes, 1979) thereby eliminating the advantages of crop rotation; they may act as a source for potato blight, will compete directly with the crop for water and nutrients, and will interfere with the harvesting of cereals with consequent increased costs.

Preliminary investigations at the Weed Research Organisation (Lutman *et al.*, 1982) showed the potential of fluroxypyr for reducing the problem of volunteer potatoes in cereals. The herbicide fluroxypyr, first available commercially in 1984, has been widely used for the control of cleavers in cereals up to GS 39, and has been instrumental in revolutionising broad-leaved weed control in cereals.

This paper describes the field experiments which have resulted in a recommendation for the use of fluroxypyr for the control of potato volunteers. The initial results of these experiments have been previously reported (Bunn *et al.*, 1986). This application has been used commercially in 1986 and 1987 with good results.

MATERIALS AND METHODS

Volunteer potato control trials

The unreplicated trials conducted in 1984 have been described by Bunn et al. (1986). In 1986 two further unreplicated trials were carried out to evaluate the activity of different doses of fluroxypyr 'Starane* 2' at two timings. In addition, glyphosate 'Roundup' which has provided farmers with a potential method of volunteer potato control (O'Keeffe, 1980) was applied pre-harvest. Applications were made using a Hardi tractor mounted sprayer with 12m boom and flat fan 110° nozzles. Doses and other experimental details are given in Table 1. After harvesting the wheat and removing the straw, five potato plants (identified by dead haulm in the stubble) were lifted in each plot and the daughter tubers retained to assess viability. Tubers were stored over winter in frost-free conditions and then transferred to a heated glasshouse in January 1987 to encourage sprouting; assessments were made on 26 March.

Straw was removed from the 1986 sites and the stubble ploughed in during December. The sites were drilled with carrots in early and mid-May 1987. Estimates of the percentage ground cover of potato volunteers were made in late June 1987.

TABLE 1

Summary of treatment data for 1986 unreplicated trials

	Treatment		Date Sprayed	Crop Growth Stage	Spray Volume
1	Fluroxypyr	200 g a.i./ha	23 June	GS 39	300 l/ha
2	Fluroxypyr	350 g a.i./ha	23 and 27 June	GS 39 and 45	300 l/ha
3	Fluroxypyr	400 g a.i./ha	23 and 27 June	GS 39 and 45	300 l/ha
4*	Glyphosate	1440 g a.i./ha	28 August	GS 90	300 l/ha
5	Unsprayed				

	Site 1	Site 2
Location	Yaxley, Cambs	Holme, Cambs
Soil type	Peat	Peat
Volunteer potato variety	Maris Piper (grown 1985)	Maris Piper (grown 1985)
Potato haulm height	65cm	65-80cm
Daughter tuber diameter at spraying (treatments 1 to 3)	0.5 - 1.5 cm	0.7 - 1.5 cm

* Applied 14 days before wheat harvested.

In 1987 replicated trials (with three replicates) were carried out to define the rate and timing of fluroxypyr for volunteer potato control in cereals. Applications were made using a modified Oxford Precision Sprayer with flat fan 80° nozzles. Experimental details are give in Table 2.

TABLE 2

Summary of treatment data for 1987 replicated trials

Treatment 1	Fluroxypyr	300 g ai/ha
Treatment 2	Fluroxypyr	350 g ai/ha
Treatment 3	Fluroxypyr	400 g ai/ha
Treatment 4	Unsprayed	

	Site 1	Site 2	Site 3
Location	Holme, Cambs	Nornea, Norfolk	Lindholme, Yorks
Soil type	Peat	Clay loam	Peat
Date sprayed	10 and 23 June	16 and 23 June	10 June
Crop growth stage	GS 32 and 39	GS 41 and 53	GS 45
Spray volume	300 l/ha	300 l/ha	300 l/ha
Vol potato variety	Maris Piper	Maris Piper	Cara
Potato haulm height	20 - 40cm	30 - 40 cm	30 - 45cm

Varietal susceptibility trial

Field observations indicated varietal differences in susceptibility of potatoes to fluroxypyr. Unreplicated trials were made in 15 cultivars in 1986 (Bunn *et al.*, 1986) and 12 cultivars in 1987. In 1987 each plot was sprayed with 400 g a.i./ha at the stem elongation stage. In early October 1986 five plants were lifted from each of six varieties (Desiree, Cara, Maris Piper, Record, Estima) to assess the daughter tuber yield.

Commercial usage monitoring

Clearance was granted both in 1986 and 1987 for the application of fluroxypyr at 400 g a.i./ha to a limited area of winter cereals at growth stages up to GS 39.

RESULTS

Volunteer potato control

In all field trials the haulm of unsprayed potato volunteers remained green and healthy up to the final assessment.

The percentage control of volunteer potato top growth in the 1984 and 1986 trials was reported by Bunn *et al*. (1986). The results for 1987 are given in Table 3. The level of control was similar at each assessment timing for each application timing. Percentage control increased with time after treatment.

TABLE 3

Percentage control of volunteer potato top growth with fluroxypyr applied in 1987, assessed two, four and eight weeks after treatment (WAT). Mean ± standard error of three replicates (untransformed data).

Treatment	Dose g a.i./ha	Cereal GS	% kill of potato shoots 2WAT	4WAT	8WAT
Untreated			0	0	0
Fluroxypyr	300	32	21.0±4.93	56.6±6.67	95.0±5.00
Fluroxypyr	350	32	33.3±4.41	69.7±14.95	93.3±6.67
Fluroxypyr	400	32	41.0±7.57	70.0±14.43	86.7±8.82
Fluroxypyr	300	39	71.7±1.67	93.3±6.67	NA
Fluroxypyr	350	39	75.0±2.89	93.3±6.67	NA
Fluroxypyr	400	39	71.7±8.33	83.3±8.82	NA
Fluroxypyr	300	41	36.7±8.82	50.0±5.77	76.7±14.53
Fluroxypyr	350	41	33.3±6.67	70.0±5.77	90.0±10.00
Fluroxypyr	400	41	40.0±5.77	60.0±5.77	85.0±8.66
Fluroxypyr	300	45	60.0±5.77	61.7±4.41	NA
Fluroxypyr	350	45	60.0±5.77	70.0±5.77	NA
Fluroxypyr	400	45	75.0±2.89	75.0±2.89	NA
Fluroxypyr	300	53	36.7±6.67	43.3±8.82	83.3±8.82
Fluroxypyr	350	53	46.7±3.33	53.3±3.33	66.7±8.82
Fluroxypyr	400	53	43.3±3.33	50.0±0.00	83.0±10.16

NA = Not available

The lifting of daughter tubers from volunteer potatoes following the wheat harvest of 1986 showed that tubers continued to increase in size after all treatments. The largest tubers however came from the untreated and glyphosate treated plots. The effect of fluroxypyr on the tubers was manifest as a scaly or flaky appearance at the eye end, and blackening of some eyes. Tubers from the glyphosate treated plot were prone to rotting and during storage from early October to late March, 32% of tubers rotted. In addition 73% of glyphosate treated tubers produced abnormal "cauliflower-like" shoots during storage, these however recovered later and grew normally. Table 4 shows the mean viability of tubers following storage over winter.

TABLE 4

Viability of daughter tubers lifted following treatments in 1986. (mean of two sites)

Treatment	Dose g a.i./ha	% (range) of eyes sprouting following Application at GS 39	 Application at GS 45	 Application at GS 90
Fluroxypyr	200	55(50-60)	-	-
Fluroxypyr	350	77.5(65-90)	75(50-100)	-
Fluroxypyr	400	52.5(45-60)	65(30-100)	-
Glyphosate	1440	-	-	62.9(60-77)
Untreated		100	100	100

The second year regrowth assessments were made in the carrot crops that followed the wheat at the 1986 sites. Volunteer potatoes growing from daughter tubers or seed were scored as % ground cover (Table 5).

TABLE 5

Second year regrowth of volunteer potatoes assessed in 1987 following treatments in 1986.

Treatment	Dose g a.i./ha	% (range) of eyes sprouting following Application at GS 39	 Application at GS 45	 Application at GS 90
Fluroxypyr	200	25 (1 site)	-	-
Fluroxypyr	350	10 (1 site)	21.3(12.5-30)	-
Fluroxypyr	400	12.5(10-20)	17.5(10-25)	-
Glyphosate	1440	-	-	19.4(15-22)
Untreated		←	40.6(35-50)	→

The range in coverage by volunteer potato foliage was variable but in all instances levels were greater (i.e. control was less successful) at the Holme site where soil fertility and crop management were of a lower standard. The level of cover where fluroxypyr was applied at the earlier timing was less than would be predicted from the tuber viability results shown in Table 4. Whereas about 50% of eyes were viable following application of 400g fluroxypyr at GS 39, the % ground cover following this treatment was only about 30% of the level in the untreated plot.

Varietal susceptibility

Assessments were made on the visual reduction in height and vigour of the potato haulm compared with untreated. Results from 1986 were reported by Bunn et al. (1986) and those for 1987 are given in Table 6.

TABLE 6

Percentage control of potato top growth with fluroxypyr at 400 g a.i./ha (applied 1987) in variety screens in the absence of other crops assessed at one to eight weeks after treatment (WAT).

Cultivar	Height at spraying (cm)	Mean diameter of plants at spraying (cm)	1 WAT	2 WAT	4 WAT	6 WAT	8 WAT
Kingston	15	25	40	30	83	82	85
Marfona	15	30	30	35	97	97	98
Wilja	13	30	25	35	99	97	97
Estima	15	25	30	40	100	100	100
Record	12	25	30	25	85	85	92
Romano	13	27	30	35	87	90	92
Pentland Squire	14	25	40	25	85	95	97
Pentland Dell	16	25	40	30	80	80	90
Maris Piper	17	30	40	40	75	75	80
Pentland Crown	16	30	40	40	90	90	96
Cara	20	35	40	30	75	65	65
Desiree	15	30	30	40	95	92	95

The varieties Marfona, Wilja, Estima and Desiree were consistently more susceptible at all timings, whilst Cara, Record and Maris Piper appear more tolerant. The growth stage of the potatoes in the 1987 trials was intermediate between that at the early and late applications in 1986 (Bunn _et al_., 1986). The highest degree of control was achieved in this 1987 trial, indicating that, for optimum control, applications of fluroxypyr at 400 g a.i./ha would best be applied at a time when potato plants are 15-20 cm high in the absence of crop competition.

Commercial usage monitoring

The results achieved by growers in 1986 (reported Bunn _et al_., 1986) and the preliminary returns from growers in 1987 are in good agreement with experimental findings. Even where the volunteer potato variety was more tolerant, such as Cara and Maris Piper, farmers achieved up to 100% control of foliage in the year of treatment.

DISCUSSION

Results from 1984, 1986 and 1987 trials and from commercial usage showed that fluroxypyr have acceptable control of volunteer potatoes in winter cereals. Control of the foliage in the season of application was accompanied by a reduction in the weight of daughter tubers and a substantial decrease in their viability. The yield of daughter tubers (Bunn _et al_., 1986) correlated with the degree of control of potato haulm, with a greater reduction in tuber weight in the more susceptible varieties Wilja, Estima and Desiree. The reduced viability was reflected by a reduction in the number of potato volunteers in the following season. This is important because although potato crops are frequently followed by winter cereals, the potato volunteers may persist for many years after the last potato crop and are thus a serious problem in many other crops such as sugar beet, carrots, onions, peas etc. where the options for control are few, if any.

The opportunity to reduce volunteer potatoes using fluroxypyr in winter cereals therefore has long term benefits throughout the rotation.

The trials indicated a dose response over the range tested with high levels of control achieved with 400 g a.i./ha. Application of fluroxypyr doses above this are unlikely to be commercially cost effective and are not recommended. Results and observations show that the action of fluroxypyr takes effect relatively quickly, removing the competition for water and nutrients during the life of the cereal crop and minimising the green matter than would otherwise be present at harvest. In addition the prevention of flowering and hence sexual seed production is important since volunteers will also grow from seed (Lawson, 1981).

In the variety screens in the absence of crop competition, there were differences between susceptible varieties, but best control was achieved when potato plants were 15 to 20 cm high. In competition with a cereal crop, similarly aged potato plants would tend to coincide with winter cereals at GS 39. Although later applications of fluroxypyr at cereal GS 45 often gave higher levels of control in the year of treatment, the delay in application had a knock-on effect in terms of the greater level of regrowth the following season. Application of fluroxypyr at cereal GS 39 is therefore an optimum in terms of maximising benefits.

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A QSAR STUDY OF SUBSTITUTED TETRAZOLINONE HERBICIDES

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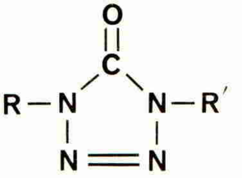
ABSTRACT

The recently patented class of 1-dialkylaminocarbonyl-4-phenyltetrazolinone preemergence herbicides was studied to determine structural modifications that would result in a compound of greatest activity against grass weeds. Whole-plant studies indicated that carbamyl tetrazolinones having a 2-alkyl- or 2-alkoxy-phenyl moiety are more active than similar compounds in which the phenyl ring is unsubstituted or substituted in the 3 or 4 positions. Alkyl substitution imparted greater activity than substitution with halogen, trihalomethyl, alkoxy, carboethoxy, methylthio, methylsulfinyl or methylsulfonyl. Carbamyl nitrogen substitution with alkyl resulted in greater activity than substitution with cycloalkyl. The activity was greatest (ED_{90} of 0.01 Kg/ha) when both carbamyl nitrogen substituents were isopropyl. These observations have been summarized in quantitative structure-activity studies.

INTRODUCTION

Although substituted tetrazolinones 1 (see below) have been known for many years (Elderfield, 1967), their potential as herbicides has been demonstrated only recently. A patent issued to Uniroyal Chemical describes the potent premergence herbicidal action of compounds 2 against grass weeds (Covey *et al*. 1986).



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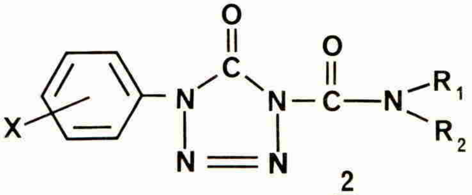

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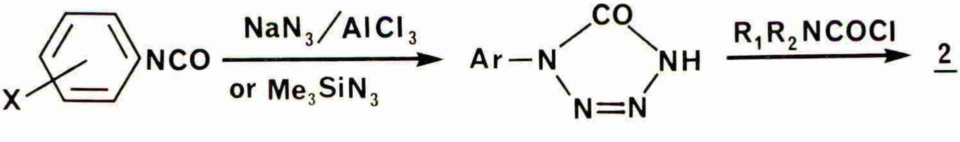
We report here the scope of active structures, the herbicidal activity and the relation of structure to activity.

METHODS

Synthesis

A series of analogs of 2 was prepared by the sequence



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The list from which compound 2 substituents were drawn is shown in TABLE 1. The combinations used, which included two or more substituents on the phenyl ring, are shown in TABLE 2.

TABLE 1

Substituents of 2 compounds

X = 2-H, Me, Et, i-Pr, F, Cl, Br, OMe, OEt,

SMe, p-SC$_6$H$_4$Me, SOMe, SO$_2$Me, CF$_3$, COOEt;

3-H, Me, Cl, OMe, CF$_3$;

4-H, Me, OMe, OC$_6$H$_5$;

5-H, Cl, OMe;

6-H, Me, Et, Cl;

R$_1$ = Me, Et, n-Pr, allyl, i-Pr, n-Bu, i-Bu;

R$_2$ = Me, Et, n-Pr, allyl, i-Pr, n-Bu, i-Bu,

s-Bu, 2-hexyl, cyclohexyl, 2-heptyl;

Yields for the above compounds were in the range of 60-80%; yields for the second step were generally in the range 35-70%. No attempt was made to optimize yields.

Herbicidal assay

Each compound was dissolved or dispersed in a mixture of acetone and Tween 20 and then diluted to a given concentration with distilled water. For example, 25 mg of X was dissolved in 5 ml of acetone and 15 mg of Tween 20. Then 95 ml of distilled water was added to yield a solution containing 250 mg/l of X. At least three concentrations of each compound were selected based on previous tests in order to bracket the expected ED$_{50}$.

Well-drained greenhouse soil, contained in test pots 11.3 cm in diameter and 8.5 cm deep, was sown with *c.* 200 seeds of each weed species: *Echinochloa crus-galli*, *Eleusine indica*, *Setaria viridis*, *Panicum virgatum*, *Avena fatua* and *Setaria glauca*. The seeds were covered with 3-6 mm of soil and initially watered by subirrigation at 100-120 ml per pot. The test solutions (46 ml each) were then applied evenly to the soil surface in each pot. The 46 ml drench of a 250 mg/l solution applied to 11.3 cm diameter pot corresponds to a field rate of 11.2 kg a.i./ha. Lower rates were applied by dilution of the 250 mg/l solution prior to drenching on to the soil surface. For example, dilution to 25 mg/l resulted in a field rate of 1.12 kg a.i./ha. After initial watering, soil in each pot was brought up to field capacity twice daily by sub-irrigation. Each test was conducted in duplicate.

After two weeks, weed control was determined as the percent control of each species by visual comparison with untreated pots. Herbicidal activity for each compound was then determined for each weed species as the dose in moles per hectare required for 50% control (ED_{50}).

Since the relative strength of weed control activity among the test compounds was similar for all test species, we have chosen *E. crus-galli* for discussion.

Quantitative Structure-Activity Relationships (QSAR)

Earlier work demonstrated the possibility of obtaining useful QSAR from whole-plant herbicidal activity (Doweyko *et al.*, 1983). In this study QSAR for the tetrazolinones were determined by two methods:

1. a conventional Hansch-type regression of log $1/ED_{50}$ *vs.* parameters for oil-water partition, electron demand, and space-filling by the substituents X, R_1 and R_2.
2. the Biosar "hyper-molecule" approach which defines the minimum structure for activity and establishes the nature of parameter dependence.

RESULTS AND DISCUSSION

Hansch QSAR

When stepwise regression was used to correlate log $1/ED_{50}$ for seventy tetrazolinones with parameters describing steric, electronic and solubility properties of the molecular fragments X, R_1 and R_2 the following equation was obtained:

$$\log 1/ED_{50} = 1.086Fr_1 + 0.673I_{ortho} - 0.726F_x - 0.329MR_x - 1.493L_1 - 146.3F_1 - 2.271$$

$$n = 70 \quad r = 0.866 \quad s = 0.434 \quad F = 31.5$$

ED_{50} was for *E. crus-galli* in units of gram-moles/hectare. The independent variable terms are listed in decreasing order of statistical importance. They indicated positive effects on activity of (1) lipophilicity of carbamoyl alkyl (Fr) and (2) an ortho substituent on the phenyl ring. There were negative effects by (1) inductive electron withdrawal at the phenyl ring (F_x) or carbamoyl substituent (F_1), (2) carbamoyl substituent length (L_1) and (3) substituent bulk on the phenyl ring (MR_x).

When pi values for R_1 and R_2 were summed and the total and squared total were made forced variables in stepwise regression the equation

$$\log 1/ED_{50} = 1.729Fr_{tot} - (0.189Fr_{tot})^2 + 0.654I_{ortho} - 0.0289MR_x - 0.539F_x - 0.239L_2 - 1.872$$

$$n = 70 \quad r = 0.862 \quad s = 0.440 \quad F = 30.4$$

was found. Again, ortho substitution on phenyl was shown to enhance activity and there were negative influences by bulky aryl substituents, by inductive electron-withdrawal from the phenyl ring and by long carbamoyl substituents. Further, an optimum pi for the alkyls can be calculated from coefficients of the linear and squared pi terms

$$\text{pi}_{\text{opt}} = 1.729/(2 \text{ x } 0.189) = 4.57$$

which corresponds to about seven to eight carbon atoms. This agrees with the observed maximum.

The values of statistically significant parameters used in regression are listed in TABLE 2.

TABLE 2

E. crus-galli control, rank and structural parameters for regression.

	Compound 2 Substituents			log $\frac{1}{ED_{50}}$								
Code	X	R_1	R_2		Rank	I_o	F_x	MR_x	Fr_1	F_1	L_1	Fr_2
B7288	3,4-diCl	Me	Me	-1.75	1.0	0	.81	14.8	.77	-.04	3.0	.77
B7317	2,4,5-triCl	Me	Me	-1.52	2.0	1	1.32	19.6	.77	-.04	3.0	.77
B7167	4-Cl	Me	Me	-1.17	3.0	0	.41	10.0	.77	-.04	3.0	.77
B7311	4-PhO	Me	Me	-1.09	4.5	0	.34	31.8	.77	-.04	3.0	.77
B7422	3,4,5-triMeO	Me	Me	-1.05	4.5	0	.83	24.7	.77	-.04	3.0	.77
B5866	H	Me	Me	-.98	9.0	0	.00	5.2	.77	-.04	3.0	.77
B7171	4-MeO	Me	Me	-.93	9.0	0	.26	11.7	.77	-.04	3.0	.77
B7299	2-F	Me	Me	-.90	9.0	0	.54	4.8	.77	-.04	3.0	.77
B7310	3-Cl	Me	Me	-.88	6.5	0	.40	10.0	.77	-.04	3.0	.77
B7168	4-Me	Me	Me	-.86	11.5	0	-.04	9.9	.77	-.04	3.0	.77
B7423	3-CF_3	Me	Me	-.83	6.5	0	.37	9.2	.77	-.04	3.0	.77
B8085	H	Allyl	Allyl	-.82	26.0	0	.00	5.2	1.40	-.05	5.1	1.40
B7300	2-Cl	Me	Me	-.74	13.0	1	.51	10.0	.77	-.04	3.0	.77
B7301	3,4-diMe	Me	Me	-.59	11.5	0	-.08	14.6	.77	-.04	3.0	.77
B8084	H	n-Bu	n-Bu	-.50	19.5	0	.00	5.2	2.51	-.06	6.2	2.51
B7176	2,4-diMeO	Me	Me	-.49	14.0	1	.58	18.2	.77	-.04	3.0	.77
B7318	2-EtO(C=O)	Me	Me	-.47	15.0	1	.41	21.4	.77	-.04	3.0	.77
B7990	2,3-Benzo	Et	Et	-.33	18.5	1	.03	20.6	1.43	-.05	4.1	1.43
B8639	2-MeO	n-Bu	n-Bu	-.21	21.0	1	.32	11.7	2.51	-.06	6.2	2.51
B9665	H	Me	2-Hep	-.20	19.5	0	.00	5.2	.77	-.04	3.0	4.00
B7895	3-MeO	Et	Et	-.19	24.5	0	.25	11.7	1.43	-.05	4.1	1.43
B8931	2-(4-MePhS)	i-Pr	i-Pr	-.09	22.5	1	.22	44.1	1.84	-.05	4.1	1.84
B7421	2,4,6-triMe	Me	Me	.09	25.5	1	-.13	19.0	.77	-.04	3.0	.77
B7449	4-Me	Et	Et	.09	25.5	0	-.04	9.9	1.43	-.05	4.1	1.43
B7272	2,5-diMeO	Me	Me	.12	17.5	1	.57	18.2	.77	-.04	3.0	.77
B9561	H	Et	2-Hex	.15	24.5	0	.00	5.2	1.43	-.05	4.1	3.46
B7738	2-EtO	i-Pr	i-Pr	.20	28.5	1	.27	16.5	1.84	-.05	4.1	1.84
B7448	H	Et	Et	.29	34.5	0	.00	5.2	1.43	-.05	4.1	1.40
B7851	2MeO	Et	Et	.30	38.0	1	.32	11.7	1.43	-.05	4.1	1.43

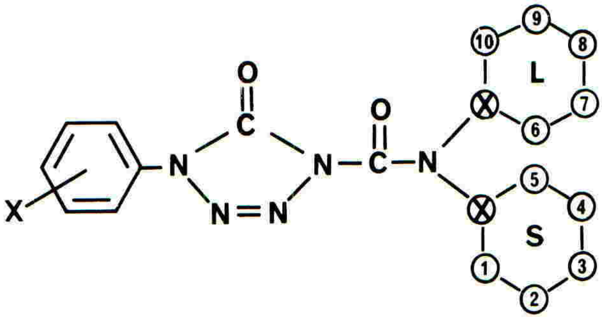
TABLE 2 (continued)

E. crus-galli control, rank and structural parameters for regression.

	Compound 2 Substituents			log 1								
Code	X	R_1	R_2	ED_{50}	Rank	I_o	F_x	MR_x	Fr_1	F_1	L_1	Fr_2
B9200	H	Me	n-Bu	.31	34.5	0	.00	5.2	.77	-.04	3.0	2.51
B9357	2,3-Benzo	i-Pr	i-Pr	.37	32.0	1	.03	20.6	1.84	-.05	4.1	1.84
B7273	2-EtO	Me	Me	.39	38.0	1	.27	16.5	.77	-.04	3.0	.77
C2968	2-MeS	i-Pr	cyHex	.41	28.5	1	.25	18.2	1.84	-.05	4.1	3.27
C3514	2-MeS(=O)	i-Pr	i-Pr	.45	36.0	1	.65	17.9	1.84	-.05	4.1	1.84
C3508	2-MeSO$_2$	i-Pr	i-Pr	.47	22.0	1	.68	17.7	1.84	-.05	4.1	1.84
B9518	H	Me	cyHex	.48	38.0	0	.00	5.2	.77	-.04	3.0	3.27
B7893	3-Me	Et	Et	.49	28.5	0	-.04	9.9	1.43	-.05	4.1	1.43
B7878	2,6-diEt	Et	Et	.55	32.0	1	-.12	24.0	1.43	-.05	4.1	1.43
C2948	2-Br	i-Pr	cyHex	.61	38.0	1	.55	12.8.	1.84	-.05	4.1	3.27
B7867	2-i-Pr	Et	Et	.65	42.0	1	-.06	19.2	1.43	-.05	4.1	1.43
B8770	3-Me	i-Pr	i-Pr	.65	42.0	0	-.04	9.9	1.84	-.05	4.1	1.84
B8624	2-MeO	n-Pr	n-Pr	.68	48.5	1	.32	11.7	1.97	-.06	5.1	1.97
B8771	2-i-Pr	i-Pr	i-Pr	.69	45.5	1	-.06	19.2	1.84	-.05	4.1	1.84
B9341	H	i-Pr	cyHex	.69	42.0	0	.00	5.2	1.84	-.05	4.1	3.27
B7843	2,6-diMe	Et	Et	.71	41.0	1	-.10	14.6	1.43	-.05	4.1	1.43
C2949	2-Cl	i-Pr	cyHex	.73	36.0	1	.51	10.0	1.84	-.05	4.1	3.27
C2947	2-EtO	i-Pr	cyHex	.74	50.5	1	.27	16.5	1.84	-.05	4.1	3.27
B8848	2,6-diMe	i-Pr	i-Pr	.75	45.5	1	-.10	14.6	1.84	-.05	4.1	1.84
B8772	2-CF$_3$	i-Pr	i-Pr	.80	50.5	1	.47	9.2	1.84	-.05	4.1	1.84
B7841	2-Me	Et	Et	.91	45.5	1	-.05	9.9	1.43	-.05	4.1	1.43
B8010	H	n-Pr	n-Pr	.93	53.0	0	.00	5.2	1.97	-.06	5.1	1.97
B9201	H	Et	n-Bu	.93	45.5	0	.00	5.2	1.43	-.05	4.1	2.51
B8736	2-Me	n-Pr	n-Pr	.96	55.5	1	-.05	9.9	1.97	-.06	5.1	1.97
B9543	H	i-Bu	i-Bu	.97	55.5	0	.00	5.2	2.45	-.06	5.1	2.45
B7892	2-CF$_3$	Et	Et	.99	48.5	1	.47	9.2	1.43	-.05	4.1	1.43
B7619	H	i-Pr	i-Pr	1.11	59.0	0	.00	5.2	1.84	-.05	4.1	1.84
B9547	H	n-Pr	i-Pr	1.11	59.0	0	.00	5.2	1.97	-.06	5.1	1.84
B8735	2-Me	i-Pr	I-Pr	1.13	62.0	1	-.05	9.9	1.84	-.05	4.1	1.84
B8632	2-MeO	i-Pr	i-Pr	1.15	59.0	1	.32	11.7	1.84	-.05	4.1	1.84
B8861	2,6-diMe	n-Pr	n-Pr	1.15	57.0	1	-.10	14.6	1.97	-.06	5.1	1.97
B8934	2-MeS	i-Pr	i-Pr	1.17	62.0	1	.25	18.2	1.84	-.05	4.1	1.84
C2558	2,5-diMeO	i-Pr	i-Pr	1.19	62.0	1	.57	18.2	1.84	-.05	4.1	1.84
B8858	2,6-diCl	i-Pr	i-Pr	1.20	53.0	1	1.02	14.8	1.84	-.05	4.1	1.84
B8936	2-Br	i-Pr	i-Pr	1.22	64.5	1	.55	12.8	1.84	-.05	4.1	1.84
B8922	2-Et	Et	Et	1.41	69.0	1	-.06	14.6	1.43	-.05	4.1	1.43
B9190	H	i-Pr	S-Bu	1.43	66.0	0	.00	5.2	1.84	-.05	4.1	2.38
B7615	2-EtO	Et	Et	1.44	64.5	1	.27	16.5	1.43	-.05	4.1	1.43
B8911	2-Et	i-Pr	i-Pr	1.45	68.0	1	-.06	14.6	1.84	-.05	4.1	1.84
B8199	2-EtO	n-Pr	n-Pr	1.47	53.0	1	.27	16.5	1.97	-.06	5.1	1.97
C2927	2-Me	i-Pr	cyHex	1.49	68.0	1	-.05	9.9	1.84	-.05	4.1	3.27

"Hyper-molecule" treatment

The generic structure for the series is written as



where L = larger group and S = smaller group. Examples of the protocol for filling structures are NPr_2 = 1,2,6,7 ; N-Et i-Pr = 1,6,10. The compounds were ranked by total herbicidal activity at all use rates, a method which assesses order of activity in the presence of large standard deviations for ED_{50} ($S \sim 0.4 \log_{10}$ unit). Activities having the same rank were assigned a rank intermediate between the preceding and succeeding rank. Descriptors other than indicator variables were also ranked from high to low in a similar fashion. The matrix was processed by multiple regression for significant correlations. The regression of rank order for *E. crus-galli* (ECG) control on physicochemical parameters and filled/empty locations in the hyper-molecule is:

$$\text{ECG RANK} = 17.87\,\text{Fr}_{\text{tot}} - 2.42\,\text{Fr}^{2}_{\text{tot}} - 0.237\,\text{sigma}_{\text{tot}} - 0.535\,U_{3\text{-}5} + 16.01\,P_5 + 35.21$$

$$n = 70 \qquad r = 0.833 \qquad S = 11.29 \qquad F = 29.4$$

$\text{Sigma}_{\text{tot}}$ is the sum of Hammett sigma for phenyl substituents, $U_{3\text{-}5}$ is the sum of Charton steric parameter for meta and para substituents and P_5 is an indicator of an atom at position 5 of the hyper molecule. Since P_5 implies P_1 (filled first) the minimum structure for high activity is $N(iPr)_2$. Again the optimum pi corresponds to about six to seven carbon atoms in the alkyl groups. As in the Hansch QSAR, electron withdrawal from the phenyl and steric bulk of substituents on phenyl have a negative effect on herbicidal activity.

CONCLUSION

Both the Hansch and hyper-molecule QSAR show that maximum herbicidal activity in the 1-dialkylcarbamoyl-4-phenyl tetrazolinones is achieved with (a) small, electron-releasing substituents (e.g. methyl or methoxy) on phenyl and (b) a total of six to eight carbon atoms in the N-alkyl groups, where diisopropyl or isopropyl + cyclohexyl are preferred.

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STRUCTURE-PHYTOCIDAL ACTIVITY RELATIONSHIP STUDIES ON SOME DERIVATIVES OF 4-ISOOCTYLOXYMETHYLENE-MORPHOLINIUM CHLORIDE

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ABSTRACT

Some 4-isooctyloxymethylenemolrpholinium chlorides were obtained by modifications of the lenght of alkyl chain at the nitrogen. The phytocidal activity of these compounds against a series of crop and weed species as bioindicating plants was studied under laboratory and greenhouse conditions. The contribution of the alkyl substituents to phytocidal activity was determined. Phytocidal activity depended upon the lenght of alkyl chain and plant species. Bioavailability of soil applied compounds was eliminated.

INTRODUCTION

Results presented here were obtained from experiments which were a continuation of the research project concerned with some compounds from the quaternary ammonium salts group obtained on the basis of chloromethyl alkyl ethers (Ptaszkowska and Oświęcimska, 1983).

The objective of this research was to test the contribution of the alkyl substituents to phytocidal activity of some 4-isooctyloxymethylenemorpholinium chlorides.

MATERIALS AND METHODS

Laboratory and greenhouse experiments were carried out with four quaternary ammonium salts obtained by quaternization of tertiary amines of the 4-methylmorpholine types with suitable chloromethyl alkyl ethers. Compounds included in the test were:

IPO-8521=4-decylenemorpholinium-4-isooctyloxymethylene chloride
IPO-8522=4-dodecylenemorpholinium-4-isooctyloxymethylene chloride
IPO-8523=4-isooctyloxymethylene-4-tetradecylenemorpholinium chloride
IPO-8524=4-hexadecylenemorpholinium-4-isooctyloxymethylene chloride

The experiments were carried out on ten crop plant species and eight weed species. Buckwheat, cucumber, flax, French bean, maize, oat, pea, ryegrass, sugar beet and white mustard have been used as crop plant species. Echinochloa crusgalli, Plantago lanceolata, Anthemis arvensis, Chenopodium album, Daucus carota, Apera spica-venti, Melandrium album, and Vicia hirsuta were adopted as bioindicating weed species.

Root growth of germinating seeds on filter paper treated with the test chemicals was observed. Discs of filter paper impregnated with the given chemical compounds were placed in Petri dishes and seeds of bioindicating plant were placed on the surface of each paper. The closed dishes were stored in darkness at 25°C. After such incubation, lenght of the roots on the chemically treated papers was compared with that of roots in the controls. All treatments were replicated four times.

The agar test was also used in studying root growth of the bioindicating plant. Seeds of flax were germinated in tubes on solidified agar containing water plus the test chemical and the root growth studied. The tubes were stored in an upright position in darkness at a temperature of 25°C for the duration of the test. Cotton-wool corks prevented drying of the agar. The lenghts of the roots were recorded after five days of incubation. All treatments were replicated four times.

Studies on phytocidal activity under greenhouse conditions were carried out in pre-emergence and post-emergence biotests. In the pre-emergence tests, chemical compounds were applied on the surface of the soil in pots previously seeded with bioindicating plants and in post-emergence tests, they were applied after the plants had emerged from the soil. Sandy loam with 2% organic matter and 10% clay was used in these experiments. Chemicals were applied with a laboratory sprayer at a volume rate of 1000 l/ha.

The scoring of phytocidal activity was carried out three weeks after treatments in pre-emergence tests and two weeks after direct application to plants. All species were evaluated separately and the following scoring index was adopted: 0=unaffected plants, 1=very slightly affected plants, 2=slightly damaged plants, 3=moderately damaged plants and 4=killed plants.

The predominant symptoms were chlorosis of leaves which was followed by burning and withering and eventually by the death of the plant.

RESULTS

Phytocidal effect of the chemicals on cucumber root growth is shown in Table 1.

TABLE 1

Contribution of alkyl substituents to phytocidal activity against cucumber as expressed by root growth reduction in filter paper test

Chemical compound 500 ppm	Alkyl chain	Mean growth reduction in %
IPO-8521	$C_{10}H_{21}$	90
IPO-8522	$C_{12}H_{25}$	79
IPO-8523	$C_{14}H_{29}$	66
IPO-8524	$C_{16}H_{33}$	70

It appears that, elongation of the alkyl chain at the nitrogen of 4-isooctyloxymethylenemorpholinium chloride caused some decrease in phytocidal activity.

Generally similar bioreaction of the root growth of some weed species was observed after the introduction of alkyl substituents (see Table 2).

TABLE 2

Contribution of alkyl substituents to phytocidal activity against weeds as expressed by root growth reduction in filter paper test

Chemical compound	Alkyl chain	Mean growth reduction in %									
		P.lanceolata			M.album			V.hirsuta			
		300	150	75	300	150	75	300	150	75	ppm
IPO-8521	$C_{10}H_{21}$	85	69	50	100	96	92	100	72	50	
IPO-8522	$C_{12}H_{25}$	100	69	42	94	91	85	100	82	59	
IPO-8523	$C_{14}H_{29}$	83	67	25	80	73	67	74	56	37	
IPO-8524	$C_{16}H_{33}$	76	53	27	85	79	70	68	54	40	

Shorter alkyl chain usually induced greater root growth reduction. Some deviation from the rule was observed in the case of P.lanceolata in higher concentrations but as a rule IPO-8521 and IPO-8522 proved more active in comparison with IPO-8523 and IPO-8524. 300 ppm concentration of IPO-8521 completely inhibited root growth of M.album and V.hirsuta, while IPO-8522 in this concentration prevented the growth of P.lanceolata and V.hirsuta roots.

Of the compounds evaluated on flax in the agar test, chemicals substituted with shorter alkyl chains entirely inhibited root growth (Table3).

TABLE 3

Contribution of alkyl substituents to phytocidal activity against flax as expressed by root growth reduction in agar test

Chemical compound 250 ppm	Alkyl chain	Mean growth reduction in %
IPO-8521	$C_{10}H_{21}$	100
IPO-8522	$C_{12}H_{25}$	100
IPO-8523	$C_{14}H_{29}$	39
IPO-8524	$C_{16}H_{33}$	21

There were no sings of injury at 5 kg/ha rate when chemical compounds were applied to the soil surface before emergence of the plants under greenhouse conditions.

Phytocidal activity of the derivatives of 4-isooctyloxymethylenemorpholinium chlorides against ten plant species in post-emergence treatments under greenhouse conditions is illustrated in Table 4.

TABLE 4

Contribution of alkyl substituents to phytocidal activity against ten crop species in post-emergence treatments

Crop bioindicator	Chemical compound at 5 kg/ha with proper alkyl chain			
	IPO-8521 $C_{10}H_{21}$	IPO-8522 $C_{12}H_{25}$	IPO-8523 $C_{14}H_{29}$	IPO-8524 $C_{16}H_{33}$
Maize	1	1	1	1
Oat	2	2	2	3
Ryegrass	2	2	2	2
Bean	2	2	2	2
Beet	4	4	4	4
Buckwheat	2	3	2	3
Cucumber	3	3	2	2
Flax	4	4	3	2
Mustard	4	2	3	2
Pea	2	2	2	2

The response was similar under greenhouse and laboratory conditions in reference to cucumber and flax. The data showed that chemicals with shorter alkyl chain provided highest phytocidal activity. Significant species differentiation was observed. Maize plants were very slightly affected by all chemicals. The response of bean, pea and ryegrass within given species was similar for all chemicals regardless of the length of alkyl chain at the nitrogen.

Studies on the contribution of alkyl substituents to phytocidal activity against some weed species in post-emergence treatments are presented in Table 5.

TABLE 5

Contribution of alkyl substituents to phytocidal activity against seven weed species in post-emergence treatments

Weed bioindicator	Chemical compound at 2.5 kg/ha with proper alkyl chain			
	IPO-8521 $C_{10}H_{21}$	IPO-8522 $C_{12}H_{25}$	IPO-8523 $C_{14}H_{29}$	IPO-8524 $C_{16}H_{33}$
<u>E.crusgalli</u>	1	1	1	1
<u>A.spica-venti</u>	2	2	1	1
<u>P.lanceolata</u>	2	1	1	1
<u>A.arvensis</u>	2	2	1	1
<u>C.album</u>	2	2	1	1
<u>D.carota</u>	1	2	1	2
<u>V.hirsuta</u>	2	2	0	0

Bioassay results indicated that phytocidal activity depended upon the lenght of alkyl chain and plant species. The compounds IPO-8521 and IPO-8522 provided higher phytocidal activity in comparison with chemicals of the longer alkyl chains. Increasing the chain length resulted in decreased phytocidal activity against five weed species. Some species differentiation was observed. Only <u>E.crusgalli</u> tended to be most resistant to all compounds irrespectively of the length of alkyl chain.

DISCUSSION

Many test methods have been used for structure-activity and screening studies. Results reported herein demonstrated that biological methods based on plant root bioassay and direct chemical application on the plants grown in pots appeared suitable for studies on the structure-phytocidal activity relationship. The response of the bioindicators was similar in the trials carried out under laboratory and greenhouse conditions.

From the results of the tests carried out to establish the relationship between the structure of some derivatives of 4-isooctyloxymethylenemorpholinium chlorides and their phytocidal activity, the conclusion can be drawn that phytocidal activity depended upon the length of alkyl chain at the nitrogen.

Phytocidal activity was usually lower for the longer alkyl chain compounds. The differences in responses achieved by applying the same compound to different plant species was noted. Bioavailability of soil applied compounds was apparently eliminated by soil sorption because in the agar test they were easily absorbed by roots from agar substratum.

In interpreting data on the different compound´s activity, one should take into consideration the fact of possible changes in bioavailability of the compounds of different shape and structure. Perhaps larger organic molecules were less available. Different mechanisms could be operating here to various degrees. Phytocidal activity is not a simple physiological property and may result from many physiologically and biochemically distinct processes. A number of factors may operate in determining given response of the plant such as the extent to which the applied compound is absorbed, the ease with which it moves within tissues, potential activity of the compound at the site of action and its stability within the plant. If the inverse relationship between the length of alkyl chain and phytocidal activity occurs as a result of bioavailability, then the rate of absorption and eventual translocation to sensitive loci in the living system should be taken into consideration. Studies on eventual systemicity of the compounds are running in our biological laboratory.

More knowledge of the relationship between the shape and size of chemical molecules and their phytocidal activity is needed for future progress in the screening of more promising herbicides.

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SESSION 4A

ENVIRONMENTAL IMPACT – MANAGEMENT AND MANIPULATION OF VEGETATION INCLUDING BRACKEN

CHAIRMAN	DR A. S. COOKE
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INVITED PAPERS	4A-1 to 4A-3
RESEARCH REPORTS	4A-4 & 4A-5

ENVIRONMENTAL IMPACT OF CHEMICAL WEED CONTROL IN ARABLE FIELDS IN THE FEDERAL REPUBLIC OF GERMANY

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ABSTRACT

In the Federal Republic of Germany, the protection of the environment is ruled by the "polluter pays" principle, the principle of prevention of damage, and the principle of co-operation. The intensification of agriculture has resulted in a decline in the diversity of weed floras. Chemical weed control is considered to be the major contributory factor. Weed species communities are being conserved on unsprayed and less fertilised field margins thus linking agriculture and nature conservation. The weed-feeding fauna is mainly influenced via indirect effects on food chains. Side-effects of herbicides on soil micro-organisms have to be assessed according to inhibition or stimulation of microbial activities.

INTRODUCTION

The protection of natural resources has become important to the people in the industrialised countries. In Germany it is ruled by three principles:

i) principle of "polluter pays" (Verursacherprinzip)
ii) principle of prevention (Vorsorgeprinzip)
iii) principle of co-operation (Kooperationsprinzip)

Principle of "polluter pays"

Anybody responsible for adverse environmental impact has to pay either for their avoidance or for counteracting the effects of any damage caused (Bundesregierung 1986). In Industry this principle was introduced to limit emissions of dust, chemicals, waste and noise. It has not yet been developed in Agriculture because the requirements of environmental protection are more difficult to define; the main problem being the assessment of damage, with respect to changes in the natural vegetation of arable fields following soil cultivation, drainage, fertilisation, and plant protection. Criteria for defining adverse effects cannot easily be found because of their often gradual impact, and the inter-dependent nature of the abiotic and biotic components of the environment. (Abiotic components soil, water and air will not be considered here.)

Economic pressures cannot excuse environmental impact. All areas of production and consumption are under such pressures. Industrial production is subjected to international competition without any EEC marketing guarantees but nevertheless has to comply with certain environmental restrictions (Heydemann 1983a). But in the Federal Nature Conservation Act it is stated that good agricultural practice and its associated pest control is not defined as a factor limiting nature and landscape. This agricultural clause causes much discussion in Germany, and its repeal is required by among others, the 'Council of Environmental Experts' who demand restrictions and guidelines on land use to reduce pressure on the environment. Chemical weed control is agronomically, a reasonable measure, yet there is no known environmental threshold at which "good agricultural practice" becomes "environmental impact". Therefore certain compounds must not be used for weed control and regulations have been introduced to ensure the environmental safety of crop production.

Principle of prevention

Taking actions to prevent environmental damage is also a political principle (Bundesregierung 1986). Research and Advisory Services, both of the State and of Industry are responsible for the development and dissemination of knowledge for legislation and its practical application. Man has had an impact on ecosystems by his very use of them. If irreversible damage is to be avoided, then ecosystem stability and the potential sources of stress must be evaluated, criteria of human impact developed, and proposals for the necessary limitation of risk found. This is a task of ecological research, and its results should be the basis of political decisions for adequate environmental protection (Becker 1987).

The high political importance of environmental protection has been expressed in increasing amounts of legislation in Germany especially in the 1970's when the protection of the total environment (Naturhaushalt) was demanded; for example the 'Federal Forest Act' (Gesetz zur Erhaltung des Waldes und zur Förderung der Forstwirtschaft, 1975), the 'Federal Nature Protection Act' (Gesetz über Naturschutz und Landschaftspflege, 1976, 1987), the 'Fertiliser Act' (Düngemittelgesetz, 1977) and the 'Chemicals Act' (Gesetz zum Schutz vor gefährlichen Stoffen, 1980) (Herfs 1982). In the latest 'Plant Protection Act' (Gesetz zum Schutz der Kulturpflanzen, 1986) the protection of the total environment (Naturhaushalt) has been especially highlighted. Here the term "Naturhaushalt" refers to the ecological system of soil, water and air as well as of plants and animals (noxious organisms, the targets of plant protection measures are exempted). The incorporation of this demand into the law has led to the introduction of further ecological testing. Moreover, this legislation now includes an extensive supervision of plant protection equipment. This regulation should help to diminish or to avoid unwanted side-effects e.g. phytotoxocity, unacceptable crop residues, drift, and unnecessary harm to wildlife.

Principle of co-operation

Improving environmental safety by the development of guidelines, legislation, advice, and its practical application in agriculture and landscape management is a public task which can only be solved by intensive co-operation and exchange of information between University Institutes, Federal and Industrial Research Centres, Advisory Services, Nature Conservation Authorities, and farmers.

IMPACT OF HERBICIDE USE ON ANIMATE COMPONENTS OF ARABLE FIELDS

Effect of chemical weed control on the weed flora

In central Europe the greatest diversity of species is found in cultivated landscapes not in "natural" ones. During the past 5000 years a diverse flora has developed which, in Germany, contains 2667 species (Sukopp *et al* 1978). Roughly 10% of them may occur as arable weeds of which only some 10% are the agronomically determined targets of weed control. Agricultural crops are grown in the Federal Republic of Germany on 7.2 million ha (29% of the total land area). More than 80% of this area is treated with herbicides annually (Hanf 1986) (Table 1).

There have been considerable changes in crop rotations because of effective and specific herbicides. Sugar beet may now be grown on fields formerly infested with *Agropyron repens*. Chemical weed control has enabled

TABLE 1

Estimate of chemical weed control in different arable crops in the Fed. Rep. of Germany (after Hanf 1986)

Crop	Percentage of total land area %	Percentage of crop treated with herbicides %
Winter cereals	13.0	95
Spring cereals	6.5	85
Maize	4.0	80
Sugar beets	2.0	98
Oil seed rape	1.0	98
Potatoes	1.0	50

farmers to grow maize on 1 million ha in Germany, equivalent to 14% of arable fields but atrazine-resistant plants have arisen in several species e.g. *Amaranthus retroflexus, Chenopodium album, Senecio vulgaris, Solanum nigrum* and *Stellaria media* (Kees 1978, 1986). Wheat monoculture has been practised for decades made possible by chemical weed control, and minimum tillage could only be practised with the use of effective herbicides.

Decline of arable weed species

Methods of weed control have always influenced their distribution; the most important development of which has been the expanding scale and diversity of herbicide use. The principal ecological effect of this has been to change the composition of weed populations on arable land (Fryer 1977). By 1962, there was already concern about the strong influence of the intensification of agriculture on the typical flora of arable fields which resulted in more simple plant communities (Tüxen 1962). This might have only concerned plant-sociologists if such changes did not disturb or destroy total agro-biocoenoses (Heydemann 1983a). Several German authors (Meisel 1977, Holzner 1978, Sukopp *et al* 1978, Schumacher 1980, 1987, Wilmanns 1984) also believe that herbicide use has been the major contributory factor in the decline of the diversity of the weed floras of arable land over the past 30 years. Herbicide efficiency affects the numbers of seeds individual plants return to the soil. After long-term and effective herbicide use one would expect to see a considerable reduction in density of weed populations and finally the possible elimination of species.

About one third of the 250-300 plant species potentially growing on arable land in Germany are listed in the Red Data Book of Endangered Plant Species (Blab *et al* 1984), 15 of them are considered to be either extinct or not recently observed, and 75 species are endangered to some extent (Eggers 1984). Fifty-five of these species belong to cereal plant communities, 29 among them to the basiphilic ones, 4 restricted to the growing of flax, and 3 typically growing on very light sandy soils. Twenty-three of the endangered species belong to root crop and vineyard communities, and 12 species, belonging to communities growing on temporarily wet arable fields.

Reasons for these declines cannot easily be identified, but it is thought to be due to a complex of factors determining their habitats. The former habitats which resulted in the occurrence of certain characteristic species and sociological groups have largely been improved to more uniform and productive levels suitable for today's agriculture. Among the species influenced by fertilisers are many very characteristic species e.g. *Caucalis platycarpos* on basic soils or *Arnoseris minima* on acid (sandy) soils (Eggers 1984). Better drainage has resulted in the decrease of those species found on soils at least temporarily wet on the surface. Of minor influence (in terms of number of species) have been factors such as seed cleaning, discontinuance of certain crops and intensification of soil cultivation. Half of the threatened weed species in Germany are at the limits of their distribution in this country. Such species are at particular risk from the competition of cultivated plants and from agricultural practices (Holzner 1978). As the typical species belonging to weed communities decline as a result of today's methods of cultivation and weed control, ubiquitous companion species (e.g. *Alopecurus myosuroides, Galium aparine, Matricaria spp., Mercurialis annua, Veronica spp., Viola arvensis*) have increased.

Conservation of threatened arable weed species

As arable weeds depend on regular cultivation of the land and quickly disappear from fallow land, they cannot be protected by usual conservation methods. As well as cultivation and seed storage of threatened species in botanic gardens or seed banks, it is even more desirable to preserve these species in the wild state in their particular habitats. To ensure their conservation, suitable management of at least parts of fields (along the margins or headlands) (Nezadal 1980, Schumacher 1980, 1981) is now being practised in different parts of Germany, Denmark and in Britain. These protected parts of fields may receive less fertiliser and will be kept free from herbicides. This conservation concept for arable weeds is ruled by the idea of linking agriculture and nature conservation in the same field (Schumacher 1980). It is of great merit that farmers and conservationists co-operate successfully and thus partly overcome their long standing differences. An important contribution has also been made by the shooting fraternity and their increasing support may be expected if the experiences in Britain become better known in Germany.

Special programmes are run by some Federal Länder. In Northrhine-Westphalia several hundred kilometers of protected headlands have been established. Since 1984 the Plant Protection Service of Rhineland-Palatinate has run a similar programme on more than 60 km field margins in which 243 arable species and 8 different plant communities have been found. Some species considered to be extinct (*Adonis flammea, Bromus grossus, Galium spurium*) or near to extinction (*Agrostemma githago, Fumaria parviflora, Nonea pulla*) were rediscovered in protected field margins (Oesau 1987). In Schleswig-Holstein, in 1986 an "extensification" programme was implemented including arable field headlands. Similar work is underway in Lower Saxony where several species near to extinction (*Adonis aestivalis, Bupleurum rotundifolium, Consolida regalis, Neslia paniculata* and *Scandix pecten-veneris*) were found. Farmers are very willing to participate in the field margin programme even without financial compensation (2.5 p m^{-2}), especially if they are hunters. These conservation projects are run in collaboration with individual botanists, Nature Conservation Societies and Authorities and partly together with Game Conservation Institutions and the Plant Protection Services to ensure proper recording of the results.

The conservation of endangered species may be one aim of the field margin concept (as practised in Lower Saxony) but the sovereign aim must be the preservation of characteristic plant communities (Oesau 1987) in order to establish an ecological network. Nature reserves for the protection of arable weeds are often called for, but are still unknown. Their conception and operation is a political question which cannot be solved without substantial financial support.

Effect of chemical weed control on the fauna

The impact of weed control results in decreases in density, biomass and, possibly even species of what is the primary food source of the fauna. In central Europe some 100 arable weed species are the host plants for ca. 1200 phytophagous species. The importance of a particular plant species differs widely (Table 2). Therefore the decline or loss of a plant species may have considerable "knock-on" effects on animal species at other levels of the food chain. According to the 12:1 ratio of phytophagous animal to weed species, a decrease of plant species density (diversity) could result in an even higher decrease of animal species (Heydemann 1983a), not only of phytophagous but also of detritophagous and carnivorous ones. The significance of flowering weed species for nectar and pollen feeding insects must also be considered (Haas 1982, Heydemann 1983a).

TABLE 2

Animal species specialised to feed on arable weed species in Germany (from Heydemann 1983a)

Weed species	Number of animal species	Weed species	Number of animal species
Agropyron repens	81	*Cerastium spp.*	37
Cirsium arvense	80	*Stellaria media*	36
Senecio spp.	76	*Anagallis arvensis*	6
Poa annua	41	*Chrysanthemum segetum*	4
Chenopodium spp.	51	*Euphorbia peplus*	3
Polygonum aviculare	40		

Most investigations on the effects of agricultural practices on the agri-fauna are short term. However, the results of a comparison of the species density and abundance of some benefical epifauna between 1951 and 1982 illustrated the impact of agricultural intensification (without drainage or consolidation) (Heydemann 1983a,b) (Table 3). The largest losses were recorded in row crops on sandy soil, with high losses also occuring in winter cereals. How much chemical weed control had been involved in these changes can only be supposed but, in contrast to 1951/52, it has subsequently become an important ecological factor in these agro-biotops (Table 1).

TABLE 3

Changes in the beneficial epifauna (Coleoptera, Formicidae) between 1951/52 and 1981/82 (after Heydemann 1983b)

Agro-biotop	Mean number of species 1951/52	Mean number of species 1981/82	% loss	Mean number of individuals 1951/52	Mean number of individuals 1981/82	% loss
Winter cereals						
on sandy soils	42	22	48	400	200	50
loamy soils	34	11	68	350	73	79
Row crops						
on sandy soils	27	4	85	200	38	81
loamy soils	24	11	55	230	63	73

Currently, the Institute for Biological Pest Control of the Federal Biological Research Centre is investigating the importance of boundaries and margins for the spread of benefical arthropods into fields and whether the establishment of field margins protected from pesticide use will support the conservation of other species. First results indicated that Carabidae overwintered in the boundaries and that untreated field margins favoured their dispersal into the field. As a consequence, aphid densities were reduced below the economic threshold, thus enhancing a more integrated control programme.

Direct effects of herbicides on the fauna appear to be relatively unimportant. Ecotoxicological investigations have usuallly been made on particular species of plants and animals. Therefore only limited information upon the behaviour and impact of chemicals in ecosystems is available. One-species tests may nevertheless be worthwhile for the assessment of risks to the environment if criteria for the evidence of such tests can be established (Becker 1987). From the beginning, the Plant Protection Legislation gave priority to the protection of plants and stored products; but it also allowed for future regulation concerning the protection of beneficial organisms useful in plant protection. The 'Bee Protection Ordinance' (Verordnung zum Schutz der Bienen vor Gefahren durch Pflanzenschutzmittel, 1972) led to the obligatory testing of all products for their effects on honeybees; an important step towards the consideration of environmental aspects in the official examination of pesticides in Germany. Currently, the Federal Biological Research Centre intends to introduce obligatory testing of all pesticides for their activity against beneficial organisms. For many years the Working Group "Pesticides and Beneficial Organisms" of the International Organization for Biological Control, West Palaearctic Regional Section (IOBC WPRS) has been developing test methods (Herfs 1982). These are used on a step-wise progression from laboratory to semi-field and to a field scale. Obligatory testing of all pesticides for their effects on earthworms as primary detritophages similarly to the current guidelines for *Eisenia fetida* (Riepert 1984) shall be introduced. For the Approval Procedure, data on the acute toxicity of commercial products to birds and fish have to be presented as a basis for an assessment of their likely impact.

The overwhelming importance of herbicides is their impact on wild floras and thus on the fauna indirectly, not only insects and other invertebrates but also birds, e.g. the grey partridge (*Perdix perdix*) which feeds its chick on insects (Potts 1986) or the corn bunting (*Emberiza corlandra*). This species has drastically declined in Germany due to the lack of dicotyledonous weed seeds in cereals (Blaszyk 1966). However, some species have been observed nesting in crops where they previously did not; e.g. oyster-catcher (*Haematopus ostralegus*) and lapwing (*Vanellus vanellus*) in sugar beet and potato fields, or marsh and Montagu's harrier (*Circus aeruginosus* and *Circus pygargus*) in cereal fields. Chemical weed control led to less disturbance by soil cultivation and mechanical weed control (Blaszyk 1975).

Side-effects of herbicides on soil micro-organisms

Higher plants contribute to the soil biocenosis by the nature of their communities, and by changing the microclimate, the fauna, and the availability of nutrients. All plant protection measures, whether physical or chemical alter the stands of crops or weeds, thus affecting soil micro-organisms. Because they occur in such very large numbers and because they also participate in a wide range of conversion reactions, micro-organisms are an important component of the soil ecosystem and determine soil fertili-

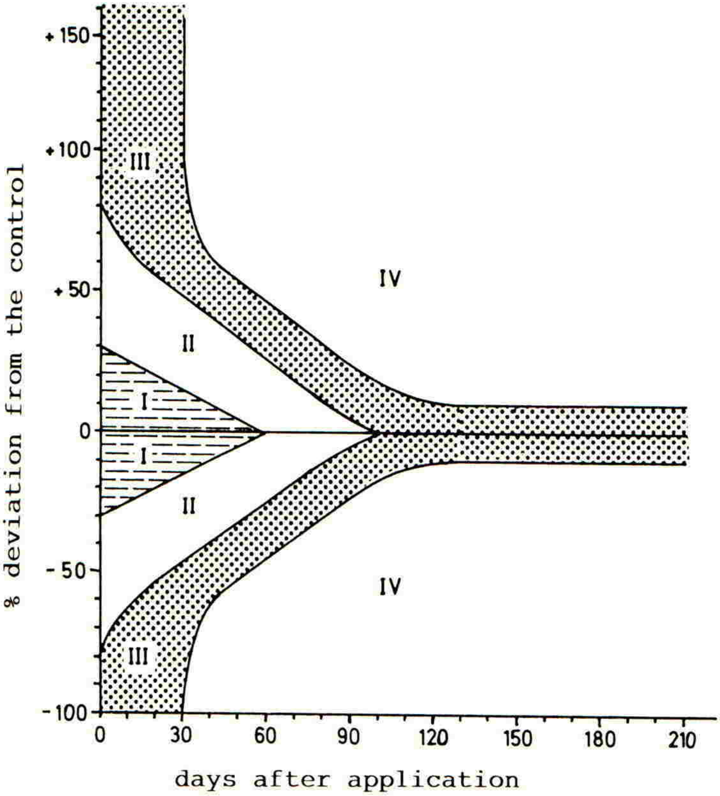

Fig. 1. Assessment of ecotoxicological effects of pesticides on soil micro-organisms (from Anderson *et al* 1987)

ty. The better knowledge of soil biology and of the importance of soil micro-organisms, more sophisticated methods of research, as well as the increase of chemical pest control resulted in an increasing literature about side-effects of pesticides on soil micro-organisms and their functions. Up to 1984/85 Malkomes (1985) found more than 3500 original papers (and more than 400 reviews), nearly 2/3 (1/2) of which dealing with the influence of herbicides. The number of herbicide papers doubled from 1971 to 1980, compared to the previous decade.

Since 1970, studies of microbial activity have taken preference over those on microbial populations. Ecotoxicological investigations should cover the total ecosystem, but this is an almost impossible task. Investigating effects on important transformation activities in the soil include straw decomposition, respiration, ammonification and nitrification. Dehydrogenase activity and respiration are indicators for overall microbial activities. Respiration rate and ATP content may also be taken as a measure of the microbial biomass in soil (Malkomes & Wöhler 1983). Studies must look not only to the effects of pesticides on biological activities but also to their duration. In laboratory trials Malkomes & Wöhler (1983) found marked inhibitions several months after application, although most of the chemicals had disappeared from the soil.

Effects of pesticides on micro-organisms must be considered to be similar to natural phenomena. Assuming a normal doubling of the soil microflora within 10 days, an ecologically tolerable recovery period of 20-30 days at 15°C may be assumed (Domsch *et al* 1983). Malkomes (1985) has developed a concept for the assessment of effects of pesticides on soil micro-organisms. Presuming that any influence should not last for longer than 3 months (thus having a regard for the following crop within a rotation), this time limits the critical period. The assessment concept includes all deviations from the control, not only inhibitions but also stimulations which may result from effects on the microbial biomass. Malkomes' (1985) assessment concept was incorporated as the basis for the official examination of pesticides according to the recent 'Guidelines on effects on activities of the soil microflora' (Anderson *et al* 1987) (Figure 1); at first the influence on respiration and dehydrogenase activity has to be studied, but further studies may be necessary according to their percentage of deviation in the I, II, III, or IV area. The examination of side-effects of pesticides on soil micro-organisms is another step towards the consideration of environmental aspects in the Approval Procedure in the Federal Republic of Germany.

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SELECTIVE GRASS WEED CONTROL IN CEREAL HEADLANDS TO ENCOURAGE GAME AND WILDLIFE

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ABSTRACT

Nine experiments were conducted over 2 years to investigate the potential for selective chemical control of black-grass (Alopecurus myosuroides) in winter cereal headlands, as part of the Cereals and Gamebirds Research Project's "conservation headlands" initiative. The aim was to allow the survival of certain broadleaved weed species which are host plants for insects eaten by gamebird chicks. In six of seven experiments with high populations of A. myosuroides, diclofop-methyl gave greater than 90% control. A sequence of tri-allate followed by diclofop-methyl gave more than 98% control in six of seven experiments. These figures compare favourably with the performance of traditional control materials. The tri-allate/ diclofop-methyl sequence had little or no effect on most of the desirable broadleaved weed species present. In addition, a useful measure of Galium aparine control was achieved by tri-allate, in two experiments where this weed was present. Chlortoluron generally controlled A. myosuroides and susceptible broadleaved species well, but effects of isoproturon were variable.

INTRODUCTION

Since 1983 the Cereals and Gamebirds Research Project has been studying the side-effects of pesticides on non-target species, and developing methods of alleviating such effects within the context of modern farming systems (Oliver-Bellasis & Sotherton 1986). One such method is to modify pesticide input over a 6m wide band of crop at the edge of cereal fields to promote the survival of certain broadleaved weeds and their associated insect fauna. The resulting increases in populations of wild gamebirds (Rands 1985, 1986, in press), butterflies (Rands & Sotherton 1986) and other insects (Sotherton et al 1985) are now well documented. More recently, potential benefits to small mammals and rare arable weeds have become apparent (Tew 1987, Wilson 1987). The technique has already been adopted in West Germany and other European countries for the conservation of the rarer components of the arable flora (Schumacher 1987).

In developing such a system, now known as "conservation headlands", the aim has been to cause the minimum impact on crop production commensurate with the benefits to be obtained. A particular concern of farmers is to ensure that headlands do not become infested with certain pernicious weed species, especially black-grass (A. myosuroides), wild-oats (Avena spp.), barren brome (Bromus sterilis) and cleavers (G. aparine) (Bond 1987). Such species are often most abundant at the edges of fields (Marshall 1985), and it has been suggested that it may often be cost-effective to apply sequential herbicide treatments to headlands for their control (Roebuck 1987).

It has therefore been necessary to develop herbicidal options against the major grass weeds and *G. aparine* which would give a high degree of control yet have minimal effect on the more desirable weed species, including knotgrass (*Polygonum aviculare*), black-bindweed (*Fallopia convolvulus*), common chickweed (*Stellaria media*), mayweeds (*Matricaria* spp.), fat- hen (*Chenopodium album*), charlock (*Sinapis arvensis*), hemp-nettles (*Galeopsis* spp.) and field pansy (*Viola arvensis*). Many herbicides commonly used to control *Avena* spp. are selective in their action, but control of other grass weeds traditionally involves the use of chemicals with broad-spectrum activity. Preliminary studies of alternative options for control of *A. myosuroides* are described in this paper.

MATERIALS AND METHODS

In autumn 1985 experiments were established in the headlands of 4 commercial winter cereal crops to study the potential of tri-allate and diclofop-methyl, alone or in sequence, as selective treatments for *A. myosuroides* control in comparison with the "standard" chemicals chlortoluron and isoproturon. In 1986/87 two further experiments were carried out in winter wheat headlands to examine a wider range of treatments, including two new chemicals, imazamethabenz and FD 4026 (ICI Plant Protection). Additional information on control of some broadleaved species was obtained from two further experiments.

TABLE 1

Site and crop details for *A. myosuroides* control experiments

Experiment	Site	Soil	Crop	Cultivar	Cultivations	Drilling date	Previous crop
1985/86							
1	Balsham Cambridgeshire	clay	barley	Halcyon	tine	8 Oct.	wheat
2	Balsham	clay	wheat	Avalon	tine	31 Oct.	wheat
3	Basingstoke Hampshire	clay loam	wheat	Brimstone	plough	17 Oct.	wheat
4	Kineton Warwickshire	clay	wheat	Mission	plough	17 Oct.	wheat
5	Ixworth Thorpe Suffolk	sandy clay loam	wheat	Galahad	plough	24 Oct.	wheat
6	Balsham	clay	wheat	Galahad	plough	17 Oct.	beans
1986/87							
7	Balsham	clay	wheat	Galahad	plough	6 Oct.	wheat
8	Basingstoke	clay loam	wheat	Rendezvous	plough	10 Oct.	beans
9	Ixworth Thorpe	clay loam	wheat	Avalon	plough	10 Dec.	sugar beet

All experiments were laid out in a randomised block design with four replicates. Plots were situated between the field boundary and the first tramline. This distance was 6m (12m at the Cambridgeshire site). Plot width was 3.6m (6m in Cambridgeshire (1986)). Details of sites and crops are shown in Table 1. Herbicide application timings are shown in Table 2.

TABLE 2

Herbicide applications dates and growth stages[1] of *A. myosuroides* and crop at spraying.

Herbicide	Application	Crop G.S.	*A. myosuroides* G.S.
1985/86			
tri-allate	4-29 Oct.	pre-emergence	pre-emergence
isoproturon	31 Oct.-12 Dec.)	pre/early post-emergence	pre/early post-emergence
chlortoluron	31 Oct.- 8 Dec.)		
diclofop-methyl	27 Jan.-21 Mar.	20-22	12-14/20(-21)
1986/87			
tri-allate	16 Oct.- 4 Nov.	pre/early post-emergence	pre/early post-emergence
isoproturon (early treatments)	16 Oct.- 4 Nov.	pre/early post-emergence	pre/early post-emergence
isoproturon (late treatments)	16-22 Dec.	12-13/20-24	13-14/20-21
imazamethabenz	21-28 Nov.^{2}	12-13	pre/early post-emergence
diclofop-methyl) FD 4026)	7 Jan.- 6 Feb.^{2}	20-24	13-14/20-21

[1] Zadoks *et al* (1974)

[2] In Experiment 3 drilling was delayed due to late harvest of previous crop. Applications of some herbicides were therefore made much later to coincide with correct crop/weed growth stages. Imazamethabenz was applied on 20 March, and diclofop-methyl and FD 4026 on 23 April.

Herbicides were applied with knapsack sprayers fitted with a 3m boom and 120° flat-fan nozzles (Experiments 1 and 2, 1986). or 1.8m boom and 80° nozzles (others). Spray pressures and volume rates followed manufacturer's recommendations. Tri-allate was applied to Experiments 1 and 2 as a liquid immediately after drilling and incorporated with a power harrow. In all other experiments tri-allate was broadcast in granule form using a "pepper-pot" technique. In all cases, fertiliser and fungicides were applied by the farm as for the rest of the field.

Grass weeds were counted in April or early May and broadleaved weeds in May or early June. Ten 0.25 or $0.1m^2$ quadrats (depending on the density of the infestation) were assessed per plot. Grass seedheads were counted in late June/early July using "floating" lathe quadrats (ten $0.25m^2$ quadrats per plot).

RESULTS

In 1985/86 the tri-allate/diclofop-methyl sequence gave consistently high levels of reduction in seedhead numbers, generally equivalent to those achieved by chlortoluron and often superior to isoproturon (Table 3). Control by diclofop-methyl alone was greater than 90% in four experiments but only 69% in the other. However, the average performance was better than isoproturon. Tri-allate alone produced useful levels of control but generally lower than other herbicides.

TABLE 3

Percentage control of *A. myosuroides* seedheads by various herbicide treatments, 1985/86.

Treatment	Dose (kg a.i. per ha)	Experiment 1	2	3	4	5	Mean
tri-allate	2.25	44	70	92	89	88	77
diclofop-methyl	1.14	92	98	94	69	99	90
tri-allate +	2.25)	92	99	100	98	100	98
diclofop-methyl	1.14)						
isoproturon	2.10	-	-	-	-	97	
isoproturon	2.50	83	92	54	100	99	85
tri-allate +	2.25)	98	-	-	-	100	
isoproturon	2.50)						
chlortoluron	2.50	-	98	94	100	-	97
chlortoluron	3.50	96	100	97	100	-	98
Seedheads m^{-2} in unsprayed treatment		182	147	1056	110	219	

A. myosuroides populations in the 1986/87 trials were lower than in the previous year, and control levels were high throughout (Table 4). Diclofop-methyl at 1.14 kg a.i. ha^{-1}, alone and in sequence with tri-allate again performed well. Diclofop-methyl at 0.76 kg a.i. ha^{-1} with "Galion" surfactant also gave good control, as did diclofop-methyl at 0.57 kg a.i. ha $^{-1}$ in sequence with tri-allate. FD 4026 gave promising results, as did imazamethabenx. The latter chemical is not claimed to give complete control of *A. myosuroides* (Anon, 1986a), but could be useful in sequence with other products.

In both years the sequence of tri-allate and isoproturon gave very good control of *A. myosuroides* in the 3 experiments in which the treatment was included (Tables 3 & 4). Reduced rates of chlortoluron (Table 3) and isoproturon (Tables 3 & 4) performed similarly to the recommended rates for *A. myosuroides* control.

Neither diclofop-methyl nor FD 4026 significantly affected any broadleaved species present in trials. Imazamethabenz reduced numbers of scarlet pimpernel (*Anagallis arvensis*) by 66% in Experiment 9, following application in March, but did not affect any other broadleaved species. No reduction in numbers of *G. aparine* due to this chemical was observed in

Experiment 7, where this species was moderately abundant (5 plants m^{-2} in unsprayed plots).

TABLE 4

Percentage control of *A. myosuroides* seedheads by various herbicide treatments, 1986/87.

Treatment	Dose (kg a.i. per ha)	Experiment 7	Experiment 8	Mean
diclofop-methyl	1.14	100	92	96
diclofop-methyl + surfactant	0.76) (0.5)[1])	99	96	97.5
tri-allate + diclofop-methyl	2.25) 1.14)	100	99	99.5
tri-allate + diclofop-methyl	2.25) 0.57)	98	98	98
isoproturon (early)	2.50	92	97	94.5
isoproturon (early)	2.10	96	-	
isoproturon (late)	2.50	99	100	99.5
tri-allate + isoproturon	2.25) 2.50)	-	100	
imazamethabenz	0.50	92	78	85
FD 4026	(3.0)[1]	87	100	93.5
Seedheads m^{-2} in unsprayed treatment		99	70	

[1] litres ha $^{-1}$ product

TABLE 5

Percentage control of broadleaved weeds by residual grass weed herbicides

	Chlortoluron		Isoproturon		Tri-allate	
	A	B	A	B	A	B
Anagallis arvensis	-	-	1(0)	-	1(1)	65
Fallopia convolvulus	3(2)	94(92-96)	3(0)	-	3(0)	-
Chenopodium album	1(0)	-	2(1)	94	2(0)	-
Galium aparine	1(0)	-	2(0)	-	2(2)	69.5(69-70)
Matricaria spp.	2(2)	88(77-99)	3(1)	100	3(0)	-
Myosotis arvensis	1(1)	100	2(0)	-	2(0)	-
Polygonum aviculare	3(3)	89(68-100)	2(0)	-	3(0)	-
Stellaria media	-	-	1(1)	79	1(0)	-
Veronica spp.	2(1)	83	5(1)	72	5(5)	81(64-98)

A = no. of trials with number showing significant control in parentheses (only levels of control significant at $P<0.05$ are shown: analysis of variance carried out on plant numbers or $\log_e$ (x+1) plant numbers).

B = mean % control with range in parentheses

Chlortoluron greatly reduced or eliminated populations of F. convolvulus, P. aviculare, Matricaria spp., forget-me-not (Myosotis arvensis) and speedwells (Veronica spp.) where these species were present (Table 5). Isoproturon was much more variable in its effects, giving high levels of control of Matricaria spp., C. album, Veronica spp. and M. arvensis in some trials, but little or none in others. Control was poorer in experiments where crops were thin, though observation suggested that weeds of susceptible species in isoproturon-treated plots were often smaller than in untreated plots. Reduced rates of chlortoluron and isoproturon gave similar levels of broadleaved weed control to full rates (data not presented).

The only broadleaved species affected by tri-allate were A. arvensis, Veronica spp.), and G. aparine. Numbers of Veronica spp. (mainly V. persica and V. arvensis) were greatly reduced by tri-allate in all 5 trials where they occurred. In the two trials where G. aparine was present, tri-allate gave around 70% control of this species.

DISCUSSION

The results indicated that a single application of diclofop-methyl presented a viable alternative approach to traditional chemicals for A. myosuroides control on cereal headlands, particularly when used in sequence with tri-allate. Flint (1985) obtained 75-97% control of A. myosuroides in 6 trials with diclofop-methyl at 1.08kg a.i. ha^{-1}. Results with lower rates were poorer and more viable. A sequence of tri-allate followed by diclofop-methyl at 0.54 kg a.i. ha^{-1} gave levels of control between 68 and 94%. A tri-allate sequence with diclofop-methyl at full rate was not tested.

In the present trials, the primary consideration was the very high level of control required to counteract the poorer conditions and high weed populations commonly associated with headlands. Cost was considered to be of secondary importance, in view of the small area involved. Accordingly, chemicals were generally applied at the recommended rates for A. myosuroides control, even where sequences were used. In the few cases where reduced rates were included for comparative purposes however, neither control of A. myosuroides nor broadleaved species was significantly affected. Similarly Flint (1985) found that isoproturon at 2.0kg a.i. ha^{-1} was as effective as 2.5 kg a.i. ha^{-1}.

Control of both A. myosuroides and broadleaved weeds by isoproturon was very variable, particularly in the 1985/86 trials. Similar results have been blamed on a build-up of ash residues from straw-burning in minimum cultivation systems (Flint 1985), but this is unlikely to be a factor in these experiments. Isoproturon is known to be less persistent in the soil than chlortoluron, and its persistence is further reduced when a prolonged period of wet weather follows application as it did in autumn 1985 (Luscombe 1983). Hewson & Read (1985), summarising trials carried out over 11 years, reported that control of A. myosuroides by isoproturon was poorer in years with wet autumns. Furthermore, headland conditions are often not ideal for the action of soil-applied herbicides, due to soil compaction, formation of clods, and less competitive crops (Roebuck 1987). The very poor control of A. myosuroides in Experiment 3 is probably the result of a thin, uncompetitive crop. Black-grass is strongly influenced by crop plant density: in a thin crop, its tillering capacity is greatly enhanced (Moss 1980).

The effect of isoproturon on broadleaved species present in the spring was even more variable, control of some species ranging from 0-100% in different trials: tri-allate was much more consistent. The persistence of isoproturon over winter varies depending on rainfall, whereas tri-allate is unaffected (Luscombe 1983). The survival of spring-germinating seedlings following autumn isoproturon depends on the competitive ability of the crop as well as residual herbicide activity. Under suitable conditions however, resistant species (e.g. P. aviculare) may benefit from removal of competition by other weeds (unpublished data). Conversely, where the weed flora is predominantly composed of susceptible species (eg. S. media, Matricaria spp.), weather conditions are favourable, and/or a vigorous crop in present, few "desirable" weeds may remain.

Diclofop-methyl appears to have several advantages in the context of conservation headlands. It is totally selective, having no effect on non-target species. Being a foliar-acting herbicide, it is unnaffected by soil conditions, and it works without the need for crop competition (Anon, 1986b). The main disadvantage of diclofop-methyl is the need for timeliness of application at a difficult time of year. Seedlings must be emerged at spraying, but the chemical is only effective when applied before tillering. This generally implies application in the middle of winter, when very few "spray days" are available (Spackman 1983). Early application of tri-allate is therefore a useful insurance measure. An added benefit of using tri-allate is the very useful degree of G. aparine control exhibited by this chemical. Unfortunately it also controls Veronica spp., but these are among the less valuable species as hosts for insects eaten by gamebird chicks, although they can be useful nectar sources for butterflies.

Another interesting possibility is enhancement of the activity of diclofop-methyl against older A. myosuroides plants by addition of an adjuvant. Ayres (1987) has obtained good control of A. myosuroides with several tillers in this way. In the current trials good control was achieved by diclofop-methyl at 0.76 kg a.i. ha^{-1} plus "Galion" surfactant, applied at the 3-4 leaf stage, but later applications were not investigated.

New chemicals with selective modes of action may increase the options available. Both FD 4026 and imazamethabenz are promising candidates for increasing the flexibility of selective control programmes, but current data is limited and more work is required. It is to be hoped that the recent increase in new products with a selective mode of action will continue and that agrochemical companies will not be tempted to release such chemicals only in mixtures with other broad-spectrum compounds.

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THE ENVIRONMENTAL IMPACT OF BRACKEN

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ABSTRACT

Bracken is an opportunistic pioneer which has exploited historical changes in land use and become one of the most successful weeds in the British Isles. It is currently spreading at the rate of 1-4% per annum. The consequence of lost grassland and moorland is a reduction in grouse and sheep productivity and ultimately the sale of land to the alternative land use of afforestation.

In conservation terms bracken carries fewer birds, mammals and insects than the ground it replaces and can introduce parasites harmful to sheep and grouse. The future role of using a biological control to control bracken or the idea of harvesting bracken as a biofuel is summarised.

INTRODUCTION

In the ecological sense, bracken (*Pteridium aquilinium*) is a remarkably successful weed. It is tolerant of a wide band of climatic conditions, it is physically and biochemically unpalatable, it is highly resistant to diseases, it releases allelopathic compounds thereby inhibiting the growth of other species and with its highly developed and effective rhizome system it spreads quickly, has a long life expectancy and can withstand severe burning (Page 1986). Clearly bracken exhibits the characteristics of a highly adapted opportunistic pioneer and it is perhaps not surprising to discover that it has exploited ground disturbed by man and his livestock and so become a highly successful weed.

Although bracken is considered the most widespread vascular plant in the world it would seem that there are few places where it is grows so vigorously and densely as it does in northern and western Britain. There is no doubt that this weed has caused serious loss of agricultural land and continues to encroach on threatened habitats while possessing features which cause problems with land management. Environmentally its only saving grace is that it turns to a golden brown in the autumn and appears aesthetically pleasing to the tourists which flock to Britain's upland areas. While extensive research on bracken continues around the world there are still problems with effectively controlling the weed. In this short paper I wish to evaluate the impact of bracken on the uplands of Britain (Figure 1) by considering the historical spread of the weed and the consequences of this, both directly and indirectly, on land use and upland conservation.

The history of bracken encroachment

At all localities within the British Isles where the rate of bracken encroachment has been monitored it is spreading and not receding. For Great Britain, the overall rate of encroachment has been estimated as 2.8% per annum (Taylor 1986), a rate which would result in an area the size of England being obliterated by bracken within a century. While the likelihood of such an event is negligible it is important to realise the

Fig. 2. Principal upland areas where bracken is considered a problem and conflicts with land use, based on Birnie & Miller 1986, Hudson 1986b and Taylor 1986. The 400 metre contour is shown as a dotted line.

scale of the problem; the rate of expansion is equivalent to the spread of forestry and urban development. Taylor (1986) emphasised this by pointing out that for every 4 hectares of farmland lost to forestry and urban development an area of between 1 to 2 hectares is lost to bracken.

We know from the examination of spore records that bracken was widely distributed in the British Isles during Mesolithic times although it was probably a minor component in the natural woodland vegetation. Some 5000 years ago as Neolithic man reduced the extent of this natural woodland and the climate became more oceanic then bracken increased, particularly in areas cleared by man where the competitive ability of the trees was reduced and the bracken could invade the disturbed ground. Coupled with felling there was a steady increase in stump removal as the ground was ploughed while the incidence of fires increased and grazing pressure prevented tree regeneration. Within the past century the rate of bracken spread has accelerated as increased sheep grazing has selectively reduced the competitive ability of the more palatable grasses and produced a vacuum within which bracken could increase; the vicious circle of increased grazing pressure on smaller bracken-free areas has continued to exacerbate the problem. Furthermore, since the last war man's persecution of bracken has decreased as it is no longer cut for bedding, fuel or used in the manufacture of soap. Over the same time there has been a fall in management inputs into the uplands, abandoned areas of cultivation around crofts have allowed bracken to spread and the reduced numbers of keepers and shepherds have often resulted in poor burning practices on hill ground which has allowed the rapid expansion of bracken. In recent years it is possible that increased acid deposition and drainage have improved conditions for bracken and assisted with an accelerating rate of spread. In short, bracken spreads principally because it is an aggressive competitor and has expanded its range as it has taken advantage of natural and man-induced changes in land use.

Vegetation loss and consequences for land use

Bracken tends to favour areas of acidic grassland and heather while avoiding the water-logged blanket bog and the less acidic limestone areas. Consequently, the traditional site for bracken has been the steep sides of moorland hills. In recent years the conditions for bracken have improved on some of the flatter areas where it has a far greater impact on farming and conservation interests. On hill ground the benefits from spraying are marginal, even when additional stock is available to utilise improved areas. In areas like the North York Moors, some two-thirds of the bracken ground is on the heather moorland where it is currently encroaching onto the flatter tops and reducing feeding areas for sheep and grouse.

The viability of many upland estates depends on the availability of a good and well managed heather sward. Over-grazing of the heather by sheep and the expansion of bracken have reduced the area of suitable feed and productivity of some moors for grouse and sheep. For a grouse moor to break-even financially it must harvest 30 grouse per square kilometre. In 1980, in the North York Moors when 20% of the moorland was covered in bracken the average bag was 40 per square kilometre (Hudson 1986a). Any further decline in the size of the harvest, brought about by reduced management and/or a further spread of the bracken could be sufficient to reduce the harvest below the point where upland estates were viable. When this occurs land owners are forced to sell and with current tax incentives we can expect much of this ground to be sold for afforestation. In conservation terms, the replacement of heather moorland by large scale planting is considered disastrous since most of the upland fauna is lost and the moorland habitat becomes fragmented into ecologically small units.

Direct impact and conservation value of bracken

Bracken is of low conservation value. In moorland areas only 15 species of bird breed in bracken, while 33 regularly breed on heather moorland and 25 on the acidic grasslands that the bracken has replaced (Ratcliffe 1977). There are no specialist bracken breeding birds and amongst the 18 species lost from moorland when covered in bracken are some nationally important species such as hen harriers (*Circus cyaneus*), greenshank (*Tringa nebularia*) and twite (*Carduelis flammea*). Although it can provide cover for nesting birds the bracken fronds do not reach a suitable height until most birds have finished breeding and this is no doubt part of the reason why less than half the birds recorded in heather use bracken.

Some birds, like the black grouse (*Tetrao tetrix*), will nest in bracken although the bracken replaces their more favoured habitats such as blaeberry (*Vaccinium myrtilus*) and the encroachment of bracken into small birch plantations may have also resulted in a reduced density of black grouse. It is more than likely that most birds selectively avoid bracken stands although the evidence for this is lacking. Only during periods of hot weather in late summer or when being chased by predators do birds utilise the bracken for cover.

In the North Yorkshire Moors, Brown (1986) has recorded the abundance of invertebrates in bracken and from neighbouring heather dominant vegetation. In all instances the abundance of invertebrate groups is lower in bracken ground and increases after spraying and restoration of heather moorland. Coleoptera were more abundant on sprayed bracken and burnt heather, while both the ants and harvestmen were correlated with the extent of heather. Representation of taxonomic groups was the same in bracken both sprayed and unsprayed and there was quite simply an increase in abundance of insects with the abundance of heather.

For the invertebrate predators, the bracken ground is of low productivity compared to neighbouring heather moorland. Consequently it is not surprising to find that the invertebrate predators, such as the small mammals (Brown 1986) are at a lower density within bracken ground. This could also account for why some of the insectivorous birds such as the wheatear (*Oenanthe oenanthe*) appear to actively avoid bracken beds (Ratcliffe 1977).

Indirect impact of bracken on wildlife

Probably the largest environmental impact of bracken is that it quite simply replaces vegetation favoured by man and wildlife. In addition to this bracken has toxic properties which causes bright-blindness in sheep and staggers in horses. It is also carcinogenic and produces a type of leukaemia in cattle and stomach cancer in ruminants. Furthermore bracken provides a favourable habitat for parasites harmful to grouse and sheep.

The sheep tick *Ixodes ricinus*, is an ectoparasite of grouse and sheep that transmits a number of harmful diseases including louping-ill, tick borne fever and tick pyaemia. The indirect effects (as disease vectors) of ticks are known to be harmful to grouse and sheep and it is quite conceivable that they also influence a wide range of other animals. While not on their hosts the ticks require a humid habitat in which to survive and this is provided by the thick mat layer associated with rough grasslands and bracken. Through a questionnaire survey followed up by field studies Hudson (1986b) found a close association between moorland areas with tick problems and with extensive bracken beds. Bracken ground carried significantly more ticks than heather ground and grouse chicks utilising the bracken ground carried larger infestations. Treatment of the bracken with the herbicide asulam (May & Baker) reduced the thickness of the mat layer and the tick population and consequently the probability of tick borne diseases.

Bracken control and the future

The economic and environmental consequences of bracken are considerable. By replacing vegetation of importance to farmers and land owners and causing indirect damage to wildlife the spread of bracken is pushing our traditional forms of land use nearer the edge of financial loss and the ultimate change of multiple land use (sheep, deer, grouse, conservation and tourism) to the single land use of afforestation. It is important to realise that the bracken, often associated with over grazing (Hudson, 1984), is a major force causing this switch in land use. In this respect it is surprising that with a weed of such significance to this country there are no accurate figures on the actual expense imposed by the spread of bracken (Heads and Lawton 1986). Without doubt it must be several million pounds per annum and when everything is taken into consideration probably tens of millions of pounds. Agriculturally and environmentally we need an effective method of control.

At the current time most bracken is treated with the herbicide asulam. While effective when applied correctly it must be sprayed from a helicopter with follow-up treatment such as spot spraying or crushing, labour intensive and expensive techniques. Far too often large areas of bracken are efficiently sprayed but the follow-up costs are too high to instigate on a large area so the bracken rapidly regenerates from the rhizome system and returns the bracken to its previous state.

Alternative suggestions for reducing the spread or at least providing better control have included using the bracken as an energy crop. Lawson et al (1986) provide a refreshing and alternative approach to the more typical negative view of bracken by proposing its use as a biofuel and even suggesting that its exploitation could be a more profitable form of land use in the uplands than traditional sheep farming. Bracken as a biofuel is biologically and technically feasible and close to financial viability although many of the assumptions still require to be tested on a commercial scale.

Alternative control techniques include the development of effective biological controls. In Britain the bracken appears to have relatively few enemies while in other parts of the world there are at least two species of moth whose caterpillars are known to damage bracken either by directly eating the pinnae or penetrating the plant's rachis (stem). Obviously great care must be taken before biological controls are released although an assessment of Parthenoides indicates that this could well be a suitable candidate since it eats nothing but bracken (Lawton 1986). Even so, under the Wildlife and Countryside Act it is difficult to see what evidence should be collected for and against the release of a biological control for a natural weed. The implications of the debate about the introduction of a biological control are interesting and could have far reaching repercussions to other systems where genetically engineered viruses or other pests could be introduced.

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HERBICIDE EFFECTS ON THE FLORA OF ARABLE FIELD BOUNDARIES

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ABSTRACT

Studies of field boundary floras under the Boxworth Project have continued for four seasons. Data from broad-scale surveys and detailed studies of limited areas indicated some changes in field edge flora. These did not correlate with intensity of herbicide use in adjacent fields, suggesting other factors, particularly close cultivation, were important in botanical change in field edges. Records of floras adjacent to unsprayed or "conservation" headlands on the Manydown Estate initially demonstrated a trend for increased plant diversity compared with sprayed headlands, but this was not confirmed. Experiments on the susceptibility of hedgerow plant species have shown the spectra of activity of a range of herbicides and plant growth regulators. Many species might be affected by accidental contamination from over-spraying or spray drift, particularly by mecoprop, fluroxypyr, metsulfuron-methyl and glyphosate.

INTRODUCTION

Field boundaries are increasingly viewed as refuges for wildlife in intensively-managed farmland. Concern over the impact of agricultural operations, particularly agrochemical applications, on the ecology of the field boundary habitat has, therefore, increased. Under arable regimes, the requirement for retaining stock has largely gone, which in the past resulted in some farmers viewing hedges as undesirable (Grigor 1845). The view that weeds and other pest organisms spread from the field boundary has been held for many years and is widespread today. These perceptions have contributed to unsympathetic management of this habitat. Recent studies, however, have indicated that weed spread from hedgerows is limited to a few species and that beneficial fauna are found in the field boundary (Marshall & Smith 1987).

Arable hedgerows have been the main subject of field margin studies by Long Ashton Research Station as they are the most complex and diverse boundary structures. Herbicides may affect floras following accidental or deliberate over-spraying or from drift. Little data is available on the extent of such effects or the susceptibility of hedgerow plants to herbicides. Field observations on boundary floras where herbicide applications in the adjacent fields have been manipulated are reported in this paper. Changing herbicide use may result in more or less contamination of the field boundary and changes in the composition of field edges. The data form part of two larger research programmes, the Boxworth Project (Hardy 1986) and part of the Cereal & Gamebirds Research Project (CGRP) conducted on the Manydown Estate (Rands 1985). Investigations of the effects of direct applications of some herbicides and plant growth regulators on hedgerow plant species have produced relative information on susceptibilities and the likely impact of field rate applications of chemicals (Marshall & Birnie 1985).

BOUNDARY FLORAS OF FIELDS WITH CONTRASTED HERBICIDE USE

Boxworth

Fields at the Boxworth Experimental Husbandry Farm (EHF) are presently receiving three levels of pesticide input as part of a multi-disciplinary research programme, known as the Boxworth Project (Marshall 1985; Hardy 1986). Winter wheat fields within the Full Insurance area have received on average 5.4 herbicide applications per year between 1984 and 1986, the first three seasons of treatments. In contrast, Supervised area fields have had an average of 3.4 applications and Integrated area fields have had 2.7 applications each year. Detailed investigations of the flora were made in four 50m sections of boundary, with one site in each of the Full Insurance and Integrated areas and two (A & B) in the Supervised area. Extensive surveys were made by recording species present at fixed points 50m apart round the perimeter of all fields where a boundary structure existed. Numbers of species, their frequency at survey points per field and Margalef's index of species diversity (Margalef 1951) were calculated. However, the indices did not allow valid comparisons between fields, as the numbers of sampling points were not equal. Nevertheless, trends over time within areas and individual fields are meaningful.

A quantitative estimate of individual species within boundary lengths with uniform structure and aspect has also been made for all study fields at Boxworth. A domin scale (0-6) of species cover and abundance (Greig-Smith 1964) has been used in early summer for three seasons. Detailed transect assessments of vegetative frequency from within the boundary into the crop edge have been made in four 50m lengths of boundary. In July each year, species were recorded in eleven 10cm wide transects, each divided into 10cm lengths and running from within the boundary 5m into the crop. Numbers of species in the boundary out to the crop edge (Boundary) were compared with numbers found within the crop (Crop). Using percentage frequency data for each species, the Shannon-Weaver diversity index (H') was also calculated (Pielou 1966).

Boxworth Results

Extensive surveys of species composition in the boundaries of the three treatment areas at Boxworth have shown annual changes in species numbers and in Margalef's index of diversity (Table 1).

TABLE 1.

Numbers of species found and Margalef's index of diversity in each treatment area, Boxworth 1983-1986.

Area	Number of sites	Number of species				Diversity index			
		1983	1984	1985	1986	1983	1984	1985	1986
Full Insurance	95	98	97	109	83	13.7	13.0	14.7	11.3
Supervised	88	87	80	100	83	12.3	10.8	13.5	11.3
Integrated	76	81	87	95	73	11.9	12.0	13.1	10.3

Numbers of species and diversity indices in 1983, before treatments began, varied with number of sampling points. Thereafter, changes were not consistent, though the diversity and species number in the Full Insurance area became similar to those of the Supervised area. This might indicate a relative reduction in diversity within the Full Insurance area. Mean numbers of plant species at each sampling point are given in Table 2. These data did not correlate well with differences in herbicide use between the treatment areas.

TABLE 2

Mean number of species per sampling point in different treatment areas, Boxworth 1983-1986.

	Number of species per point			
	1983	1984	1985	1986
Full Insurance	12.7	16.6	16.2	15.3
Supervised	12.7	17.6	17.7	16.5
Integrated	10.7	16.9	16.9	14.7

The number of species, excluding shrubs, in uniform hedgerow sections of approximately even length (c. 300m) in four fields and recorded in June for four years are given in Table 3. No major changes associated with field treatments were evident in either annual, perennial or biennial species. The Full Insurance field showed few changes in annual or perennial species numbers. Declines in perennial and biennial species in the Supervised (A) field in 1985 and 1986 were followed by increases in 1987.

TABLE 3

Numbers of ground flora species in uniform hedgerow lengths of c.300m from four fields, Boxworth 1984-1987.

Field	Full Insurance				Supervised (A)				Supervised (B)				Integrated			
	84	85	86	87	84	85	86	87	84	85	86	87	84	85	86	87
Life form																
Annuals	5	4	5	3	10	3	6	6	4	7	7	2	12	6	5	8
Others	14	15	13	15	29	23	17	30	13	17	17	16	15	13	15	17

In each of the 50m intensive study sites, transects traversing the boundary and extending 5m into the crop were examined in July. Results were expressed as numbers of species, including shrubs, found in the boundary and in the crop and as the Shannon-Weaver diversity index (Table 4). The mean lengths of sample transect in the boundary or crop areas are also given. There were generally fewer species recorded in the field boundaries of all four sites in 1985 and 1986. Crop edge species numbers varied in individual fields with no obvious pattern. Decreases in 1986 in species numbers in the crop in the Integrated field were probably a result of herbicide applications in April. Changes in the number and diversity of species appeared to follow changes in width of the hedgebottom out to the crop. The width between the hedge and the planted crop was reduced in most sites in 1985 and markedly in 1986, following ploughing. Such a reduction in habitat size would be expected to affect species number and diversity.

TABLE 4

Attributes of the flora of four 50m sites divided into boundary and crop areas in July 1984, 1985 and 1986.

	Transect length (m)		No. species		Diversity (H′)	
	Boundary	Crop	Boundary	Crop	Boundary	Crop
Full Insurance						
1984	1.07	2.93	16	4	1.945	1.117
1985	0.88	4.12	17	5	2.188	1.086
1986	0.60	4.40	15	7	2.044	0.921
Supervised (A)						
1984	1.95	2.05	38	10	2.976	1.559
1985	2.07	2.93	31	14	2.738	1.934
1986	1.26	3.74	29	12	2.669	1.456
Supervised (B)						
1984	1.21	2.79	13	6	1.760	0.840
1985	0.94	4.06	12	10	1.618	0.639
1986	0.36	4.64	6	6	1.477	1.293
Integrated						
1984	1.50	2.50	26	17	2.433	2.017
1985	1.05	3.95	21	16	2.485	1.959
1986	0.65	4.35	16	6	2.337	0.945

Manydown

On the Manydown Estate, the 6m of cereal crop adjacent to the boundary was either sprayed with herbicides as normal (FS), not sprayed in spring or summer (NSS) or left unsprayed during the season (NS). These experimental unsprayed headland treatments succesfully sought to increase the survival of partridge chicks by providing insect food items associated with dicotyledonous weeds (Rands 1985). The technique is being developed by CGRP and such margins are now known as Conservation Headlands. The treatments offer a measure of protection to the field boundary from herbicide contamination. Therefore, between 1984 and 1986, changes in the flora of a series of 50m lengths of hedgerow at Manydown were assessed. In the boundary the percentage cover of plant species was estimated by eye in 22 0.1 m2 quadrats along the 50m length. Assessments were made in May 1984 and in July in 1985 and 1986. Studies of the flora within the crop were also made and are reported elsewhere (Marshall 1986).

Six sites were studied for three years, while a further eight sites were investigated at least twice during the same period. The cropping of the fields and the headland treatments varied during the study. Changes in numbers of species per site were examined and the cover data used to calculate the Shannon-Weaver diversity index.

Manydown Results

The number of non-shrub plant species recorded in the boundaries are given in Table 5. In the first six fields, there was a trend for reduced herbicide use in the headland (NSS and NS treatments) to give similar or greater numbers of species in 1985 than in 1984. Fields which were sprayed up to the crop edge (FS treatments) tended to have fewer species in 1985. However, the trend was not confirmed by the data collected in 1986, which indicated considerable year-to-year variation.

TABLE 5

Numbers of non-shrub plant species in field boundaries on the Manydown Estate, 1984-1986, with crops and headland treatments.

Field	1984			1985			1986		
	Crop	Head.	Species No.	Crop	Head.	Species No.	Crop	Head.	Species No.
Hatchcroft	WW	NSS	13	WW	NS	22	SB	NSS	16
Pack Lane	WW	NSS	16	WW	FS	14	SB	NSS	18
Moores	WW	FS	20	SB	NS	17	SB	NSS	17
Lonely Meadow	SB	NSS	19	SB	NS	23	SB	NS	26
Farm Close	SB	FS	21	SB	FS	14	Peas		22
Great Woods E	SB	FS	25	SB	FS	22	Peas		22
Big Field	WW	NSS	18	SB	NSS	-	Peas		21
Scrapps Hill S	WW	FS	23	WW	FS	-	SB	NSS	31
Scrapps Hill N	WW	FS	17	WW	FS	-	SB	NSS	26
Teddys	SB	NSS	15	SN	NSS	-	Grass		17
Mothers East	SB	FS	13				Rape		21
Hansfords	WW	FS	-	WW	NSS	20	SB	FS	22
Rooksdown	WB	FS	-	WB	FS	20	WB	FS	21
Battledown S	WW	FS	-	SB	NS	32	SB	FS	32

(WW=Winter wheat; SB=Spring barley; WB=Winter barley. FS=full spray; NSS=no spring or summer sprays; NS=no sprays during the season.)

The mean percentage cover of species in the boundary were used to calculate the Shannon-Weaver diversity index (Table 6). In terms of species diversity, changes in the boundary floras at Manydown did not indicate any direct effect of reduced herbicide input from field applications.

TABLE 6

The Shannon-Weaver diversity index (H') for six boundaries and their headland treatments, Manydown 1984-1986.

Field	1984		1985		1986	
	H'	Headland	H'	Headland	H'	Headland
Hatchcroft	1.500	NSS	2.413	NS	2.169	NSS
Pack Lane	1.895	NSS	2.155	FS	1.906	NSS
Moores	2.432	FS	2.431	NS	2.253	NSS
Lonely Meadow	2.614	NSS	2.284	NS	2.040	NS
Farm Close	1.938	FS	1.591	FS	1.599	-
Great Woods E	2.224	FS	2.009	FS	2.503	-

(FS=full spray; NSS=no spring or summer sprays; NS=no sprays during the season.)

Discussion

The data collected at Boxworth, where different herbicide regimes within the entire field were applied, and at Manydown, where different headland treatments were practiced, did not indicate botanical changes which could be correlated with herbicide use. Both spatial and temporal variation without consistent trends were shown in the numbers of species found and in measures of species diversity. It is tempting to conclude, therefore, that applications of herbicides to crops do not affect field boundary floras. This might be the case, but further considerations are required. For example, the initial composition of the field boundaries may have been so affected by previous herbicide practice that botanical change was limited by lack of propagules.

The measures of botanical change that have been examined in the two studies are essentially at the community level. Broad changes in botanical diversity have been sought, while changes in individual species have not been considered. At the species level, temporal and spatial variation is likely to be large, and difficult to follow, on this scale of field monitoring. Diversity indices summarise considerable amounts of data but have been widely used in ecology, including pollution studies (Zand 1976), to describe differences in communities in time and space. The present data show changes, but these appear unrelated to herbicide use. It is likely that on the farms examined, herbicide drift is not of major significance. Under normal spraying conditions, spray drift is minimal beyond 10m and the amounts of active ingredient reaching field boundaries is thought to be small. The Boxworth data certainly indicate that factors other than herbicides were important in botanical change in the field boundary. In particular, there was some evidence that disturbance by close cultivations before the crop was drilled was the major factor affecting the flora. Other forms of disturbance, for example fertiliser contamination and burning, may also affect boundary floras. There is little information on the relative contribution of these influences or of any interaction between them. While the present studies shed some light on the role of herbicides in field boundaries, clearer insight can only be gained from further detailed and controlled experimentation.

THE SUSCEPTIBILITES OF HEDGEROW PLANTS TO HERBICIDES

While some information on the susceptibility of plant species to herbicides is available in the technical literature for commercial products, it is impractical for manufacturers to test a wide range of non-target species. Initial investigations to extend the information on hedgerow plant susceptibilities were described by Marshall & Birnie (1985). Further studies on pot-grown hedgerow plants have now been made. Pot studies may not reflect the results of field applications of herbicides. In the field, soil-acting herbicides are likely to be less effective than in pots, while low doses of some herbicides might affect the competitive ability of some species, resulting in greater changes of botanical composition than indicated in pot experiments. Nevertheless, useful relative information is obtained, some of which may indicate experimental approaches to the direct manipulation of boundary floras.

Forty-two ground flora species were established in 1 litre pots during the autumn of 1985 and were treated during the spring of 1986 (glyphosate in July). Plant vigour was scored on a ten point scale (0=dead, 9=unaffected. Marshall & Birnie 1985). Pots were sprayed with the recommended field rate of a series of herbicides and three plant growth regulators, using a laboratory pot-sprayer delivering 300 l/ha. Not all species were treated with each compound; certain species had already been tested with some herbicides and insufficient material was available for other species. A summary of the numbers of species tested and the number with significantly lower vigour scores to control plants at six or 15 weeks is presented here.

Results and Discussion

The results of the pot experiments conducted during 1986 on the hedgerow plant species are summarised in Table 7. The chemicals used are grouped according to their recommendations for use, and the numbers of grass and dicotyledonous species tested and significantly different to controls are compared.

TABLE 7

Numbers of broad-leaved and grass species tested with different herbicides and plant growth regulators and numbers significnatly reduced in vigour at six or fifteen weeks after treatment.

Chemical	Rate applied (kg (a.i.)/ha)	Broad-leaved species Tested	Broad-leaved species Affected	Grass species Tested	Grass species Affected
mecoprop	2.40	14	8	0	-
2,4-D	0.70	28	12	10	0
fluroxypyr	0.20	27	19	10	0
ioxynil+bromoxynil	0.76	15	4	0	-
clopyralid	0.20	15	4	0	-
diclofop-methyl	1.14	20	2	0	-
flamprop-isopropyl	0.60	27	3	0	-
difenzoquat	1.00	26	4	10	0
isoproturon	2.02	19	2	0	-
chlorsulfuron	0.015	22	9	0	-
metsulfuron-methyl	0.006	28	16	10	0
methabenzthiazuron	1.60	26	6	10	0
ethofumesate	2.00	30	12	0	-
glyphosate	1.40	25	20	10	10
mefluidide	1.60*	29	9	0	-
paclobutrazol	1.00	28	9	10	0
chlormequat	0.91	25	1	10	0

*=Four times recommended rate.

Of the broad-leaved weed herbicides examined, mecoprop, 2,4-D and fluroxypyr significantly affected a large proportion of species tested. Fluroxypyr was particularly active, reducing the vigour of 70% of the dicotyledonous species examined, while grasses were unaffected. Grass herbicides generally had few effects on dicotyledonous species. The soil-acting herbicides, such as isoproturon, had varied effects with the sulfonyl urea compounds, chlorsulfuron and metsulfuron-methyl, showing the widest spectrum of activity. Glyphosate, as expected, affected the most dicotyledonous and grass species, following application in July. Among the growth regulators, chlormequat affected only one species, while the grass retardants, mefluidide and paclobutrazol affected 30% of the dicotyledonous species. The effects of mefluidide may have been overestimated as the rate applied was four times that recommended. Apart from glyphosate treatments, no compound adversely affected the grass species examined.

These investigations demonstrated that many non-target species found in field boundaries were susceptible to field rates of commonly used herbicides. Certain compounds, notably mecoprop, fluroxypyr, metsulfuron-methyl and glyphosate, were capable of affecting a wide range of species. If unusual spraying conditions pertain, where considerable amounts of active material of such compounds contaminate the hedge, then severe effects on species composition might be expected.

CONCLUSIONS

Examinations of the relative susceptibility of plant species have shown that many non-target plants may be affected by field rates of some chemicals. Risk of damage to hedgerow floras is greatest from contamination by broad spectrum compounds, such as mecoprop, fluroxypyr, metsulfuron-methyl and glyphosate. The amounts of active ingredient actually deposited in the field boundary is almost infinitely variable, ranging from full field rate with accidental or deliberate over-spraying to nothing under optimum spraying conditions. Field examinations on two farms where different herbicide regimes were practiced, and hence different opportunities for contamination existed, have indicated that herbicides probably do not play a major role in changes in the existing flora.

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1987 BRITISH CROP PROTECTION CONFERENCE—WEEDS **4A—5**

WEED CONTROL AT FIELD MARGINS: EXPERIMENTAL TECHNIQUES AND PROBLEMS

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ABSTRACT

Hedgerows damaged by agrochemicals, fertilisers or fire are rapidly colonised by undesirable annual grass and broadleaved weeds. Selective herbicides used to control these species and allow regeneration of the perennial flora showed some advantages in the short term but, after 5 years there was still a need for annual herbicide applications to maintain beneficial effects.

The use of herbicides on hedge bottoms and ditch sides is unacceptable for environmental reasons. Alternative weed control techniques are being explored such as repeated topping of the panicles of annual grasses, and the use of sterile boundary strips. Experimental techniques and associated difficulties are discussed.

INTRODUCTION

A small number of species occurring in the hedge-bottom flora also appear in the crop headland. Typical of these are *Elymus repens* (common couch), *Alopecurus myosuroides* (black-grass), *Poa trivialis* (rough meadow-grass), *Bromus sterilis* (barren brome), *Galium aparine* (cleavers), *Convolvulus arvensis* (field bindweed), *Fallopia convolvulus* (black-bindweed), *Cirsium arvense* (creeping thistle) and *Veronica persica* (common field-speedwell) (Marshall & Smith 1987, Roebuck 1987). Some of these annual species readily colonise cultivated ground and are serious competitors in arable crops. Consequently, the hedgerow habitat can be an important source of weed seeds.

A recent spot survey indicated that 39% of farmers who were questioned used herbicides to control potential crop weeds in their field boundaries, and more than half of these farmers used glyphosate (Greaves & Marshall 1987). Deliberate attempts to control hedge-bottom arable weeds by spraying with desiccant or systemic herbicides have led to greater problems from the prolifically seeding annuals such as barren brome and cleavers, which establish and propagate in the bare ground left after spraying.

Regeneration of the hedge-bottom flora in such situations by natural spread of surviving perennials is very slow in the face of competition from the aggressive annuals. Selective control of these annuals could perhaps hasten the repair of hedge bottoms and ditch sides. This was attempted by using herbicides varying in selectivity against annual and perennial grass and broadleaved species on a damaged hedgerow in Buckinghamshire (Experiment 1).

In view of the adverse environmental implications of herbicide use in hedge bottoms and ditch sides a second experiment was initiated. This was designed to evaluate the use of boundary strips to control field-margin weeds and prevent their spread into the adjacent crop, whilst at the same time offering a degree of protection to the hedgerow from fertiliser and pesticide spray drift.

EXPERIMENT 1

Materials and methods

A section of hedgerow bottom and adjacent ditch side near Stoke Mandeville, Buckinghamshire, which had been sprayed with glyphosate was selected as it contained a high proportion of B. sterilis and G. aparine. Plots of 20 m length were randomised twice down each side, the plot width being 1 metre at the hedge bottom and 2 metres at the ditch side. A barrier strip of one sprayer nozzle width (0.3m) of propyzamide was used between the plots and the crop edge to keep this area weed free.

Treatments were selected for activity against annual grasses and broadleaved weeds and also selectivity for perennial species.

asulam sodium	2.0 kg/ha a.i.	(5.0 l/ha Asulox)
endothal sodium	0.8 kg/ha a.i.	(4.0 l/ha Herbon Penout + wetter)
ethofumesate	1.0 kg/ha a.i.	(5.0 l/ha Nortron)
ethofumesate	2.0 kg/ha a.i.	(10.0 l/ha Nortron)

Herbicides were applied annually during November 1982 to 1986 by knapsack or Oxford Precision Sprayer in 225 l/ha at 2.5 bar using 8002 Spraying Systems T jets.

Results

Species were recorded on a per centage ground cover basis using 0.5 m^2 quadrats. Interim results for dominant species are shown in Table 1

TABLE 1

Percentage ground cover of weed species in field boundaries after two treatment years (Stoke Mandeville, November 1984).

Treatment	Bromus sterilis	Elymus repens	Galium aparine
Ditch side			
Nil	87	0	11
asulam	88	3	9
endothal sodium	68	13	18
ethofumesate (1.0 kg)	72	15	13
ethofumesate (2.0 kg)	82	8	10
Hedge bottom			
Nil	74	10	16
asulam	50	24	26
endothal sodium	55	31	14
ethofumesate (1.0 kg)	52	27	21
ethofumesate (2.0 kg)	19	44	37

After two years of treatment there was a small reduction of B. sterilis on the ditch side, and an increase in E. repens. Control of B. sterilis was better in the hedge bottom, but there were more cleavers which were not controlled by herbicides active against this weed (e.g. ethofumesate) (Table 1).

After five years the two habitats showed increases in useful hedgerow species such as E. repens, P. trivialis, Lamium album (white dead-nettle), *Stachys sylvatica* (hedge woundwort), *Alliaria petiolata* (garlic mustard), *Anthriscus sylvestris* (cow parsley), *Urtica dioica* (common nettle) and *Glechoma hederacea* (ground ivy) (Appendix I). the area under *G. aparine* showed little change over the years and there was still a higher proportion of *B. sterilis* and *G. aparine* in the hedge-bottom flora compared to the ditch side (Table 2).

TABLE 2

Percentage ground cover of weed species in field boundaries after five treatment years (Stoke Mandeville, February 1987).

Treatment	*Bromus sterilis*	*Elymus repens*	*Galium aparine*	*Lamium album*	*Anthriscus sylvestris*	Bare ground
Ditch side						
Nil	31	29	4	4	1	31
asulam	29	34	2	14	0	21
endothal sodium	25	40	5	3	0	27
ethofumesate (1.0 kg)	3	50	3	6	0	38
ethofumesate (2.0 kg)	22	26	17	13	1	21
Hedge bottom						
Nil	29	7	10	8	2	44
asulam	45	0	25.5	1	5.5	23
endothal sodium	27.5	20	38.5	4.25	0	9.75
ethofumesate (1.0 kg)	56	0	13.5	13.5	1.2	15.75
ethofumesate (2.0 kg)	22.5	36.5	20.5	4.75	0	15.75

By this stage the herbicides were no longer helping in the recolonisation of the changed areas because seed return of *B. sterilis* was not sufficiently well controlled.

EXPERIMENT 2

Materials and methods

A single site was selected on calcareous silty loam near Newbury, Berkshire which had a history of high headland weed populations. There were four experimental treatments.

Untreated: crop directly adjacent to hedge bottom
0.3 m wide boundary strip by atrazine (2.8 kg ai/ha)
1.8 m wide boundary strip by atrazine (2.8 kg ai/ha)
1.8 m wide boundary strip by rotary cultivation

The plots were established in the normally cropped area by destruction of the growing cereal during spring 1986 and re-established in the same area by a similar technique the following season. Atrazine was applied on 4 February and 9 December 1986 using an Oxford Precision Sprayer in 225 l/ha water at 2.5 bar and 8002 Spraying Systems T jets. Rotary cultivation was carried out on 14 May 1986 and 21 May 1987. Plots size was 25 m by 8 m; the long axis being parallel to the field edge. An

8 m by 8 m weed-free buffer area was maintained between plots to prevent cross contamination with weed seeds during cultivations and harvesting. No overall herbicide applications have yet been made to the trial area since its inception.

Weed populations were assessed in 0.25 m^2 quadrats at 1, 2, 3, 4, 6 and 8 m from the field edge along five transect lines per plot which had been permanently marked. Ground cover was assessed on the narrow strip of semi-natural vegetation at the origin of each transect line.

Results

Grass weed populations were reasonably uniform throughout the considerable length of the trial prior to treatment, although the distribution of broadleaved weed tended to be rather patchy. The population of all species was higher adjacent to the field boundary and declined with increasing distance into the cropped area (Fig. 1).

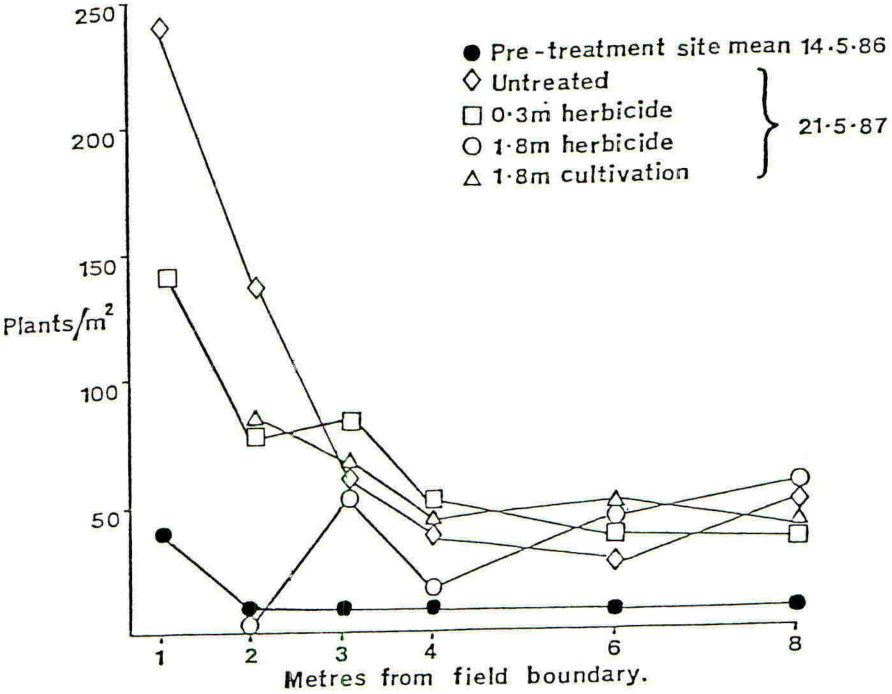

Fig. 1. Grass weed population and distribution across headlands pre- and post-treatment.

At the end of the first year, grass weed populations had risen across the entire width of the headland but the increase was greatest adjacent to the field boundary and in the untreated plots. The population of broadleaved weeds also increased overall after one year but was greatest at a point roughly 3 metres from the field boundary (Fig. 2).

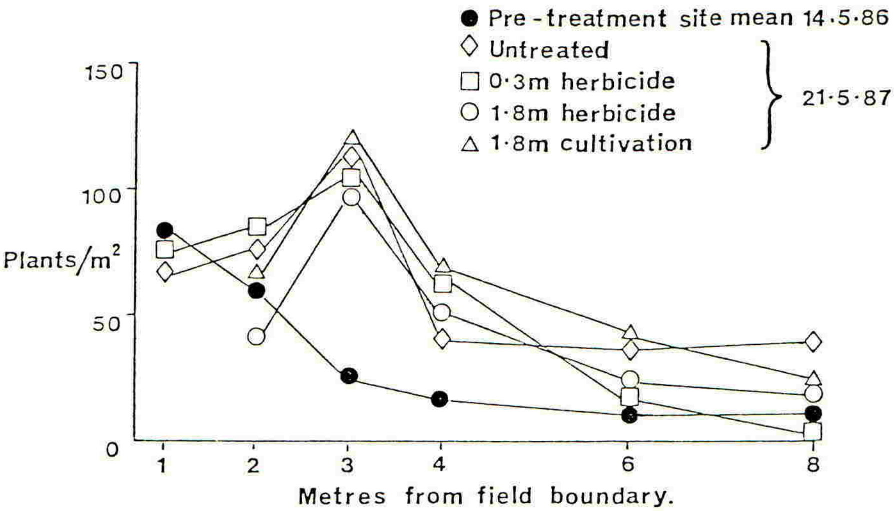

Fig. 2. Broadleaved weed population and distribution across headlands pre- and post- treatment.

Both the 1.8 m wide atrazine treated and cultivated strips remained relatively free of grass weeds until harvest by which time small broadleaved weeds were apparent. The 0.3 m atrazine strip also remained weed free, but a number of large plants of B. sterilis and G. aparine had lodged or spread over the bare soil having grown from the adjacent untreated areas.

GENERAL DISCUSSION

Experiment 1 investigated the effects of selective herbicide use on a previously damaged field margin flora. The results were encouraging and suggested that some degree of beneficial manipulation was possible using selective compounds. Unfortunately, the assessments made did not quantify the effects on all species present, but merely some indicator species. Data are available on the activity of certain broad-spectrum herbicides against a wide range of field margin species (Birnie 1984, Marshall & Birnie 1985), but not for the selective materials used in this study. Field boundaries can provide important wildlife habitats (Pollard et al 1974, Way 1972) for a variety of reasons (Hooper, 1987) and the use of any herbicide or fertiliser in these areas is becoming increasingly unacceptable. In view of this and the small likelihood of additional data likely to be forthcoming, Experiment 1 has been discontinued in its original format. The site will be used to evaluate regular mechanical topping as a management technique to control annual grass weeds.

Experiment 2 was designed to evaluate sterile boundary strips to allow natural regeneration of hedge bottoms, and at the same time protect the cropped area from weed ingress from the field margin. Some aspects of this study were based on preliminary unpublished experiments carried out by staff at Long Ashton Research Station. This technique has been frequently practiced on commercial farms, but the agronomic and environmental effects are poorly understood. Four replicates have been included to allow more precise analysis of the data than was possible with Experiment 1 which was replicated only twice, but in practice the requirement for extra plot area made selection of a reasonably uniform site very difficult. The use of facilities on a commercial farm reduced the number of treatment options; for example a boundary strip sown with grass was not included mainly for this reason, although this has been possible on further sites initiated recently on ADAS Experimental Husbandry Farms.

The management of weeds on the headlands as a whole has also proved difficult because of the compromise needed between having sufficient weeds to measure treatment differences accurately, but also to avoid excessively high populations untypical of commercial farming. It is expected that Experiment 2 will need to be continued for at least 5 years to allow subtle treatment differences to develop, and a multi-disciplinary team will be required to assess changes of both agronomic and environmental importance fully.

Annual labour inputs have been considerable for this type of experiment and for Experiment 1 have been estimated at 11 man days and at 40 man days for Experiment 2. The costs and difficulties involved need to be considered fully before an apparently simple series of experimental treatments can be initiated.

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APPENDIX I

EXPERIMENT 1

Per cent ground cover of hedgerow species after five treatment years (Stoke Mandeville, July 1987)

Treatment	Bromus sterilis	Elymus repens	Arrenatherum elatius	Alopecurus myosuroides	Galium aparine	Anthriscus sylvestris	Alliaria petiolata
Nil	18	9	1	1	19	35	2
asulam	8	16	6	0	8	16	0
endothal	29	20	2	3	1	23	0
ethofumesate (1.0 kg)	11	15	6	3	9	9	2
ethofumesate (2.0 kg)	10	14	1	1	10	20	4

Treatment	Lamium album	Urtica dioica	Convolvulus arvensis	Aethusa cynapium	Stachys sylvactica	Glechoma hederacea
Nil	2	8	1	0	1	0
asulam	9	10	3	1	9	1
endothal	7	7	2	2	0	1
ethofumesate (1.0 kg)	6	12	1	1	2	10
ethofumesate (2.0 kg)	1	12	1	1	16	6

SESSION 4B

MODE OF ACTION AND METABOLISM OF HERBICIDES: II

CHAIRMAN	DR R. C. KIRKWOOD	
SESSION ORGANISERS	DR D. J. COLE DR K. E. PALLETT	
INVITED PAPERS		4B-1 & 4B-2
RESEARCH REPORTS		4B-3 to 4B-6

HERBICIDE DETOXIFICATION AND SELECTIVITY

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ABSTRACT

Herbicide selectivity is determined by several distinct factors, such as rates of absorption into the plant and subsequent translocation, subcellular localisation, variation in target site sensitivity and the metabolic detoxification to less toxic derivatives. Though in many cases of selective action a number of these factors probably contribute to the different species responses, there is evidence to suggest that differential metabolism may constitute the most important factor for such herbicides as triazines, triazinones, aryl propionic acid esters, sulphonylureas, imidazolinone aryl carboxylates, propionanilides, methylphenylureas and substituted diphenylethers. Much of this evidence implicating the importance of differential metabolism between species with respect to selectivity is reviewed. Notable varietal reactions which may have a basis in herbicide metabolism are also discussed. Reference is also made to the usefulness of plant cell cultures in studies of pesticide metabolism by plants.

INTRODUCTION

Herbicides recommended for the selective control of weeds have been developed to exploit a difference in phytotoxicity between species adequate to kill competing weeds without significantly reducing crop yields. In some cases the margin of selectivity may be quite modest and can be rendered inadequate when the timing of application coincides with unfavourable climatic conditions, as was reported to be the case for some of the phenylureas in winter wheat in Autumn 1983. There are a number of factors which can contribute to herbicide selectivity including soil placement, rates of absorption and subsequent translocation, localisation (both within the plant and at the sub-cellular level), transformation to products of modified phytotoxicity and differences in target site sensitivity. The selective properties of herbicides often result from a complex interaction of a number of these factors though there are many examples where one dominant factor has been implicated. This is certainly true in the case of herbicide uptake and movement (Hess, 1985) and differential metabolism to less phytotoxic products. The mechanisms by which plants transform foreign compounds have been adequately reviewed previously (Lamoureux & Frear, 1979, Shimabukuro, 1985, and Cole *et al*., 1987) and include oxidations resulting in aromatic ring and alkyl hydroxylation, *N*-dealkylation, *O*-dealkylation and sulphoxidation, hydrolytic reactions, deamination and conjugation with carbohydrate residues (glycosidation) or the tripeptide glutathione.

MECHANISMS OF DETOXIFICATION

Aryl hydroxylation

Ring hydroxylation represents a very important detoxification reaction in higher plants (see e.g. Cole 1983). However, species differ in their ability to aryl hydroxylate particular parent structures. Such is the case for bentazon for which a 200-fold selectivity margin between rice and *Cyperus serotinus* is attributable to rapid conversion in rice to 6-hydroxy bentazon followed by glucose conjugation (Mine, Miyakado and Matsunaka, 1975). Metabolism in *C. serotinus* on the other hand is slow as is the case in other susceptible weed species (Mine *et al*., 1975; Penner 1975). Rapid production of water soluble glycosidic metabolites also occurs in tolerant maize, navy-bean (*Phaseolus vulgaris*), barnyard grass (*Echinochloa crus-galli*) (Mahoney & Penner, 1975; Mine *et al*., 1975) and wheat (Retzlaff & Hamm, 1976) whereas in soybean both the 6- and 8-hydroxy derivatives are formed (Otto *et al*., 1979). Differences in tolerance to bentazon between soybean cultivars have also been attributed to relative rates of ring hydroxylation (Hayes & Wax, 1975) though metabolites were not characterised in detail.

Ring hydroxylation also plays an important role in the selectivity of diclofop-methyl between resistant cereals and susceptible grass weeds. Subsequent to rapid hydrolysis of the ester the resulting phytotoxic diclofop acid is inactivated by hydroxylation of the dichlorophenyl ring followed by glycosidation (Gorbach, Kuenzler & Asshauer, 1977; Jacobson, Shimabukuro & McMichael, 1985). Hydroxylation occurred at all three available positions on the ring though the 5'-hydroxy derivative predominated. In contrast aryl hydroxylation is of minor importance in susceptible oat and wild oat (*Avena fatua*) in which diclofop is primarily converted to the neutral glycosyl ester. Though glucose esters of acidic herbicides might be expected to accumulate in cell vacuoles, as for glycosidic conjugates, the susceptibility of oat and wild oat to diclofop-methyl implies that in this case compartmentalisation of metabolites is inadequate to confer tolerance. Susceptibility presumably results from the lability of the glucose ester. Interestingly, though diclofop-methyl has the same ring chlorine substitution pattern as 2,4-D there is no indication that aryl hydroxylation of diclofop-methyl occurs via the 'NIH' shift mechanism seen in 2,4-D. Indeed an 'NIH' shift has not been recorded for ring hydroxylation of any other pesticide in plants, including the related phenoxyalkanoic acid herbicide MCPA which is hydroxylated at the ring-methyl substituent (Cole & Loughman, 1983).

Despite the remarkably high biological activity of the more recently introduced sulphonylurea herbicides the margin of selectivity between cereals and sensitive weeds can be very large, approaching some 4000-fold in the case of chlorsulfuron (Sweetser, Schow & Hutchinson, 1982). Neither herbicide uptake nor translocation by tolerant (wheat, barley, wild oat and *Poa annua* annual meadow grass) and susceptible (cotton, soybean, mustard and sugar beet) species correlated with selectivity which was attributed to a striking difference in ability of young plants to oxidise chlorsulfuron to the 5'-hydroxy derivative which accumulated in tolerant species as the *O*-glucoside (Sweetser *et al*., 1982). The observation that 5'-hydroxy chlorsulfuron was also a potent inhibitor of acetolactate synthase (Dr. H. Brown, E.I. du Pont de Nemours & Co., personal communication), the target enzyme of the sulphonylureas, suggests that in this case subsequent glycosidation rather than hydroxylation constitutes the important detoxification step. Sweetser (1985) has speculated on the involvement of an inducible cytochrome P-450 dependent mixed function oxidase (mfo) involved in the hydroxylation of chlorsulfuron in wheat based on the incorporation of one atom of ^{18}O from molecular oxygen into a hydroxylated metabolite and the sensitivity of chlorsulfuron metabolism to inhibitors of protein biosynthesis.

Alkyl hydroxylation

Oxidation of alkyl substituents is also considered to be mediated by microsomal *mfo* enzymes. For both *N*- and *O*-substitutions initial alkyl hydroxylation results in the formation of alcohol intermediates that are generally unstable and, unless rapidly glycosylated, decompose to liberate formaldehyde in the case of a methyl group. These processes are referred to as *N*-dealkylation and *O*-dealkylation respectively. Further oxidation of *C*-alkyl derived alcoholic functions to corresponding carboxylic acids is generally slow and is probably of little relevance to selectivity.

Hydroxylation of *C*-alkyl groups is of common occurrence in plants but notable species differences exist which contribute to selectivity. In contrast to graminaceous crops the tolerance of certain broadleaf species to chlorsulfuron results from hydroxylation of the 4-methyl substituent on the triazine ring and subsequent glycosylation rather than 5' ring hydroxylation (Hutchison, Shapiro & Sweetser, 1984). The herbicidal nature of the 4-hydroxymethyl derivative (Sweetser, 1985) implies that for this metabolic route the glycosylation step is also essential for detoxification. A particularly interesting feature of the sulphonylureas is that comparatively subtle modifications to the parent structure can result in targetting for selective use in different crops. Thus DPX-F5384 (Londax) is used for weed control in rice whereas chlorsulfuron is non-selective in this crop (Ray, 1985). Tolerance of rice to DPX-F5384 apparently correlated with an ability to *O*-demethylate a pyrimidine methoxy substituent to the corresponding hydroxy derivative (Dr. H. Brown, E.I. du Pont de Nemours & Co., personal communication). Differential metabolism also provides an explanation for the selectivity of the imidazolinone aryl-carboxylate herbicides which also inhibit the acetolactate synthase enzyme. Thus Assert, which is comprised of a mixture of *m*- and *p*-methyl substituted isomers, was largely de-esterified to the phytotoxic acids in susceptible wild oat whereas ring-methyl hydroxylation to the *m*- and *p*-benzyl alcohols followed by glycosylation occurred in tolerant maize and wheat (Brown, Chiu & Miller, 1987).

Selectivity of substituted phenylureas was markedly enhanced by the replacement of the *para* chlorine of diuron with a methyl group as in chlortoluron which is widely used for weed control in winter wheat. This structural modification offered an additional mode of oxidative attack and extensive ring-methyl hydroxylation was considered to be the basis of the chlortoluron-tolerance of wheat and barley (Ryan *et al*., 1981; Ryan & Owen, 1982). However the position of the ring methyl substitution can also have a profound effect on selectivity. Thus the chlortoluron isomer, CGA 43057 in which the methyl group is *meta* located, was non-selective, this being attributed to the poor ability of plants to oxidise the methyl group in this position (Ryan *et al*., 1981). The margin of selectivity of chlortoluron is inadequate for certain cultivars of wheat and barley. Studies carried out in our own laboratory (Ryan & Owen, 1983) have indicated that detoxification by ring methyl oxidation represented a minor metabolic route in leaf discs of susceptible cultivars in which metabolism was generally slow and restricted to *N*-mono-dealkylation. This metabolite profile resembled that of susceptible graminaceous weed species. The distinction was less apparent in a similar study using intact plants (Cabanne, Gaillardon & Scalla, 1985) though different cultivars were used. Wheat varieties also show parallel differences in response to the related phenylurea metoxuron and in this case a difference in relative contributions to metabolism of *N*-demethylation versus *O*-demethylation of the ring methoxy substituent was the major factor that correlated with varietal reaction (Emami-Saravi, 1979). *N*-dealkylation also plays a role in the metabolism and selectivity of *s*-triazines such as atrazine though this pathway is usually of minor significance compared to glutathione conjugation and/or hydrolysis of the C-2 chlorine.

Sulphoxidation

Sulphide groups or other oxidisable sulphur moities are of common occurrence in pesticide molecules and have been shown to be sulphoxidised by numerous plant species (Andrawes, Bagley & Herrett, 1971), though the precise mechanism of sulphur-oxidation in plants is not clear. In addition to its role in the bioactivation of various pesticides including herbicides (e.g. EPTC) where species differences can account for selectivity (Casida, Gray & Tilles, 1974), sulphoxidation of alkylsulphide groups is often an important initial step in detoxification. Thus the sulphoxides generated by the oxidation of the methylsulphide ring substituents of terbutryn (Edwards & Owen, unpublished observations) and metribuzin (Frear, Swanson & Mansager, 1985) are substrates for glutathione S-transferases which catalyse their conversion to non-phytotoxic peptide conjugates. Subsequent further metabolism of glutathione conjugates can result in the formation of phenylmethylsulphides, as was reported for PCNB (Rusness & Lamoureux, 1980), which are susceptible to sulphoxidation. Thus Blair et al. (1984) reported the ability of suspension cultures of various plant species to mediate the enzymic sulphoxidation of the model aromatic alkyl-sulphide p-chlorophenylmethyl-sulphide. A relevant observation was that rates of sulphoxidation were greatest in cotton and poorest in tobacco which served to illustrate the existence of species differences with respect to this mode of oxidative attack.

Hydrolysis

Hydrolysis of carboxylic acid ester groups of various xenobiotics is of widespread occurrence in plants. In the context of herbicides, cleavage of carboxylic esters more commonly results in bioactivation (see e.g. Cole et al., 1987) rather than detoxification and examples of herbicide selectivity attributed to species differences in capacity for ester hydrolysis are discussed elsewhere in this volume. The amide linkage is somewhat similar to that in esters and is attacked in plants by amidases. Amino acid amide conjugates of 2,4-D and 2,4,5-T have been identified for some time as prominent metabolites of these phenoxyalkanoic acid herbicides in some plant species, notably legumes such as soybean (Feung, Hamilton & Mumma, 1973; Arjmand, Hamilton & Mumma, 1978; Scheel & Sandermann, 1981). Of the 20 or so amino acid conjugates that are possible 2,4-D metabolites, those of aspartate and glutamate generally predominate. Studies on the fate of amino acid conjugates of 2,4-D in soybean callus have suggested that these metabolites are readily hydrolysed in plant tissue (Feung et al., 1973; Owen, Hamilton & Mumma, unpublished observation) which probably accounts for their observed biological activity (Feung, Mumma & Hamilton, 1974). The implication from these data is that conversion of 2,4-D to amide conjugates does not constitute an effective detoxification mechanism. Whether plant species differ significantly in ability to hydrolyse amide conjugates has not been extensively investigated though in a screen of the herbicidal properties of 2,4-D amino acid conjugates (Feung, Hamilton & Mumma, 1977) green beans, peas, sunflower and soybean responded similarly.

In contrast, available evidence suggests that arylamide bonds are generally quite resistant to hydrolytic attack in plant tissues. A notable exception is the substituted propionanilide derivative, propanil, which was rapidly hydrolysed in resistant rice plants but not in susceptible weed species such as barnyard grass (Frear & Still, 1968). Hydrolysis of propanil has been attributed to a specific arylacylamidase enzyme (Frear & Still, 1968; Hoagland, 1978) the activity of which was sixty times greater in rice compared to barnyard grass. A more recent report (Oyamada et al., 1986) of hydrolysis of the related naphthoxypropionanilide derivative, naproanilide, in rice plants suggested that the specificity of the rice arylacylamidase extends beyond propanil. A product of this cleavage reaction was the phytotoxic naphthoxypropionic acid (NOP). Tolerance of rice to naproanilide was attributed to rapid detoxification of NOP by hydroxylation and glycosidation. Amide hydrolysis was also rapid in the susceptible Sagittaria pygmaea but unlike rice further metabolism of NOP in this species produced mainly methyl and glucose esters rather than ring hydroxy derivatives. Since the methyl ester was reported to be phytotoxic (Oyamada et al., 1986) and the glucose ester represented a potential source of NOP, this difference in metabolic profile between the two plant species was considered to be a possible mechanism for the herbicidal selectivity of naproanilide.

A further competing detoxification mechanism in the case of the chloro-s-triazines is the rapid nucleophilic displacement of the 2-chloro substituent in the triazine ring to give non-phytotoxic 2-hydroxy derivatives. These reactions are not enzymic but are catalysed by the naturally-occurring cyclic hydroxamate, 2,4-dihydroxy-3-keto-7-methoxy-1,4-benzoxazine (benzoxazinone, primarily in the roots of tolerant plants such as maize (Hamilton, 1964). Species such as cotton, pea, sorghum and Johnson grass (Sorghum halepense) which do not contain benzoxazinone produced insignificant amounts of hydroxy-triazine derivatives. Thus in maize and other grass species the various metabolic options available for detoxification of atrazine and other chlorotriazines include N-dealkylation, benzoxazinone-catalysed hydrolysis of the C-2 chlorine or its nucleophilic displacement by glutathione (Jensen, Stephenson & Hunt, 1977). Rapid conversion to hydroxyatrazine alone confers tolerance in Coix lachryma-jobi in which glutathione conjugation plays a very minor role in detoxification. In contrast the ability of susceptible panicoid grasses such as barnyard grass and Setaria glauca (yellow foxtail) to carry out any of the above biotransformations was very limited (Jensen et al., 1977).

Glutathione conjugation

The role of glutathione S-transferases in herbicide detoxification and selectivity has been considered in a number of previous reviews, including Lamoureux & Frear (1979) and Cole et al., (1987). With exceptions, glutathione conjugation products represent the major metabolites in maize and other related panicoid species demonstrating field tolerance to chlorotriazines such as atrazine. Glutathione S-transferases are also important in the metabolism of other herbicides including the nitrodiphenylethers fluorodifen (Frear & Swanson, 1973; Diesperger & Sandermann, 1979) acifluorfen (Frear, Swanson & Mansager, 1983) and fomesafen (Evans, Cavell & Hignett, 1987), the chloracetanilides propachlor (Lamoureux, Stafford & Tanaka, 1971), alachlor (Mozer, Tiemeier and Jaworski, 1983) and metolachlor (Edwards & Owen, 1986; Blattman et al., 1986) and the sulphonylurea derivative DPX-F6025 ('Classic') (Dr. H. Brown, E.I. Du Pont de Nemoirs and Co., personal communication). The latter compound has been developed for broadleaf weed control in tolerant soybean which rapidly detoxifies DPX-F6025 by nucleophilic displacement of the pyrimidine chlorine by homoglutathione. The action of glutathione S-transferases on nitrodiphenylethers results in fission of the aromatic ether bond. Activity of the transferase towards fluorodifen was higher in resistant species such as cotton, maize, peanut, pea, soybean and okra than in susceptible cucumber, tomato and marrow (Frear & Swanson, 1973). Thus fluorodifen selectivity appeared to be based on distribution and concentration of the transferase. On purification and further characterisation the glutathione S-transferase of pea was found to be very specific for fluorodifen and did not utilise related nitrodiphenylethers such as nitrofen

(Frear & Swanson, 1973). Interestingly the pea enzyme did not utilise atrazine as a substrate and further studies on the metabolism of herbicides which serve as substrates for glutathione S-transferases have established the existence of isoenzymic forms which are specific for particular herbicide types. Thus isoenzyme multiplicity offered a possible explanation for the difference in response to atrazine and EPTC between maize (tolerant to both herbicides) and *Panicum miliaceum* (proso millet) (atrazine-tolerant only) despite the fact that both herbicides undergo similar routes of detoxification by glutathione conjugation (Ezra & Stephenson, 1986). More recent studies using maize cell suspension cultures suggested that the isoenzymes responsible for the detoxification of the chloracetanilide metolachlor were distinct from the enzyme which conjugated atrazine (Edwards & Owen, 1986).

Once formed tripeptide conjugates are generally broken down in plant tissues. Thus in maize the glutathione conjugate of metolachlor was rapidly converted, by the concerted action of carboxypeptidase and γ-glutamyltranspeptidase enzymes, to the cysteine conjugate which was subsequently oxidised to the thiolactic acid conjugate (Blattman *et al*., 1986; Owen and Donzel, unpublished observation). Similar pathways have been recorded for the fate of glutathione and homoglutathione conjugates of other herbicides though malonylation of the cysteine conjugates as occurs in fluorodifen metabolism may be of more common occurrence than conversion to thiolactic derivatives.

Though glutathione S-transferases are involved in the transformation of chloracetanilides their role in the selectivity of these herbicides is less certain. However, capacity for peptide conjugation may explain the differing sensitivities of cell suspension cultures of maize and rice to metolachlor in that formation of the glutathione conjugate was some 8-fold faster in maize than in rice (Owen & Donzel, unpublished observation).

In addition to the above parent herbicides the sulphoxide metabolites of dithiocarbamates (EPTC), 2-methylmercapto-*s*-triazines (e.g. terbutryn) and 3-methylmercapto-*as*-triazinones (e.g. metribuzin) are also substrates for plant glutathione-S-transferases and species differences in capacity for their conjugation can contribute to selectivity. Detoxification of metribuzine in plants occurs by three competing pathways but a recent report (Frear *et al*., 1985) suggested that homoglutathione conjugation following sulphoxidation may be the most important route in soybean.

Reductive deamination

Though reductive reactions do not generally play a major role in pesticide detoxification by plant tissues the reductive deamination of metribuzin represents an important detoxification mechanism which has been considered to be the basis of the metribuzin-tolerance of some soybean cultivars (Fedtke & Schmidt, 1983). Thus deamination in leaves of tolerant 'Bragg' and 'Tracy M' was considerably more rapid than that observed in susceptible 'Tracy' and 'Coker 156'. The deaminase enzyme activity was apparently located in the peroxisome fraction and required a reduced flavin cofactor under anaerobic (N_2) conditions (Fedtke & Schmidt, 1983). A similar enzyme system has been implicated in the detoxification of the related triazinone metamitron in tolerant sugar beet (Fedtke & Schmidt, 1979).

Glycosidation

The ability of plants to conjugate acidic and hydroxyl-groups of herbicides and their derivatives is well documented, though the extent of glycosidation may vary between both species and plant tissues. Available evidence suggests that because of their inherent instability, formation of glucose ester conjugates, even when extensive, does not constitute an effective detoxification mechanism. Nevertheless glycosidation may contribute to detoxification by virtue of the enhanced water solubility of the products which facilitates their disposal in the vacuole. However in the case of chlorsulfuron metabolism in tolerant plant species glycosidation resulted in the conversion of phytotoxic hydroxylated metabolites to inactive glycosides and in suspension cultures of soybean and wheat an *O*-glucosyl transferase was directly responsible for detoxification of pentachlorophenol (Schmitt *et al*., 1985). Though less common, formation of *N*-glycosides also occurs in plants and direct *N*-glucosidation of chloramben represents a significant detoxification pathway in tolerant species (Frear *et al*., 1978). *N*-glycoside formation also offers an additional metabolic route for detoxification of metribuzin. Smith & Wilkinson (1974) presented evidence implicating the importance of *N*-glucosidation in the tolerance of soybean cultivar 'Bragg' to metribuzin, whereas in susceptible 'Coker 102' and 'Semmes' this was a minor pathway. Intra-species variation of metribuzin *N*-glucosidation in soybean has also been recorded between tetraploid and diploid lines (Abusteit *et al*., 1985). There would appear to be little doubt that differential metabolism of metribuzin contributes to selectivity between soybean cultivars but tolerant cultivars may differ with respect to the importance of the three detoxification routes.

CONCLUDING REMARKS

Differential metabolism is clearly important in determining selectivity of many herbicides both between species and crop varieties. However, it is important to remember that metabolism may be relevant to selectivity of a particular herbicide in certain crop-weed situations only. In other cases additional factors such as uptake and translocation may be as or more important. Knowledge of the metabolic fate of pesticides in plants might lead to the development of new herbicides which exploit species differences in detoxification. The design of inactive herbicide progenitors which are activated by biotransformation might also result from a study of accumulated metabolism data.

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