Session 4C

The Management of Vegetation in Amenity, Industrial and Conservation Areas

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A SHORT-TERM METHOD TO STUDY THE EFFECT OF ADJUVANTS ON HERBICIDE ACTIVITY AGAINST YOUNG PLANTS OF *PTERIDIUM AQUILINUM*

J. LAWRIE, T.M. WEST

Department of Agricultural Sciences, University of Bristol, AFRC Institute of Arable Crops Research, Long Ashton Research Station, Bristol BS18 9AF, UK

ABSTRACT

The effect of adjuvants on herbicide activity was investigated on bracken (*Pteridium aquilinum*) grown in pots in a glasshouse. Treatments were applied to six-week-old plants and final assessments made 15 to 17 weeks later. The addition of an organosilicone surfactant significantly increased the activity of the herbicide asulam. Tribenuron-methyl activity on bracken was significantly increased by most of the adjuvants. Although young bracken plants were more sensitive to these herbicides, compared with the established plants previously used for this type of experiment, the method showed that relative differences in activity between herbicide treatments ± adjuvants, could be demonstrated.

INTRODUCTION

Increasing concern about the effects of herbicides on non-target species, and the possibilities of contamination of ground waters, have focused attention on the need to reduce herbicide doses while maintaining effective weed control. As bracken (*Pteridium aquilinum*) is a common weed of particular importance in hill farming areas of the UK, and is often associated with Environmentally Sensitive Areas, which frequently include water catchment areas, it is therefore highly desirable that its containment is achieved with minimal herbicide inputs.

In recent years there has been an increase in the number and types of tank-mix adjuvants which have the potential to increase herbicide activity and so enable dose reduction. Conversely, there are only a few herbicides available for bracken control. Asulam is currently the only herbicide recommended for selective control of bracken in hill pasture and other grassland in the UK (Ivens, 1993). In recent pot and field experiments (West & Standell, 1989; West, 1991) the herbicide tribenuron-methyl has shown some potential to control bracken with little effect on grass species. This paper reports on experiments using young bracken plants to determine whether the efficacy of these two bracken herbicides can be improved by the addition of adjuvants. Particular attention was given to a method which would give meaningful data in a relatively short time span (5 months), compared with the 24 to 30 months taken in our previous experiments comparing herbicide treatments on established plants.

MATERIALS AND METHODS

On 12 March 1992, 25 to 30mm long rhizome fragments of bracken, each with one viable bud, were taken from the same stock of Long Ashton plants as used for previous experiments (West, 1992). A single rhizome fragment was planted 30mm deep in 90mm diameter pots, containing a mixture of sandy-clay loam : peat : sand (3:2:2) plus 'Osmocote' fertiliser (18:11:10, N:P:K) at 2.0 g/l. The plants were grown in a glasshouse at 17 to 20°C with 16h supplementary lighting and were watered from above onto the soil.

Treatments were applied 6 weeks after planting (23 April 1992) to four replicate plants with 1 to 3 fronds; the most mature frond had 3 to 5 pairs of pinnae, and rhizome length was 40 to 75 mm long with 5 to 14 viable buds. Herbicides and adjuvants were applied at the doses shown in Tables 1 and 2, using a laboratory track sprayer fitted with a 'Lurmark' 80015E flat fan nozzle at 210 kPa pressure, giving a spray volume rate of 227 l/ha. The herbicide formulations used were asulam (400g a.i./l SL) and tribenuron-methyl (75% a.i. WG). The adjuvants used were 'Agral', a non-ionic wetter/spreader containing 900 g/l alkyl phenol ethylene oxide (Ag), 'Codacide Oil', 95% rape seed oil + emulsifier (Coda), 'Fyzol 11E', 99% highly refined mineral oil + emulsifier (Fyz), 'High Trees Galion', a wetter/spreader containing 60% polyoxyalkylene glycol (Gal), 'Marlipal 34/150', an alcohol ethylene oxide condensate (Marl), and 'Silwet L77', an organosilicone surfactant (Sil). After treatment, plants were returned to the glasshouse and arranged in four randomised blocks.

Effects of treatments on growth were assessed visually at regular intervals during the experiment. In mid-June (7 weeks after treatment) fronds were cut off at soil level and fresh weights were recorded. Plants were allowed to regrow and the fresh weights of new fronds were recorded in August (15 to 17 weeks after treatment). Rhizome development was also assessed at this time and the fresh weight of the rhizome recorded after carefully washing off any attached soil.

RESULTS

Asulam and adjuvants

There was a highly significant reduction in the weight of fronds on 15 June 1992 (7 weeks after treatment) in relation to asulam dose (Table 1). When the regenerated fronds and rhizomes were weighed in August there was again a strong dose response. Sil significantly increased the growth inhibitory effect of asulam at 0.55 and 1.1 kg a.i./ha compared to asulam without adjuvants. Asulam, at 2.2 and 4.4 kg a.i./ha, with or without adjuvants killed all the plants. When asulam was applied alone at 0.1375 kg a.i./ha there was a significant increase in rhizome weight.

Tribenuron-methyl and adjuvants

When the fronds were removed and weighed on 12 June 1992 there was no significant reduction in growth of plants treated with tribenuron-methyl without adjuvants (Table 2). However there was a significant reduction in frond fresh weight when Ag, Coda, Fyz or Gal were applied with tribenuron-methyl at 3.0g a.i./ha compared with untreated and tribenuron-methyl applied alone at this dose.

TABLE 1. Response of bracken to asulam +/- adjuvants, applied 23 April 1992.

Adjuvants	Asulam (kg a.e./ha)	Fresh weights (g) 15 June 1992 Fronds	17 August 1992 Fronds	17 August 1992 Rhizome
None	0	13.6	28.7	23.1
	0.1375	13.8	30.4	35.2
	0.275	9.1	27.9	32.4
	0.55	11.1	28.3	26.4
	1.1	8.9	21.4	17.7
	2.2	4.5	0	0
	4.4	1.9	0	0
Ag	0	9.8	25.7	23.0
0.1%[a]	0.1375	12.5	31.3	31.3
	0.275	8.7	29.9	29.1
	0.55	8.2	23.2	22.5
	1.1	10.9	23.0	19.3
	2.2	3.4	0	0
	4.4	2.0	0	0
Sil	0	11.3	27.8	26.5
0.3%[a]	0.1375	12.2	25.8	25.7
	0.275	7.1	19.2	17.4
	0.55	6.0	0	1.0
	1.1	7.0	3.0	3.4
	2.2	2.8	0	0
	4.4	1.9	0	0
SED	(df 60)	2.18	5.26	5.50

[a] Ag at 0.1% of spray volume, Sil at 0.3% of spray volume.

The August assessments again showed no significant reduction in frond and rhizome weights following treatment by tribenuron-methyl alone. Ag and Gal caused highly significant reductions in frond and rhizome fresh weights when added to tribenuron-methyl at 0.6 and 3.0g a.i./ha and Fyz caused a significant reduction in weights at these doses compared to tribenuron-methyl applied alone. Coda only caused a significant reduction in growth with tribenuron-methyl at 3.0g a.i./ha compared to tribenuron-methyl alone. Sil or Marl did not increase tribenuron-methyl phytotoxicity.

TABLE 2. Response of bracken to tribenuron-methyl +/- adjuvants, applied 23 April 1992.

Adjuvants	Tribenuron-methyl (g a.i./ha)	Fresh Weights (g)		
		12 June 1992	3 August 1992	
		Fronds	Fronds	Rhizome
None	0.024	10.2	29.8	25.5
	0.12	8.6	34.7	22.8
	0.6	9.5	33.5	27.3
	3.0	10.0	20.7	20.3
Ag	0.024	13.0	21.9	21.7
0.1% sv[a]	0.12	13.8	26.4	25.8
	0.6	9.9	14.3	10.0
	3.0	2.7	0.2	1.0
Coda	0.024	10.2	28.3	25.8
2.5l/ha	0.12	13.4	34.4	26.1
	0.6	13.8	25.2	23.1
	3.0	2.9	6.6	5.4
Fyz	0.024	12.5	31.5	25.9
5l/ha	0.12	13.1	32.5	29.9
	0.6	9.2	18.6	17.7
	3.0	2.2	0	0
Gal	0.024	12.9	25.9	27.9
2.0% sv	0.12	13.4	32.9	23.1
	0.6	4.4	11.3	8.1
	3.0	2.3	0	0
Marl	0.024	12.3	34.0	25.4
0.25% sv	0.12	11.2	29.1	24.2
	0.6	9.6	24.1	25.9
	3.0	13.1	27.8	22.5
Sil	0.024	13.4	33.6	24.4
0.3% sv	0.12	11.6	28.8	26.2
	0.6	13.0	28.8	26.6
	3.0	11.5	29.8	20.4
Untreated		13.2	31.2	26.5
SED	treated v treated	2.06	5.69	5.57
(df 88)	untreated v treated	1.78	4.93	4.82

[a] Adjuvant added to spray mix as either a % of spray volume (sv) or l/ha.

DISCUSSION

Our experiments have shown that the effect of a herbicide on bracken growth can be evaluated using whole plants in a relatively short period of time (5 months), compared with our previous experiments using established bracken plants in pots which took 30 months, or field trials which can take 24 to 36 months to evaluate potential treatments. Although the young bracken plants were more sensitive to the herbicides than the established plants previously tested, they still showed that the activity of asulam or tribenuron-methyl can be improved on young bracken plants by including certain adjuvants.

Sil significantly increased the activity of asulam, and this was also found by Turner *et al.* (1988) on established plants and Gaskin & Kirkwood (1987 and 1989) on pinnae explants. In New Zealand, Sil is officially recommended for adding to asulam for the control of bracken (*P. esculentum*). In the UK, the recommendation for bracken control with asulam includes the addition of Ag, at 0.1% of the spray solution volume, applied at full frond expansion. At this growth stage, movement of plant assimilates is predominantly downwards; this maximises translocation of the herbicide into the rhizome apices and the developing frond buds, and, thus, prevents regeneration the following season. Gaskin and Kirkwood (1987) showed that localised damage at the site of application of asulam to juvenile foliage gave low uptake and surfactants did not enhance uptake to the same extent as in mature foliage. However, Sil significantly increased the uptake of asulam in juvenile foliage while Ag did not increase it. This may help explain the results found on the young bracken plants in our experiment where there was increased asulam activity with Sil but little or no enhancement of activity with Ag. Asulam applied alone at 2.2 kg a.i./ha and above killed the bracken using our evaluation method. Therefore, a wider dose range between 0 and 2.2 kg a.i./ha would be better to observe adjuvant effects and give improved response curves to assess potential dose reductions.

In our experiments, Ag, Gal and Fyz, increased the activity of tribenuron-methyl (a sulfonylurea herbicide) on bracken. Turner *et al.* (1988) showed that Gal can improve the response of other sulfonylurea herbicides on bracken. Coda appeared only to enhance the activity of the highest dose of tribenuron-methyl. West & Lawrie (1993) found enhanced activity of tribenuron-methyl on established bracken in pots with the addition of either Ag, Fyz, Coda or Marl. Coda may warrant further investigation, particularly if the vegetable oil-based adjuvant is considered to be preferable on environmental grounds. Sil and Marl appeared not to enhance the activity of tribenuron-methyl on bracken. However, Gaskin and Zabkiewicz (1990) indicated increased uptake of the sulfonylurea, metsulfuron-methyl with Sil on *P. esculentum*. In this study very low doses of tribenuron-methyl (0.024 to 3.0g a.i./ha) have been used to observe enhanced affects from adjuvants, compared to the rates used on established plants in pots (West & Standell, 1989) and in field trials (West, 1991). However, even at 3.0g a.i./ha, tribenuron-methyl plus Ag, Coda, Fyz or Gal caused plant death or severely reduced regeneration. As mentioned earlier, our experiments were intended to obtain quick answers as to which adjuvants increase herbicidal activity on bracken whole plants. However, smaller difference between herbicides with and without adjuvants may have been obtained with young plants than would have been obtained with mature plants because the plants may not have had time to establish before treatments were applied. Also, the maturity of fronds can alter the effect of adjuvants on herbicidal activity (Gaskin & Kirkwood, 1987; Gaskin & Zabkiewicz, 1990). However, as a quick assessment technique,the use of young plants would seem to be validated by work carried out by West & Lawrie (1993).

The results obtained from our experiments indicate the potential of using Sil with asulam and Ag, Gal or Fyz with tribenuron-methyl to improve the activity of these herbicides and, therefore, permit the use of lower doses of these herbicides. As well as making bracken control more economic, the reduced herbicide dose may also reduce the damage to understorey vegetation which can occur with asulam (unpublished). However, this must be confirmed by appropriate experiments.

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A PRELIMINARY ASSESSMENT OF METHODS OF ESTABLISHING *CALLUNA VULGARIS* ON EX-ARABLE LAND

CHRISTINA M. WILLIAMS

Department of Land Resources, SAC-Aberdeen, School of Agriculture,
581 King Street, Aberdeen, AB9 1UD, UK

ABSTRACT

With increased interest in the preservation and re-creation of remnant lowland heath, methods of restoring heathland vegetation to ex-arable land are being studied. The transplanting of young *Calluna* appears the most promising method of introducing *Calluna* to ex-arable sites of those trialled thus far.

INTRODUCTION

Vegetation dominated by sub-shrubs - heath - has become scarce and fragmented in lowland Britain as a consequence of changed land use practices (Harrison, 1974). The remnant lowland heath is recognised as having conservation value and many of the surviving sites are protected by statutory or voluntary bodies. There is now interest in restoring heath vegetation on land where it occurred in the past (Webb & Crane, 1985) and on new sites such as road cuttings (Putwain & Rae, 1988). Surplus farmland in one of the EC Set-aside schemes may provide venues for heath creation in the future.

The principal sub-shrub of most British heaths is *Calluna vulgaris* (Pigott *et al.*, 1991). Currently, I am attempting to devise effective methods of establishing this species on ex-arable land. Several methods of introducing *Calluna* to the site are being trialled and managements designed to facilitate its subsequent spread on such a fertile soil are being tested. Given here is a preliminary assessment (after 2 years) of the relative success of the different methods used.

METHODS

The site on which I am attempting to establish *Calluna* lies approximately 4 km north-west of Aberdeen on Craibstone Estate at an altitude of 125 m on a south-facing slope (National Grid reference NJ864107). Mean annual rainfall is 815 mm. The soil is a freely-drained iron podzol derived from granitic till. Prior to 1991, the field had been in an arable rotation for at least 50 years.

Two inter-related problems were anticipated in attempting to establish *Calluna* on ex-arable land: how to best introduce the species, and; how to best control fast-growing weeds so that the *Calluna* is able to persist and spread. Thus, although below reference is made to 'methods of introducing *Calluna*', the practices so designated are in some cases an integral part of a strategy for managing the volunteer weed flora.

A split-plot design has been used for the trial, with the plots in three randomised blocks. The treatment which differs between plots is the method of introducing *Calluna*. Methods of soil modification are being tested in 3-m x 3-m sub-plots and the effect of mowing in 3-m x 1.5-m sub-sub-plots. The treatments are not replicated within blocks. Site preparation involved the application of a total herbicide (diquat + paraquat) in September 1990. The area was then ploughed, disced and rolled in April 1991 to give a firm weed-free surface.

Four methods of introducing *Calluna* are being trialed: laying turves cut from heathland; planting young *Calluna;* incorporating seed-rich litter and surface soil collected from heathland, and; incorporating heath litter and surface soil and sowing a nurse-crop of *Agrostis castellana*.

The *Calluna* donor sites were on the Macaulay Land Use Research Institute's Glensaugh Research Station, a hill farm near Fettercairn, about 40 km south-west of Aberdeen. The turves were collected between 23 April and 8 May 1991 from a part of Thorter Hill last burnt in 1987 (National Grid reference NO656803). The turves were cut manually using a spade and so varied in size. Typically they were *c.* 12-cm deep with a surface area of *c.* 0.1 m^2. To prevent desiccation, the turves were transported to Craibstone on the day that they were cut, stored in a cool shed and laid in position at the trial site within 48 h.

Young *Calluna* plants (< *c.* 4-cm tall) and litter and surface soil were collected from an area on Cairn o'Mounth 'brashed' with a flail topper in 1988 (National Grid reference NO650808). The young plants were lifted on 1 May 1991 using a soil corer. Placed over a plant and pushed into the soil, the corer extracted the plant on a disc of soil 10 cm in diameter and 5- to 7-cm deep. This was a quick method of collecting the young *Calluna* plants which also minimised root disturbance. The young *Calluna* were replanted in their trial plots at Craibstone within 24 h of being lifted. Care was taken to preserve the integrity of the soil discs during transport and when replanting. The litter and surface soil were collected from 0- to 5-cm depth on 14 May and 15 May 1991. Germination tests showed that the material collected contained > 300 germinable ericoid seeds/kg.

There are three soil treatments per plot: a control (no soil modification); acidification with sulphur, and; addition of horticultural peat to increase the organic matter content. Both soil modifications were designed to make the soil of the trial site more closely resemble a typical heathland soil. When analysed in April 1991, the trial site soil had a pH of 5.6 and an organic matter content of 10.8% at 0- to 10-cm depth.

Elemental sulphur was added at 10 g/m to the appropriate randomly-selected sub-plots on 24 April 1991 (i.e. before the *Calluna* was introduced) and subsequently (see below). This rate of sulphur application had been found to reduce the pH of soil from the trial site from 5.5 to 4.7 in a pot experiment (Williams, 1991). Such a drop in soil pH would be expected to reduce the availability of many mineral nutrients and make the soil less suitable for most weed species.

As with the sulphur treatment, peat was added to the appropriate sub-plots on 24 April 1991. The peat was applied at a rate of 3 l/m, raked in and firmed down. The firming was intended to minimise any loss that may have been caused by wind blow or water run-off. No peat has been added subsequently.

When planting the trial, the heath litter and surface soil mixture was applied at a rate of 1.25 kg/m^2, raked in and firmed down. The young *Calluna* were planted 33.3-cm apart in a grid pattern. Adjacent turves were placed as close together as possible and any cracks between them were filled with loose soil from the turf donor-site. The *Agrostis castellana* was sown at a rate of 6 g/m^2 on 16 May 1993, the same day as the heath litter and surface soil mix was applied.

Sulphur has been re-applied to the sulphur-treatment sub-plots whenever their soil pH has risen above 4.6 or whenever the soil pH in these sub-plots has become not significantly different from that of the controls. All S re-applications have been at 10 g/m^2. Re-applications of sulphur were made on 10 February 1992, 7 May 1992 and 11 February 1993.

The cover-abundance of the different plant species has been recorded by eye according to the Domin scale (McVean & Ratcliffe, 1962) at 3-monthly intervals.

In July 1992, in response to the growth of arable weeds on all but the turf plots and the increased height of the perennial grasses there, it was decided to divide the sub-plots into two sub-sub-plots and top the vegetation in one sub-sub-plot. This was done with a tractor-mounted drum mower. For ease of management the western sub-sub-plot was cut in each sub-plot. It is planned that mowing will be carried out once annually from now on in these sub-sub-plots.

RESULTS AND DISCUSSION

Thus far, no differences attributable to the imposed treatments have developed between the vegetation cover of the sub-plots or sub-sub-plots. However, after 24 months, there are great differences between the plots reflecting the different methods of introducing *Calluna* (Table 1). The use of turves has effectively prevented the growth of arable weeds or volunteer *Trifolium repens* (a serious problem in the other treatments). Nevertheless, the turves have not been particularly successful, due probably to the high cover of perennial grasses in the turves used. On the arable soil the grasses have grown vigorously and become taller, overtopping the *Calluna*, which has declined (Table 1). Taken from a less grassy donor site, turves might be a successful method of establishing *Calluna*-dominated vegetation on farmland, though the damage to the donor site must be taken into account. The cutting and laying of turves is also labour-intensive, and thus expensive unless volunteers can be used.

TABLE 1. Change in vegetation cover over 24 months

Introduction method	Plant Species	% Cover May 1991	% Cover May 1993
Turves	*Calluna*	30	5
	Perennial grasses	70	95
	Arable weeds	0	0
	volunteer *Trifolium repens*	0	0
Young plants	*Calluna*	3	15
	Perennial grasses	0	5
	Arable weeds	0	60
	volunteer *Trifolium repens*	0	40
Litter	*Calluna*	0	0
	Perennial grasses	0	5
	Arable weeds	0	60
	volunteer *Trifolium repens*	0	40
Litter + nurse crop	*Calluna*	0	0
	Perennial grasses	0	85*
	Arable weeds	0	10
	volunteer *Trifolium repens*	0	10

The two methods based on the introduction of *Calluna* by seed have failed. Where a nurse crop was sown, no *Calluna* seedlings were found. In the absence of a nurse crop, a few seedlings appeared in autumn 1991. None of these suvived the following summer, when they were heavily-shaded by dense weed growth. Effective weed control would thus appear to be necessary for any introduction method based on *in situ* germination of *Calluna* seed to succeed, both because light is required for germination (Gimingham, 1972) and because the seedlings are susceptible to excessive competition.

The transplanting of young *Calluna* plants has proved to be the best introduction method, at least on the basis of the results after 24 months. The cover of *Calluna* in this treatment has increased from *c*.3% to 15% over this period, though it was > 25% in autumn 1992. The fall over winter 1992/93 was apparently due to rabbit grazing. Each summer, the *Calluna* in these plots has been overtopped by arable weeds, and has become markedly etiolated. Most plants, however, have survived and many have flowered. If the ground cover of the *Calluna* increases, so the number of arable-weed seedlings each spring may decline. It is not yet clear whether the *Calluna* will become dominant on these plots in due course without intervention to control weeds, and in particular the vigorous growth of volunteer white clover.

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SELECTIVE CONTROL OF *BROMUS STERILIS* IN FIELD BOUNDARIES WITH FLUAZIFOP-P-BUTYL

N D BOATMAN

The Game Conservancy, Fordingbridge, Hampshire, SP6 1EF

ABSTRACT

Many farmers view field boundaries as reservoirs of weeds and spray them with broad spectrum herbicides, thus destroying valuable wildlife habitat. The aim of this work was to examine the potential for selective control of barren brome (*Bromus sterilis*), thus avoiding removal of non-target plants. Six experiments were carried out over two years, in which fluazifop-P-butyl was applied to field boundary vegetation at two doses and timings during the period November to early January. High levels of *B. sterilis* control were generally achieved, though levels were lower at one site in each year, especially at the later timing. Other grasses, though exhibiting initial symptoms, had recovered by the following May, and with one or two exceptions showed no reduction in cover due to herbicide application. Cover of broad-leaved species increased on herbicide treated plots. The implications of the results for the implementation of this technique are discussed.

INTRODUCTION

Barren brome(*Bromus sterilis*) is an annual grass commonly found in field boundary vegetation, which since the 1970s has become a serious weed of cereals (Froud-Williams *et al*, 1980). *B. sterilis* can cause considerable yield loss (Cousens *et al*, 1988), and is difficult to control selectively in cereals with herbicides (Rule, 1989). Straw burning was an effective control measure, (Froud-Williams, 1983), but is now illegal.

Because of the difficulty in controlling *B. sterilis* in the crop, many farmers attempt to prevent field infestations by controlling the weed in the field boundary. Surveys have shown that a high proportion of farmers use herbicides in hedge-bottoms, mainly to control *B. sterilis* and cleavers (*Galium aparine)* (Boatman, 1989). Such spraying is generally unselective, damaging non-target species and thus reducing botanical diversity and habitat value. Furthermore, removal of perennial vegetation may improve conditions for re-establishment of annual weeds in subsequent years (Boatman, 1989). An experiment carried out between 1988 and 1990 indicated that there may be potential for selective control of *B. sterilis* in field boundary vegetation by the application of fluazifop-P-butyl in late autumn, when the target species is young and susceptible, whereas established perennial grasses are making little or no growth (Boatman, 1992). Further experiments, investigating the effects of different doses and timings at several sites over two years, are reported here.

MATERIALS AND METHODS

Three experiments were carried out in 1989/90, and a further three in 1990/91, at different sites on chalk soils in Hampshire. Experimental plots were 5m long and 2m wide, and were situated next to hedges or fences in "semi-natural" herbaceous field boundary vegetation.

Fluazifop-P-butyl was applied as Fusilade 5 at one of two doses (125 or 187.5g AI/ha) on one of two timings (mid-November or late December/early January). In all cases the surfactant Agral (containing 900g/l of alkyl phenol ethylene oxide) was added at a concentration of 0.1% of the spray solution. Date of application and *B. sterilis* growth stages at spraying are shown in Table 1.

TABLE 1. Site locations, spraying dates and growth stages of *Bromus sterilis* at spraying

Site		Spray date	*Bromus sterilis* growth stage	
No.	Location		mean tiller no.	Zadoks growth stage (range)
1989/90				
1	Basingstoke	17 Nov	0.8	12-22
		4 Jan	0.6	11-21
2	Headbourne Worthy	13 Nov	0.3	11-22
		3 Jan	0.3	11-22
3	Damerham	15 Nov	0.3	12-22
		11 Dec	0.2	11-21
1990/91				
4	Basingstoke	19 Nov	1.5	11-24
		13 Jan	0.2	12-21
5	Winterbourne Gunner	15 Nov	0.9	12-23
		18 Dec	0.8	13-25
6	Cholderton	15 Nov	0.9	11-27
		18 Dec	1.9	12-26

Herbicide was applied using an Oxford Precision Sprayer with 2m side-mounted boom, at a volume rate of 270 l/ha (1989/90) or 350 l/ha (1990/91) and a pressure of 300Kpa, through Lurmark 02-F80 nozzles. Treatments were replicated three times in each experiment, in a randomised block design with two unsprayed control plots per block.

Eight weeks after spraying the appearance of grass species was scored on a 0-6 scale as follows:

0 Dead
1. Moribund - virtually all tissue chlorotic or necrotic
2. Some green tissue
3. Severe chlorosis or necrosis
4. Moderate chlorosis or necrosis
5. Slight chlorosis, necrosis or other symptoms in comparison with untreated plants.
6. Healthy - indistinguishable from untreated.

In May or early June of the following summer, percentage cover of each species present in five 0.25m^2 quadrats per plot was estimated. Cover data were subjected to analysis of variance after arcsine transformation.

RESULTS

Vigour Scores

Eight weeks after treatment, all grass species showed some effect of herbicide application, mainly in the form of partial chlorosis of some or all leaves (Table 2). Only species present in most plots were recorded. *B. sterilis* showed more severe symptoms than other species. The effects of different doses and timings at this stage were similar.

TABLE 2. Mean vigour scores* for grasses eight weeks after treatment with fluazifop-P-butyl.

Species	Year and Site					
	1990			1991		
	1	2	3	4	5	6
Bromus sterilis	0.4	0.1	1.1	2.5	2.3	2.1
Elymus repens	2.8	-	3.1	-	4.5	4.7
Arrhenatherum elatius	-	3.8	-	-	3.2	-
Agrotis stolonifera	-	-	3.6	-	-	4.6
Dactylis glomerata	-	-	2.6	-	-	-
Lolium perenne	-	-	-	3.2	-	-

*0-6 scale (see text)

Control of *B. sterilis*

High levels of control were achieved by all treatments at two sites in 1989/90, with lower levels of control by the lower dose at the third site (Table 3). In 1990/91, high levels of control were again achieved at two sites, but a lower level of control was evident at the third site, being poor at the later timing (Table 3).

TABLE 3. Pecentage control of barren brome by fluazifop-P-butyl. Derived from assessments of percent cover in May/June following application in the previous autumn.

Site	Treatment dose (g AI/ha) and timing			
	125		187.5	
	Nov	Dec/Jan	Nov	Dec/Jan
<u>1989/90</u>				
1	99	99	92	96
2	98	99	100	100
3	68	60	99	80
<u>1990/91</u>				
4	84	81	88	95
5	94	88	96	93
6	77	43	79	20

Effects on other grass species

Only species distributed uniformly throughout an experiment were analysed. Total grass cover for all grasses other than *B. sterilis* was also analysed. In 1990, species analysed and respective sites were common couch (*Elymus repens)* (1, 2), *Arrhenatherum elatius* (false oat-grass) (2), and *Agrotis stolonifera* (creeping bent) (3). In 1991 they were *E. repens* (5, 6), *A. elatius* (5), *A. stolonifera* (6), *Lolium perenne* (perennial ryegrass) (4), and *Poa* ssp. (meadow-grasses) (6). *Poa* spp. at site 6 were a mixture of *P. patensis* and *P. trivialis*.

Poa spp. were the only grasses other than *B. sterilis* to be significantly affected by treatment with fluazifop-P-butyl; a higher level of control (96%) was evident at the earlier timing than the later timing (57%). There was no effect of any treatment on total grass cover (other than *B. sterilis*) at any site in either year.

Effects on broad-leaved species

Herbicide application increased the number of biennial and perennial broad-leaved species at site 3 in 1990, from a mean of 3.5 in untreated plots to 5.4. In 1991, the number of annual broad-leaved species was increased at site 4 from 6.0 to 8.9 and at site 5 from 3.2 to 4.7.

Cover of annual species was significantly increased by herbicide use at all sites in both years (Table 4). In 1990, the major broad-leaved annual at all sites was *G. aparine*, and this species accounted for most of the increases in cover. In 1991, *G. aparine* did not dominate the annual flora to the same extent and cover of other annual species was increased by herbicide application at all three sites. There were no significant effects of herbicide dose and timing. Effects of herbicide application on cover of biennial and perennial species were less marked and varied between sites (Table 4).

TABLE 4. Mean effect of fluazifop-P-butyl applied in late autumn/early winter on (arcsine transformed) percentage cover of annual and biennial and perennial broad-leaved plants in May/June of the following year (Data in parentheses are untransformed).

Site	Annuals			Biennials and Perennials		
	Untreated	Treated	SED	Untreated	Treated	SED
1989/90						
1	12.0(5.9)	27.2(21.9)	3.2	37.4(38.1)	33.1(30.9)	4.1
2	14.8(7.7)	25.4(19.4)	3.2	39.3(36.9)	43.2(46.5)	4.4
3	6.7(1.5)	21.1(14.2)	4.4	37.2(38.6)	53.6(63.9)	5.8
1990/91						
4	19.4(10.9)	25.3(18.7)	2.2	45.4(50.7)	43.5(47.5)	2.9
5	18.9(12.4)	31.1(27.2)	4.4	32.1(28.7)	38.6(39.0)	2.8
6	8.9(3.0)	17.1(9.3)	2.5	23.4(17.1)	32.2(29.9)	5.1

DISCUSSION

These experiments have confirmed that it is possible to achieve a high level of *B. sterilis* control by late autumn/early winter application of fluazifop-P-butyl with minimal effects on other grass species. However, in each year, control was poorer at one of the three sites. Additional evidence collected in the second year of trials, suggested that this might have been due to higher soil fertility enabling more rapid growth and greater recovery from the effects of the herbicide. Early application gave better results in this situation. Further work is needed to confirm effects of soil fertility, but *B. sterilis* is known to be responsive to nitrogen fertiliser, and has been found to be more competitive at high levels of nitrogen application (Lintell-Smith *et al*, 1991). Fertiliser misplacement in the field boundary may have contributed to high soil fertility in these trials.

The only other grasses significantly affected by fluazifop-P-butyl application were *Poa* spp. Unfortunately, at the sites where these were abundant, the two species were growing in intimate mixture and cover values could not be estimated separately. However, in an earlier experiment, although *P. trivialis* was reduced in the first year after spraying, in the second year it had re-established itself at levels similar to untreated plots (Boatman, 1992).

Annual broad-leaved herbs, especially *G. aparine*, increased in response to herbicide use, presumably as a result of reduced competition from *B. sterilis*; and possibly also from other grasses immediately after spraying. Since *G. aparine* is also a serious weed, it may be necessary also to control this species where abundant, using a similar selective approach (Bain & Boatman, 1989; Boatman, 1992).

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THE POTENTIAL FOR CONSERVATION HEADLANDS IN LINSEED

J.A. TREE

Royal Holloway, University of London, Egham, Surrey. TW20 0EX

N.D. BOATMAN

The Game Conservancy Trust, Fordingbridge, Hampshire. SP6 1EF

ABSTRACT

Experiments were carried out in headlands of linseed to assess the potential for Conservation Headlands.

The abundance of broad-leaved weeds was significantly greater in the unsprayed areas. There was no relationship between weeds and the eventual yield of linseed, nor were moisture content and thousand seed weight affected. Contamination by weed seeds was small even in plots not treated with herbicide. There was no significant difference between the yield of the sprayed and unsprayed plots in the headlands. The yield from the sprayed headlands was 37% less than the rest of the crop. At one site, there was a negative relationship between seedhead density of the main grass species *Alopecurus myosuroides* and yield of linseed.

Conservation headlands are only currently practised in cereals, however it was concluded from this trial that this regime could be extended to linseed without causing reduced profitability or interfering unduly with farming operations.

INTRODUCTION

Intensive use of pesticides can disrupt the food chains of many wildlife species such as gamebirds which forage for insects and weed seeds in crops. One solution to this problem is to modify the use of pesticides used in crop margins to enable the establishment of certain broadleaved weeds on which insects survive; this technique is now known as "Conservation Headlands" (Sotherton *et al*, 1989). The agronomic costs and consequences of Conservation Headlands in cereals have been analysed by Boatman and Sotherton (1988). At present Conservation Headlands are only recommended in cereal fields, however since there has been an increase in the area of linseed (*Linum usitatissimum*) grown in Britain from less than 330 hectares planted in 1980 (Nix, 1991) to 105 000 hectares in the spring of 1991 (Appel, 1991) similar advantages to wildlife species might be obtained from extending this conservation practise to linseed fields.

There is a lack of detailed information on the effects of broad-leaved weeds on linseed in the UK and no information on the performance of linseed in the field margin. The Canadian researcher, Friesen (1986) carried out 26 experiments in which 25 showed an increase in seed yield (on average 79%) where weed control was practised, however the drier climate found in Canada is likely to enhance the competitive effects of weeds on linseed. In Britian, Freer (1991) reported on five trials conducted over several years, concluding that there was little yield response from herbicide application on linseed, yet Turner (1987) summarising a survey of 49 British linseed crops, believed that crops containing weeds were rarely high yielding.

This paper reports on research carried out to determine whether Conservation Headlands are a viable proposition in linseed.

MATERIALS AND METHODS

Experimental details

Experiments were carried out in two fields ("Pilverlands" and "Foots") on a farm near Basingstoke, north-east Hampshire in 1991. Each of the two experiments was set up in the west-facing headland of the field next to a hedgerow (approximately 2 metres high), and consisted of five blocks placed contiguously along a headland in a linseed crop. One plot per block was chosen at random and sprayed with herbicide, the other plot remaining herbicide free. Plots (6 x 20m) were situated between the field boundary (edge of sterile strip) and the first tramline. The fields were drilled with linseed (variety Atalante) at 72 kg/ha on the 30th April. A mixture of bromoxynil (240 g/ha) + clopyralid (50 g/ha) ("Vindex") and bentazone (480 g/ha, "Basagran") was applied in 200 litres of water/ha on 23 May to the main crop and the selected headland plots.

Weed assessments

At the end of June, the density and percentage cover of the broad-leaved weed flora was determined in ten random 0.25 m^2 quadrats in each plot of three blocks. The cover value was estimated by eye. From within five of the random quadrats an area of 0.125 m^2 was harvested to ground level. Linseed, grasses and individual weed species were separated and dried in paper bags at an oven temperature of 100^oC to constant weight.

In July and August the above procedure for biomass was repeated in the same plots. This time the percentage cover of the weed flora was assessed in all the plots in both fields. A "floating" wooden quadrat 0.25 m^2 was placed, at random, on top of the linseed and those grass panicles which fell inside the quadrat were counted. This was repeated ten times in each of the ten plots in both fields during July.

Crop performance

In June the number of linseed plants were counted in five random 0.25 m^2 quadrats in each treatment of the three selected blocks used to assess the biomass of weeds in each field. In July the number of stems per random 0.25 m^2 quadrat were counted in the same selected plots. Fifty random crop height measurements were made in all plots using a metre rule. The height of the crop was taken to be the distance from the ground to the highest capsule.

The desiccant Reglone (2.5 litres/ha) was applied to both fields on the 3rd of September. Five random 0.125 m^2 quadrats were harvested from each plot in three blocks per field. From these samples the number of capsules per stem were counted on twenty stems from each quadrat, making a total of 100 counts, per plot.

The crop was harvested on the 13th September. Each plot was combine harvested separately at a similar speed. After each plot the combine was allowed to run for a few minutes to prevent cross contamination of plots. The output of the combine was collected in hessian sacks, and sieved (5mm) to remove capsule remnants. A 50g treatment sample was extracted from each immediately after the harvest and from this the weight of the weed seeds contaminating the sample was determined. Two sieves (4 and 3.5 mm) were used to remove the fine contamination and weed seed from the 50g samples but some weed seeds were similar in size to linseed and were not filtered out, so these seeds were extracted by hand. 50 linseed seeds were also separated from the sample in order to determine the thousand seed weight. The weed seed and 50 seed samples were weighed. The 50 seed samples were dried at 60^oC for seven days and then reweighed to determine the percentage seed moisture for each plot.

RESULTS

Broad-leaved weeds

Of the two fields, Pilverlands had more of weed species (26) than Foots field (20). Table 1 lists the botanical composition (20 species) found in the unsprayed plots of the two fields in June.

TABLE 1. Botanical Composition (mean number of individuals m^{-2} (n=30) and the mean percentage cover (n=30)) of herbicide free plots in the headland at each site in June.

Field	**Pilverlands**		**Foots**	
Species	No.	% Cover	No.	% Cover
Tripleurospermum inodorum	2.13	1.76	0.27	0.07
Sonchus asper	1.47	2.27	0.4	0.4
Cirsium arvense	1.73	3.4	-	-
Galium aparine	0.4	0.17	-	-
Sinapis arvensis	0.26	0.4	0.67	1.23
Chenopodium album	3.73	4.57	0.53	0.33
Fallopia convolvulus	0.13	0.17	6.00	5.73
Viola arvensis	4.53	2.17	16.27	6.17
Stellaria media	28.13	9.93	37.73	12.2
Veronica persica	38.53	10.72	16.3	4.7
Papaver rhoeas	1.2	1.2	0.67	0.13
Senecio vulgaris	-	-	0.27	0.17
Fumaria officinalis	0.27	0.07	0.27	0.07
Legousia hybrida	0.8	0.47	-	-
Kickxia elatine	0.13	0.17	-	-
Sonchus arvensis	1.3	0.67	-	-
Solanum tuberosum	-	-	0.27	0.33
Rumex obtusifolius	0.13	0.13	-	-
Plantago media	-	-	0.13	0.17
Sinapis alba	-	-	0.13	0.33

The mean density (n=30) of weeds was greater in the unsprayed than the sprayed plots in June (Table2). There were similar densities of weeds in each field, in each treatment. The mean (n=15) total weed dry weight of broad-leaved weeds is shown in Table 2; spraying with herbicide greatly reduced the biomass of broad-leaved weeds ($p<0.001$ in all cases). The herbicide did not affect grass weeds.

TABLE 2. The effect of herbicide on weed numbers, weed dry weight and weed seed contamination of linseed.

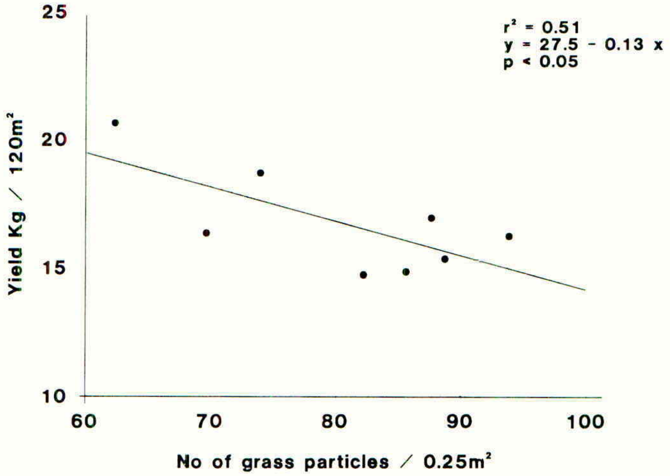
		Pilverlands		**Foots**	
		+herbicide	-herbicide	+herbicide	herbicide
mean weed no/m^2		24.8	84.4	19.1	76.9
mean dry weight/m^2	-June	1.92	32.40	0.41	9.05
	-July	2.13	24.15	0.40	19.04
	-Aug.	1.36	51.52	0.07	17.76
fresh weight weed seeds per 50g linseed sample		0.06	0.09	0.09	0.25

There was no relationship between the percentage cover of weeds and the eventual yield of linseed. Even when the mean total percentage cover of weeds reached 78% in Pilverlands field in July the yield of linseed from the same plot was no less than or greater than a plot which had only had a mean of 10.5% total weed percentage cover.

Grass weeds

The main grass species present in both fields was *Alopecurus myosuroides*. Regression analyses were performed comparing the yield of linseed with counts of grass panicles from the same plots in each field. In Pilverlands field there was no relationship between density of *A.myosuroides* and yield; however in Foots field, where the density of grass was higher, there was a significant relationship between yield and grass panicle density (Figure 1)

FIGURE 1. Relationship between the number of panicles of *Alopecurus myosuroides* and the yield of linseed from the same plots in Foots field.



Crop performance

The crop performance is summarised in Table 3. There was no significant effect of herbicide treatment and no significant difference between the fields, nor was there any significant interaction between field and treatment.

TABLE 3. Crop parameters (± one standard error) in the experimental headlands for sprayed and herbicide free plots.

Crop Parameter	Treatment Unsprayed	 Sprayed	p
No of plants/m (n=30)	582.7 ± 17.44	599.9 ± 18.28	NS
No of stems/m (n=30)	767.1 ± 26.6	755.3 ± 21.04	NS
Crop height (cm) (n=500)	73.85 ± 1.11	74.04 ± 0.85	NS
No. of capsules/stem (n=600)	8.17 ± 0.21	8.65 ± 0.28	NS
T.S.W. (g) (n=10)	7.5 ± 0.08	7.4 ± 0.05	NS
% Moisture (n=10)	5.7 ± 0.17	6.1 ± 0.20	NS
Yield Kg/ha (n=9)	1421.2 ± 710	1427.2 ± 420	NS

NS, No significant effect. Treatment x field interaction = NS.

The effect of herbicide on weed seed contamination

There was no significant effect of herbicide treatment on the weight of weed seeds in samples from Pilverlands field. In contrast, the mean weight of weed seeds was greater in the unsprayed plots in Foots field than in the herbicide treated plots ($P<0.05$, Table 2). However, the overall weed contamination in the headlands of both fields was very small, and the weeds were desiccated along with the crop.

Yields of headland treatments in relation to the rest of the crop

The mean yield from plots treated as Conservation Headlands was 1421 kg/ha and from plots which were fully sprayed was 1427 kg/ha. The yield from the rest of the crop in Pilverlands and Foots field, which was herbicide treated was 2260 kg/ha. Therefore, there was a 37.1% reduction in the unsprayed headland plots compared to the rest of the field and 36.8% reduction in the sprayed headland plots, i.e. a difference of 0.3% between the two treatments in the headland.

DISCUSSION

Spraying with herbicide reduced the density, variety, cover and biomass of broad-leaved weeds compared with herbicide free plots in the linseed headlands. Herbicide restricted the weed flora to between two and five species, the most frequently occurring species being *Viola arvensis* and *Veronica persica*. The common broad-leaved weeds that were abundant in the unsprayed areas but susceptible to herbicide include *Tripleurospermum indorum, Sinapsis arvensis, Stellaria media, Chenopodium album* and *Fallopia convolvulus*. These broad-leaved weeds (including *Polygonum aviculare*) are the host plants for many phytophagous insect species (Sotherton *et al.*, 1989).

At no time was there a significant relationship between the linseed yield from the harvest and the total percentage cover of weeds in June, July and August, suggesting that the crop competes effectively with broad-leaved weeds. There was no significant effect of treatment on the number of established linseed plants, stem density, crop height, number of capsules per stem or number of seeds per capsule. Linseed is slow to establish and becomes susceptible to weed competition, especially smothering weeds such as *Stellaria media*, at an early stage. However the time of drilling can influence the effect of weed infestations on this crop (Lutman, 1991). In this trial the linseed was sown late, on the 30th April 1991, as a result the crop emerged quickly and was less susceptible to broad-leaved weed competition. Also, the crop was drilled at 72 kg/ha, giving 560 established plants per square metre in the unsprayed areas and 583 plants per square metre in herbicide treated areas. It can perhaps be assumed that at this seed rate linseed is competing effectively with broad-leaved weeds. Turner (1991) concluded from trials carried out between 1988 and 1990 that commercial linseed should be drilled at 600 seeds/m^2 to produce a population of 400 plants/m^2 (acceptable range 250-500 plants/m^2). Further investigation is required to determine whether at a lower seed rate than sown in this trial, weeds would have a much more serious effect on crop performance in Conservation Headlands.

There was a negative relationship between the density of *Alopecurus* and the yield of linseed in Foots field in this one year study. Usually *A. myosuroides* germinates in the autumn but on this farm it also germinated in the spring.

There was a 37% yield difference between the headland and the rest of the field. Headlands generally yield less than the rest of the field in crops even when they have been fully sprayed. Soil compaction (from tractors turning during cultivations) and poor seed-bed conditions (Boatman and Sotherton, 1988) may be the cause of this reduction. In this trial shading was not likely to be a major factor because the plots were placed next to fairly short hedges.

A small increase in grain moisture content in cereal crops from the field margins irrespective of whether the headlands were sprayed has been reported in cereals (Boatman and Sotherton, 1988). Moreover, the moisture content was about 1-2% greater when field margins were treated as Conservation Headlands. Wilson (1982) also found that herbicide free plots yielded grain with a higher moisture content than sprayed plots in winter cereals. In this trial, however, there was no significant difference between the sprayed and unsprayed plots. This is probably because prior to harvest, the linseed crop is routinely treated with a desiccant which reduces the moisture content of the crop and weeds alike. The ideal seed moisture for storing linseed, without drying, is 8-8.5%. The percentage moisture of the yield from both treatments in this trial was well below this threshold.

The biggest demand (97%) for linseed in the EC is for crushing, so that oil can be extracted and utilised (Turner, 1987). The total weight of contaminants from this trial was well within the contract standard for crushing crops, which is a maximum of 2% admixture, and if the farmer mixed the headland yield with the rest of the seed from the herbicide treated field the weed seed contamination would be diluted.

To conclude, it appears from this initial study that Conservation Headlands may be a viable proposition in linseed.

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NOTES

AMENITY AND INDUSTRIAL USE OF HERBICIDES: THE IMPACT ON DRINKING WATER QUALITY

S.L. WHITE, D.C. PINKSTONE

Department of Environment and Science, Thames Water Utilities, Reading Bridge House 2, c/o Nugent House, Vastern Road, Reading RG1 8DB

ABSTRACT

Pesticides, and in particular herbicides, account for the majority of failures to meet the standards for drinking water quality in England and Wales. Most of these herbicides can be attributed to uses in the non-agricultural sector.

In addition to installing new treatment processes Thames Water has been working with manufacturers and users of non-agricultural herbicides and Government Departments to reduce the amounts reaching water sources. The aim has been to increase awareness of water quality and encourage improved practices in the use and disposal of herbicides. The initiative to control herbicides at source has produced a significant decline in the concentration of atrazine and simazine in water sources. However, in several sources there have been small but significant increases in the concentrations of diuron.

The need for further research on the movement of non-agricultural herbicides in the environment is discussed.

INTRODUCTION

Since the privatisation of the water industry there has been a marked increase in public awareness of water quality issues. This interest has been stimulated by media coverage of incidents, reports on water quality data and questions about the cost of meeting standards set by the European Community. The presence of pesticides in drinking water has been central to this debate.

The Water Supply (Water Quality) Regulations 1989 fully incorporate, and go beyond, the requirements of the EC Drinking Water Directive. Within the Regulations there are two standards for pesticides, 0.1ug/l for individual substances, and 0.5ug/l for "total" pesticides. These standards are not based on health and apply irrespective of the data on the hazards posed by these substances. The origin and validity of these two standards has been debated at length elsewhere and will not be considered in detail here.

This paper considers how the use of herbicides, particularly in amenity and industrial areas, can influence the quality of water supplies. The steps that are being taken to address this situation are also reviewed.

DATA ON PESTICIDES IN DRINKING WATER

Every year the Drinking Water Inspectorate publishes a report on Drinking Water Quality in England and Wales (DWI 1991,1992,1993). Amongst other things this report summarises water quality monitoring data collected by the water supply companies. These data illustrate the importance of pesticides as a cause of non-compliance with the Regulations (see Table 1). In almost all cases the pesticides recorded were herbicides.

TABLE 1. Contraventions of standards in water supply zones in England and Wales 1990-1992

Parameter	Number of contraventions (% of total) 1990	1991	1992
Pesticides	13209 (51)	27585 (66)	35679 (75)
Coliforms	3835 (15)	2709 (6)	2318 (5)
Iron	2226 (9)	2515 (6)	2033 (4)
Nitrite	1743 (7)	2228 (5)	2086 (4)
Lead	1598 (6)	1736 (4)	1354 (3)
Nitrate	1117 (4)	1170 (3)	852 (2)
Others	2204 (8)	3781 (9)	3317 (7)
Total	25932	41724	47639

The number and type of pesticides present in drinking water vary across the country. Key factors are:

the nature of pesticide use in the water catchment area eg agricultural/non-agricultural uses;

the type of water source, eg upland catchment/lowland river;

the nature of water treatment. Many companies have now installed treatment processes to remove pesticides.

Figure 1 shows the number of contraventions of the standard for individual pesticides recorded by the ten water utility companies (the former water authorities) in England and Wales during 1991. The pesticides are broken down into non-agricultural herbicides and all other pesticides.

Clearly pesticides in drinking water are more of an issue in the South and East of the country than the North and the West. This almost certainly reflects the different types of water sources. In the North and West most water is derived from upland catchments where pesticide use would be limited. In the South and East, areas predominated by arable agriculture and urban development, most supplies come from lowland rivers or groundwaters.

Figure 1 also shows that herbicides widely used in non-agricultural situations, such as atrazine and diuron, account for the majority of failures in many areas. This is despite the fact that the quantities of these herbicides used across the country are much smaller (10-100 fold) than the amounts of cereal herbicides, like isoproturon and mecoprop.

Although it is not entirely understood why non-agricultural herbicide use poses such a risk to water resources there are a number of factors which are thought likely to contribute;

Applications are often onto hard surfaces like tarmac, concrete or railway ballast. Such surfaces give little opportunity for adsorption onto organic matter or microbial degradation.

Sites with hard surfaces tend to be freely draining and, after rainfall, the soluble herbicides will tend to move down the hydraulic gradient into rivers or groundwater, via surface drains or soakaways.

Many of the herbicides used in non-agricultural situations have prolonged residual action. They are designed to resist microbial degradation within the environment, or by sewage treatment processes, more so than most agricultural herbicides.

Non-agricultural pesticide use is not uniform and may be greater close to water resources. For example, roads and railways tend to follow river valleys and urban areas have often developed around river crossings.

Application rates of herbicides in non-agricultural situations are often greater than in agriculture. In addition contract specifications imposed by local authorities or utilities often include penalty clauses for regrowth of weeds. This tends to encourage greater herbicide use.

WATER TREATMENT FOR HERBICIDES

Where standards for pesticides have been contravened water companies are required to take steps to meet the regulatory requirements. These steps form the basis of legally binding "Undertakings" to the Government. For Thames Water these Undertakings involve the installation of new treatment processes, such as granular activated carbon (GAC) and ozone, at more than 25 treatment works, both groundwater and surface water works. These works account for more than 80% of Thames Water's supplies.

Installing treatment plant to remove pesticides is expensive. Across the Thames Water area the capital cost is approximately £400 million. Annual operating costs of the new plant are approximately 10% of the capital costs. A major factor in these costs is the cost of periodically regenerating the GAC. The period between regenerations is heavily dependent upon the pesticide concentrations in the raw water.

New treatment processes cannot be installed overnight. They need to be integrated with existing treatment streams without presenting any risk to the quality, or quantity, of drinking water put into supply. Pilot plant studies, process and engineering designs, planning permission and construction mean that timescales are measured in years rather than months. New treatment plant has already been installed at more than ten works but at some of the large works serving London, work will not be completed until after 1995.

These long timescales suggested that Thames Water should investigate if concentrations of herbicides could be reduced by improving controls at source.

CONTROLLING HERBICIDES AT SOURCE

In recent years there have been major changes in the use of non-agricultural herbicides. These changes have been brought about by concerns over the appearance of atrazine and simazine in water sources. While many organisations responded voluntarily to these concerns the Government's decision to revoke the approval of atrazine and simazine in non-agricultural situations has forced some organisations to change their weed control operations.

Despite the concerns expressed by water companies, many organisations have substituted diuron for atrazine and simazine as the cheapest available residual acting total weedkiller. This has resulted in increased concentrations of diuron in many water supplies.

The increasing concentrations of diuron in water supplies suggests that the answer to water contamination by non-agricultural herbicides does not lie simply in the banning of active ingredients. Indeed such an approach can result in the greater use of a smaller pool of approved substances. Instead the approach promoted by Thames Water, and other water companies, has been to introduce "better practice" in the use of herbicides, so as to minimise the impact on water resources.

This approach has involved encouraging organisations to revisit their weed control practices and ask questions about why and how they use herbicides. Assessing the risk to water resources, application methods and timing, improved training of operatives and proper disposal of rinsings and washings are amongst the issues being addressed. However the most important and fundamental objective has been to create a greater awareness of drinking water quality and the implications of the pesticide standard. The fact that 200g of a herbicide is enough to cause a day's water supply to London to contravene the 0.1ug/l pesticide standard comes as a surprise to many people involved with pesticides, users and manufacturers alike, and helps put their activities into context.

In October 1990 Thames Water wrote to all local authorities and British Rail regions in the Thames catchment area asking them to review their use of herbicides, stressing the need to protect water resources. The appearance of atrazine, simazine and diuron in drinking water was mentioned.

In general the responses to this letter were encouraging. Many organisations asked for further advice and they were directed to ADAS or the National Rivers Authority. The most surprising aspect was that even in organisations using considerable quantities of herbicides, there was limited technical expertise available and often considerable confusion and uncertainty over the nature and extent of herbicide use.

The replies to this initial letter indicated that there was clearly considerable scope for reducing herbicide use and protecting water resources and encouraged Thames Water to commit itself to a more general initiative to control herbicides at source. This has involved further liaison with users of pesticides, developing links with manufacturers (directly and through the industry associations) and supporting initiatives by Government Departments. Of particular note are;

The agreement by British Rail not to use residual acting herbicides in areas identified as being close to groundwater sources and rivers;

Working with the manufacturers of diuron, Rhône-Poulenc, to improve awareness amongst major users in the river Lee catchment;

Assistance in the preparation of two booklets from DoE on weed control in non-agricultural situations (DoE 1992a&b).

Most recently a questionnaire has been sent to a wide range of organisations who undertake weed control in non-agricultural situations, such as local authorities, utilities, airports, supermarkets and Government Departments. This questionnaire covered weed control policies, use of different herbicides, sources of information on herbicides and disposal methods. The results of this survey are to be circulated to the participants and other interested parties.

Figure 2 summarises the replies to questions on sources of information and the role of other factors. Although the replies to such questions are inevitably subjective there is a perception that advice could be improved.

CHANGING HERBICIDE CONCENTRATIONS

The changing use of herbicides in the non-agricultural sector has been reflected in their concentrations in water resources and hence water supplies. Figure 3 shows the concentrations of atrazine, simazine, and diuron from a treatment works serving London which has not had any new treatment processes installed. This works is supplied by large storage reservoirs, fed by the Thames. These reservoirs act to reduce the variation in herbicide concentrations which are characteristic of river systems. The pesticide data have been plotted as the annual average of the monthly mean concentrations to reduce seasonal variation and the effects of sampling frequency.

Since mid-1992 the concentrations of atrazine and simazine appear to have stabilised. This may be because organisations are using up old stocks prior to the revocation of approvals, a result of increased rainfall or a measure of agricultural uses of these herbicides. Since 1990 there has been a small but steady increase in the diuron concentration at this works. This small increase does not reveal the increasing importance of diuron as a cause of non-compliance with the pesticide standard, both within the Thames Water area (see Figure 4) and across England and Wales as a whole. One reason for this is that a 0.1ug/l standard acts as a threshold. At 0.09ug/l a sample passes the standard but an increase of only 0.02ug/l would mean a sample would fail.

THE FUTURE

As ozone and GAC are installed at water treatment works, and the number of contraventions of the drinking water standards decrease, it is possible that herbicides in water will fade as a matter for public debate. However the public debate on water quality, now includes the cost of meeting standards, some of which cannot be readily justified in health terms. A recent report by the Parliamentary Office of Science and Technology (POST 1993) said that the priority given to removing pesticides from drinking water appeared to be misplaced. POST also suggested that an alternative to new treatment plant would be to restrict the use of pesticides in water catchments.

At a technical level the future will require a better understanding of how herbicides move in the environment and the risks posed to water resources. This will be particularly true for new herbicides or substances, such as imazapyr, where sufficiently sensitive analytical methods are only just beginning to emerge.

To date studies on the environmental fate of herbicides has concentrated on agricultural uses. This probably reflects how MAFF and the agrochemical industry have historically perceived the subject of pesticides in water. Relatively little work has been done on the movement of non-agricultural herbicides applied to hard surfaces.

Areas of fruitful research might include;

To determine the factors affecting herbicide movement in surface runoff from hard surfaces. The results could help in developing better application strategies (method, timing, placement etc), or new formulations, that pose a smaller risk to water resources.

Studies on the movement of herbicides through drainage systems into soakaways and ultimately into groundwater. This could determine the risk to water resources posed by applications of herbicides to railway tracks and roads and be used to delineate areas of greatest risk to groundwater.

Investigations on how "water sensitive" weed control strategies, such as herbicide rotations, reduced application rates and non-chemical methods, compare with "traditional" strategies of repeated annual applications of residual herbicides.

Research in these areas may be encouraged by the prospect of water protection zones for pesticides - analogous to nitrate sensitive areas.

The water and the agrochemical industries have broadly similar views on the standards for pesticides in drinking water. However with no immediate prospect of a change to the standards, the future will demand that the two industries work closely with each other, and the user community, to find the best ways of ensuring compliance. Improved advice and education will be key components as will the development of new weed control strategies.

ACKNOWLEDGEMENTS

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4C-6

CROP DESICCATION IN ENVIRONMENTALLY SENSITIVE AREAS WITH DIQUAT

P.J. EDWARDS

Zeneca Agrochemicals, Jealott's Hill Research Station, Bracknell, Berkshire, U.K.

ABSTRACT

Diquat as 'Reglone' is used world-wide as a crop desiccant. It may be applied by aircraft, thus there is potential for accidental overspray and drift onto uncultivated areas which may be conserved for wildlife. Such a situation exists in the prairie pothole region of Canada, where small wetlands are frequent in fields. These small wetlands are of international importance for breeding and migratory birds, including waterfowl, shorebirds and passerines. Their value to wildlife is dependent on the quality of the plant community. Quantitative measurements of plant cover and the relative abundance of wetland plants following direct overspray in the autumn showed there were no effects of diquat the following summer, other than minor effects on 2 broadleaved species. The low impact on wild perennial plants is due to the non-systemic foliar activity and deactivation in soil. As a consequence diquat is a valuable desiccant for use in environmentally sensitive areas.

INTRODUCTION

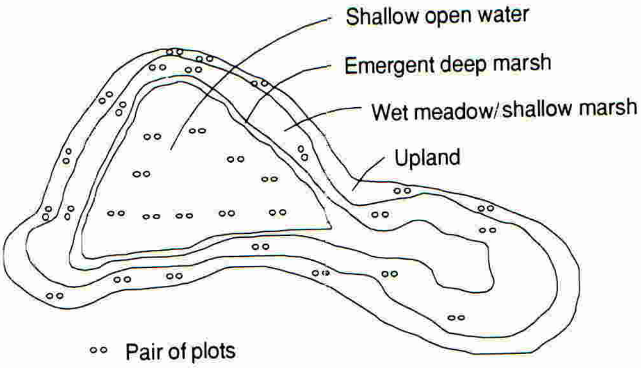
Agricultural activity puts pressure on wildlife habitats in many ways, from cultivation and drainage to accidental overspray with agricultural chemicals. Careful management and the correct choice of herbicides can minimise any impact and even improve upon traditional methods. Good examples of this include the use of foliar herbicides to kill weeds prior to drilling seed directly into soil without cultivation (Edwards and Lofty, 1982). Another example, yet to be exploited, is the use of selective graminicides like fluazifop-p-butyl to destroy volunteer cereals and invasive grass weeds, like sterile brome, in Set-aside. Such uses can prevent the need for cutting and/or cultivation, which can have such damaging effects on ground nesting birds and other wildlife (Potts 1993). A third example is described in this paper, which provides evidence for the safe use of diquat to perennial wild plants which may be oversprayed accidentally or exposed to spray drift during crop desiccation with diquat. This is particularly valuable because crop desiccants are often applied by aircraft which provides greater potential for overspray and drift than ground applications.

Diquat is non-systemic and is not available to the plant through root uptake because it binds strongly to soil. These properties while limiting its application for perennial weed control are a strength for use in environmentally sensitive areas, where damage to permanent wildlife cover can have a detrimental impact on wildlife. Experimental work was carried out in the field, in the prairie pothole region of Saskatchewan, Canada. This is an environmentally sensitive agricultural region containing many small and shallow wetlands called 'potholes' or 'sloughs' which are of international importance for their breeding and migrating wildfowl, shorebirds and some prairie songbirds, not to mention the wetland flora itself.

METHOD

Six sloughs were chosen mostly in fields of lentils. Sloughs provided 4 plant communities; upland, wet meadow/shallow marsh, emergent deep marsh and shallow open water (Millar, 1976) and assured a wide variety of species were investigated. These communities predominantly comprised perennial species. Within each community zone and on each slough, 10 homogeneous areas were selected. Areas were large enough to hold 2, 1m diameter plots, 1m apart (Fig 1.). Plots were assigned to treatment (control or diquat) at random. Sloughs and adjacent lentil fields were sprayed with diquat, as 'Reglone', by aircraft during the evening on six days in August 1989, at the maximum recommended rate for desiccation of 550 g ion/ha. Spray deposit cards were used to check the application rate adjacent to each diquat plot and on the lentil field. Mean measured deposition was 73% of nominal. A 1m diameter cover was placed over control plots just before spraying to protect vegetation from diquat and removed early in the morning the following day. To protect aquatic plants in the shallow open water, covers were pushed into the sediment making a effective barrier for diquat. Residues of diquat had dissipated from the water phase in <7 days when vertical covers were removed.

FIGURE 1. Map of a study slough showing plant community zones and location of pairs of plots.



The plant community structure was compared on diquat and control plots the following summer by 4 methods; 1) observational comparison with full photographic record; 2) measuring the frequency of species in upland and wet meadow/shallow marsh cover using a point quadrat and measuring point contact height, (Brown, 1954; Grant, 1981); 3) by measuring stem density and full plant height in the emergent deep marsh and 4) by measuring aquatic plant biomass in the shallow open water. These assessments provided a quantitative measure of a) cover which gives protection and shelter to wildlife, such a birds nests and chicks; b) effects on the species composition of the plant community; and c) biomass of aquatic plants which are the major source of primary production in these invertebrate rich sloughs.

Plant communities were analysed separately by a split plot analysis of variance, with sloughs representing main plots and the different plot pairs as sub-plots (analogous to experimental blocks). This provided an estimate of sub-plot error which was used to conduct T-tests between the means of the treated and control plots.

RESULTS

Oversprayed vegetation was evenly damaged by diquat, with foliage necrosis complete within 7days of spraying. There were no initial effects observed on aquatic macrophytes. Covers gave full protection from diquat. There were no visible differences (qualitative) between treatments in the plant community in the following summer.

a) Plant cover in upland and the wet meadow/shallow marsh was unaffected in the year following the diquat application. A cover index was derived from the square root of the mean % cover x mean plant height and expressed as a ratio, diquat/control. Thus the closer the index to 1 the greater the similarity between plots. Table 1. below gives the mean cover indices (all plots on all sloughs).

TABLE 1. Plant Cover Indices

Plant Community	Cover Index
Upland	0.99
Wet meadow/shallow marsh	0.98
Emergent deep marsh	1.01

b) A total of 29 species were common or abundant in upland, wet meadow/shallow marsh and emergent deep marsh (Table 2). Two species, declined significantly (P=0.05), in upland only. Both were late flowering broadleaf species, *Aster hesperius* and *Sonchus arvensis*. Compensating for this decline in cover was an increase in the grass, *Hordeum jubatum* (Figs 2,3&4). Both broadleaf species remained common or abundant in the community indicating these minor effects had no biological significance.

TABLE 2. Abbreviations of common species of plants featured in Figures 2 to 4 and type.

Key	Species	Type
AR	Agropyron repens	perennial grass
BI	Bromus inermis	perennial grass
CI	Calamagrostis inexpansa	perennial grass
HJ	Hordeum jubatum	perennial grass
MC	Muhlenbergia richardsonis	perennial grass
PN	Puccinellia nuttalliana	perennial grass
PPA	Poa palustris	perennial grass
PPR	Poa pratensis	perennial grass
PA	Phalaris arundinacea	perennial grass
SF	Scholochloa festucacea	perennial grass
AC	Astragalus canadensis	perennial broadleaf
AH	Aster hesperius	perennial broadleaf
CA	Cirsium arvense	perennial broadleaf
DS	Descuriana sophia	annual broadleaf
EG	Erucastrum gallicum	annual broadleaf
PAN	Potentilla anserina	perennial broadleaf
SA	Sonchus arvensis	perennial broadleaf
RA	Ranunculus aquatilis	annual broadleaf
EC	Elaeagnus commutata	woody broadleaf
SO	Symphoricarpus occidentalis	woody broadleaf
CL	Carex lanuginosa	perennial sedge
CAT	Carex atheroides	perennial sedge
CP	Carex praegracilis	perennial sedge
JB	Juncus balticus	perennial rush
EP	Eleocharis palustris	perennial rush
SAC	Scirpus acutus	perennial rush
SV	Scirpus validus	perennial rush
SP	Scirpus paludosus	perennial rush
TL	Typha latifolia	perennial cattail

Composition of the Plant Community in upland, wet meadow/shallow marsh and emergent deep marsh.

FIGURE 2. Upland

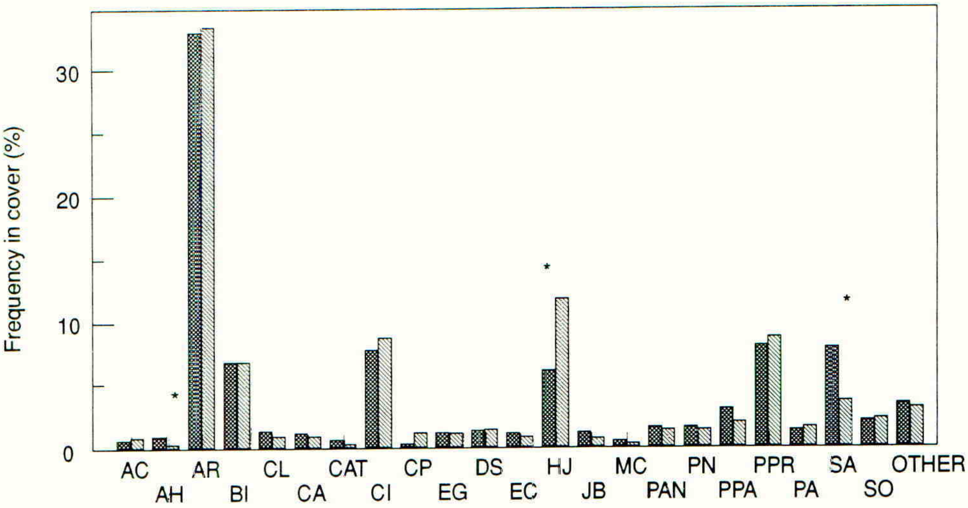


FIGURE 3. Wet Meadow/Shallow Marsh

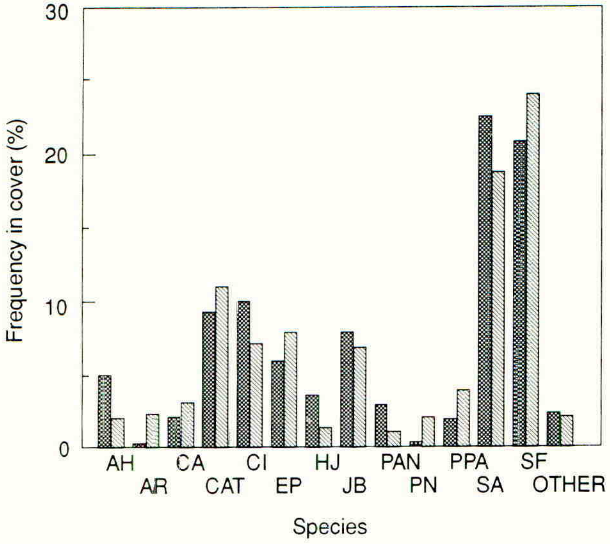
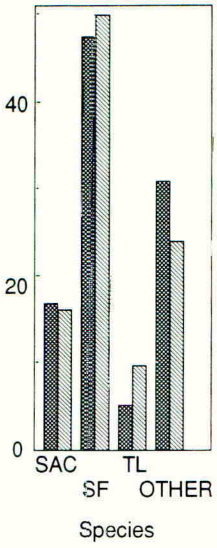


FIGURE 4. Emergent Deep Marsh

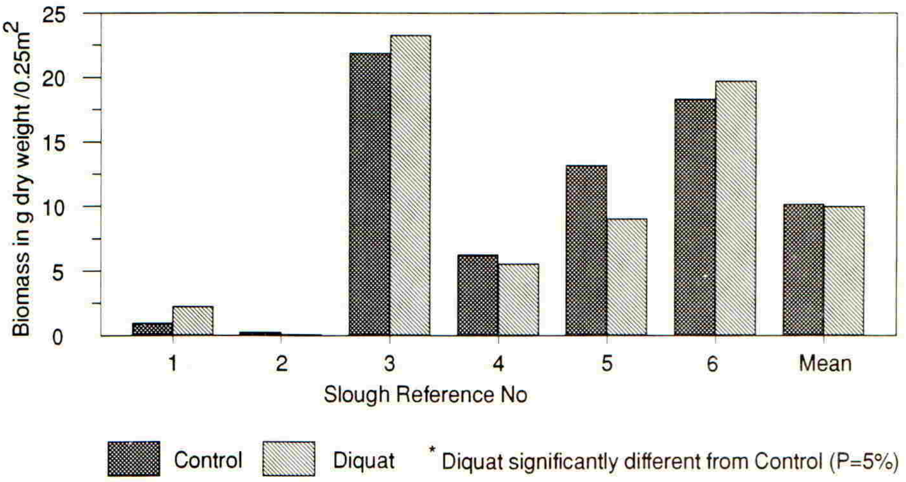


▩ Control ▨ Diquat

* Diquat significantly different from Control (P=5%)

c) *Myriophyllum exalbescens* was the dominant aquatic plant species in shallow open water. There were no significant treatment differences (P=5%) in biomass, expressed on a dry weight basis, (Fig 5).

FIGURE 5. Aquatic Plant Biomass



DISCUSSION

Throughout the world agricultural encroachment has put pressure on wildlife populations through modification of habitat. The prairie pothole region of North America is a classical example (Sheehan *et al.*,1987). Many wildlife are sustained by uncultivated field boundaries, areas too wet for cultivation and areas set-aside for conservation purposes. Desiccation is a technique to improve crop yield and quality by evening-up ripening eg. pulses and to make harvesting easier by killing tops eg. potatoes. High crop value encourages desiccation by aircraft. This however, has greater attendant risks of overspray and drift compared with ground spraying. This study has shown that the properties of diquat make it a very environmentally attractive herbicide for use in such environmentally sensitive areas particularly if aerial applications are necessary. The absence of any biologically significant effects on the following years growth of perennial plants is due to the low systemic activity of diquat, associated with fast herbicidal activity, and deactivation in soil.

CONCLUSIONS

Diquat is ideally suited for desiccation in environmentally sensitive areas, particularly where it is difficult to avoid spray-drift and overspray, because of its low impact on perennial plant community composition and structural cover the following season.

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BRIGHTON CROP PROTECTION CONFERENCE - Weeds - 1993

A STRATEGY FOR PROTECTING UK WATER QUALITY THROUGH A CONCERTED DIURON STEWARDSHIP PROGRAMME

A. B. DAVIES, J. NOBLE, R. JOICE, J.A. BANKS, R.L. JONES

Rhône-Poulenc Environmental Products, Fyfield Rd, Ongar,
Essex, CM5 0HW.

ABSTRACT.

Diuron is a widely used urea based residual herbicide which has been used increasingly following the loss of approval of the triazine herbicides for non-crop usage in the amenity. To meet the EC drinking water standard in the United Kingdom, a product stewardship programme has been undertaken. This involved modifying product use recommendations, education and training for users, improved lines of communication and research on diuron transport mechanisms. Properties, use and potential effect on water quality are outlined as a background to the main body of the stewardship programme. Diuron product placement is aimed at ensuring an established active ingredient is used with due care and attention to avoid undesirable effects.

INTRODUCTION

Developed in the 1950's, diuron is a widely used broad spectrum herbicide. It's primary use in Europe is control of weeds on industrial and amenity land, where total weed control is required for safety and economic reasons. The residual activity allows cost effective weed control without the need for repeated spray treatments. Diuron is also used in crop situations, primarily in orchards, vineyards, on asparagus and in certain ornamental crops.

To date, the amount of herbicides found in water sources have been limited and do not pose a health or ecological risk, however, the European Community require, as part of the Drinking Water Regulations, that no single pesticide exceeds 0.1 µg/litre in drinking water. To meet this standard water companies have invested in new treatment processes. Control at source has also been identified as having a major role to play.

Diuron is now the major residual herbicide in non-crop areas following the revocation of the triazine herbicides. The scale of use has increased significantly with a resultant risk of water contamination. The main potential problem areas were considered:

a) Use of high application rates
b) Direct introduction of product into drains and channels
c) Overall application on non-porous surfaces
d) Spraying during periods where the risk of run-off is high

To reduce the risks of contamination of water at source a diuron stewardship programme was initiated. This programme briefly involves:

1) Clarification of correct use
2) Education and training for users
3) Improving communication between bodies concerned with and potentially affected by diuron use
4) Further research on diuron transport mechanisms.

The properties and potential impact of diuron on water quality and the stewardship programme are described in this paper.

PROPERTIES OF DIURON

Diuron is a urea based residual herbicide. It is taken up by the roots of weeds and prevents the natural chlorophyll production essential for growth. To be effective it should, therefore, be applied before weed growth commences, or if used later in the season, in combination with a foliar acting product to control the vegetation already present. Diuron has a low mobility in soil due to strong adsorption by the soil colloids. It remains available in the upper soil layer controlling successive germination of weeds.

Microbial degradation is a major factor in the upper soil layer. Under Western European climatic conditions this results in a half-life of 1 - 1.5 months. The degradation process of diuron is concluded in the production of, CO_2, H_2O and N_2. (Hance and Holly (1990) have confirmed that the optimum time for diuron application is in the spring. Cool, moist conditions are favoured by this urea derived herbicide).

USES OF DIURON

Unwanted plant growth in amenity and industrial sites poses several difficulties. The Noxious Weed Act (1959) and the Wildlife and Countryside Act (1981) place legal requirements on managers to control specific plant species. Public safety can be put at risk by vegetation obscuring signs, hiding obstacles, reducing sight lines, creating fire hazards or causing trip points on non porous surfaces.

Although active ingredients may combine more than one mode of action, those like diuron, that are soil applied, are generally classed as residual herbicides. Activity may be maintained for at least two to three months after application. These active ingredients suppress seedling germination thereby slowing the re-colonisation of treated areas. This restricts the damage caused by growing plants and the need for costly repair to surfaces.

Diuron is widely used to keep industrial sites, such as oil refineries, road ways and industrial areas free of weeds.

IMPACT ON WATER

All pesticides have the potential to reach either ground or surface water. Pathways to surface water could include spray drift, runoff water, drainage water, direct introduction and point sources. Potential routes to ground water include movement through the soil profile, recharge of surface water and point sources.

For non-crop herbicides, three types of transport mechanisms appear to be the most important. Herbicides can be directly introduced into surface water by spraying into drains, ditches or streams or indirectly through spray drift. Water running along sprayed surfaces can carry herbicides into adjacent drains and ditches. This mechanism is especially important for herbicides sprayed directly on to non-porous surfaces (eg paving). Point sources can result in residues in either surface or ground water. Common point sources includes spills caused by accidents during transport and handling; improper storage practices; improper loading; mixing and washing practices; and incorrect disposal of surplus chemicals, tank washings or empty containers.

DIURON STEWARDSHIP PROGRAMME

The objective is to minimise the amount of herbicide reaching water sources. The diuron product stewardship programme was initiated in March 1992.

1) Clarifying correct use of diuron

The existing product use recommendations have been amended to stress the following ideas:

a) Avoid application to drains and channels

Restricting the incidence of the direct contamination of water with diuron was the obvious first step. Until recently, road sweeping units have been used to apply residual herbicides along kerb lines and over open drains.

b) Apply lower rates

Increased environmental awareness has modified customer expectation. Shorter periods of control are now acceptable, enabling rates to be reduced.

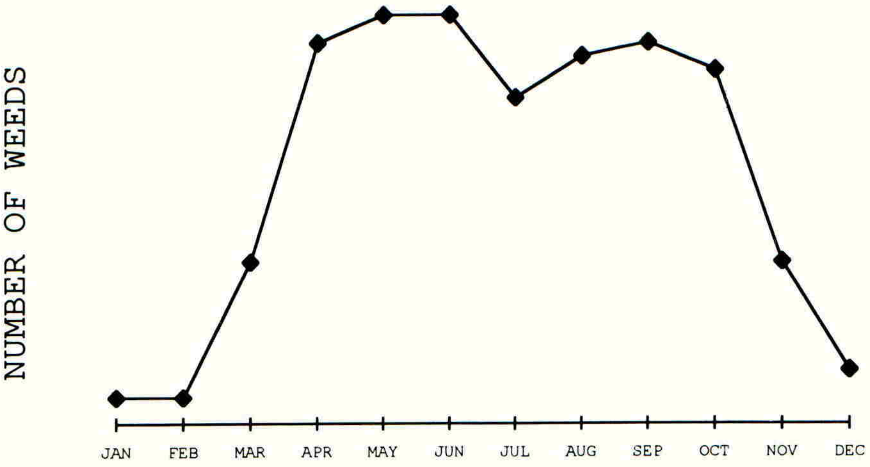
c) Spray only on areas of weed growth

Paved and tar macadam areas with kerb lines constitute the majority of the local authority weed control area. Weed growth occurs only in the joints and cracks where soil particles and other forms of detritus gather. Overall spraying with fixed booms has been common practice. Hand held directed spray to the site of weed growth is now recommended. This targeted approach ensures active ingredient is only sprayed where it is required.

d) Use at the optimum time for diuron activity

Spring application ties in well with the pattern of weed seedling emergence (Figure 1). Applying diuron either before weeds emerge or when they are at the establishment stage means lower levels of active ingredient are required to give effective control. Early application makes the most effective use of this active ingredient.

FIGURE 1. The seasonal pattern of weed seedling emergence. (Davies 1992)



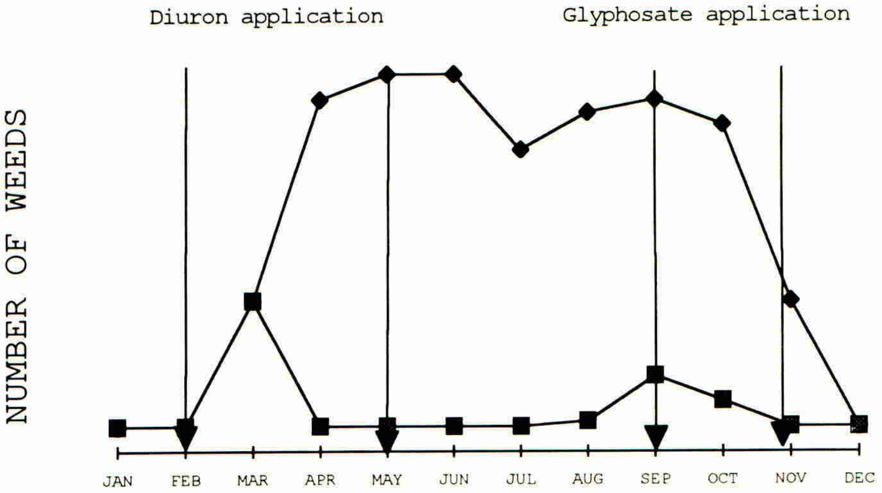
2 Education and training for users

Having clearly defined how diuron should be used, a major educational campaign was undertaken. The theme underlining the programme was:

Right Product
Right Place
Right Time

Emphasis was placed on the operators assessing the impact of their actions on the environment with particular reference to water sources. Selecting appropriate active ingredients for each site was of paramount importance. In excess of one hundred seminars were held throughout Britain in the spring of 1993, with over a thousand participants. Groups of up to twenty local authority weed control managers spent at least two hours in an interactive presentation based around a video. A summarising booklet (Davies 1993) detailed the strategy for protecting drinking water sources from contamination with herbicides (Figure 2). Care has been taken to ensure the recommendations for diuron product placement concur with both the Department of the Environment (1992) and Agricultural Development and Advisory Service (1992) publications.

FIGURE 2. The impact of an early season application of diuron (Freeway) and a late season treatment with glyphosate (Spasor) - ■ - on the pattern of weed seedling emergence - ◆ -. (Davies 1992)



3 Improving communication between bodies concerned with and potentially affected by diuron use

An integral part of the programme was to establish and develop liaison with all groups involved in the herbicides use. Discussions were held with water supply companies and contractors servicing large industrial users. As a starting point attempts were made to identify sensitive areas. Working procedures to protect the water sources were developed. In the case of groundwater, boreholes at risk from direct contamination were identified by water supply companies. Contamination of surface water sources was approached by eliminating the direct introduction of product into rivers, streams, drains and channels. This exercise will be analysed at the end of 1993 with all involved. The intention is to improve procedure and communication and widen the participation in the future.

4 Further research on diuron transport mechanisms

Refinement of the diuron stewardship in catchments has to be based on a clear understanding of which pathways pose the greater risks in this non-agricultural sector. The type of surface on which diuron is used will greatly affect the water contamination risk. This is a different situation to that seen for any agricultural pesticide usage, where products are used over large areas of relatively uniform soil type.

Factors which are important in the study of diuron in any area include an understanding by the operators involved, formulation type and combinations of products used. It is essential that the pathways between diuron application and possible water contamination can be identified and quantified to update the product use advice. To this end specific user catchment areas in England are being monitored for diuron usage and detection in water.

Organisations involved in application of diuron have been contacted in these areas. Details of their usage of the active ingredient during 1992 and 1993 are being established. Information on raw water samples will be provided by the appropriate Water Supply Company. Further detailed analysis of diuron users should, in the future, enable a link between the product usage and any contamination of raw water to be made.

CONCLUSION

The stewardship programme on diuron has been welcomed by end users and others as a valuable approach to the effective use of the herbicide. It is essential that commitment to education of the use of diuron for existing and new end-users is maintained. With appropriate pro-action strategies, in collaboration with water companies, the use of cost effective residual herbicides can be maintained whilst minimising the risk of water contamination at source.

ACKNOWLEDGEMENTS

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RESPONSE OF *CALAMAGROSTIS EPIGEJOS* AND *HOLCUS MOLLIS* TO GLYPHOSATE APPLIED AT DIFFERENT DATES AND TO PLANTS OF DIFFERENT AGES

J. LAWRIE

Department of Agricultural Sciences, University of Bristol, AFRC Institute of Arable Crops Research, Long Ashton Research Station, Bristol BS18 9AF, UK

D.V. CLAY

Avon Vegetation Research, PO Box 1033, Nailsea, Bristol BS19 2FH, UK

ABSTRACT

Glyphosate was sprayed on pot-grown *Calamagrostis epigejos* and *Holcus mollis* on seven dates from April to October. Applications in late June gave the best control of these two perennial grasses, with applications in early August allowing greater regeneration of *C. epigejos*. Establishment period of *C. epigejos* affected its response to glyphosate applied in April, with 12-month-old plants showing more tolerance to glyphosate than 6-month-old plants. However, the response of *H. mollis* to glyphosate was not affected by the time of plant establishment.

INTRODUCTION

Although glyphosate is recommended for perennial grass control (Williamson & Lane, 1989), variable results have been noted in a number of pot experiments (Turner *et al.*, 1980; Clay & Lawrie, 1990) and in the field (Oswald, 1976). Therefore, pot experiments were set up to assess the response of two forestry grass species, *Calamagrostis epigejos* (wood small-reed) and *Holcus mollis* (creeping soft-grass) to glyphosate applied on different dates to plants of different ages. The long-term effect of glyphosate on grass growth was also studied.

MATERIALS AND METHODS

Two pot experiments were established. In the first experiment, *C. epigejos* and *H. mollis* were prepared by dividing established plants and repotting in 15 cm diameter pots in the autumn before treatments in a loam-based compost as in previous work (Clay & Lawrie, 1988). Grasses in the second experiment were prepared by dividing established plants and repotting in 15 cm diameter pots as described above, 6 (October 89) and 12 (March 89) months before treatments were applied. The plants were kept outdoors on a gravel surface and watered using trickle irrigation lines as required.

Glyphosate ('Roundup', 360g a.e./l) was applied at the dates and doses shown in

Tables 1 to 4, using a laboratory track sprayer fitted with a 'Lurmark' 8001 flat fan nozzle at 210 kPa giving a spray volume of 105 l/ha (Expt. 1) or using three spray nozzles on a 1m boom to give 100 l/ha (Expt. 2). After treatment the grasses were kept under cover for 24 hours to protect from rain, then placed outside in their final location in four randomised blocks.

During both experiments damage was assessed visually at intervals. Foliage fresh weight was recorded in the year after treatment in Experiment 1 and in the summer of treatment and the year after in Experiment 2.

RESULTS

Experiment 1

Treatments with higher doses of glyphosate caused severe or complete dieback of the sprayed foliage within a month of treatment. However, plants regrew later in the season or in the following year (data not shown). Application of glyphosate, at 1.8 kg a.e./ha or less to *C. epigejos* on 3 August 1989 caused no significant reduction in plant weight (Table 1). However, glyphosate applied at 0.45 kg a.e./ha in late June or early October reduced *C. epigejos* growth by 44% and 46%, respectively, with further growth reductions at higher rates.

TABLE 1. Effect of glyphosate application date on *Calamagrostis epigejos* (Expt. 1).

	Total shoot fresh weight (g) 19 July 1990					
Application	Dose (kg a.e./ha)					
date	0	0.45	0.9	1.8	3.6	Mean
	84					
5 April 89		81	63	33**	0.2***	44***
3 May 89		73	26***	16***	26***	35***
31 May 89		84	64	31**	20***	50**
29 June 89		47*	30**	13***	0***	22***
3 Aug 89		116	82	63	5***	66
6 Sept 89		89	32**	13***	0.1***	33***
2 Oct 89		45*	30**	0***	0.4***	19***
SED	treated v treated 18.1					9.1
(df 88)	untreated v treated 15.7					11.1

*,**,*** Indicate values significantly lower than those of untreated at (P = 0.05, 0.01 or 0.001 respectively).

TABLE 2. Effect of glyphosate application date on *Holcus mollis* (Experiment 1).

Application date	Total shoot fresh weight (g) 19 July 1990 Dose (kg a.e./ha) 0	0.45	0.9	1.8	3.6	Mean
	42.7					
5 April 89		11.1 ***	11.5 ***	5.9 ***	16.7 ***	11.3 ***
3 May 89		43.7	31.7	16.9 **	0.1 ***	23.1 ***
31 May 89		24.2 *	38.8	9.2 ***	0 ***	18.1 ***
29 June 89		30.4	21.0 **	0.2 ***	1.8 ***	13.3 ***
3 Aug 89		37.4	40.5	32.6	3.4 ***	25.5 **
6 Sept 89		37.3	34.0	23.1 *	7.2 ***	25.4 **
2 Oct 89		32.0 *	45.2	9.3 ***	13.7 ***	25.0 **
SED	treated v treated 8.95					4.48
(df 88)	untreated v treated 7.75					5.48

*,**,*** Indicate values significantly lower than those of untreated at (P = 0.05, 0.01 or 0.001 respectively).

TABLE 3. Effect of glyphosate applied on 5 April 1990 to 6 and 12 month old *Calamagrostis epigejos* (Experiment 2).

Dose kg a.e./ha	Total shoot fresh weight (g) 20 July 1990 6 month	 20 July 1990 12 month	 14 June 1991 6 month	 14 June 1991 12 month
0	88.9	83.6	199	214
0.45	14.4 ***	89.7	125	228
0.9	7.6 ***	71.3	94 *	243
1.8	1.1 ***	40.9 ***	32 ***	246
3.6	0 ***	38.4 ***	0 ***	225
SED (df 27)	7.91		41.4	

*,*** Indicate values significantly lower than those of untreated at (P = 0.05 or 0.001 respectively).

TABLE 4. Effect of glyphosate applied on 5 April 1990 to 6 and 12 month old *Holcus mollis* (Experiment 2).

Dose	Total shoot fresh weight (g)			
	20 July 1990		14 June 1991	
kg a.e./ha	6 month	12 month	6 month	12 month
0	57.6	39.3	89.5	96.8
0.45	24.4 ***	18.9 **	79.3	90.8
0.9	0 ***	4.2 ***	0 **	84.0
1.8	4.8 ***	0 ***	49.7	3.0 **
3.6	0 ***	2.0 ***	50.0	1.7 **
SED (df 27)	6.70		27.36	

,* Indicate values significantly lower than those of untreated at (P = 0.01 or 0.001 respectively).

All doses applied to *H. mollis* in early April severely reduced regrowth (Table 2) with other application dates giving increased reduction in regrowth with increasing dose. At 1.8 kg a.e./ha, late June was the most effective application date, early August the least effective.

Experiment 2

The effect of glyphosate on 6-month-old *C. epigejos* was much greater than that on 12-month-old plants (Table 3), with 0.45 kg a.e./ha causing a 84% reduction in growth of 6-month-old plants and having no effect on 12-month-old plants 15 weeks after treatment (20 July 1990). Also 3.6 kg a.e./ha glyphosate completely stopped growth of 6-month-old plants and caused a 54% reduction in growth of 12-month-old plants in the year of treatment.

When plants were allowed to grow on for another year, 0.45 kg a.e./ha of glyphosate had no significant effect on 6 or 12-month-old plants but activity increased with increasing dose on 6-month-old plants, with 3.6 kg a.e./ha of glyphosate completely preventing regeneration. However, 12-month-old plants totally recovered even at the highest dose.

Glyphosate applied to *H. mollis* affected 6 and 12-month-old plants to similar extents. Glyphosate at 0.45 kg a.e./ha caused a 52 to 58% reduction in growth 15 weeks after treatment of 6 and 12-month-old plants (Table 4). In the year after treatment regrowth of 6-month-old plants was significantly reduced by 0.9 kg a.e./ha. Although higher doses caused large (44%) reductions in regrowth, these were not statistically significant. However, the regrowth of 12-month-old plants was suppressed significantly by doses of 1.8 kg a.e./ha and above (Table 4).

DISCUSSION

It would appear from our work that the ideal date to apply glyphosate to *C. epigejos* or *H. mollis* was late June or early July, as reported by Turner *et al.* (1980), rather than in early August. This was probably related to the development stage of the plant, with flowering, the rate of vegetative growth, the rhizome to green leaf ratio at the time of spraying all being important factors in relation to tolerance (Caseley & Coupland, 1985). Bishop and Field (1983), also found tolerance in *Lolium perenne* when glyphosate was applied during its early reproductive development stages. The increase in the number of potential 'sinks' associated with reproduction will probably dilute the concentration of glyphosate in the plant, reducing glyphosate activity (Caseley & Coupland, 1985). In addition, in early August, most of the flow of carbohydrates will be to the inflorescence which will act as the major 'sink' for glyphosate (Lund-Høie, 1980). Consequently little or no movement to the vegetative structures and roots will occur, thus reducing glyphosate activity.

C. epigejos was also more susceptible to an early October application than it was in August, whereas in *H. mollis*, there was no difference in response between these dates. This was also observed by Turner *et al.* (1980) and may be due to a physiological difference between the species, affecting translocation of the herbicides to the rhizome/root system. Alternatively, morphological features of the grasses at this time may be important. *C. epigejos* has long wide upright leaves with a large vegetative area exposed to the spray. *H. mollis*, on the other hand, has narrow leaves and, at this time, is dominated by senescing leaves and flowerheads.

The increased activity of glyphosate on *C. epigejos* from April applications in Experiment 1 may be related to the degree of plant establishment at spraying. This is supported by the results of Experiment 2 in which 12-month-old plants, which have a large ratio of rhizome to foliage area, were unaffected, whereas 6-month-old plants were killed by higher doses of glyphosate. Again the greater biomass of rhizome in older plants may well have diluted glyphosate more than in younger plants (Caseley & Coupland, 1985).

The results demonstrate the importance of continuing assessments of herbicide effects into the year after treatment because effects on subsequent regeneration of growth from rhizomes are important. With *H. mollis* plant age (establishment) appears to be less important than with *C. epigejos*. However, the variable results obtained at higher rates would seem to indicate potential problems of regeneration from rhizome fragments of *H. mollis* which had not produced foliage at the date of spraying. Therefore, future herbicide evaluation work should use only plants raised from single rhizome fragments of *H. mollis* (Clay & Lawrie, 1988). However, in the field, the rhizome system is frequently fragmented and this will be an important factor in determining the efficacy of control measures.

Williamson and Lane (1989), suggest that applications of glyphosate to grasses generally can be effective between June and September, but efficacy is likely to be reduced when leaf growth is reduced or affected by drought or senescence (Ivens,1993). However, it seems more likely that different species will be controlled most effectively by applications at different times in this broad period. Thus, while our work shows that *C. epigejos* and

H. mollis are most affected by treatment with glyphosate in late June, and Turner *et al.* (1980), showed this to be the best treatment time for the control of *Molinia caerulea*, these authors also showed that glyphosate gives better control of *Deschampsia caespitosa* when applied in September.

Clay and Lawrie (1988, 1990), have shown that adjuvants can be used to increase glyphosate toxicity and rainfastness in *H. mollis* and *C. epigejos*. This raises the possibility that adjuvants may be used to increase the time-span during which glyphosate will give effective control of perennial grass weeds.

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SELECTIVITY OF TRALKOXYDIM AND ITS POTENTIAL FOR USE IN CONSERVATION MANAGEMENT

L. CANNING, J. F. H. COLE

Zeneca Agrochemicals, Jealott's Hill Research Station, Bracknell, Berkshire, RG12 6EY.

N. D. BOATMAN

The Game Conservancy Trust, Fordingbridge, Hampshire, SP6 1EF.

ABSTRACT

The use of conservation headlands around cereal fields has been shown by the Game Conservancy to enhance wild plant populations, particularly those beneficial to wildlife. Farmers, while generally supportive of this practice, are concerned that in some instances these areas may form reservoirs for invasive grass weeds. Data on the graminicide tralkoxydim, in routine screening programmes and specific studies on non-target plant species, have therefore been used, in combination with the results of Game Conservancy field studies, to investigate the potential for this herbicide to be used in the selective control of unwanted grass species in cereal field headlands. A range of grass weeds including wild oat and blackgrass were effectively controlled, while thirteen important broad-leaved species from ten families such as knotgrass and mayweed and two graminaceous crop species were relatively unaffected. Tralkoxydim was therefore considered to be appropriate for use in cereal conservation headlands.

INTRODUCTION

There are a number of areas in modern farming in the U.K. that involve conservation management, e.g. in bordering areas of sites of special scientific interest (S.S.S.I.s), set-aside, mid-field ridges for beneficial arthropods and conservation headlands. It is the last of these that provides farmers with the opportunity to increase wild gamebird production, while maintaining standards of crop hygiene and yield. Conservation headlands potentially involve large areas immediately bordering and directly associated with crops, and are considered with regard to selective herbicide use in this paper.

The concept of conservation headlands has been developed from the work of the Cereals and Gamebirds Research Project primarily as a method of increasing survival of grey partridge and pheasant chicks. The term 'Conservation Headland' refers to a system of modified pesticide use over a 6m wide band of crop at the edge of cereal fields, whereby herbicide use is restricted to those with specific activity against species most damaging to crop production (Boatman, 1987 & 1989). This method allows the survival of the less damaging species typically found in cereal fields, along with their associated phytophagous invertebrate fauna. These species provide food sources for other faunal groups, including gamebirds (Potts, 1986) and predatory arthropods important in biological pest control (Sotherton, 1992). Butterflies and declining plant species also benefit.

The grey partridge (*Perdix perdix*) and pheasant (*Phasianus colchicus*) nest almost entirely in cereal field boundaries and after hatching the chicks move into the crop to feed on insects for the first two weeks (Potts, 1986; Rands, 1986 &1987). Increased herbicide usage over the past four decades has removed the favoured plants of these gamebird food insects, many of which are annual weed species reliant on disturbed habitats.

The problem with this practice as perceived by farmers is that if important invasive weed species are left uncontrolled in the headlands then adjacent crops will suffer extensive infestation as a consequence. Unacceptable grass weed species include black grass (*Alopecurus myosuroides*) and wild oat (*Avena fatua*) (Bond, 1987; Boatman & Wilson, 1988). These species are often more abundant at the edges of the field where gamebird chicks feed (Marshall, 1985). However, while it is necessary to control these species, it is desirable to minimise the effect on beneficial plant species as removal of these greatly decreases insect density in cereals and other crops (Boatman, 1987 & 1989). Herbicide use on Conservation Headlands should therefore be restricted to those compounds with specific activity against species most damaging to crop production, and which will leave the majority of the broad-leaved weeds in the headlands unaffected. Many herbicides commonly used to control *Avena* spp. are selective in action, but control of other grass weeds traditionally involves use of chemicals with broad spectrum activity (Boatman, 1987).

Data on the graminicide, tralkoxydim, from routine screening and specific studies on non-target plant species, have been used in combination with the results of Game Conservancy field studies, to devise a strategy for the selective control of unwanted grass species in field headlands.

MATERIALS AND METHODS

Tralkoxydim, formulated as 'GRASP' (a 25% SC), is a foliar applied, translocated herbicide for the selective control of wild oats and blackgrass in winter and spring cereals. It is currently registered in the U.K. for use at an application rate of 350g AI ha^{-1} (1.4 litres AI ha^{-1}). In recent years, tralkoxydim has been tested in a number of standard studies at Jealott's Hill Research Station, including primary and secondary herbicide glasshouse screens, and non-target plant regulatory glasshouse studies using similar methods. In addition, two types of field trial have been performed, i.e. initial screening trials and more detailed evaluation trials. As a result, a vast amount of data is available on a large number of plant species, at a number of application rates, using a range of different formulations. When considering conservation headlands, however, a large proportion of these data were irrelevant. Therefore, the data included in this paper were for:
(1) "unfavourable" (damaging to crop production) U.K. arable weed species, particularly grasses, and (2) "favourable" (arthropod host plants) UK arable weed species important in conservation headlands, for technical and formulated material at application rates as close as possible to the registered UK field rate. The data from primary and secondary screens between 1981-1992, from one non-target plant study carried out in 1990 and a number of field trials performed between 1990 and 1993 have been summarised.

The Game Conservancy have also carried out a number of studies on Tralkoxydim over the past years. These studies have been in the form of field trials performed in conservation headlands. Data from trials carried out in 1987 and 1993 have been summarised here.

The data from the glasshouse and field trials were compared with the data obtained from the Game Conservancy field trials.

Glasshouse studies

Screening studies

Primary screen studies were performed by applying tralkoxydim as the technical material to a range of plant species grown in 8cm pots in a low organic matter compost. The chemical was applied at 400 litres ha^{-1} using a hydraulic track-sprayer fitted with an even flat fan jet when the plants were at the 2-3 leaf stage. 3 replicates were included. The plants were then transferred to a glasshouse set to 24°C day/18°C night, 16h day length for 13 days. Assessments were carried out to determine percentage damage as compared to the control. Secondary screens were carried out using similar methods, however, the chemical was applied at an application volume of 200 litres ha^{-1}, the glasshouse conditions were slightly cooler (16°C day/12°C night), and the plants were assessed after a period of approximately 28 days.

Regulatory studies

Tralkoxydim in the 25% wettable grain formulation was tested on a range of plant species representing plant kingdom diversity and potential non-target plants using similar methods as outlined above.

Field trials

In screening trials, the chemical was applied using a three-nozzle, hand-held, pressurised boom-sprayer to rows of weeds and crops in three replicates of 2m wide plots, when the plants were between 2-3 leaves and 2-3 tiller stage. Percentage damage as compared to the controls was measured from 21 days after application.

Evaluation trials are designed to mimic a natural weed problem in a field situation. Three to four replicates of 2.5m wide by 5-10m long plots were used. An initial count of the plant population was carried out before chemical application. Application of tralkoxydim was made up to tillering (Zadoks 23) using a five-nozzle, hand-held, pressurised boom-sprayer. Assessments of percentage damage as compared to the control were carried out at approximately 14, 21 and 42 days after application. Later assessments were also carried out on some trials.

All work was carried out using the 25% Soluble Concentrate formulation with a surfactant added at 0.375-0.5% by volume for application rates of 200-350g ai ha^{-1}.

Game Conservancy field trial

In autumn 1987 three experiments were established in winter wheat headlands to study the potential for tralkoxydim to selectively control *A. myosuroides*. A randomised block design was employed with 4 replicates. The plots were situated between the field boundary and the first tramline and were up to 12m long and 4-6m wide. The herbicide was applied with a knapsack sprayer fitted with a 3m boom and 120° flat fan nozzles. Plants were counted in April/early May and broad-leaved weeds in May or early June. Ten quadrats of 0.25 or 0.1m^2 (depending on the intensity of the infestation) were assessed per plot. Grass seedheads were counted in late June/early July using 'floating' lathe quadrats (ten 1m^2 quadrats per plot). In May 1993 a similar study was established at a different site in a winter barley headland. The chemical was applied with an Oxford Precision sprayer at an application volume of 225 litres ha^{-1}, when the crop was at a growth stage of Zadoks 32 and the other species ranged from 100-250mm in height. Grass seedheads were counted in the same way, but percent damage was assessed by observing percent ground cover.

RESULTS

Glasshouse screens and field trials

High levels of control were achieved in the glasshouse for wild oats (*A. fatua*), blackgrass (*A. myosuroides*), loose silky-bent (*Apera spica-venti)*, barren brome (*Bromus sterilis*) and annual meadowgrass (*Poa annua*); see Table 1 for a summary of the glasshouse data. Data from field screening trials illustrated good control of wild oats (*A. fatua*), blackgrass (*A. myosuroides*), italian ryegrass (*Lolium multiflorum*) and canary grass (*Phalaris* spp.); the data from the field screening and evaluation trials are summarised in Table 2. Game Conservancy field trial data (summarised in Table 3) suggest only moderate control of wild oats (*A. fatua*), compared to the glasshouse and field screens (Tables 1 and 2), which indicate a high degree of susceptibility to tralkoxydim.

TABLE 1. Summary of % damage data, as compared to the control, from glasshouse studies on tralkoxydim (- = species not tested).

Species Tested	Family	% Damage		
		1	2	3
Unfavourable species				
Avena fatua	Gramineae	93	87(100)	100
Alopecurus myosuroides	Gramineae	84	99(95)	-
Elymus repens	Gramineae	20	40	-
Apera spica-venti	Gramineae	-	100	-
Bromus sterilis	Gramineae	-	98	-
Poa annua	Gramineae	-	98	-
Galium aparine	Rubiaceae	-	5	-
Favourable Species				
Triticum aestivum	Gramineae	41	22(1)	7
Polygonum aviculare	Polygonaceae	0	1	-
Chenopodium album	Chenopodiaceae	0	0	-
Beta vulgaris	Chenopodiaceae	0	1	0
Stellaria media	Caryophyllaceae	-	2	-
Brassica napus	Cruciferae	-	-	0
Sinapis alba	Cruciferae	-	-	11

1 = Primary screen results of technical material (plus adjuvant) at 200g AI ha^{-1}.

2 = Secondary screen results of technical material (plus adjuvant), averaged between 200-400g AI ha^{-1}, (25% commercial formulation in parentheses).

3 = Regulatory study results using 25% WG formulation at 350g AI ha^{-1}.

TABLE 2. Summary of % damage data from screening and evaluation field trials (- = species not tested).

Species	Family	Screening Trials 200-300g ai ha^{-1}		Evaluation Trials 230-350g ai ha^{-1}
		22-49 DAT	104-164 DAT	28-90 DAT
Unfavourable species				
Avena fatua	Gramineae	88	100	94
Alopecurus myosuroides	Gramineae	80	97	94
Bromus sterilis	Gramineae	0	-	-
Lolium multiflorum	Gramineae	81	-	98
Phalaris paradoxa	Gramineae	77	-	-
Phalaris canariensis	Gramineae	79	-	-
Galium aparine	Rubiaceae	3	0	-
Favourable species				
Triticum aestivum	Gramineae	1	0	0
Hordeum vulgare	Gramineae	2	0	0
Viola arvensis	Violaceae	2	-	0
Polygonum aviculare	Polygonaceae	10	-	-
Chenopodium album	Chenopodiaceae	0	-	-
Stellaria media	Caryophyllaceae	5	0	-
Tripleurospermum inodorum	Compositae	0	0	-

TABLE 3. Summary of Game Conservancy field trial results for tralkoxydim sprayed (as formulated product) on conservation headlands in winter cereal crops- data expressed as % control of plant species (- = data not collected).

Species	Family	1987 studies (means) 300g AI ha^{-1}		1993 study 350g AI ha^{-1}	
		Plant numbers	Seedhead numbers	Effect on cover	Seedhead numbers
Unfavourable species					
Avena fatua	Gramineae	-	-	65	58
Alopecurus myosuroides	Gramineae	98	94	95	97
Poa annua	Gramineae	28*	22	-	-
Poa trivialis	Gramineae	28*	89	50	48
Bromus sterilis	Gramineae	0	0	-	-
Galium aparine	Rubiaceae	0	-	0	-
Favourable species					
Triticum aestivum	Gramineae	-	-	0	-
Hordeum vulgare	Gramineae	-	-	0	-
Brassica napus	Cruciferae	0	-	0	-
Tripleurospermum inodorum	Compositae	0	-	7	-
Matricaria matricarioides	Compositae	0	-	21	-
Myosotis arvensis	Boraginaceae	0	-	13	-
Stellaria media	Caryophyllaceae	0	-	0	-
Geranium dissectum	Geraniaceae	0	-	0	-
Veronica spp.	Scrophulariaceae	0	-	-	-
Anagallis arvensis	Primulaceae	0	-	-	-

* assessed as *Poa* spp.

DISCUSSION

There are a number of pernicious grass weed species such as black grass (*A. myosuroides*) and wild oats (*A. fatua*) which are so damaging to crop production that they must be controlled. However, while it is necessary to control these species in conservation headlands, it is desirable to minimise the effects on those beneficial plant species including knotgrass (*P. aviculare*), common chickweed (*S. media*), mayweeds (*Matricaria* spp.), fat hen (*C. album*) and charlock (*S. arvensis*), as removal of these species greatly decreases insect density in cereals and other crops. For these reasons it is necessary to develop a herbicide that is selective in its action, i.e. controlling important grass weeds while leaving those beneficial broad-leaved species unaffected.

These data clearly show that tralkoxydim is very effective in the field for the control of a range of unfavourable grass weed species likely to be a problem in conservation headlands including, blackgrass (*A. myosuroides*), canary grass (*Phalaris* spp.) and italian ryegrass (*L. multiflorum*). The Game Conservancy field data (Table 3) suggested only moderate control of wild oats (*A. fatua*), but this species has been shown to be extremely susceptible to tralkoxydim in glasshouse and field screens (Tables 1 and 2). Tralkoxydim tested in the glasshouse, was found to be very active on loose silky bent (*A. spica-venti)* and have some control on couch grass (*E. repens*), though no field data is available for these species. Tralkoxydim is in general, however, particularly active under glasshouse conditions when compared with the field. This accounts for the apparent discrepancy between the glasshouse results for barren brome (*B. sterilis*) and *Poa* spp. in Table 1 where good control is indicated, and the field data in Table 2 where it is not; these species are usually highly tolerant to tralkoxydim in the field.

Thirteen broad-leaved weed species were tested from ten families, and little or no effect was observed in the glasshouse or the field on all of these species including the most favourable; knotgrass (*P. aviculare*), chickweed (*S. media*), speedwells (*Veronica* spp.), field forget-me-not (*M. arvensis*), scarlet pimpernel (*A. arvensis*), cut-leaved cranesbill (*G. dissectum*) and field pansy (*V. arvensis*). Tralkoxydim had little or no effect on fat hen (*C. album*) and sugarbeet (*B. vulgaris*) from the family Chenopodiaceae, scentless mayweed (*T. inodorum*) and rayless mayweed (*M. matricarioides*) from the Compositae, and oilseed rape (*B. napus*) and white mustard (*S. alba*) from the Cruciferae.

Tralkoxydim is therefore appropriate for use in Conservation Headlands, where the ability to selectively remove grass weeds is important. It can be applied over a wide range of growth stages, and can be used in wheat and barley. Such flexibility is important if farmers are to be able to achieve conservation aims in conjunction with profitable crop production in a modern arable system.

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WEED CONTROL FOR NATIVE GRASS ESTABLISHMENT

H. LOEPPKY

Agriculture Canada, Research Station, Melfort, Saskatchewan, Canada,
S0E 1A0

P. CURRY

Ducks Unlimited Canada, Box 2139, Melfort, Saskatchewan, Canada, S0E
1A0

D. KRATCHMER

Saskatchewan Wheat Pool, Agricultural Research And Development Farm,
Box 670, Watrous, Saskatchewan, Canada, S0K 4T0

ABSTRACT

Cultivation of marginal lands has led to serious soil management and erosion problems. Re-establishing native grasslands on these fragile soils provides soil protection and restoration, multispecies wildlife habitat, and improves the hydrological cycle. Native grasses, however, are generally characterized by poor germination and slow establishment, and hence do not compete well with weeds. Experiments carried out in Saskatchewan, Canada have demonstrated that 4 major species of native prairie grasses [northern wheatgrass (*Elymus lanceolatus*), western wheatgrass (*Pascopyrum smithii*), slender wheatgrass (*Elymus trachycaulus*), and green needlegrass (*Stipa viridula*)] showed acceptable tolerance to the selective graminicide tralkoxydim, while it provided good control of the main invasive and exotic grasses (wild oats and green foxtail). Fenoxaprop would be a suitable alternative for grass mixtures not containing slender wheatgrass, while imazamethabenz would be suitable for all four species in areas where green foxtail was uncommon. These herbicides show potential as management tools in re-establishing native grasslands.

INTRODUCTION

Native grasslands provide an important habitat for the protection and maintenance of wildlife. Grassed uplands, in association with wetland complexes, also play an important role in improving soil water recharge for semiarid regions (Adams *et al.*, 1992). Portions of the original Canadian Prairie grassland have been cultivated which are now deemed as marginal lands. Continued cultivation of these marginal lands for annual crop production has led to serious soil management and erosion problems in many instances. The restoration of marginal lands to native grasslands is a primary objective of various wildlife organizations involved in managing waterfowl habitat throughout North America under the auspices of the North American Waterfowl Management Plan (NAWMP). Previous reclamation or revegetation efforts, however, have emphasized the establishment of readily available, vigorous exotic grasses on specific sites rather than the establishment of persistent, biologically diverse native plant communities (Call and Roundy, 1991). Little information is available on the use of native plant material for this purpose (Smreciu and Currah, 1986). While several studies have demonstrated the use of idle stands of tame grasses by upland nesting ducks (Duebbert and Kantrud, 1974; Duebbert and Lokemoen, 1976; Livezey, 1981; Kantrud, 1993), nesting in stands containing established native grasses has also been shown to provide quality multi-species wildlife habitat, soil protection and restoration, and improve the hydrological cycle of a specific area (Klett et al. 1984). These benefits are all consistent with long term environmental sustainability objectives as a diverse native grassland, once re-established is a self perpetuating ecosystem requiring no further inputs.

Re-establishing native grasslands on previously cropped lands involves certain difficulties. Native grasses are generally characterized by variable germination, specific moisture requirements for germination and establishment and slow establishment compared to other cultivated crops (Fulbright *et al.*, 1984; Frasier *et al.*, 1987; Ries and Svejcar, 1991). As a result, they do not compete well with weeds (Duebbert *et al.*, 1981). Discriminate use of herbicides during the establishment year of native grassland may be of benefit. However, there are no herbicides registered for use in native grass establishment in Canada and there is very little data available on the sensitivity of these grasses to graminicides in particular.

Research is currently being conducted near Melfort and Watrous, Saskatchewan, Canada, to determine the seedling tolerance of northern wheatgrass, western wheatgrass, slender wheatgrass, and green needlegrass to several graminicides including tralkoxydim, imazamethabenz and fenoxaprop alone and with broadleaved weed killers. Preliminary results from ongoing trials aimed at developing weed control options for native grass establishment are reported here.

MATERIAL AND METHODS

Two field experiments were conducted at Pleasantdale (1991) and Watrous (1992) in northeastern Saskatchewan to evaluate native grass tolerance to graminicides. Northern wheatgrass cv. Critana and Elbee, western wheatgrass cv. Rodan and Walsh and slender wheatgrass cv. Revenue were tested at both sites. Green needlegrass cv. Lodorm was tested only at Pleasantdale. The grasses were sown in late May. Herbicides were applied in 110 l/ha total spray volume when the grasses were in the 2-3 leaf stage. A push type CO_2 pressurized sprayer equipped with Teejet 8001 flat fan nozzles was used with 275 kPA and 207 kPA pressure at Pleasantdale and Watrous, respectively. A split block design was used with herbicide treatments within crop blocks. Herbicides varied slightly between sites (Tables 1 & 2). At Pleasantdale 2, 0.25 m^2 quadrats were harvested August 21, 1991, and the crop and weed material was separated and dried. At Watrous, the grasses were harvested July 17, 1992 and the fresh weights were recorded. Data were analyzed using SAS. The least significant difference (LSD) and Duncan's Multiple Range Test (DMR) at the %5 level were used to establish differences between means.

RESULTS AND DISCUSSION

TABLE 1. Effect of herbicide treatment on forage dry matter yield of native grasses and grass control at Pleasantdale, 1991.

Herbicides		Northern wheatgrass		Western wheatgrass		Slender wheatgrass	Green needlegrass	Weed control	
Treatment	Rate kg a.i. ha^{-1}	Critana	Elbee	Rodan	Walsh	Revenue	Lodorm	Wild oats	Green foxtail
		Forage dry weight (g/m^2)						% control	
Check, weedy		12	10	10	9	37	16	0	0
Check, weeded		30	40	45	31	127	44	100	100
Diclofop	0.7	7	14	22	26	75	28	100	100
Diclofop	1.4	19	17	22	31	68	21	100	100
Difenzoquat	0.7	13	6	13	16	30	12	98	7.5
Difenzoquat	1.4	7	10	12	9	16	8	100	45
Imazamethabenz -methyl + acidulate	0.4 + 0.292	22	24	33	27	146	29	100	36
Imazamethabenz -methyl + acidulate	0.8 + 0.584	23	13	23	25	77	27	99	38
Tralkoxydim + TF8035	0.25 + 0.5%	25	14	37	13	84	17	100	100
Tralkoxydim + TF8035	0.50 + 0.5%	16	16	23	21	70	19	100	100
Fenoxaprop-p-ethyl	0.088	16	14	23	20	45	18	100	100
Fenoxaprop-p-ethyl	0.176	22	15	23	18	36	9	100	100
Fenoxaprop/ MCPA/ thifensulfuron	0.088 + 0.420 + 0.015	62	75	83	46	143	62	99	100
Fenoxaprop/ MCPA/ thifensulfuron	0.176 + 0.840 + 0.030	55	65	55	57	174	47	100	100
	C.V.	59	78	66	52	83	67	8.8	1.9
	LSD (5%)	20	27	29	18	97	24	8.3	2.4

Weed control

The Pleasantdale test was conducted on marginal land, where Ducks Unlimited was establishing nesting cover (Table 1). In addition to wild oats and green foxtail, broadleaved weeds, particularly wild mustard (*Sinapis arvensis*) and Canada thistle (*Cirsium arvense*) were present throughout the test area. Fenoxaprop/MCPA/thifensulfuron was the only herbicide that controlled broadleaved weeds. As a result, forage yield was affected in all plots except those that were treated with this broad spectrum herbicide. While there were significant differences between treatments, and grass species in some cases, there were no significant species x treatment interactions. Green foxtail dry matter yield was significantly higher in the western wheatgrass plots relative to the other native grasses (15 g/m^2 vs 9 g/m^2). Wild oats and green foxtail, the predominant grassy weeds, were generally controlled by all herbicides with the exception that difenzoquat and imazamethabenz did not adequately control green foxtail. The Watrous test area was kept free of weeds (Table 2).

TABLE 2. Effect of herbicide treatment on forage yield of native grasses at Watrous, 1992.

Herbicides						
	Rate	Northern wheatgrass		Western wheatgrass		Slender wheatgrass
Treatment	(kg a.i. ha^{-1})	Critana	Elbee	Rodan	Walsh	Revenue
Check, weeded		178	171	197	157	587 A
Imazamethabenz-methyl + acidulate	0.4 + 0.292	224	180	213	155	552 A
Imazamethabenz-methyl + acidulate	0.8 + 0.584	175	170	163	155	573 A
Tralkoxydim + TF8035	0.2 + 0.5%	218	144	150	122	575 A
Tralkoxydim + TF8035	0.4 + 0.5%	234	168	143	135	524 AB
Fenoxaprop/ MCPA/ thifensulfuron	0.088 + 0.420 + 0.015	220	153	166	136	368 A
Fenoxaprop/ MCPA/ thifensulfuron	0.176 + 0.840 + 0.030	188	159	161	153	392 A
	C.V.	20	23	26	22	17
		NSF	NSF	NSF	NSF	DMR (5%)

Grass tolerance

Grass tolerance was assessed using two criterion; firstly whether yield was reduced relative to a weeded check and secondly whether yield was lower with the higher rate of herbicide relative to the lower herbicide rates (Tables 1 & 2). Using these criterion, in a weed free situation, the wheatgrasses were all generally quite tolerant to the herbicides tested although there was one exception. While there were differences between treatments and species, there were no treatment x species interactions.

Slender wheatgrass seemed to be particularly sensitive to fenoxaprop/MCPA/thifensulfuron under weed free conditions. Enhanced weed control appears to have compensated for herbicide injury under weedy conditions since yield was not reduced. Imazamethabenz and tralkoxydim show potential for grassy weed control in slender wheatgrass.

Although northern wheatgrass yield in herbicide treated plots was not significantly different from the check, it tended to be lower at the higher rate of imazamethabenz and fenoxaprop, while it was higher at the higher rate of tralkoxydim relative to the low rate. This may indicate a greater tolerance to tralkoxydim than to the other graminicides.

Rodan western wheatgrass seemed more sensitive to tralkoxydim and the fenoxaprop mix than Walsh, in that yield decreased with an increase in herbicide rate in Rodan while the opposite occurred with Walsh. Imazamethabenz application resulted in good forage yield but the higher rate of herbicide resulted in the poorest yield in both Rodan and Walsh.

Green needlegrass exhibited some sensitivity to the herbicides tested but forage yield was higher than the weeded check when fenoxaprop was applied with MCPA and thifensulfuron.

CONCLUSIONS

Although the native grasses showed some sensitivity to the graminicides tested, forage yields were generally acceptable in a weed free situation. Native grasses are frequently established on marginal lands where weeds are abundant and cultivation should be avoided. Under these conditions, forage yield was significantly increased with a single application of a broad spectrum herbicide. Herbicide application during the establishment year of Altai wild ryegrass (*Leymus angustus*) improved establishment, resulted in increased individual cuts for 1-3 years and also increased the cumulative forage dry matter yields significantly (Malik, 1991). Although mowing or burning may be used as an alternative once the grass is established, discriminate herbicide use in the establishment year can greatly improve the vigor of the stand and have long term benefit.

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CONTROL OF *LANTANA CAMARA* IN THE KRUGER NATIONAL PARK, SOUTH AFRICA, AND SUBSEQUENT VEGETATION DYNAMICS

D.J. ERASMUS

Plant Protection Research Institute, Agricultural Research Council, Private Bag X134, Pretoria 0001, Republic of South Africa

K.A.R. MAGGS, H.C. BIGGS, D.A. ZELLER

National Parks Board, Private Bag X402, Skukuza 1350, Republic of South Africa

R.S. BELL

SA Cyanamid (Pty) Ltd, P O Box 58, Isando 1600, Republic of South Africa

ABSTRACT

Lantana camara (lantana) has invaded large areas of South Africa including conservation areas. Field trials initiated three years ago (1990) to control lantana on the Sabie River in Kruger National Park show that: (a) although chemical and manual control were comparably effective for initial control, chemical control was less costly; (b) one incident of off-target imazapyr phytotoxicity occurred; (c) both methods of follow-up control were effective with chemical control being less costly; (d) rapid establishment of indigenous species occurred after lantana control resulting in increased species diversity and wildlife carrying capacity.

INTRODUCTION

Lantana (*Lantana camara* L., Family Verbenaceae) is rated as one of the ten worst weeds in the world (Holm *et al.*, 1977). The species originates from South America and was introduced to South Africa as different cultivars since 1858 (Stirton, 1983). It is now one of the prominent alien invasive plants in southern Africa. Lantana is an invader of commercial forestry plantations, rights-of-way, pastoral areas and indigenous vegetation (Cilliers, 1983). In addition to displacing desired vegetation at least some cultivars are known to be toxic to livestock (Wells & Stirton, 1988).

Although it has been shown that biological control agents introduced to South Africa reduce lantana growth (Cilliers, 1983), the impact on populations has been minimal (Julien, 1987). While manual control of lantana is effective, it is labour intensive and considered to be comparatively expensive. Six herbicide treatments are currently registered in South Africa (Vermeulen *et al.,* 1991) but reservations are often expressed concerning their potential negative effects if used in conservation areas.

The earliest record of lantana in the Kruger National Park (KNP) is an herbarium specimen collected by van der Schÿff in 1952. In 1958 a resolution was passed by National Parks Board in which lantana, amongst others, was declared undesirable in the KNP and combat actions were initiated in 1959 (Annual Report of the Nature Conservation Division, Kruger National Park, Skukuza). Notwithstanding the combat actions launched, lantana is currently one of the three top priority alien invasive plants in the KNP. Due to the costs being incurred with the control of lantana, an investigation was initiated in the KNP with the following objectives: (a) compare the efficacy and cost of chemical control with that of manual uprooting; (b) determine the extent of off-target phytotoxicity of imazapyr on indigenous species; (c) ascertain the cost of subsequent follow-up control using either glyphosate or hand-pulling; and (d) determine the effect of lantana control on the indigenous flora dynamics. In this paper a broad overview is presented of the results obtained thus far in the investigation.

PROCEDURE

A heavily lantana-infested section of the Sabie River was selected for the investigation. Soil pits and a vegetation survey confirmed that the study area was generally uniform with an almost continuous cover of 2 - 3 m-tall lantana. The study area was divided into four blocks of at least 5000 m^2 each. For the vegetation monitoring procedure, fixed belt transects were situated in each of the four blocks. The belt transects which covered approximately 10% of each block, were divided into contiguous 3 x 3 m quadrats for sampling of shrubs. Of this a 1.5 x 1.5 m subquadrat was sampled for herbaceous and grass species. The transect quadrats were sampled for species, species frequency and species abundance before initiation of the lantana control actions (T_0) and again one (T_1) and three (T_2) years later. For the grasses, aerial and basal cover (using the point method) was recorded while for prostrate creepers only aerial cover was recorded.

Two blocks were left untreated (untreated controls). In a third block initial control of lantana consisted of cutting the plants near ground level to expose the base of plants which were then manually uprooted using mattocks (manual control). Subsequent control of reinfesting plants (follow-up control) was effected either by hand-pulling (seedlings) or by means of mattocks (coppiced plants). Lantana in the fourth block was cut near ground level and the freshly cut surfaces of stems on the stumps treated with imazapyr (2 g AI/ℓ in water; 100 g AI, Chopper®) applied at low pressure by hand-sprayers (chemical control). In this block, follow-up control was effected by spot-spray application of 2% glyphosate (180 g a.e./ℓ, Sting®) to seedlings and coppiced plants.

The cost of the two control methods was compared by recording the labour and herbicide inputs in a work-study type procedure. Also, the number of plants treated in the initial and follow-up control was recorded. The efficacy of the two methods was established by recording the mortality of plants in the transect. In addition, 200 lantana stumps tagged for the phytotoxicity investigation in the chemical control block were also assessed. In both the treatment blocks, mortality was further assessed during follow-up treatment.

The possible phytotoxic effect of imazapyr on non-target species was assessed by tagging indigenous seedlings and saplings up to 1 m tall in areas of highest lantana density. The height and stem diameter of these were recorded at time of herbicide treatment and again one year later. Plants were examined for signs of phytotoxicity and their growth compared to that of seedlings and saplings in the manual control block.

RESULTS AND DISCUSSION

Efficacy and cost of control

Both manual and chemical control proved to be extremely effective for the control of lantana. With both methods >95% control was achieved. Similarly, follow-up control by either method was effective.

Initial control by manual means required 25.0 man days/ha compared to 18.7 for initial chemical control (Table 1), a saving of 25%. Taking into account the number of individual plants treated, almost double the number of plants were treated in the same time with chemical control compared to manual control (Table 1). The volume of imazapyr applied was equivalent to 0.44 l/ha the price of which is markedly lower than the saving made on labour input. Initial control by chemical means was therefore less costly than mechanical control. The labour input for chemical control in this investigation was lower than that recorded by Erasmus & Clayton (1992), probably due to the different habit of the target plants. The majority of lantana plants in the study area were mature plants and although the aerial cover was high, the actual density was lower in comparison to the study area used by Erasmus & Clayton.

TABLE 1. Labour used for initial and follow-up control of lantana and the number of lantana plants controlled per man day.

	Initial control		Follow-up control	
Control method	Man days per ha	Plants per man day	Man days per ha	Plants per man day
Manual	25.0	60	6.8	345
Chemical	18.7	108	2.1	712

Follow-up control using glyphosate was also cheaper than manual uprooting of the plants. With manual control, the equivalent of 6.8 man days/ha was required while only 2.1 man days/ha was used for chemical control (Table 1), a saving of 32%. In the same time, more than double the number of plants could be treated by chemical control versus manual control (Table 1). The volume of glyphosate product applied was 0.6 l/ha the cost of which is again markedly lower than the saving made on labour input.

Off-target phytotoxicity of imazapyr

Due to imazapyr being non-selective and comparatively persistent in the soil, its effect on non-target species was also investigated. Only one incident of phytotoxicity was noted in the 300 plants tagged for the investigation. One *Grewia flavescens* Juss. seedling died but this was probably due to the ensuing drought rather than the effect of the herbicide. It was concluded that the off-target phytotoxicity of the imazapyr in this investigation was inconsequential. It is the opinion of the authors that the impact of manual uprooting of the lantana was by contrast, severe. Due to the comparatively high density of the lantana in the study area, major disturbance was necessitated in the uprooting actions and this effect, although transient, was less desirable than the application of imazapyr. The target specific application of imazapyr to only the cut surface of stumps therefore offsets its non-selectivity and worrisome persistence in the soil.

Species biodiversity and implications

Although care was taken to select a study site with visually homogenous vegetation and random positioning of treatment blocks, analyses of biodiversity using the Shannon Index (Magurran, 1988) shows that at T_0 there were differences in the species diversity in the four blocks. The difference was significant (p=0.0357) for the woody component but not the herbaceous component.

The changes in the biodiversity, as measured with the Shannon Index, of the treated and untreated blocks over time are shown in Figure 1. In the untreated and manual control blocks (Figure 1a and b), no major change in biodiversity occurred. However, in the block where chemical control was implemented, a marked increase in biodiversity was been recorded (Figure 1c). Analysis of the data for T_2 using the T_0 biodiversity data as the covariate in two-way ANOVA shows that there was a significant (p=0.09) increase in biodiversity over time (Figure 2). Multiple comparisons indicate that the chemically treated block has a higher biodiversity than the mechanically treated or untreated blocks. The lack of difference

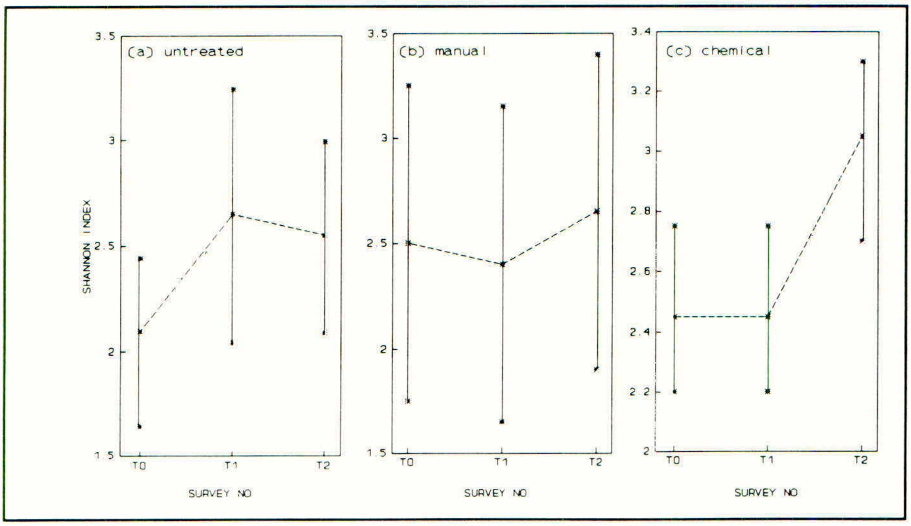

Figure 1 Biodiversity as measured by the Shannon Index for (a) untreated, (b) manual control and (c) chemical control blocks at T_0, T_1 and T_2 after initial control (vertical bars represent 95% confidence limits)

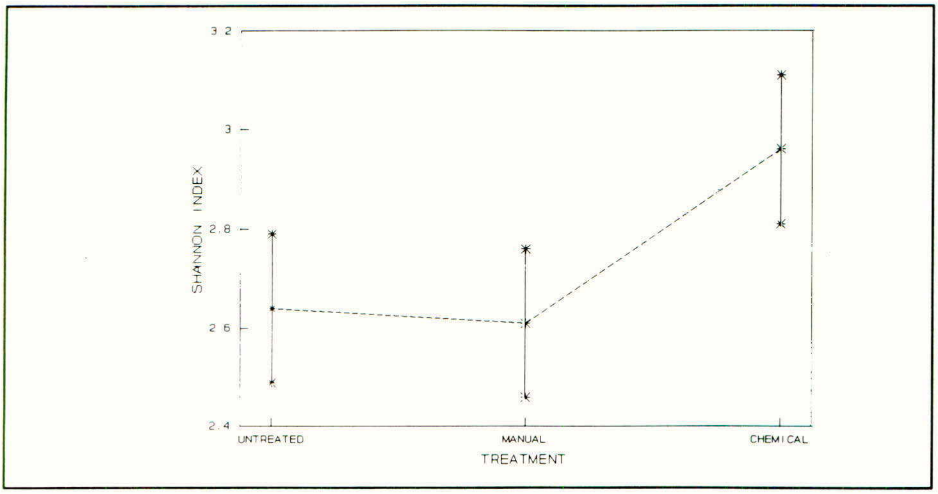

Figure 2 Biodiversity, as measured by the Shannon Index, three years after initial control of lantana (vertical bars represent 90% confidence limits)

between the mechanically controlled block and the untreated blocks may be due to the short-term effect of disturbance on especially the woody vegetation component.

Another notable change is that of the grass component. The basal cover increased appreciably over time in the two blocks where lantana was controlled (Table 2). Grass aerial cover one and three years after initial control of lantana was markedly higher in both the manual and chemical control blocks than that in the untreated block (Table 2). This was confirmed by the dry mass of the standing crop at T_1 and T_2 (Table 2). Although a valid comparison between T_1 and T_2 is not possible, the cover at each time is legitimate assuming that grazing in the study area was random. The grass standing crop data show that the carrying capacity of the blocks where lantana had been controlled was markedly higher than that of the untreated blocks even though it is probable that grazing pressure is likely to have been higher in the more accessible lantana-controlled blocks.

TABLE 2. Percentage basal and aerial grass cover and dry mass of the standing crop of grass at the initiation of the investigation (T_0) and one year (T_1) and three years (T_2) later.

Control	Basal cover (%)			Aerial cover (%)			Dry mass (kg/ha)	
method	T_0	T_1	T_2	T_0	T_1	T_2	T_1	T_2
Manual	1.3	2.6	3.9	16	28	42	230	1056
Chemical	1.2	3.0	3.3	16	36	32	650	654
Untreated	0.7	1.0	1.0	8	9	13	125	468

CONCLUSIONS

The control of lantana in conservation areas by either manual or mechanical means is warranted on the basis of increased biodiversity and increased wildlife carrying capacity at least in the short-term. Not only was it found that control by chemical means was less costly than manual control but the disturbance caused by the latter had at least a transient negative effect on subsequent vegetation biodiversity. Target specific application of imazapyr in an ecologically sensitive area had no adverse effect on the non-target plant species. It is planned to monitor in detail the effects of the control measures and the removal of lantana for at least a further two years.

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CURRENT AND FUTURE PRACTICES AND PROBLEMS IN WEED CONTROL IN LOCAL AUTHORITY, INDUSTRIAL AND AMENITY PLANTINGS.

A. J. GREENFIELD

ADAS Oxford, Marston Road, New Marston, Oxford, OX3 0TR

ABSTRACT

Herbicides have been used for decades on roads, grass verges, amenity areas and hard surfaces. Atrazine and simazine regularly occurred as contaminants of drinking water, and as a result of this and public pressure to reduce the use of pesticides, they are no longer available for this purpose. Contractors now use alternative residual herbicides which could also become contaminants of water as a result of their persistence and mobility. Users have also begun to use more non persistent foliar herbicides, or residuals requiring lower rates of AI. This may require a different strategy, with repeat treatments to obtain the same result without damage to desirable trees and plants.

This paper discusses the current practices and problems encountered, the herbicides available, and the strategies necessary to make the best use of them. Some solutions are suggested to help overcome the difficulties faced by users.

INTRODUCTION

Herbicides have been used for several decades to achieve weed control in many non-cropped areas such as roads, roadside verges, amenity areas, and in industrial areas covered with hard surfaces. Weed control was generally successfully achieved using long lasting residual herbicides that were both cheap and very effective against a wide weed spectrum. Often high doses were used in order to lengthen the period of weed control to cover the whole season. Given such widespread use at high doses, often on to non-absorbtive hard surfaces, it is not surprising that the most widely used chemicals have become common environmental pollutants.

The triazine herbicides atrazine and simazine, the two most commonly used, have been regularly detected by the major UK water supply companies as contaminants of drinking water. Thames Water and Severn Trent Water, two of the largest companies covering both urban and industrial areas, both of whom extract water from ground sources rather than surface, have both had major problems, with a significant number of the samples that they are obliged to take to monitor water purity being contaminated with these and other herbicides. As a result, they are having to spend millions of pounds installing treatment equipment to remove these chemicals from drinking water.

TABLE 1. Herbicide usage 1990. Active ingredient classified by chemical group.

Chemical group	%
Triazines	39
Phenoxy compounds	21
Urea compounds	13
Heterocyclic nitrogen compounds	10
Inorganics	5
Benzoic acids etc.	4
Other herbicides	7
Growth regulators	1

Legislation

Pesticide legislation

There is an increasing amount of both national and EC legislation covering the use of pesticides and also the results of their use. All pesticide use in the UK is covered by the Control of Pesticide Regulations, 1986, (COPR), made under the Food and Environment Protection Act, 1985, (FEPA). Under these regulations all pesticides must be approved by the Pesticide Safety Directorate (PSD) to ensure that all uses to which chemicals are put are safe to the operator, the consumer ,and to the environment. Should there be any evidence which raises doubts about the safety of any aspect of use, approval may be withdrawn by PSD, and some or all uses forbidden. By law, pesticides must be used strictly in accordance with the product label instructions which are a statement of the conditions under which approval has been granted.

The Control of Substances Hazardous to Health Regulations 1988, (COSHH), similarly lay down that all work must be planned in such a way as to minimise the risks to workers and the public. Safe practices must be instituted for the transport, storage, handling , application and disposal of all pesticides, and staff must know how to deal with any emergencies that arise. Several Codes of Practice have been published giving guidance to users of pesticides and these should be followed by all using chemicals for weed control.(Health and Safety Executive / Health and Safety Commission, 1991; Ministry of Agriculture, Fisheries and Food / Health and Safety Commission, 1990; National Turfgrass Council / National Association of Agricultural Contractors, 1991). Guidance notes are also available dealing specifically with weed control on non-agricultural land and environmental protection, (Dept. of the Environment, 1992).

Water legislation

The EC Drinking Water Directive has set a maximum permitted concentration of any pesticide in drinking water of 0.1 microgrammes per litre (µg/l), and a total pesticide concentration of 0.5 µg/l. These limits have been incorporated by the UK Government into the Water Supply (Water Quality) Regulations 1989. Under the Water Resources Act 1991 there are general duties to avoid pollution of water. Pesticides which are highly toxic or persistent and classed as List 1 substances under the EC Groundwater Directive (80/68/EEC) may not be disposed of directly or indirectly to groundwater.

As a result of the contamination by herbicides that has already occurred in many areas, a review of the uses of the two herbicides atrazine and simazine was carried out by PSD in 1991. Following this review, action was taken to revoke the approvals for use of both herbicides in non-agricultural situations from September 1993. From this date such users have had to make use of alternative methods and chemicals to achieve the required degree of weed and vegetation control. Some of these alternative herbicides have already begun to appear in drinking water at levels above the maximum set by the EC Directive. If such contamination becomes commonplace it is possible that further action will be taken by government to remove more herbicides from the list of those permitted in this situation.

PRESENT PRACTICE

Even before the legislation revoking the use of atrazine and simazine had taken effect, users of herbicides in non-agricultural situations had begun to move to alternative chemicals, or non-chemical methods. Often such moves were made without considering the changes of strategy necessary to make these chemicals or methods work successfully, and as a result satisfaction has not always been achieved.

Non-chemical methods

Opportunities for non-chemical weed control are rather limited and seldom the chosen option unless there are other good reasons for doing so. Nevertheless some operations carried out by local authorities, for example road sweeping, have a great effect on weed growth and reduce the need for herbicides. Mechanical cultivation is not possible on most non-cropped or hard surfaced areas, but is often used in amenity plantings. Various forms of mulching with natural organic materials such as wood, bark chips or straw can also be successful, and where the visual impact allows, gravel, stone and plastic sheeting all reduce the need for chemical control. The cost of such methods must be compared with chemicals, however, as all operations must be cost effective.

Other non-chemical methods of weed control such as infra red heat, high pressure water jets or high voltage electric current are technically possible but are not at present economically or practically feasible. Some interest in such methods does exist, however, and it is possible that in future they may become used as pressure to reduce herbicide use increases.

Chemical weed control

Public and Government concern, and the revocation of the approvals for use of atrazine and simazine in non-cropped areas has led to changes of the chemicals themselves and the ways in which they are used. Some local authorities have stopped using residual herbicides completely with varying degrees of success. In many cases the operations managers of authorities are highways engineers with little basic knowledge of the modes of action of herbicides, resulting in inappropriate use of chemicals or incorrect timing and subsequent failure of the programme.

Residual herbicides

A number of residual herbicides remain available for use in the situations where atrazine was previously the most likely choice. In the UK, bromacil, diuron, dichlobenil propyzamide and imazapyr are the four from which the choice is usually made, with diuron and imazapyr being the most common alternatives. With the exception of dichlobenil which is available only as a granule, these herbicides are spray formulations. Granules have some advantages for application on certain surfaces, but are of limited use on many of the hard surfaces where atrazine was previously used. Of these herbicides, diuron propyzamide and dichlobenil only can be used in amenity plantings of trees and shrubs; both bromacil and imazapyr are root absorbed and cause damage to plants.

Other soil acting residual herbicides which are approved for use in these situations include tebuthiuron, picloram and sodium chlorate. These have useful properties in certain situations but are seldom used in practice, other chemicals having advantages such as lower solubility and greater selectivity, and thus less likelihood of damage to desirable plants or leaching to water.

Foliar acting herbicides

This group of herbicides can be separated into two main categories, those that control both broad leaved and grass weeds, and those that are effective only against broad leaved weeds. Most of the herbicides are translocated, moving within the plant and capable of a total kill, but paraquat, diquat and glufosinate-ammonium are not translocated.

The most commonly used herbicide in this group is glyphosate. This chemical has become the basis of many weed control programmes as a result of its wide weed spectrum, lack of soil activity, quick breakdown and lack of toxicity. Glufosinate-ammonium has similar advantages, but paraquat and diquat are not often used as a result of their toxicity

For broad leaved weed control in grass several selective herbicides are approved. From the phenoxy acid group, 2,4-D and mecoprop are commonly used, along with other active ingredients such as dicamba and triclopyr.

Future possibilities

There is at present some manufacturers' interest in herbicides that could partly replace the use that was made of atrazine prior to September 1993. Registration authorities will be taking great care in future, however, to ensure that there is minimum risk to the environment and especially water, and it seems likely that only chemicals that are immobile as a result of insolubility and strong adsorbance properties are likely to be approved. Isoxaben is a compound which has some of these desirable characteristics and has recently been granted approval for amenity plantings of trees and shrubs.

COMMONLY USED PROGRAMMES

Hard surfaces

In spite of the fairly wide range of herbicides available with approval for use in the non-crop situations, there are in practice only a small number of programmes that are commonly chosen for application to hard surfaces. Mostly these consist of a mix of both foliar acting and residual herbicides, though in some cases the users have taken the decision to cease use of residuals totally and use only foliar herbicides. Glyphosate is commonly used in nearly all programmes, most often with the residual herbicide diuron, often as a tank mix, or as separate applications. Imazapyr is increasingly used, often in programmes with glyphosate or diuron.

Soft surfaces

Amenity grass

Most areas of amenity grass are not treated with herbicides as standard practice, mowing controlling most unwanted species sufficiently for general purposes. Where high quality turf is of paramount importance, eg. golf greens or bowling greens, and some sports grounds, broad leaved weeds can and are removed by the use of selective herbicide mixtures, eg. 2,4-D, mecoprop and dicamba.or the recently approved fluroxypyr. Occasional use of these mixtures on lower quality turf may be necessary if weed growth becomes a problem and threatens the grass.

On rough grass areas such as roadside verges, no herbicides are generally used. Diversity of plant species is now a very important factor in choice of programme, such areas often having importance for conservation purposes. Mowing in the period between the spring and summer flowering of wild plants is usually the chosen option on such areas, this treatment having the less effect on species diversity than chemical treatments.

Occasionally, particularly where access to the site for mowing presents difficulties due to traffic movement plant growth regulators such as maleic hydrazide are used. This is not common practice, however, as discolouration of grass is sometimes noted after use of this type of chemical.

Amenity plantings

Simazine was often used in the past for weed control in tree and shrub plantings but as from September 1993 this use in amenity plantings has not been legal and alternatives have been required. With the exception of simazine which is specifically restricted from such uses, all herbicides with a manufacturer's recommendation for use in hardy ornamental nursery stock can legally be used in amenity plantings. Where the manufacturer does not make a specific recommendation for amenity situations, however, any such use is entirely at the user's risk.

In most cases residual herbicides are not used in amenity plantings, with the exception of dichlobenil which is sometimes used in highly valued areas where visual impact is of paramount importance and weed growth can not be accepted. More commonly weed growth is kept under control by use of mulches of wood or bark chips supplemented with spot treatments of glyphosate to remove large perennial weeds as soon as they appear.

PROBLEMS IDENTIFIED

The changes that have been forced on weed control operations as a result of the loss of atrazine and simazine from the armoury has raised several practical problems for the users. This may be a related to the chemical alternatives themselves, or the need for changes to the strategies utilised by managers. Much greater care is needed in contract management, whether weed control is carried out by direct labour organisations, or by outside contractor; increases in cost of operations must be kept to a minimum without compromising success of the programme, and damage to desirable amenity plantings must also be avoided

Changes of strategy required

In the past, managers of weed control programmes in these non-crop situations were able to specify one treatment at the beginning of the year which would successfully control weeds for the remainder of the season. With the removal of atrazine, managers and specifiers have had to make major changes to programmes and the way the herbicides are used. Unfortunately not all managers are aware of this need for change, or if they are aware, they are not always technically capable of making the appropriate correct decisions.

The change from atrazine to alternative residual herbicides, usually at lower doses than were used in the past, or to foliar acting, non residual herbicides, requires that managers draw up specifications in much greater detail than before. A single application of herbicide early in the season may not be appropriate any more for most situations, particularly where foliar active herbicides alone are to be used. Managers must be made aware that applications of glyphosate must not be made prior to the presence of weeds, as such treatments do not control germination as did the residual herbicides. They will also need to repeat treatments through the year if they are to retain weed freedom and satisfy the public that the presence of dying weeds is to their long term advantage.

To obtain the best from such foliar herbicides it is necessary to understand the seasonal growth pattern of most weed species. In spring there is a period of fast weed growth following germination of annual species or the onset of growth of perennial species. During the summer growth is slower, but the rate increases again in autumn. For best effect the first application of the foliar herbicide should be applied after the first flush of growth, but whilst the weeds are still susceptible. Subsequent treatment should take place only when weed growth warrants action, and not according to a previously set time interval. In this way maximum effect can be obtained with minimum chemical use, as few applications as possible, and hence the least cost.

Cost increases

One of the major advantages of atrazine programmes was their removal of weeds before they were visible to the public and very low chemical and labour costs. Programme managers now often criticise the alternative chemicals for their costliness. This, however, takes little account of the cost of chemical being only a small part of the total. Some contractors have suggested that chemicals account for only ten to fifteen percent of the total cost, the remainder being labour, overheads and other associated expenses. The need for repeat treatments does increase the total cost considerably as well as the risk of spraying in inappropriate conditions.These risks and costs must be reduced as far as possible by managers.

One way such cost savings can be achieved, assuming some degree of weed control is essential, is by careful prioritization of needs, and performance specifications being drawn up which allow differing levels of weed growth in different areas. Managers must be persuaded to ask themselves if they really do need total control or if a degree of low level weed infestation is acceptable. In many cases it is probable that lower levels of control would be acceptable, thereby reducing the labour input and greatly reducing the cost of the contract. No longer can weed control programme managers simply request complete control over all the areas for which they have responsibility.

Herbicide damage

One result of the changes that have been made by specifiers, managers and contractors has been an increase in the number of cases of damage that have been brought to the attention of consultants in the field. Atrazine was safe to trees and shrubs in roadside plantings once they were established, provided doses were kept to that required for maintenance of weed control. The move that has already been made by contractors and managers to alternative chemicals has increased the risk of uptake of herbicide and in a few cases, total death of some trees and considerable growth reduction of others has been noted. It has not been possible to discover with certainty which herbicides have caused the problem, but circumstantial evidence has suggested either glyphosate or imazapyr to be the culprit, both having been used in the programme in question.

This problem has arisen over the last two years following the change from an atrazine programme to alternative treatments containing both glyphosate and imazapyr. Both chemicals may have been used without the necessary degree of care detailed on the product labels. Glyphosate labels all warn of the damage that can occur if contact is made with growing plants, or in the case of trees, epicornic shoots arising from the base of the trunk. The labels of imazapyr products warn that they must not be used in areas under which the roots of desirable plants may extend. This in practice excludes it from most if not all roadside areas. Before changes are made to programmes and alternative herbicides are chosen it is therefore vital to check that the uses to which the herbicides are to be put do not compromise the safety of the programme as a whole, nor contravene the safety instructions and restrictions on the label. There is little point in avoiding water pollution if other environmental damage is caused by the alternative treatments.

Contract management and monitoring

Having taken the decisions about which herbicides are to be used and at what times, it is imperative that managers ensure that their decisions are carried out according to their wishes. In order to do this it is necessary for the contractor carrying out the work to be carefully regulated and monitored. Situations have occurred in the past where contractors have not followed the specifications laid down by the client, but have for example increased doses of chemical to ensure the success of the operation and avoid the possible need to return and repeat treatment. Managers must therefore ensure that the records demanded by the various Codes of Practice are kept and can be inspected by themselves or their contract managers. These requirements should always be written into contracts, and contractors themselves should be made aware of the importance of following the specification. Inspection of both the spraying operation and the success or failure of weed control following spraying should also be carried out regularly, with amendments made to programmes as and when required.

Where managers are not qualified to advise on herbicides or draw up specifications, the task must be given to a suitably qualified employee, or to an outside contractor or consultant who is BASIS (Registration) Ltd. Similarly managers must ensure that all spray operators are appropriately certificated to National Proficiency Test Council (NPTC) standards and are aware of the need for them to protect the environment in which we all live.

STEPS TO BE TAKEN BY WEED CONTROL MANAGERS

i) Define the standards: is total weed freedom really necessary?

ii) Establish the need: are herbicides the best or only option in the situation?

iii) Compare the alternative herbicides: can non-persistent herbicides replace residuals; will spot treatments suffice?

iv) Assess the risk to operators and the public: has a COSHH assessment been carried out?

v) Assess the risk to water and the environment

vi) Check legal obligations and liabilities: is work carried out to the standards laid down in the Codes of Practice and are operators properly certificated?

Only when all these questions have been addressed and satisfactory answers obtained, should work commence.

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CONSERVING BRITAIN'S CORNFIELD FLOWERS.

P.J. WILSON

Farmland Ecology Unit, The Game Conservancy Trust,
Fordingbridge, Hampshire, SP6 1EF

ABSTRACT

Recent developments in arable farming have led to the decline of many species of cornfield flower, but relatively little is known about their ecology or about how to conserve them in our arable landscapes.

Existing conservation measures include legally protected Sites of Special Scientific Interest, voluntary agreements with conservation bodies and the practice of Conservation Headlands. In the future, positive conservation may be extended to larger areas of the countryside through the various Set-aside Schemes and extensions to the Countryside Stewardship programme.

The aims of "The Wildflower Project" are to investigate the decline of traditional cornfield flowers and to formulate scientifically-based conservation methods. Initial results suggest that omission of nitrogen and herbicides are essential in areas in which cornfield flowers are to be conserved.

INTRODUCTION

Recent decades have seen great developments in arable farming. The horse has been replaced by the tractor, the hoe by the herbicide, highly nitrogen-responsive crop varieties have been developed and crop rotations have changed. As a result of these and other changes, yields have increased dramatically and crop production is no longer the precarious business that it was in the past.

At the same time, we have seen the decline of many species of plant once widespread in arable crops. Between 1986 and 1987 a survey carried out by the Botanical Society of the British Isles and the Nature Conservancy Council (now English Nature) (Smith, 1986), showed that several species such as *Arnoseris minima* and *Caucalis platycarpos* had become extinct, and that many others including some which were once regarded as problems to the farmer had become extremely rare (Table 1). Species such as *Ranunculus arvensis* and *Centaurea cyanus* have declined faster than any other species in the British flora.

Declines similar to those in Britain have also been observed in Europe. In Germany the conservation of cornfield flowers is regarded as a priority, and programmes involving the omission of herbicide and nitrogen from field margins have been set-up by several states (Schumacher, 1987). Despite their threatened status, the conservation of these species has until now received relatively little attention in Britain.

Table 1. The status of some uncommon cornfield flowers in Britain in terms of the number of 10km squares in which they have been recorded (Perring & Walters, 1976; Smith, pers comm). Figures exclude casual records.

	1930-1960	1986-1990
Adonis annua	36	12
Agrostemma githago	150	0
Bupleurum rotundifolium	17	0
Centaurea cyanus	264	3
Galeopsis angustifolia	238	18
Galium tricornutum	77	2
Myosurus minimus	59	16
Ranunculus arvensis	432	22
Scandix pecten-veneris	426	20
Torilis arvensis	136	10

CORNFIELD FLOWER CONSERVATION IN PRACTICE IN BRITAIN.

1. Legal protection

English Nature is concerned with the management of Sites of Special Scientific Interest (SSSIs) for plants of disturbed land. The species involved have however been mostly those of naturally disturbed or occasionally cultivated land rather than that which is regularly cropped. Schedule 8 of the Wildlife and Countryside Act (1981) lists 10 species which receive legal protection, although only two of these, *Filago pyramidata* and *Lythrum hyssopifolia* may still be found in arable land.

Currently four arable field SSSIs are managed by farmers under the guidance of English Nature. Only one of these, in Kent, can be regarded as typical arable land and consists of two small fields which have been managed for eight years with no agrochemical inputs, the farmer being compensated for lost income. This site has flourishing populations of a number of uncommon species including *F. pyramidata*, but is experiencing serious problems from a build-up of perennial weed species.

Another SSSI in the ownership of the Somerset Wildlife Trust has what may be the richest arable flora remaining in Britain with populations of *Torilis arvensis*, *Valerianella rimosa* and *R. arvensis*. It is intended that this will be managed in the future as a working arable unit but without agrochemical inputs. Informal agreements exist with landowners at several other sites.

2. Initiatives taken by other conservation bodies.

The National Trust has the largest land-holding of any voluntary conservation organisation in Britain. Much of its land is arable. At five Cornish properties it is considering the possibilities of managing its land for the conservation of cornfield flowers.

Interest has been shown by several County Wildlife Trusts in cornfield flower conservation. Apart from the Somerset reserve described above, most initiatives have so far been on an informal basis with individual farmers. An interesting project is in progress in Buckinghamshire where the local trust and Castle Cement Ltd grow traditional cereal crops containing populations of cornfield flowers. These have been largely grown from seed originating from topsoil stored during chalk extraction work. The main role of this site is educational.

The Game Conservancy Trust has been at the forefront of research into farmland ecology and conservation. The "Wildflower Project" described below is being carried out in association with the Farmland Ecology Unit. The Conservation Headland technique developed for gamebird management in arable fields (Sotherton, 1990) has been used by farmers for several years. Although this mainly involves the manipulation of herbicide use in otherwise conventionally farmed field headlands, it has undoubtedly had a beneficial effect on populations of uncommon cornfield flowers.

3. Countrywide schemes.

There is considerable potential for conservation in a rotational set-aside scheme. Under this scheme fields are left uncultivated and unsown after harvest, the vegetation being allowed to develop naturally. Under such conditions of low competitive pressure, cornfield flowers would be expected to perform well. In 1992/93, the first year of this scheme however, farmers were required either to plough their set-aside land after 1st May, or to cut the vegetation in June. Both of these practices are inimical to the continued persistence of annual plant species. It is likely that they will be requirements of the scheme to be introduced in 1993, although there is the probability of allowing a derogation for the conservation of cornfield flowers (MAFF, in press).

The Countryside Commission's Countryside Stewardship Scheme has concentrated mainly on the management and reconstruction of established habitats (Countryside Commission, 1993). It does however recommend the use of Conservation Headlands where Countryside Stewardship land abuts arable land, and there are possibilites for extending the scheme to arable field headlands where there is an existing floristic interest.

Environmentally Sensitive Areas have been declared by MAFF in 22 places in England. In four of these areas, payments are on offer to farmers who use Conservation Headlands. Payments are also available to farmers in Breckland who leave strips uncropped around their fields specifically for the rare arable flora of this region (N. Critchley, pers comm).

THE "WILDFLOWER PROJECT"

A scientific basis is essential for effective conservation, but until recently, little was known about the ecology of the rarer species. Following the observation of uncommon species in Conservation Headlands, a project was set up in 1987 to investigate the biology of some of these, concentrating on features relevant to their conservation. Some of the results are summarised below (Wilson, 1990)

1. Germination periodicity, and performance in relation to crops sown at different times.

As a result of the inherent germination periodicity of different species of cornfield flower (Roberts, 1964), crops sown on different dates can support very different weed communities, even when the seed-bank is known to be the same. Differences are greatest between autumn- and spring-sown crops, but can also be large between early and late autumn sowings or early and late spring sowings (Table 2). It is possible that changes in crop rotations and sowing times have affected species which have very narrow germination periods.

Table 2. Date of cultivation and crop sowing for maximum plant number and seed production.

	29 Sept	14 Oct	3 Nov	20 Nov	17 Feb	10 Mar	28 Mar
Petroselinum segetum	+	+					
Torilis arvensis		+	+				
Scandix pecten-veneris		+	+				
Ranunculus arvensis		+	+				
Buglossoides arvensis		+	+				
Valerianella rimosa		+	+	+			
Adonis annua			+	+			
Papaver hybridum				+			
Chrysanthemum segetum						+	+
Silene noctiflora						+	+
Misopates orontium							+

2. Herbicide sensitivity.

Many uncommon cornfield flowers are susceptible to a wide range of herbicides. Species such as *Chrysanthemum segetum* and *Buglossoides arvensis* are however resistant to many compounds, and even *Scandix pecten-veneris* is only susceptible to a few. Use of herbicides is thought to have been a major factor in the decline of many species. Restriction of their use is essential in areas in which cornfield flowers are to be conserved.

3. Competitive ability in relation to crops at different levels of nitrogen application

Levels of nitrogen applied to highly competitive modern crop varieties have increased by up to 900% between 1943 and 1988 (Chalmers et al, 1990). Most of the species which have decreased most rapidly are relatively slow-growing annuals which might be expected to compete poorly with a fully fertilised crop. In experiments, fertilised crops were found to suppress the growth of many weeds almost as effectively as herbicides (Table 3). It is likely that the increase in use of nitrogen has had a large role in the decline of many species.

Table 3. Number of plants per m2 present at harvest time in plots of cereals to which nitrogen was applied at three levels. + = statistically significant at P<5%, - = not significant.

	Quantity of nitrogen (Kg/ha)			
	0	75	150	
Papaver hybridum	1.2	0.6	0.06	+
Silene noctiflora	2.3	2.0	1.2	+
Chrysanthemum segetum	1.2	0.9	0.6	-
Misopates orontium	0.9	0.02	0	+
Papaver argemone	0.7	0.3	0.2	+
Filago pyramidata	3.2	0.9	0.3	+
Arnoseris minima	0.2	0	0	+
Myosurus minima	0.3	0	0	+
Scandix pecten-veneris	1.8	1.1	0.8	-
Ranunculus arvensis	3.0	1.8	1.6	+
Buglossoides arvensis	2.0	1.3	2.2	-
Valerianella rimosa	3.0	1.7	0.6	+

4. Distribution of seed-banks within fields.

The greatest diversity of cornfield flowers is usually found within 4m of the field edge. This may result from lower intensity farming operations at the field margin and resulting poorer crop performance and lower competitive pressure. In most cases, conservation efforts will be best aimed at crop edges. The large-scale removal of field boundaries in recent years may have been detrimental to populations of cornfield flowers.

Phase I of this project identified several potential reasons for the decline of some cornfield flowers, but did not study the effects of these factors on naturally occurring communities of plants, the use of these factors in conservation management, or their effects on crop yield and quality. A second phase was initiated in 1992 with the aim of testing options for the conservation management of cornfield flowers within the context of modern farming. Initial results from experiments set up in the headlands of winter and spring cereal crops between October and March 1992 and 1993 suggest that omission of both nitrogen and broad-leaved herbicides results in the greatest floristic diversity (Table 4).

Table 4. Mean numbers of species of cornfield flower per 2.5m^2 in plots of winter wheat and barley grown under three regimes on three farms in Norfolk, Suffolk and Hampshire.

	Farm			
	1	2	3	mean
Full nitrogen and herbicide	8.3	3.3	14.0	8.6
Full nitrogen, no herbicide	22.3	16.7	20.3	19.8
No nitrogen, no herbicide	24.3	19.0	25.7	23.0

CONCLUSIONS.

There is increasing interest in conserving Britain's cornfield flowers. MAFF and The Countryside Commission have launched initiatives which show considerable potential, and English Nature, County Wildlife Trusts and the National Trust are all involved in conservation at individual sites.

With the current work being conducted by the "Wildflower Project", it is hoped that future conservation management will be precisely directed and will become more acceptable to farmers and government agencies. It is however essential that conservation is freed from transitory market regulatory mechanisms such as Set-aside, and becomes estasblished in more permanent schemes such Countryside Stewardship, SSSI agreements and specifically managed reserves.

ACKNOWLEDGEMENTS

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CONCEPTS FOR "DESIGNER HERBICIDES "IN AMENITY USE

R HAQ, J.M.PERKINS

DowElanco Europe, Letcombe Regis, Wantage, Oxfordshire, OX12 9JT

ABSTRACT

Traditionally herbicides have been developed primarily for agrochemical use with little attention being paid to their potential environmental impact when used in the amenity market. Amenity use has recently been implicated in some catchment areas as the source of herbicide residues in drinking water.

Building upon the ideal characteristics required for a herbicide, this paper considers the use of short-term early stage studies in designing compounds whose range of application includes amenity use. The areas covered are computer modelling (based on physico-chemical data and persistence), photolysis, hydrolysis and mobility studies.

The data generated are used to produce environmental profiles which,in conjunction with ecotoxicological data, can define compounds with the potential for safe amenity use. With these favourable properties in combination with low use rates and appropriate formulation technology; products can be designed to have minimal impact on the aqueous environment and meet the current regulatory requirements.

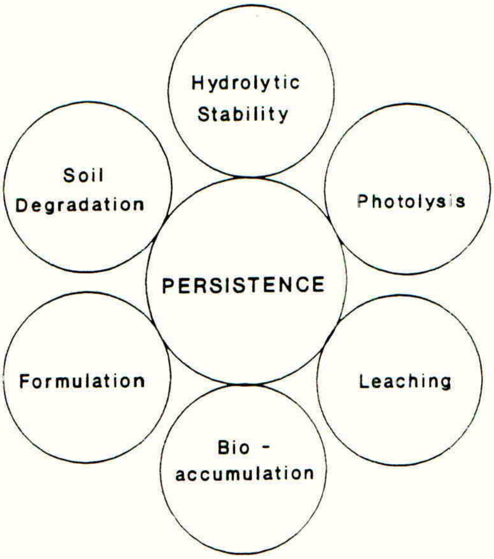
INTRODUCTION

One of the major amenity uses of herbicides is to control vegetation on roads, pathways and land adjacent to railways, power lines and industrial installations. Ensuring that the legal obligations for them to be maintained in a safe manner is met. The application of herbicides is a more effective and efficient method of weed maintenance than conventional non-chemical methods. However this specific use has been implicated as the source of residue of some herbicides (e.g. atrazine and simazine) in the drinking water from certain catchment areas, particularly within the Thames area. The recent withdrawal of these compounds from this segment of the market has resulted in the search for replacement herbicides. Water companies have expressed concerns that this replacement procedure may result in the problem simply reoccurring with a different compound.

In order to reduce the likelihood of this happening it is essential to understand the factors (Figure 1) that control the environmental fate of these compounds in this amenity context.

A major difference from agrochemical usuage is the specific application to `hard surfaces' or surfaces that have minimal soil content. The absence of soil reduces the chance for absorption so increasing the rate of transportation of the molecule to the aquatic environment. More importantly, it reduces the opportunity for microbial action to act as a major route of degradation. In certain situations this effect is compounded by inherent drainage systems (railway embankments, motorways) which enhances the probability of transport of the compound into the aquatic environment.

FIGURE 1. Major parameters governing the fate of an amenity herbicide.



DESIGN CRITERIA

Once a candidate molecule has successfully fullfilled the conventional early efficacy and toxicological screening,its environmental fate can be estimated using the of the physico-chemical parameters of the molecule. eg melting point, boiling point, octanol-water partition coefficient and vapour pressure. Insertion of these values into a series of empirical equations (Briggs, 1990) will give a prediction of the environmental behaviour.

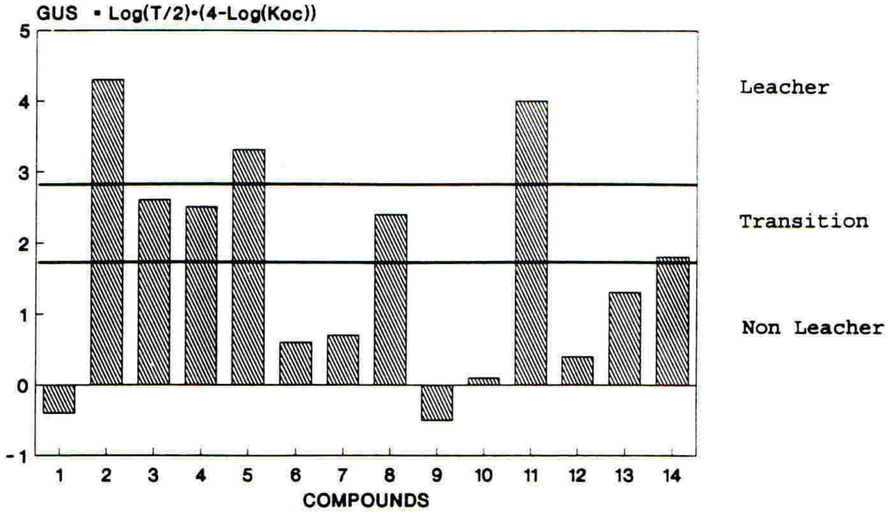
Theoretical Prediction of Environmental Fate

Use of the Briggs equations allows for an estimation of-

water solubility
soil sorption coefficient (Koc)
evaporation rate from a soil column
volatilisation from moist soil
groundwater ubiquity score (GUS).

The GUS value has been extensively used by regulators and by the water industry (Water Research Centre, 1992) as an indication of the potential for leaching. Figure 2 shows the GUS values calculated for a number of compounds and together with bands of values for compounds considered to be potential leachers, transitional or non-leachers. Currently, the generation of half-life values in soils from theoretical structural-degradation correlation is in its infancy and therefore the half-life values used are determined experimentally.

FIGURE 2 Ground Water Ubiquity Score



Low leaching potential is a desirable characteristic. However `non- leachers' can also be transported in association with particulate matter via run-off to the aquatic environment. The degree of sorption can effect not only the rate of transportation but also the bioavailability of the compound and consequently its impact on aquatic organisms can assume greater importance. In these situations the significance of soil half-life is greatly reduced; hydrolytic and photolytic degradation become more significant.

These factors are examined in a series of short-term studies which are undertaken as part of the tiered approach to provide answers to the questions raised in Figure 1.

Short Term Studies

These studies are conventionally used to give an indication of the fate of agrochemical herbicides. Extension or adaption of the studies can be used to answer questions specific related to amenity use. They are designed to reflect the most demanding environmental conditions and are undertaken at concentrations that would represent the worst case scenario be expected from normal application.

Hydrolitic stability

The hydrolysis rate can be determined at different pH, e.g. pH 4, 7 and 9 and at ambient (20°C) or elevated (70°C) temperatures. These experiments are conducted for approximately seven days and hydrolysis monitored using analytical techniques such as Thin Layer Chromatography and High Performance Liquid Chromatography.

An indication of the degradation in water in the presence of sediment should be determined. This experiments normally continues for about a month with analysis at a minimum of three time points.Variations in this study can include addition of the test compound to the water or pre-treating of the sediment prior to addition of water to simulate transport associated with particulates.

Photolytic stability

Photolysis is a possible major route of degradation prior to compound entering the aquatic environment. This is an essential parameter when determining the suitability of a given molecule for amenity use. The photolytic stability can be determined both on an inert surface and in water. Using controlled environment chambers with high intensity lighting these experiments can be conducted over a few days. For aqueous photolysis, the pH is chosen on the basis of the compounds hydrolitic stability.

Absorption/desorption

Although soil may not be present at some of the locations where amenity herbicides are used, it is still essential to know the degree of sorption to soil since it will give an indication of the ability of the molecule to bind to stones, gravel, tarmac, etc. which in turn may well influence the rate of photolytic degradation.

The Koc values can be determined by conducting an absorption/ desorption study with a sandy soil. The distribution of the compound between the soil and water components will then be used to calculate Kd (distribution constant). The Koc can then be calculated correcting for the organic carbon content of the soil.

An indication of the degree to which a compound binds to soil and its potential for leaching can be obtained from soil column leaching studies. A sandy soil is placed in a column and after addition of the test compound to the top of the column, the equivalent to 20 cm of water is added in 48 hours and the concentration in the leachate determined. This experiment can be adapted to look more specifically at the amenity use context by using gravel in the columns instead of soil. Variations in this technique can include spraying different formulations onto the gravel and allow it to dry before adding it to the column.

Soil Half Life

Soil half-life is required for predicting leaching potential and also to give an indication of fate in sediment. Soil is incubated under standard conditions for 1-3 months with sufficient sampling points to allow half-life determination from the decline curve.

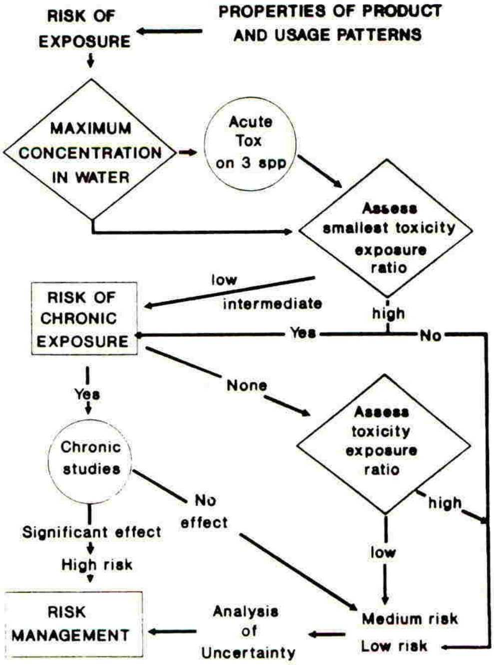
Modelling

The short-term tests will have determined basic parameters e.g. leaching potential through soil or gravel, half-life Kd and Koc, estimated GUS value, as well as hydrolytic and photolytic stability and water/sediment partitioning. Many of these parameters are used in conventional run-off or leaching models. At present none of these models specifically deal with amenity use where run-off is from a hard surface or bypass flow conditions exist in gravel soak aways. The development of these models and the inclusion of the results into a catchment area model would enable early evaluation of any perceived problem.

Ecotoxicological Evaluation

The use of Predicted Environmental Concentrations (PECs) has been outlined in various draft legislation and been incorporated into decision making schemes (European and Mediterranean Plant Protection Organization (EPPO) 1993). Considerable emphasis is placed on understanding which of the environmental fate parameters control these predicted concentrations. Results from the probe studies allows PEC for water other than that derived from direct application to water, to be calculated. Used in inconjunction with the LC50s for fish, daphnia and algae, the toxicity/exposure ratio (TER) for each organism can be calculated and this will give an indication of the environmental acceptability. This component can then be incorporated into the overall risk assessment (Figure 3).

FIGURE 3 Simplified diagram of risk assessment to surface water



Effect of formulation

If the ecotoxogical evaluation indicate that the safety margin is not satisfactory, additional improvements can be made in the areas of formulation and delivery systems which will ensure more efficient and effective use of herbicides. The opportunity to formulate a compound specifically to adhere to inert material and to allow sufficient time for photolytic breakdown has to match the requirement of efficacy and residuality in order to make it cost effective. These changes can result in significant reduction in the amount of compound reaching the aquatic environment and subsequently its environmental impact. Candidate formulations can then be tested in appropriate short term studies to determine their environmental acceptability.

DISCUSSION

A Government report (Parliamentary Office of Science and Technology, 1993) has highlighted the potential cost to the consumer as a result of implementing the EEC drinking water directive, to be one billion pounds. Additionally, ecotoxicological guidelines resulting from the application of Environmental Quality Standards have in certain cases resulted in more stringent restrictions (e.g. Red List) being applied than to drinking water. The requirement for better designed herbicides to reduce the aquatic concentrations of herbicides is self evident from both a product stewardship and legal viewpoint.

The generic nature of the transport processes involved in the movement of compounds to the aquatic environment will mean that any reduction in the amount of compound applied will reduce the amount of material reaching the aquatic environment, providing the environmental profiles are similar. However increased herbicidal activity against weeds may be reflected in increased ecotoxicity. Under these circumstances the acceptability in terms of toxicity/exposure ratio would not necessarily improve.

Using the criteria outlined in this paper the potential environmemtal impact for a range of new chemistries can be readily determined. In addition commercialisation of a compound from a series of structurally related molecules can include the optimisation of the environmental fate dimension. Inorder for this process to succeed itis essential to have an interactive data flow system that allows feedback at an early stage to synthesis chemists and formulators.

This paper illustrates the opportunities to identify potential problems and to influence the design of herbicides so that they are environmentally acceptable in the amenity context.

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RESPONSE OF BRACKEN AND HEATHER TO TRIBENURON-METHYL IN THE PRESENCE AND ABSENCE OF ADJUVANTS AS COMPARED WITH ASULAM

T.M. WEST, J. LAWRIE

Department of Agricultural Sciences, University of Bristol, AFRC Institute of Arable Crops Research, Long Ashton Research Station, Bristol BS18 9AF, UK

ABSTRACT

The effect of five different adjuvants on the activity of the herbicide tribenuron-methyl was investigated in an outdoor experiment on established, container-grown plants of bracken (*Pteridium aquilinum*) and heather (*Calluna vulgaris*). Asulam, the recommended herbicide for bracken control, was included for comparison. Treatments were applied in August 1991 and assessments made during 1992. Tribenuron-methyl without added adjuvants at 15 g AI ha^{-1}, the highest dose tested, caused only moderate suppression of bracken growth and had only slight initial effects on heather; lower doses had no effect on bracken or heather. The activity of tribenuron-methyl was significantly increased on bracken, giving effective control at 7.5 g AI ha^{-1}, with the adjuvants Agral, Silwet L-77 or Marlipal 34/150, whereas heather was unaffected (Silwet L-77 was not tested on heather). Asulam considerably suppressed bracken growth at 1100 g AI ha^{-1}. This dose reduced the new extension growth of old heather shoots, but plants recovered after a spring cutting. The potential of tribenuron-methyl for bracken control is discussed.

INTRODUCTION

Bracken (*Pteridium aquilinum*) is one of the world's most successful weeds and there has been much concern in recent years about its effects on human and animal health (Taylor, 1990). The loss through bracken encroachment of agricultural land and natural habitats (e.g. heather moorland) has both economic and serious ecological drawbacks, such as restricting species diversification. Research at Long Ashton Research Station has investigated control strategies for bracken. Recent pot and field experiments (West & Standell, 1989; West, 1991) have found the herbicide tribenuron-methyl (with a non-ionic adjuvant added) to be active against bracken while grass species were tolerant. This, together with its low toxicity to mammals, insects and fish, its short soil persistence and low dose rates suggest it may be an environmentally favourable treatment for bracken control in grassland, amenity or conservation situations.

This paper presents data from experiments in which various adjuvants were added to tribenuron-methyl to investigate herbicide activity on bracken and to determine the tolerance of heather (*Calluna vulgaris*). These treatments were compared with asulam (with the recommended non ionic adjuvant added at 0.1% of the spray volume), the only herbicide available for selective control of bracken in heather moorland in the UK.

MATERIALS AND METHODS

Bracken rhizomes were collected from a natural population near Long Ashton (National Grid Reference ST 542 707) in April 1990. One 20cm fragment, bearing one to three viable buds, was planted 8cm deep in 25cm diameter pots containing a soil/sand/peat mixture (3:2:1) with added fertiliser (Osmocote 18.11.10 at 3.3 g AI ha^{-1}). Pots were kept outside and watered using trickle irrigation to supplement natural rainfall. During winter pots were plunged into ashes to protect rhizomes from frost.

Heather seeds were sown into trays containing an ericaceous compost in February 1990 and germinated under a mist sprayer in a heated glasshouse. In April 1990, seedlings were pricked out, one per pot, into 10cm diameter pots containing the same compost and kept in a glasshouse throughout 1990 and overwintered in an unheated glasshouse to reduce "winter kill". In March 1991, plants were potted on into 20cm diameter pots containing the growing medium described previously for bracken then put outside and connected to the trickle irrigation.

Treatments were applied to three replicate plants of bracken and heather on 1 August 1991, using a laboratory track sprayer fitted with a Lurmark 8001 flat fan nozzle at a pressure of 210 kPa giving a volume rate of 250 l ha^{-1}. The herbicide formulations used were tribenuron-methyl (75% AI WG) and asulam (400g AI litre^{-1} SL). The adjuvants used were Agral, an alkyl nonylphenol polyethoxylate (AG); Silwet L-77, an organosilicone (SIL); Codacide Oil, a 95% emulsifiable vegetable oil (CODA); Marlipal 34/150, a C_{13}/C_{14} alcohol polyethoxylate (MAR) and Fyzol 11E, a 99% emulsifiable highly refined mineral oil (FYZ). Concentrations of herbicide and adjuvants used are given in Tables 2 and 3.

At the time of treatment, all bracken plants were at full frond expansion but were graded according to frond height and number, largest in replicate one and smallest in replicate three. One typical spare plant from each replicate was destructively assessed to determine growth stage and is shown in Table 1. Heather plants were generally similar in vigour and had a mean height of 27cm and shoot fresh weight of 67g. Plants in replicates one and two had about 20-30% of shoots in flower and those in replicate three had less than 5% in flower. Plants were returned outside 24h after spraying and set out in three randomised blocks. Overwintering of plants in 1991-92 was as described for 1990-91.

Table 1. Growth stage of bracken plants at time of treatment.

	Fronds			Rhizomes	
Replicate	Number	Height (cm)	Fresh wt (g)	Bud number	Dry wt (g)
1	40	65	548	285	146
2	34	59	382	221	116
3	17	45	284	61	58

In August 1992 bracken fronds were cut off at soil level and the number and fresh weight per pot recorded. Soil was removed and rhizome development assessed. All viable buds on the rhizomes, that is developing frond buds and apical rhizome buds, were counted. Rhizomes were oven dried at 90°C for 48h and dry weights recorded.

In April 1992, the number of old-flowered shoots with new extension growth on heather plants were counted and the extension growth removed and weighed. All shoots were cut to 10cm above the soil surface, simulating a spring cutting of heather on moorland, to encourage new shoots and seed production, as reported by Aquilina (1992) who suggested that cutting had certain advantages over the traditional burning. All green tissue (leaves and new shoots, excluding woody branches) were removed from the cut shoots and weighed. In August 1992, heather plants were cut off at soil level and fresh weights recorded. Analysis of variance was carried out on all the bracken and heather data.

RESULTS

Bracken

Before senescence in 1991, fronds treated with tribenuron-methyl, without added adjuvant, showed no obvious herbicide symptoms; but with added adjuvant there was, generally, chlorosis of the upper pinnae. Fronds treated with asulam showed scorch and necrosis of the uppermost pinnae, typical phytotoxic symptoms of this herbicide.

Assessments in August 1992 showed that without added adjuvant tribenuron-methyl at 3.75 and 7.5 g AI ha^{-1} was virtually inactive on bracken. However, 15 g AI ha^{-1} did cause a significant reduction of frond fresh weights and an appreciable reduction of frond number and viable buds on the rhizomes. The adjuvants AG and SIL produced the greatest enhancement of tribenuron-methyl activity and, when added to 3.75 or 7.5 g AI ha^{-1} of tribenuron-methyl, gave more than 95% reductions of frond fresh weights and viable buds on rhizomes. MAR also significantly enhanced the activity of 3.75 and 7.5 g AI ha^{-1} of tribenuron-methyl. The increased activity of tribenuron-methyl at 3.75 and 7.5 g AI ha^{-1} by adding FYZ was also significant, compared with no added adjuvant, but the reduction of frond number and fresh weight from the 3.75 g AI ha^{-1} dose was significantly less than when AG or SIL were added. Activity of tribenuron-methyl at 3.75 and 7.5 g AI ha^{-1} was not significantly enhanced by the addition of CODA. Tribenuron-methyl at 15 g AI ha^{-1}, with any of the adjuvants tested, gave a complete kill of bracken.

Asulam at 2200 and 4400 g AI ha^{-1} prevented new growth and 1100 g AI ha^{-1} considerably reduced new frond growth and numbers of viable buds on the rhizomes.

Heather

Tribenuron-methyl at 3.75 and 7.5 g AI ha^{-1} with or without added adjuvants, or treatments of the adjuvants applied alone, did not affect heather growth (results not tabulated). Tribenuron-methyl at 15 g AI ha^{-1} without added adjuvant reduced the new extension growth, but not significantly. Adding adjuvant to tribenuron-methyl at 15 g AI ha^{-1}, did not significantly increase herbicide activity compared with no added adjuvant, although extension growth was appreciably reduced when AG was added. However, new growth from lower down the old shoots of heather was vigorous from all tribenuron-methyl treatments at 15 g AI ha^{-1}; the total weight of green tissue collected from cut shoots showed no differences when compared with the untreated plants.

Asulam (at 1100 g AI ha^{-1}) reduced new extension growth, but not significantly, and new shoot growth from the lower branches of all asulam treated plants was as vigorous as that from the untreated plants.

At the August assessment, all treated plants had recovered from the spring cutting, all were flowering and there were no differences between treated and untreated plants.

TABLE 2. Response of bracken to herbicide treatments applied 1 August 1991 assessed in August 1992. (Values are means of 3 replicates)

Treatment	Herbicide dose (g AI ha^{-1})	Fronds		Rhizomes	
		Number	Fresh wt (g)	Viable bud number	Dry wt (g)
Tribenuron-methyl (No adjuvant)	3.75	35.7	645	753	254
	7.5	35.3	555	575	214
	15.0	22.7	283	340	139
Tribenuron-methyl + AG (0.25% sv[a])	0	40.3	741	792	288
	3.75	3.7	39	28	120
	7.5	1.3	5	20	124
	15.0	0	0	0	102
Tribenuron-methyl + SIL (0.25% sv)	0	38.7	714	673	297
	3.75	3.0	19	17	114
	7.5	0.7	4	6	110
	15.0	0	0	0	99
Tribenuron-methyl + CODA (2.5 l ha^{-1})	0	32.3	754	694	278
	3.75	39.3	677	796	230
	7.5	25.7	421	485	162
	15.0	0	0	0	119
Tribenuron-methyl + MAR (0.25% sv)	0	34.7	730	655	280
	3.75	9.3	125	224	167
	7.5	1.0	9	19	157
	15.0	0	0	0	119
Tribenuron-methyl + FYZ (5 l ha^{-1})	0	34.7	716	687	288
	3.75	16.7	259	401	172
	7.5	11.7	75	250	155
	15.0	0	0	0	121
Asulam + AG (0.1% sv)	1100	6.0	143	187	177
	2200	0	0	16	142
	4400	0	0	0	126
Untreated	-	35.7	724	704	282
SED (df 52)		6.35	56.6	207.4	28.7

[a] Adjuvant added to treatment solution as either a % of spray volume (sv) or l ha^{-1}.

TABLE 3. Response of heather to herbicide treatments applied 1 August 1991 assessed in April and August 1992. (Values are means of 3 replicates)

Treatment	Herbicide dose (g AI ha^{-1})	April			August
		No. old shoots with extension growth	Extension growth wt (g)	Wt of all green tissue (g)	Shoot fresh wt (g)
Tribenuron-methyl (No adjuvant)	15.0	23.7	4.24	32.0	78.5
Tribenuron-methyl + AG (0.25% sv^{a})	15.0	8.0	0.76	27.0	95.2
Tribenuron-methyl + CODA (2.5 l ha^{-1})	15.0	21.0	3.96	29.5	79.1
Tribenuron-methyl + MAR (0.25% sv)	15.0	30.7	5.69	32.9	85.7
Tribenuron-methyl + FYZ (5 l ha^{-1})	15.0	31.7	5.69	30.9	81.1
Asulam	1100	26.3	4.11	24.9	82.9
+ AG (0.1% sv)	2200	15.3	1.87	25.2	80.5
	4400	12.7	1.27	22.6	75.1
Untreated	-	39.3	7.81	25.4	80.0
SED (df 44)		9.46	2.818	7.50	12.00

^{a} Adjuvant added to treatment solution as either a % of spray volume (sv) or l ha^{-1}.

DISCUSSION

Previous experiments (West & Standell, 1989) have shown that tribenuron-methyl at 15-45 g AI ha^{-1} (with AG added), can give effective control of container-grown bracken. In the transition from container to field trials higher doses of tribenuron-methyl (60-90 g AI ha^{-1}) were needed for good control (West, 1991 ; West, unpublished data)

The work reported here showed that different adjuvants affected the activity of tribenuron-methyl on established bracken to varying degrees, AG, SIL and MAR producing the greatest enhancement. However, the results obtained with SIL and MAR contrast those found on young bracken plants (Lawrie & West, 1993), where tribenuron-methyl activity was not enhanced by these adjuvants.

The treatments of tribenuron-methyl at 7.5 g AI ha^{-1} with adjuvants that were effective on bracken did not affect heather; heather plants fully recovered from all treatments of tribenuron-methyl at 15 g AI ha^{-1} with adjuvants that killed bracken. These results indicate a good margin of selectivity, which compared well with the standard asulam treatment in this experiment. This suggests that tribenuron-methyl with a suitable adjuvant, and with its environmentally favourable characteristics, may be a potential treatment for bracken control in heather moorland.

Our results, although interesting, were obtained via a rather slow and inefficient method of testing. Further work should include more concentrations of herbicide and adjuvants, to determine the optimum levels for maximum activity on the target while retaining tolerance of the non-target species. By using the young bracken plant method (Lawrie & West, 1993) many herbicide and adjuvants combinations can be evaluated more quickly but, as seen from the present work, some potentially effective adjuvants for older plants e.g. SIL, may not be identified. An improved method for selecting candidate adjuvants is needed. Work by Stock *et al*, (1993) suggests that a foliar uptake activation model, based on relationships between structure, concentration and physiochemical properties of adjuvant and pesticide, and the nature of the plant species can help in selecting effective combinations. Future experiments should employ this more rationalised approach in an attempt to avoid wasting resources on potentially poor or even antagonistic herbicide / adjuvant combinations.

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