Session 7D

The Role of Weed Control in Land Use Change

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Poster Papers 7D-1 to 7D-11

THE POTENTIAL FOR HERBICIDE USE IN THE CONSERVATION OF BRITAIN'S ARABLE FLORA.

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ABSTRACT

The use of herbicides in arable farming since the 1940s is thought to have been one of the major reasons for the disappearance of many species of arable plant from Europe in recent years. The use of broad-spectrum herbicides should therefore be discouraged where species-rich plant communities and rare species still occur. Some selective graminicides however have a negligible toxicity to non-target species, and may be valuable where there are large quantities of grass weeds.

INTRODUCTION

Herbicides have become the major means of weed control in European agriculture during the past 50 years. They are thought to have been one of the major factors involved in the decline during this period of many plant species formerly associated with arable farming, and which are now a conservation priority (Eggers, 1987; Wilson, 1990). Plant species are however known to be differentially sensitive to any one compound, and different herbicides can have widely varying spectra of activity. In managing areas of arable fields for the conservation of rich arable floras and individual rare species, it is therefore possible to propose a strategy that proscribes broad-spectrum compounds but which permits the use of highly selective herbicides aimed at particular problem species.

METHODS AND RESULTS

The effects of broad-spectrum herbicides on arable plant communities.

Work carried out by The Game Conservancy Trust has shown that broad-spectrum herbicides can have a profound effect on the composition of arable plant communities (Boatman, 1989). Effects on populations of many annual species will however be buffered by their seed banks, and in some but by no means all cases, herbicide omission from a field headland can lead to the rapid recovery of populations of both rare and common species, even when fields have been intensively managed for many years.

Field plot experiments carried out between 1992 and 1994 have demonstrated the effects of omission of broad-spectrum herbicides on species-rich arable plant communities. In all fourteen of the experiments where broad-spectrum herbicides were tested, numbers of species per plot were significantly higher where they were not applied (Table 1). Numbers of plants of many individual species also showed significant differences between plots treated or not treated with herbicide.

Table 1. Number of species in ten $0.25m^2$ quadrats in plots treated and not treated with herbicides in 14 field plot experiments carried out between 1992 and 1994. Significance levels: * P <0.05, ** P <0.01, *** P<0.001

	Number of species		
	No herbicide	With herbicide	P
Dorset spring barley	16.33	9.53	**
Hampshire spring barley 1	13.00	4.38	**
Hampshire spring barley 2	20.55	9.89	**
Hampshire spring barley 3	16.78	5.77	***
Hampshire spring barley 4	24.92	15.58	**
Hampshire spring barley 5	14.57	5.65	***
Hampshire winter barley	14.23	9.87	**
Hampshire winter wheat	17.18	9.11	*
Hampshire winter wheat 2	19.91	8.27	**
Norfolk spring barley 1	8.72	4.58	***
Norfolk spring barley 2	17.24	3.56	***
Norfolk winter barley	22.49	9.62	***
Suffolk winter wheat	17.32	4.16	***
Wiltshire winter wheat	17.81	8.33	***
Means	17.22	7.74	

It has however been shown by sampling the seedbank of the Broadbalk long-term winter wheat experiment (Thurston, 1968), that applications of broad-spectrum herbicides over a period of 30 years have had a profound effect on its composition (Table 2; Wilson, 1990). Some species have been completely eliminated from herbicide-treated plots.

Table 2. Mean numbers of seedlings per m^2 of surface area germinating from soil cores taken from plots of the Broadbalk which have never received herbicide and those which have had herbicide applied since 1957. Significance levels: * P <0.05, ** P <0.01, *** P<0.001

	No herbicide	Herbicide applied	P
Alopecurus myosuroides	7535	717	***
Aphanes arvensis	8738	131	***
Capsella bursa-pastoris	621	4	***
Legousia hybrida	949	85	*
Papaver rhoeas	12775	501	*
Scandix pecten-veneris	87	0	*
Veronica hederifolia	1113	3	***

Herbicide screening in field plot experiments have shown that some graminicides have a wide spectrum of activity (Boatman, 1989). Tri-allate, isoproturon, imazamethabenz and chlortoluron in particular have such a broad spectrum that their use in arable conservation areas would be discouraged. A range of broad-spectrum herbicides was tested against a selection of common and uncommon arable plants in a pot trial (Wilson, 1990). The herbicides were applied at normal farm rates using a knapsack sprayer, and all gave unacceptably high levels of control of at least some of these species (Table 3). The ioxynil/bromoxynil mixture was most phytotoxic, and *Chrysanthemum segetum* and *Viola arvensis* were resistant to two of the four chemicals used.

Table 3. Mean plant vigour scores (Richardson & Dean, 1974) for a range of species five weeks after application of four herbicides. Significance of results in relation to control plants (vigour score = 7) is indicated by * $P<0.05$, ** $P<0.01$, *** $P<0.001$.

	Herbicide and application rate of active ingredient (kg/ha)							
	Mecoprop (1.28		Chlortoluron 1.38		MCPA 1.4		Ioxynil/ Bromoxynil 0.38/0.38)	
Buglossoides arvensis	5.0	*	2.5	*	5.3		0	**
Chrysanthemum segetum	6.0		1.5	*	6.3		1.3	*
Misopates orontium	-		-		5.0	*	0	*
Papaver hybridum	3.0	***	0	**	5.0	*	0	*
Papaver rhoeas	1.3	**	0.3	**	3.7	*	0	*
Ranunculus arvensis	0.8	**	1.3	*	-		-	-
Scandix pecten-veneris	3.3	***	1.8	**	4.3	**	2.0	*
Silene noctiflora	2.3	*	0.8	*	5.0		0	***
Viola arvensis	6.3		5.3	*	6.3		1.3	**

The control of problem species in arable conservation areas.

Species which can pose problems in arable conservation areas include many of those that are also problems in conventional modern arable farming systems. Among these are the annual grasses *Alopecurus myosuroides, Avena fatua, A. sterilis ssp. ludoviciana, Bromus commutatus* and *B. sterilis* and the perennial grasses *Arrhenatherum elatius var. bulbosus* and *Elymus repens*, all of which thrive under high nitrogen levels. Problems have also been encountered with some perennial broad-leaved species including *Sonchus arvensis, Cirsium arvense* and *Tussilago farfara* which can occur in overwhelming proportions. Similar increases in perennial species have also been noted in long-term arable conservation areas in Germany (Oesau & Jörg, 1994).

For chemical control of problem species to be acceptable where the primary aim is the conservation of endangered species, the herbicide used must not affect non-target species. This can either be achieved by careful timing of application or by the use of a highly selective compound. Two selective herbicides, flamprop-m-isopropyl and diclofop-methyl+fenoxaprop-ethyl were tested in a field-plot and screening experiments with pot-grown plants.

Field plot experiments

A series of field plot experiments were carried out by The Game Conservancy Trust between 1985 and 1989 as part of the Cereals and Gamebirds Research Project (Boatman, 1989). These identified the herbicides diclofop-methyl, tralkoxydim, flamprop-m-isopropyl and fenoxaprop-ethyl as of potential value for the control of grass weeds without effects on non-target plant species. Diclofop-methyl and fenoxaprop-ethyl are now available as a mixture, and both this and flamprop-m-isopropyl were selected for further screening against uncommon species.

A field-plot experiment was carried out on the Fivehead Arable Fields Reserve owned by the Somerset Wildlife Trust. This site has long been known for its rich arable flora which includes such rare species as *Valerianella rimosa, Torilis arvensis* and *Euphorbia platyphyllos*. Its continuing richness may owe much to past difficulties in management which have also contributed to the presence of large quantities of *A. elatius var. bulbosus, A. myosuroides* and *A. sterilis ssp. ludoviciana*. These species had increased to such proportions by 1994 that they threatened not only the crop grown but also the less competitive annual species. Three replicates of each herbicide were applied to 15m X 6m plots in April 1995 at normal farm rates using a knapsack sprayer, and the percentage cover of each species was recorded in July with additional counts of grass weed inflorescence production. Due to the extremely heterogeneous distribution of the seed-bank of most species, few individual species showed significant differences between treatments. Inflorescence production by *A. elatius* was however significantly reduced by the flamprop-m-isopropyl application, and that of *A. myosuroides* was significantly reduced by the fenoxaprop-ethyl/diclofop-methyl treatment.

Table 4. Number of seed-heads produced per m^2 by three grass species in a field-plot experiment under three herbicide treatments - means (bold-type) back transformed from square root transformed data (normal type), and total numbers of species present per plot - means back-transformed from log transformed data. Confidence intervals apply to transformed data. Significance levels: * P <0.05, ** P <0.01, *** P<0.001

	No herbicide		Diclofop-methyl + F.-p-ethyl		F.- isopropyl		95% ci	P
Alopecurus myosuroides	**69.69**	8.35	**42.24**	6.50	**66.37**	8.15	0.58	**
Arrhenatherum elatius	**16.84**	4.10	**12.59**	3.55	**4.09**	2.02	0.51	***
Avena sterilis ssp. ludoviciana	**2.76**	1.66	**0.31**	0.56	**0.96**	0.98	0.28	***
Total number of species	**23.50**	3.16	**31.00**	3.43	**34.99**	3.56	0.15	**

A. sterilis ssp. ludoviciana was significantly affected by both chemicals. At the same time, the number of other species present in each plot was significantly higher where either of the two herbicides had been applied (Table 4).

Fenoxaprop-ethyl/diclofop-methyl was also used in a further field-plot experiment on a Hampshire farm in 1994. The herbicide significantly reduced numbers, inflorescence production and dry weight of *A. myosuroides* without affecting any other species.

Screening experiment

Centaurea cyanus has undergone one of the most rapid recent declines of any species in the British flora. A range of herbicides were tested against this plant and two common species. Plants of *A. myosuroides*, *Papaver rhoeas* and *C. cyanus* were grown in 20cm clay pots. The herbicides were applied in May at normal application levels for use in cereal crops, using a knapsack sprayer. Plant vigour, mortality and dry weight were assessed five weeks after spraying (Table 5). Flamprop-m-isopropyl affected none of the species, while the diclofop-methyl/fenoxaprop-ethyl mixture had a significant effect not only on *A. myosuroides*, but also on *C. cyanus*.

Table 5. Dry weights (g) of pot-grown plants of three species five weeks after application of four different herbicide treatments. Means (bold type) back transformed from log transformed results (normal type). Confidence interval applies to transformed results. Significance levels: * P <0.05, ** P <0.01, *** P<0.001

Herbicide and rate of active ingredient (l/ha)	*Alopecurus myosuroides*		*Papaver rhoeas*		*Centaurea cyanus*	
No herbicide	**3.00**	1.10	**16.78**	2.82	**21.98**	3.09
Flamprop-m-iso. (3.5)	**1.84**	0.61	**14.30**	2.66	**24.29**	3.19
Isoproturon (4.2)	**0.28**	-1.27	**8.41**	2.13	**5.26**	1.66
D.-methyl/F.-ethyl (2.5)	**1.19**	0.17	**10.28**	2.33	**12.43**	2.52
95% ci		0.64		0.68		0.23
P		*		*		*

DISCUSSION

There is considerable evidence that the long-term use of herbicides in cereal crops has been among the most important factors in the decline of many arable annual plants. It is hardly surprising that the prevention of seed production by generations of annual plants eventually will lead to depletion of the seed-bank and finally its elimination. The rate at which this occurs for each species will depend on the longevity of the buried seed and the proportion which germinates each year, and the susceptibility to the herbicides used. For some species this may be very rapid (Wilson, 1990).

Herbicides can however be useful tools in the management of areas in which species-rich communities of arable annuals still occur. These areas are as much at the mercy of modern cereal weeds as are conventionally grown crops, but with the added complication that any herbicidal treatment must have a minimal impact on non-target species. The selective graminicides fenoxaprop-ethyl, diclofop-methyl and flamprop-m-isopropyl appear to have relatively little effect on broad-leaved species, although some caution should be exercised (especially in relation to use of the latter two compounds on *C. cyanus*), but can achieve adequate control of grasses including *A. myosuroides*, *A. elatius var bulbosus* and *A. sterilis*. Rare annual grasses including *Briza minor*, *Gastridium ventricosum* and *Apera interrupta* may also be affected by these herbicides, and care should be taken not to use them where these species might be present.

It is possible that a broad-spectrum translocated herbicide such as glyphosate may be of use in the control of perennial species. This can be applied relatively late in the growing season after most annual species have produced seed and senesced, but while the perennial species are still in active growth. Further work is required to determine the timing and effects of such application and on the selection and spectrum of activity of other selective graminicides.

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CLODINAFOP-PROPARGYL - A USEFUL TOOL FOR MANAGEMENT OF CONSERVATION HEADLANDS.

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ABSTRACT

Correct management of Conservation Headlands using selective herbicides to remove competitive weed species has been shown to enhance the wildlife value of such areas and maintain biodiversity. A series of trials was set up to investigate the potential for using a new graminaceous herbicide, clodinafop-propargyl, as a product for use in Conservation Headlands.

INTRODUCTION

Work carried out by Willmot Pertwee and The Game Conservancy Trust, has shown that field margins, when correctly managed, can be of enormous benefit to wildlife (Sotherton 1991). "Managed" headlands can support a diverse flora which, in turn, provides a niche for a wide range of invertebrates. These can be a critical food source for breeding bird species, for example, grey partridges (*Perdix perdix*). These areas can also provide a refuge for some of Britain's rarest flowering plants, including species such as pheasant's eye (*Adonis annua*), red hemp-nettle (*Galeopsis angustifolium*) and shepherd's needle (*Scandix pecten-veneris*) (Wilson & Sotherton 1994). However, a Conservation Headland must be actively and correctly managed if it is to be beneficial to wildlife and not become a significant problem for the grower.

Weed control is of paramount importance because a diverse flora can only be maintained by removal of highly competitive species such as annual grass weeds. Failure to control species such as this results in a less diverse weed flora and an area of low wildlife value. The use of selective graminaceous herbicides can remove these competitive species, allowing the less competitive flowering species to proliferate. A new graminicide containing clodinafop-propargyl and cloquintocet-mexyl was examined to see if it can be used in such situations.

METHODS

Experiment 1. In 1990, a trial was carried out to evaluate the impact of an application of clodinafop-propargyl to a plot containing a mixture of annual, arable wild flower species (Table 1). The trial was a randomised block design, comprising three replicates and an untreated control. The seed mix was sown on 7 March at a rate of 6.08kg/ha (15kg/acre). Spring wheat (cv Tonic) had been drilled two days previously at a rate of 125.6kg/ha. The plots measured 3m x 10m and the flower mixture was sown into the plot over four passes, each plot receiving 120g seed in a mixture with 2.3kg of silver sand (Nowakowski & Marshall 1990).

Table 1. Composition of seed mixture of annual cereal weeds, expressed as a percentage by weight.

Species	%	Species	%
Vicia sativa	19.10	*Silene alba*	6.87
Vicia lutea	15.28	*Sinapis arvensis*	1.93
Agrostemma githago	14.60	*Chrysanthemum segetum*	1.54
Centaurea cyanus	12.50	*Papaver argemone*	0.75
Adonis annua	9.25	*Legousia hybrida*	0.75
Fumaria officinalis	9.20	*Misopates orontium*	0.75
Viola arvensis	6.99	*Linaria vulgaris*	0.35

Clodinafop-propargyl was applied on 22 May 1990, at a rate of 0.6l/ha (2.4 times the maximum approved field rate), using an Azo sprayer calibrated to deliver 200l/ha through Lurmark 02-F110 nozzles. The plots were visually assessed on 10 July with species being marked as present if noted in six 0.1m quadrats/plot.

Experiment 2. In 1993 a trial was carried out, to investigate the potential for clodinafop-propargyl as a candidate herbicide for it's selective weed control properties. The trial was established in a 6m wide Conservation Headland, the plots measuring 6m x 2m. The layout was a randomised complete block design, comprising four replicates. The trial was erroneously established in barley, for which clodinafop-propargyl is not approved, but this was not considered to affect the results on non-target broad-leaved species. The following treatments were applied:

1. Untreated
2. clodinafop-propargyl+Codacide Oil (0.125l+2.5l)

The treatments were applied using an Oxford Precision Sprayer calibrated to deliver 200l/ha through Lurmark 02-F80 nozzles. Clodinafop-propargyl was applied on 30 April. No other herbicide inputs were applied to the plots. The growth stages of weed species present at application are shown in Table 2.

A final assessment was carried out between 1-5 July when % cover of each species was estimated in ten 0.25m quadrats per plot. The number of flowering grass heads per quadrat was also counted at this time.

Table 2. Growth stage of broad-leaved species present in plots at application

Species	Growth Stage
Brassica napus napus	11 - 13
Matricaria perforata	9 - 12
Chamomilla suaveolens	9 - 12
Myosotis arvensis	9 - 11
Stellaria media	11 - 14
Galium aparine	9 - 12
Geranium dissectum	6 - 12
Sonchus asper	10 - 12
Viola arvensis	10 - 14

Key to growth stages: 6 - four expanded true leaves, 7 - six expanded true leaves, 8 - plants up to 25mm across/high, 9 - plants up to 50mm across/high, 10 - plants up to 100mm across/high, 11 - plants up to 150mm across/high, 12 - plants up to 250mm across/high, 13 - flower buds visible, 14 - plant flowering. (Lutman & Tucker 1987).

Experiment 3. In 1995, a glasshouse study was established in order to investigate the sensitivity of rare arable weed species to clodinafop-propargyl applications. A selection of such species was sown into plastic trays containing a fine sandy loam soil. The trays were sown on 13 April and herbicide applications applied on 24 May.

Table 3. Growth stages of plant species at application.

Species	No. plants/10cm	Growth stage	Size (mm)
Chrysanthemum segetum	14	2-4lvs	30-60
Papaver argemone	80	5-6lvs	20-30
Buglossoides arvense	4	2-4lvs	40-60
Silene noctiflora	50	4lvs	30-60
Adonis annua	3	4-6lvs	20-30
Ranunculus arvensis	15	4-6lvs	30-50
Scandix pecten-veneris	7	4lvs	100-120
Centaurea cyanus	25	4lvs	20-30
Misopates orontium	45	4lvs	20-30

The treatments were applied using a CIBA precision plot sprayer calibrated to deliver 200l/ha, through Lurmark F02-110 nozzles. Clodinafop-propargyl was applied at the field use rate of 0.125l/ha with 1.0l Actipron (Mineral oil). The growth stages at application are given in Table 3. The trays were assessed visually at one and three weeks after application on a percentage control basis.

RESULTS

The results obtained from the three experiments are shown below.

Table 4. Mean frequency score (6x0.1m^2 quadrats/plot) of naturally occuring and cornfield species sown into wheat. Experiment 1

Species	Untreated	Clodinafop (0.6l/ha)
Veronica persica	1.62	2.32
Viola arvensis	3.74	3.25
Centaurea cyanus	5.35	5.34
Agrostemma githago	5.84	4.72
Vicia sativa	4.42	3.70
Sinapis arvensis	4.93	5.34
Vicia lutea	5.68	5.34

The results shown in Table 4 indicate that clodinafop had no effect on the growth and survival of the species listed when compared to the untreated control. The additional species sown in the mixture, not listed in the above table, either failed to germinate or were present at insignificant levels. *Veronica persica* and *Viola arvensis* germinated naturally and were included in the assessments.

Table 5. Mean percentage cover of naturally occurring broad-leaved weeds (Assessed 1-5 July). Experiment 2.

Species	Untreated	Clodinafop+Codacide oil 0.125l+2.5l/ha
Brassica napus napus	4.5	4.5
Matricaria perforata	14.3	14.8
Chamomilla suaveolens	8.9	11.3
Myosotis arvensis	1.3	1.3
Stellaria media	0.7	3.5
Galium aparine	0.7	0.7
Geranium dissectum	0.4	0.5
Sonchus asper	0.6	0.1
Viola arvensis	0.4	0.4

The results obtained suggest that clodinafop+Codacide oil had minimal effect on the naturally occurring broad-leaved weed flora of the plots examined, with very similar populations of each species being found in both untreated and treated plots. It appears that the application of clodinafop increased the survivorship of both *C. suaveolens* and *S. media*. This was probably related to the control of the very competitive grassweeds (Table 6).

Table 6. Mean percentage cover and number of seedheads of grass weed species per quadrat. (% control in parantheses). Experiment 2.

Treatment	% Cover			No. seedheads/m^2		
	WO	BG	RSMG	WO	BG	RSMG
Untreated	1.92	0.26	0.33	6.0	3.2	6.0
clodinafop+Codacide	0.02	0	0.01	0.12	0	0.08
0.125l+2.5l/ha	(99)	(100)	(97)	(98)	(100)	(99)

WO = Wild oats (*Avena fatua*), BG = Black-grass (*Alopecurus myosuroides*), RSMG = Rough-stalked meadow grass (*Poa trivialis*)

Virtually complete control of all three weed grasses was obtained, thereby reducing competition with the crop and desirable broad-leaved species. The data obtained also suggests that grass weed seed return was reduced to a minimum.

Table 7. Final Percentage control of rare cornfield species sown in trays in glasshouse compared with number of plants/10cm in untreated control. Experiment 3

Species	No. plants/10cm (Untreated)	% Control
Chrysanthemum segetum	14	0
Bugloissoides arvense	2	0
Adonis annua	3	*
Scandix pecten-veneris	5	0
Papaver argemone	80	20#
Silene noctiflora	60	0
Ranunculus arvensis	6	15#
Centaurea cyanus	12	0
Misopates orontium	45	15#

# denotes discolouration rather than reduction in plant number. These plants recovered without any population loss.
*insufficient plants in plot to assess control

Treatment with clodinafop had no effect on the species tested in terms of their survivorship. The discolouration noted was transient and had no effect on the long-term survival of the plants.

CONCLUSIONS

The results show that clodinafop-propargyl had little or no activity on broad-leaved species. This inherent lack of activity on dicot species coupled with good levels of control of competitive grass weed species such as *A. myosuroides, A. fatua* and *P. trivialis* make it an ideal product for use on Conservation Headlands. The glasshouse trial (Experiment 3.) carried out on scarce species shows that clodinafop-propargyl could possibly be used in situations where rarer native species are growing or have been sown, thus it could be used to control competitive grass weeds in areas sown with wildflower mixes, eg. permanent set-aside.

These trials, two of which were carried out by independent bodies, show that as well as fulfilling a major role as a black-grass and wild oat killer for intensive cereals, clodinafop-propargyl, TOPIK 240EC is a useful product for those growers wishing to incorporate conservation areas into their farms.

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SUCCESSIONAL CHANGES IN THE FLORA OF A SOWN FIELD MARGIN STRIP MANAGED BY CUTTING AND HERBICIDE APPLICATION

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ABSTRACT

Application of three graminicides, fluazifop-P-butyl, cycloxydim and alloxydim -sodium, to a sown grass and wild flower field margin strip, controlled several weed grasses and allowed a diverse sward to develop. Over a five-year period, botanical diversity declined on all plots from a peak in the second season. Application of fluazifop-P-butyl to sub-plots in the second season resulted in significantly greater species diversity that year. However, in the fourth and fifth years, the overall decline in diversity was significantly reduced on sub-plots which were cut twice a year. Certain species, notably *Leucanthemum vulgare*, declined markedly in the fifth year, while other species, for example, *Achillea millefolium* and *Phleum pratense*, were maintained on plots mown twice a year.

INTRODUCTION

Studies on the ecology of field margins have demonstrated that they influence the ecology of agricultural areas. As relics of natural habitat, such linear features may be important for the maintenance of biodiversity in lowland areas of England (Barr *et al.*, 1993). Over 500 plant species have been recorded from hedgerows in Britain and there are also many beneficial insects associated with field margins. Other studies have indicated that field margin flora may influence the flora of the adjacent crop edge (Marshall, 1989). The creation of sown perennial vegetation strips at arable field edges has the potential to limit weed ingress, particularly of annuals (Marshall & Smith, 1987), but also for perennial species.

Several initiatives on extending field margins for environmental and agricultural benefits have been reported (Marshall & Nowakowski, 1991, Smith *et al.*, 1993). Sowing seed mixtures, as opposed to relying on natural regeneration, may be appropriate in many arable situations, where seed banks and adjacent habitats are often impoverished and the likelihood of recreating diverse flora is low. Initial data have shown that high levels of soil fertility with competitive weeds, such as *Bromus* spp., *Alopecurus myosuroides* and *Galium aparine*, may affect the sown species adversely during the critical establishment phase. Thus, a herbicide, fluazifop-P-butyl, applied in the first year, controlled weed grasses, whilst not affecting sown *Festuca rubra* and encouraged sown dicotyledonous species (Marshall & Nowakowski, 1991). In order to investigate the longer-term stability of sown swards and the effects of initial management treatments, a field experiment was initiated in autumn 1989. In this paper, the changes in the plant communities over five years, on plots sown with a complex seed mixture and treated in different ways are contrasted with plots left to revegetate naturally.

METHODS

An arable field edge adjacent to a grass bank and farm track was selected on Radcot Bridge Farm, Oxfordshire. Twenty seven contiguous main plots, each 8 m long and 3 m wide were marked out. The main plots were arranged in three blocks of nine; within each block a plot was randomly chosen to receive one of nine treatments (Table 1) in the first year. The first year treatments (main plots) included natural regeneration and eight sown treatments that were either mown or treated with a herbicide or growth retardant. In subsequent years, the main plots were divided into two sub-plots and, in 1991, were randomly selected and either sprayed with fluazifop-P-butyl or mown in the spring. Thereafter, the mown sub-plot was re-mown each spring. The entire experiment was mown at harvest time each year, with the clippings blown onto the adjacent track.

Table 1. Details of treatments and dates applied in 1990 (Year 1), 1991 (Year 2) and subsequent years.

1990 main plot treatments, after sowing on 06/09/89:

No.	Sowing	Treatment
1	Unsown	Unmanaged (= natural regeneration)
2	Sown	Unmanaged
3	Sown	Cut on 11/04/90, 07/05/90, 14/06/90, 06/09/90, cuttings removed
4	Sown	Cut on 11/04/90, 06/09/90, cuttings removed
5	Sown	benazolin (225g a.i./ha) + clopyralid (3.75g a.i./ha), 14/02/90
6	Sown	fluazifop-P-butyl (125g a.i./ha) + quinmerac (750g a.i./ha), 08/03/90
7	Sown	cycloxydim (100g a.i./ha) + 1% v/v mineral oil, 08/03/90
8	Sown	alloxydim-sodium (93.7g a.i./ha), 08/3/90
9	Sown	mefluidide (480g a.i./ha), 06/04/90

1991-1994 sub-plot treatments:

A:	cut and leave clippings 15/03/91	B:	fluazifop-P-butyl (93.7g a.i./ha), 05/03/91
A:	cut and remove 28/10/92	B:	unmanaged
A:	cut and remove 22/04/93	B:	unmanaged
A:	cut and remove 22/04/94	B:	unmanaged

All plots mown, clippings removed: 06/09/90; 18/08/91; 27/07/92; 31/08/93; 05/08/94

After cultivating to a fine seed bed, drilled plots were sown on 6 September 1989 at a rate of 37.2 kg/ha (89.3g per plot). All plots were ring-rolled to improve seed-soil contact. The seed mixture was dominated by *Festuca* spp., which show tolerance to the herbicide fluazifop-P-butyl (Marshall & Nowakowski, 1991). The mixture contained nine grass species amounting to 70% by weight, five annual herbs (7.7%) and 22 perennial herbs (22.3%).

In July each year, the vegetation in the plots was assessed using a simple presence-absence technique. In 1990, the first year of the experiment, presence was noted in six quadrats randomly thrown into each main plot. In subsequent years, presence was recorded in five quadrats in each sub-plot. Collected data, expressed as counts out of five, were analysed using analysis of variance. Initially, the data were expressed as mean numbers of species per quadrat, taken from the sum of species scores. The mean number of species per quadrat was analysed for all species and for seven species groups: sown grasses, perennial dicotyledons, annuals and unsown grasses, perennials, annuals and biennials. For the groups with low numbers of species, data were transformed to normalise the variance.

RESULTS

Vegetation in the first season

In August 1990, there were no significant differences in the numbers of unsown species between the different plots (Table 2). Amongst the sown species, the number of annuals was decreased by repeated cutting, while treatment with benazolin+clopyralid reduced numbers of sown perennial dicotyledonous species. There was also a trend towards fewer sown grasses on mefluidide-treated plots than on drilled, unmanaged plots, which, on average, had the most sown grass species. Analyses of the sums of species occurrences showed similar results, with indications of lower frequencies of sown grasses on mefluidide- and cycloxydim-treated plots, reductions in sown perennials on benazolin+clopyralid-treated plots and smaller amounts of sown annuals on regularly mown plots. The number of unsown grasses was reduced by fluazifop-P-butyl+quinmerac and mefluidide treatments.

Table 2. Numbers of sown and unsown species in 1990 on field margin plots receiving different treatments (see Table 1 for details). SG=Sown grasses; UG=Unsown grasses; SP=Sown dicotyledonous perennials; UP=Unsown dicotyledonous perennials; SA=Sown annuals; UA=Unsown annuals; UB=Unsown biennials

	SG	SP	SA	UG	UP	UB	UA
Treatment							
1	1.33	0.67	0	6.33	0.67	1.0	6.0
2	6.67	10.33	2.33	4.33	0.33	0.33	2.67
3	5.0	9.67	0.33	3.33	0.33	1.33	2.67
4	5.33	9.00	2.33	3.33	0.33	1.0	3.0
5	5.33	5.67	2.0	4.67	0	0	3.0
6	5.0	11.67	2.0	2.33	0.67	0	3.0
7	5.33	11.33	2.0	3.67	0.33	0	4.0
8	5.0	13.00	2.0	3.33	0	0.67	4.67
9	3.67	9.67	2.33	3.33	1.0	1.0	3.33
SED(df=15)	0.780	1.891	0.629	N.S.	N.S	N.S	N.S

Mean numbers of species per quadrat 1991-1994

There was a clear trend of declining species number over time on all plots (Table 3). The unsown plots (treatment 1) were least diverse in 1991 but, by 1994, these plots were not significantly different from treatments which were cut in 1990 or treated with benazolin or mefluidide. The subplot treatments were not significantly different in 1991 or 1992. However, by 1993, the cut sub-plots were significantly more diverse than those treated with fluazifop-P-butyl in 1991 and only cut once a year in August.

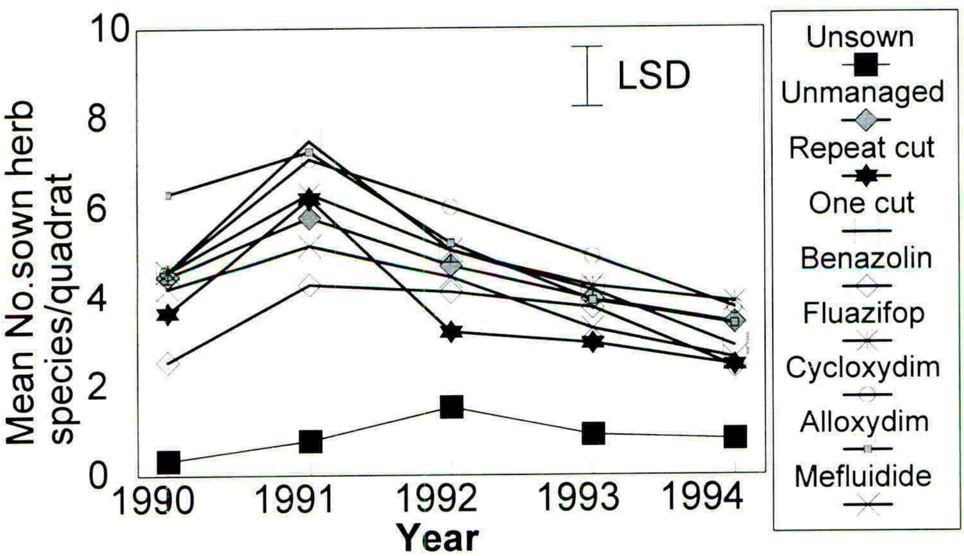
Table 3. Mean number of species per quadrat on field margin strips.

	Treatment								
Year	1	2	3	4	5	6	7	8	9
1990	6.5	13.0	9.8	11.4	9.7	10.6	10.3	13.5	10.1
1991	9.5	12.6	13.6	13.7	10.3	12.6	13.3	13.7	12.4
1992	7.9	10.2	9.0	10.6	9.9	10.1	12.2	10.0	10.7
1993	7.0	10.0	9.1	10.8	9.4	9.7	11.4	8.6	8.9
1994	7.4	9.1	8.4	8.1	9.0	9.8	9.7	9.3	7.7
SED (1991-94) = 0.872 (31df)									

Unsown plots supported the least numbers of sown grasses throughout the five years, though there was some evidence of an increase over time on these plots, indicating colonisation from sown plots. Sub-plots which were mown, maintained sown grasses better than the uncut sub-plots. Unsown plots supported the most unsown weed grasses; excluding this treatment, analyses showed there were no differences between the main plot treatments, but there was a significant increase in unsown grasses from 1991 levels.

Undrilled plots had fewest numbers of sown dicotyledons over the five seasons. In 1991, there were significant differences between treatments (Fig. 1), with fewest on benazolin-treated plots. However, a general decline in diversity by 1994 led to no significant differences between main plot treatments.

Fig. 1. Mean numbers of perennial dicotyledonous species on field margin plots treated in different ways in the first year.

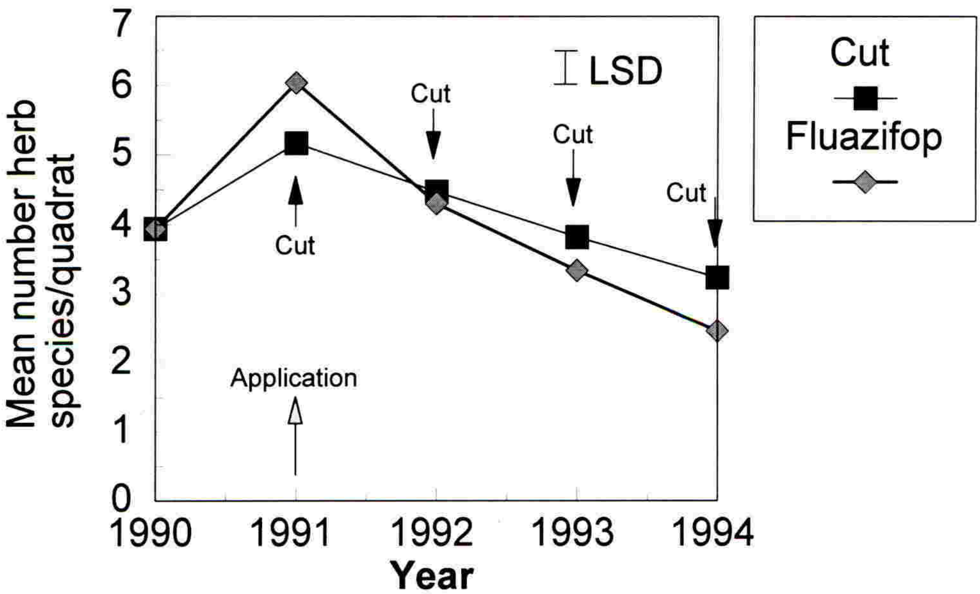


The sub-plot treatments had varied effects. In 1991, sub-plots sprayed with fluazifop-P-butyl were more diverse than cut sub-plots. However, this effect was reversed over time, so that by 1994, there were significantly more sown dicotyledons on cut sub-plots (Fig.2).

Numbers of unsown perennial dicotyledon species, such as *Ranunculus repens,* were low, but greatest on unsown plots. Overall, there was a significant increase in numbers over time, irrespective of the main or sub-plot treatment.

Sown annual species were low in numbers after the first season and the only significant effect was a decline in abundance with time. Unsown annuals were most abundant on unsown plots in 1991. Thereafter, there were no significant effects or interactions. Unsown biennials were most abundant in 1991 and on unsown plots in that year, but numbers were very low throughout the study.

Fig. 2. Mean numbers of sown perennial dicotyledonous species on the sub-plots either mown or treated with fluazifop-P-butyl in the Spring 1991. in the first year.



Individual species

The finer-leaved grasses, *Cynosurus cristatus* and *Anthoxanthum odoratum*, but not *Festuca rubra*, declined to low frequencies by the third season. *Alopecurus pratensis* increased from low frequencies in the first two years, to become common on all plots, except undrilled plots and those treated with fluazifop-P-butyl in the first year. There was a significant overall decline in frequencies of *Phleum pratense*, but frequencies were maintained on most subplots that were mown twice a year. The three gaminicides, fluazifop-P-butyl, cycloxydim and alloxydim, significantly reduced frequencies of *P. pratense* in 1992.

The herbicide benazolin had temporary effects on the frequencies of *Leucanthemum vulgare* and *Achillea millefolium*, which had recovered by 1991. In contrast, *Rumex acetosa* and

Centaurea nigra frequencies remained low throughout the five years on benazolin-treated plots. *R. acetosa* showed marked differences between years, with significantly higher frequencies in 1991 and 1993. *L.vulgare* frequencies declined dramatically in the fourth and fifth years; this decline was significantly less on subplots mown twice a year. A similar pattern, with higher frequencies on mown subplots, was apparent for *A. millefolium* in the fifth year. Both *A. millefolium* and *C. nigra* maintained high frequencies for the five years. *Anthyllis vulneraria* showed a significant decline in numbers over the study to very low frequencies.

DISCUSSION

These data indicate that over a period of five years, successional and dynamic changes occurred in the plant communities created by sowing a diverse seed mixture. Overall species diversity declined after the second season, a result of reducing frequencies of sown perennial herbs. A slight decline in sown grasses was matched by an increase in unsown grasses. The decline in herb species, may have reflected the inherent fertility of an ex-arable soil, which maintained a vigorous cover of grasses. The competitive effect of the grasses may explain the decline in herb species.

Application of the graminicides, fluazifop-P-butyl, cycloxydim and alloxydim, in the establishment year resulted in significantly greater occurrence of dicotyledonous species and increased overall diversity. Application of fluazifop-P-butyl in the second year to some sub-plots, resulted in significantly higher botanical diversity for that season. Subsequently, mown sub-plots were able to maintain higher diversity, possibly as a result of reduced fertility created by removing plant material in both April and August. It is possible that an annual application of fluazifop-P-butyl could check grass growth and competition, allowing herb species to survive. However, this was not tested for within the present experiments.

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VEGETATION MANAGEMENT IN THE ESTABLISHMENT OF POPLAR AND WILLOW SHORT-ROTATION COPPICE

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ABSTRACT

In a feasibility study vegetation management systems designed to reduce herbicide inputs in establishment of coppice were compared with complete chemical weed control treatments. Plots of wheat, rye and rye-grass and natural weeds were established in autumn and killed before or after planting poplar and willow cuttings in spring. Uncontrolled weeds or rye-grass reduced growth of coppice by 95% compared with growth on plots kept bare with residual herbicides. Where cover crops or weeds were killed with glyphosate before planting coppice, weeds were suppressed for some months but crop yields were reduced by 60%. Killing cereal or rye-grass with a selective graminicide in May or June did not result in good crop growth and yields were reduced by 95%. In these treatments there was vigorous development of perennial weeds in summer. Least crop competition was found where a light cover of weeds was killed with glyphosate pre-planting with no further treatment. The study indicated that ground-cover vegetation killed before or after planting coppice did not prevent ingress of competitive weeds. The implications of these results for low herbicide input systems in coppice are discussed.

INTRODUCTION

Effective weed control is essential in establishing short rotation coppice, but the bare soil systems and the chemical inputs involved are not always acceptable. Autumn ploughing and spring cultivation and planting is normal but both nitrogen leaching and soil erosion are enhanced in this system. Establishment of a vegetative ground cover in the autumn before planting could reduce nitrogen leaching in winter and reduce soil erosion as well as possibly reducing herbicide inputs after planting the crop. There are several possible methods of using ground-cover. Cover crops or weed growth can be established in the autumn and killed pre-planting by a non-persistent foliar-acting herbicide. Residues of some species such as winter rye and subterranean clover are reported to have weed-suppressing properties (Clay, 1993). With graminaceous cover crops, poplar and willow cuttings could be planted through the growing cover crop which could then be either killed with a selective herbicide before competition occurred, or suppressed to a non-competitive level by use of occasional low doses of a graminicide. There is no experience of the effects of such ground cover on coppice establishment and growth, so a simple, non-replicated trial was set up to appraise the feasibility of such systems and their effect on crop growth. Growth of poplar and willow planted into seven different 'cover crops' and managed in different ways was compared with growth in bare-soil plots treated with residual herbicides post-planting.

MATERIALS AND METHODS

The site used was at Claverham near Bristol, the soil was a deep silt loam with a pH of 6.6 and an organic matter of 5.6% (loss on ignition method). The selected area was ploughed in March 1992, weed growth killed with glyphosate herbicide in July, rotary cultivated deeply and consolidated in August. Plots 10m x 3m were marked out at the beginning of September and the ground cover treatments listed in Table 1 were sown. Perennial rye-grass cv. Francis and Barcredo (slow growing cultivar) were sown at 22 kg/ha on 29 September, winter wheat cv. Mercia at 146 kg/ha and winter rye cv. Rheidol at 86.8 kg/ha on 8 October. The mixed weed seeds were sown on the 16 October at 53 g/plot and comprised 32% *Stellaria media* (chickweed), 32% *Veronica persica* (field speedwell), 10% *Papaver rhoeas* (field poppy), 6.5% *Matricaria inodora* (scentless mayweed), 6.5% *Lamium purpureum* (red dead-nettle), 6.5% *Viola arvensis* (field pansy) and 6.5% *Myosotis arvensis* (forget-me-not). The plots were then subsequently raked or cultivated to incorporate the seeds into the top 5cm of soil. At the end of March the pre-planting treatment of glyphosate was sprayed on to the appropriate plots. Cuttings were planted on 14 April with four 3m rows of willow cv. Bowles Hybrid planted alternately 1m apart with four rows of poplar cv. Beaupre. Cuttings were spaced 0.5m apart along

Table 1. Ground cover treatments and subsequent management of plots

Ground cover at planting	Pre-plant treatment	Post-plant treatment Herbicide	Time
1. Killed rye-grass	glyphosate[a]	cycloxidim[b]	May
2. rye-grass (killed May)	hand weed	cycloxidim	May
3. rye-grass (killed June)	hand weed	cycloxidim	June
4. rye-grass (suppressed)	hand weed	cycloxidim[c]	rpt. low dose
5. rye-grass - slow (killed June)	hand weed	cycloxidim	June
6. rye-grass - slow (no control)	hand weed	None (allow to grow)	
7. Killed winter wheat	glyphosate	None	
8. Winter wheat (killed May)	hand weed	cycloxidim	May
9. Winter wheat (killed June)	hand weed	cycloxidim	June
10. Killed winter rye	glyphosate	None	
11. Winter rye (killed May)	hand weed	cycloxidim	May
12. Killed natural weeds	glyphosate	None	
13. Bare soil (dug + residuals)	dug	residual[d]	April
14. Killed sown weeds	glyphosate	None	
15. Sown weeds (no control)	None	None (allow to grow)	
16. Bare soil (residual herbicide)	glyphosate	residual[d]	April
17. Bare soil(cultivate no control)	glyp/cult[£]	None	
18. Bare soil (no control)	glyphosate	None	

[a] Roundup (360 g a.i./litre glyphosate) at 1.5 litres/ha. [b] Laser (200 g a.i./litre cycloxidim) at 2.25 litres/ha + Actipron. [c] Laser at 0.25 litres/ha + Actipron.
[d] Mixture of Gesatop 500FW (500 g a.i./litre simazine) at 3 litres/ha + Stomp 400 (400 g a.i./litre pendimethalin) at 5 litres/ha + Butisan S (500 g a.i./litre metazachlor) at 2.5 litres/ha. [£] glyphosate + cultivated.

the row. All cuttings were 25cm long, 10 to 15 mm diameter and all poplar cuttings had primary buds present along their whole length. Treatments 13 and 16 were sprayed with residual herbicide on 20 April, the May cycloxidim treatments were applied on 1 May and the June cycloxidim application on 30 May. Herbicides at the doses shown in Table 1 were applied with a pressurized knapsack sprayer with a 2.5m boom.

Assessments were made of the % ground covered by vegetation, and the growth of the willows and poplars throughout the duration of the experiment using the central 2m x 8m of the plot, and shoot fresh weight recorded in December. All crop measurements were made on the central 16 plants of each species per plot.

RESULTS

Most of the cover crops established well to give 60 - 70% ground cover at the time of planting (Table 2). Broad-leaf weeds particularly *Matricaria inodora* developed on these plots and were hand weeded and weighed in April; there was most on the slow growing rye-grass plots and least on the winter rye (data not shown). Where weeds were sown in October, there was 75% ground cover by March. On plots cultivated in October ground cover in March was only 20%. Both plots treated with residual herbicides were virtually free of weeds for the whole growing season. The glyphosate application in March killed the ground cover crops slowly and complete kill was not seen until some weeks after planting. (Rye-grass was not completely killed by the glyphosate and required

Table 2. Summary of vegetation ground-cover assessments.

	20 March	10 June		8 July		5 October	
Treat.	% cover	% live	% trash	% live	% trash	% live	% trash
1	65	20	60	80	10	90	10
2	65	35	40	80	15	90	10
3	65	80	10	30	70	90	10
4	65	60	30	70	25	100	0
5	65	90	5	75	25	100	0
6	65	100	0	85	15	85	15
7	60	-	-	80	0	80	15
8	60	60	25	40	25	80	20
9	60	80	15	50	30	60	40
10	75	25	20	65	5	90	10
11	75	40	30	35	40	70	30
12	75	60	10	75	10	80	20
13	75	0	0	10	0	1	0
14	50	-	-	80	0	80	15
15	50	80	5	95	5	30	60
16	20	0	0	0	0	2	0
17	20	15	0	50	0	30	60
18	20	15	5	60	0	80	15

subsequent treatment with cycloxidim to give control). On these plots weeds gradually re-established to give 60 - 80% ground cover by July (Table 2). On the plots treated with glyphosate where there was little weed in spring, weeds developed more slowly giving 50 - 60% cover in July. The cycloxidim application killed the graminaceous species slowly taking around three weeks to produce dead foliage. Broad-leaf weeds were present on these plots when sprayed and developed during the summer; although ground cover values were lower when recorded a month after spraying they soon recovered to give a complete cover for the rest of the summer (Table 2).

There was little difference between treatments in height of the crop in June, apart from appreciable reductions in the winter wheat plots (data not shown). By mid July however, shoot height was reduced in all the plots with cycloxidim-treated ground cover or untreated weeds and rye-grass. When shoot height and weight were recorded in December growth on the bare soil, residual herbicide plots, was greatest (Table 3). Weight on plots cultivated in October and sprayed with glyphosate pre-planting was reduced by 50 to 60% compared with the bare soil plots. Where ground cover or weeds were killed with glyphosate pre-planting, with no subsequent weeding, crop weight was reduced by 70 to 80%. Where cover crops were treated with cycloxidim or where there was no weed control, weight was reduced by around 95%; shoot height was affected to a similar degree by the treatments. Survival of poplar and willow was nearly 100% on all treatments; shoot numbers per plant were not consistently affected by treatments (Table 3).

Table 3. Effect of ground cover treatments on crop growth recorded on 14 December 1993.

	Mean stems /plant		Maximum height (mm)		Fresh weight (g)/plot	
Treat.	Willow	Poplar	Willow	Poplar	Willow	Poplar
1.	2.00	1.13	131	144	672	1248
2.	1.33	1.07	73	75	208	304
3.	1.13	1.13	95	99	336	544
4.	1.53	1.00	66	75	208	288
5.	1.19	1.07	66	68	208	240
6.	1.13	1.00	70	83	192	336
7.	1.81	1.00	153	139	1104	1184
8.	1.07	1.00	55	86	128	368
9.	1.29	1.44	52	30	128	96
10.	1.75	1.00	139	158	1068	1677
11.	1.40	1.07	72	84	195	324
12.	2.00	1.06	135	145	963	1213
13.	2.19	1.25	253	202	5570	5273
14.	1.89	1.13	121	133	827	1070
15.	1.00	1.00	59	72	120	197
16.	1.75	1.81	209	214	3645	7156
17.	2.20	1.07	176	149	2121	3974
18.	1.69	1.00	167	174	1528	2428

DISCUSSION

Although plots were largely unreplicated there were clear indications of the consistent adverse effects of ground-cover on crop growth. The results confirm previous evidence of the serious effect of 'weed' competition on the growth of newly-planted poplar and willow (Clay 1993). Growth was clearly less affected by weed competition later in the growing season; plots where ground cover was killed pre-planting and remained weed-free for 2 to 3 months produced around 50% shoot fresh weight compared with weed-free plots, whereas there was 95% reduction on plots with weed all season. This corresponds to earlier work with hardy ornamental plants where growth was more affected by weed presence in May and June than later in the season (Davison & Bailey, 1980). The main factor reducing crop growth in weedy plots is likely to be soil moisture (Davies, 1987) although shading by tall cover crops or weeds might also reduce growth. It is possible that nutrient removal by weeds growing before or in the crop may have affected poplar and willow plots, although P and K levels at the start of the experiment were satisfactory. Where glyphosate was applied pre-planting, plots with denser ground-cover at the time of spraying produced less poplar and willow shoot growth than those with a small ground-cover. This may have been due to the number of weed seedlings emerging; *Polygonum aviculare* was the most abundant weed on the plots with greater initial ground-cover. It is possible that more small seedlings on these plots survived the glyphosate spray because of shielding by the vegetation cover. The depression of crop growth in the plots treated with the graminicide cycloxidim is likely to be due to competition rather than the herbicide. Herbicides such as cycloxidim are used selectively on a wide range of broad-leaf crops with no problems from crop damage. Earlier work in this project showed that young poplar and willow plants were not adversely affected by high doses of cycloxidim (Clay & Dixon, 1993). Perennial weeds, particularly *Agrostis stolonifera* and *Trifolium repens* developed vigorously on the plots in the summer. Some of the growth reduction in the plots with ground-cover may also have been due to slugs. These damaged willows more than poplars; the plots with cereals were worst affected, particularly those not sprayed with cycloxidim until June.

The experiment has also shown that if ground-cover is to be grown before planting coppice, careful management of cover crops is required. Treatment with selective herbicides is likely to be necessary in the autumn or spring if broad-leaf weeds are not to interfere with cover crop growth. Alternatively a higher seed rate leading to denser crop cover could suppress autumn germinating weeds. Growth of *M. inodora* was suppressed on the winter rye treatments which may have been due to crop vigour or allelopathic effects (Perez & Ormeno-Nunez, 1993). There are definite 'environmental' advantages in establishing ground-cover vegetation before planting coppice, particularly in terms of reducing nitrogen leaching and soil erosion in winter. However this experiment has illustrated the problems to be faced if a cost-effective system is to be developed. The system involving lowest inputs would be to allow natural weed to develop after autumn cultivations and kill this with a single herbicide application pre-planting. The duration of weed control this gives may depend on the amount of weed cover present and timing of spraying. The later the application the less likely are weeds to germinate. There is a need for more information on this aspect. The possibility of prolonging weed-free conditions with a low dose of soil-acting herbicide applied with the pre-planting spray should also be considered.

Use of autumn-sown cover crops is attractive 'environmentally' but would impose a significant cost for seed and probably also for selective herbicides in order to obtain a pure stand of cover species. In this experiment the low density of the crops at the time of the pre-planting spray may have limited their subsequent weed-suppressing performance. Further work using higher seed rates and different spraying and planting times may be justified.

Leaving the killing of the cover crop to some weeks after planting lead to severe crop reduction. Herbicides such as cycloxidim are relatively slow acting so early spraying may be needed to prevent cover crop competition when soil moisture becomes limiting in May. There was no indication that the crops benefitted from the greater shelter provided by the cover crop. This could have been masked by the adverse effect of slugs, favoured by the conditions in the ground-cover. Molluscicide application would be effective but adds to cost and reduces the 'environmental' benefit of the system.

All systems involving the establishment of ground-cover in autumn mean soil will have consolidated by planting time. There was no consistent effect of compaction on crop performance in this experiment in that the willow crop was better on the recently dug plot compared with the comparable undisturbed plot, whereas poplar grew less well. Any real effect would need to be established in a replicated trial. The use of ground-cover to suppress weeds would require a planting method which does not disturb soil and promote weed germination. The Swedish Step planter would probably provide this successfully.

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FACTORS AFFECTING WILD PLANT COMMUNITIES OCCUPYING SHORT ROTATION COPPICE CROPS ON FARMLAND IN THE UK AND EIRE

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ABSTRACT

Short rotation coppice (SRC) willow and poplar crops may provide new opportunities for wild plants on farmland. The species composition and relative abundance of the existing plant communities at 29 SRC sites were assessed. From these data, plant communities characteristic of certain SRC plot types were identified using TWINSPAN. Species were also categorised into one of three classes based on their main establishment strategy for general interpretation. A few SRC plots were completely devoid of other plants, while some supported a complete ground cover. Over 129 different species were recorded. Communities differed between SRC plots on ex-cropland in east and central Britain and on ex-grassland in west Britain and Ireland. The age of establishment was also an important determining factor indicating that a stable situation has not been achieved in SRC plantations. The trend however was towards a more stable and diverse community with fewer annuals and invasive perennials and more slower growing perennials.

INTRODUCTION

Short rotation coppice (SRC) may become a widespread crop on farmland taken out of food production in the UK. It is grown to produce wood chips for energy production (heat or electricity). The technologies for production are in place although developments in harvesting methods, clonal choice, management and conversion technologies are ongoing (DTI, 1994).

SRC production systems begin with the planting of unrooted willow (*Salix* spp.) or poplar (*Populus* spp.) cuttings in the spring at around 1m by 1m spacings. These grow roots and arial shoots which are cut back after one year to produce a coppice stool, from which regrowth occurs. The stems are then harvested on a cycle of 2 - 4 years. Hybrids of the Osier (*Salix viminalis*) produce 30 or more stems per stool and exceed 3m in height in one year. Poplar coppice tends to produce fewer but thicker stems. After winter cutting, canopy closure of the coppice regrowth usually occurs by late June so the unshaded period within the crop (outside winter) is restricted to the spring of year one.

Most SRC production plantations will be planted on ex-arable set-aside land and the crop represents a significant land-use change where large areas are proposed. At present, it is difficult to assess the likely plant communities that will develop in SRC over a long period of time as most plantations are less than 10 years old (Sage *et al.*, 1994). Due to the shadiness and relative stability of perennial SRC crops however, they will probably be very different to those found in other arable crops. This paper provides an insight into the plant communities that occurred in these young SRC plantations and the factors affecting their composition.

STUDY SITES

Of the 51 known SRC sites in Britain and Ireland in 1993, 29 were selected for ground flora surveys. Neglected and small (<0.3 ha) sites were excluded. The majority had been planted since 1986 and were 4 ha or less. However the sample included several larger (around 10 ha) production plots (Sage *et al.*, 1994). Within each site, one or more plots of coppice of at least 0.2 ha, each of consistent age class and species were surveyed. In total ground vegetation surveys were undertaken at 59 plots between 28 April and 4 June 1993.

METHODS AND ANALYSIS

For each within-crop ground vegetation assessment, lists of all vascular plants encountered within five quadrats, each 10m long by 1m wide and randomly distributed through the plot, were compiled. These large quadrats suited the often sparse occurrence of plants within the crop. Estimates of abundance (cover classes 1, 2 & 3 equivalent to 0 - 5%, 5 - 25% and 25 - 100%) within the quadrat were assigned to each species. Some plants were identified to family only and were grouped with other species from that family. Environmental variables that may influence the plant species present were also recorded and are listed in Table 1.

Table 1. Environmental variables tested in the analysis.

SRC species	Willow or poplar
Establishment age	Years since planting
Northing or Easting	National grid reference
Age of regrowth	Years since last cut
Soil type	Heavy, medium, light
Last herbicide use	Contact or residual, years
Previous land-use	Cropland or grassland

The five quadrat samples were combined to give one sample per plot for analysis. These data were analysed using TWINSPAN (Two-way Indicator Species Analysis). This analysis worked by splitting the plot samples into two groups and by listing the plant species that were characteristic of (i.e. that are relatively common in) each group. Each group of sample plots were then split again and new plant species identified as characteristic of the new groups. The process was repeated until the plot sample size in a further split would be too small to be meaningful. TWINSPAN effectively treats plant species of different cover classes as different species. A full explanation of this technique can be found in Malloch (1988). At each split it was then possible to investigate which if any of the measured environmental variables differed significantly between the two plot types using a paired 't' test. Species lists for all TWINSPAN groupings are not presented due to space limitations.

Each plant species was also classified according to their main establishment strategy, to allow more general interpretation of the data (after Grime *et al.*, 1988). These were:

Class 1. Seed-bank forming species (mostly annuals), or those able to propogate from buried fragments (e.g. couch grass *Elymus repens*)
Class 2. Invasive perennial species characteristic of disturbed habitats (short-lived perennials).
Class 3. Perennial species characteristic of stable habitats (mostly long-lived perennials).

RESULTS

A total of 129 plant species were identified and recorded during the spring survey period. A further 13 plants were identified to family only, giving a maximum of 142 species. Bare ground occurred in almost all survey plots. All plant species recorded from more than one plot are summarised in Table 2. While there are similar numbers of species from each class, there were more long-lived class 3 perennials recorded on only one occasion (and hence do not appear in the table) than class 1 annuals or class 2 invasive perennials. However, of the 33 species that occurred at 10% or more of the sites, only seven were long-lived perennials. This indicates that although class 3 species richness was relatively high overall, where they did occur they were usually less abundant than the class 1 and class 2 species.

Table 2. Summary list of plant species recorded from at least two UK SRC plots. Species and families have been classified into three classes as shown. The most frequently encountered species in each class occur at the top of each column and then in descending order. A further 29 species were recorded from one plot each.

Class 1. Mostly annuals	Class 2. Short-lived perennials	Class 3. Long-lived perennials
Cirsium arvense	*Urtica dioica*	*Holcus* spp.
Galium aparine	*Chamaenerion angustifolium*	*Hypericum* spp.
Poa spp.	*Epilobium* spp.	*Ranunculus acris*
Elymus repens	*Ranunculus repens*	*Ajuga reptans*
Alopecurus myosuroides	*Rumex* spp.	*Angelica sylvestris*
Lolium spp.	*Cirsium vulgare*	*Veronica serpyllifolia*
Sonchus spp.	*Rubus fruticosus*	*Juncus* spp.
Chenopodium album	*Taraxacum officinale*	*Trifolium* spp.
Bromus sterilis	*Agrostis stolonifera*	*Vicia* spp.
Capsella bursa pastoris	*Senecio* spp.	*Dactylis glomerata*
Convolvulus arvensis	*Cardamine* spp.	*Filipendula ulmaria*
Polygonum spp.	*Potentilla reptans*	*Sanicula europaea*
Myosotis spp.	*Heracleum sphondylium*	*Bellis perennis*
Sinapsis arvensis	*Lamium* spp.	*Carex* spp.
Sisymbrium officinale	*Crepis* spp.	*Lathyrus pratensis*
Stellaria media	*Glechoma hederacea*	*Stachys sylvatica*
Avena fatua	*Conium maculatum*	*Symphytum officinale*
Matricaria spp	*Aegopodium podagraria*	*Cardamine pratensis*
Geranium spp.	*Convolvulus arvensis*	*Deschampsia* spp.
Fumaria officinale	*Plantago* spp.	*Galium* spp. *(not G. aparine)*
Veronica persica	*Anthriscus syvestris*	*Lychnis flos cuculi*
Anagallis arvensis	*Geum urbanum*	*Potentilla erecta*
	Ranunculus ficaria	

The effect of location

The first split in the plant species database identified by TWINSPAN indicated that differences between plots in the arable lowlands of East/central Britain and the grazing land in West Britain/Ireland had the most important effect on the plant communites present (t-test, easting $P<0.005$, previous land-use $P<0.001$). Four plants were found to occur commonly in the ex-cropland plots (n=50) but not commonly in the ex-grassland plots (n=9). These were *Senecio* spp. (mostly groundsel *S. vulgaris*), the grasses creeping bent (*Agrostis stolonifera*) and black-grass (*Alopecurus myosuroides*) and St John's-wort species (*Hypericum* spp.) (all at cover class 1). Bare ground (cover 2 or 3) was also characteristic of the ex-cropland plots.

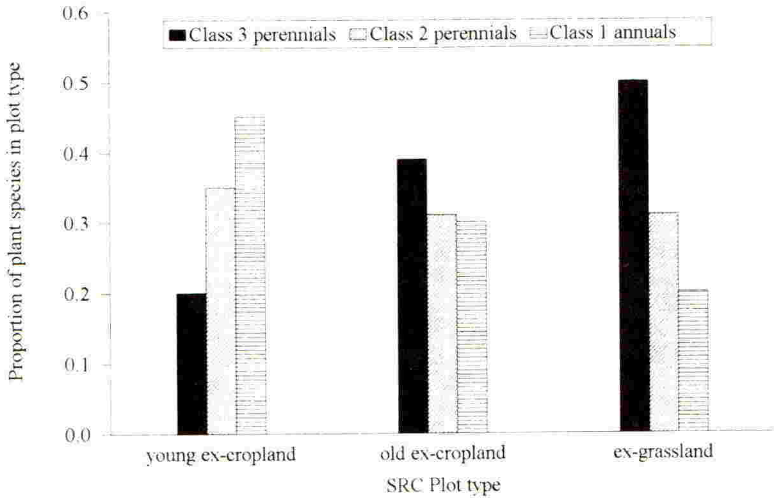
Twenty plants were characteristic of the western ex-grassland plots of which half were long-lived perennials (class 3 species). These included rushes (*Juncus* spp.) and sedges (*Carex* spp.), meadow grasses (*Poa* spp.) (cover 2 and 3), foxtails (*Alopecurus* spp., not *A. myosuroides*) (cover 2) and *Holcus* spp. (mostly Yorkshire fog *H. lanatus*). Characteristic herbs included bugle (*Ajuga reptans*), cuckooflower (*Cardamine pratensis*), meadowsweet (*Filipendula ulmaria*), field buttercup (*Ranunculus acris*) and sorrel (*Rumex acetosa*). Creeping buttercup (*Ranunculus. repens*), creeping cinquefoil (*Potentilla reptans*) and bramble (*Rubus fruticosus*) were commonly found in both plot types at low cover classes (1), but were characteristically more abundant in the ex-grassland plots (cover 2 or 3). Seventy-one different species were recorded at least once in (but were not necessarily characteristic of) the western plots over half of which were long-lived class 3 perennials. The ex-grassland plots therefore contained a greater abundance and diversity of plants than the ex-cropland plots. Unvegetated ground within the crop often supported a covering of moss in the western plots.

<u>The effect of plantation age and herbicide use in the ex-cropland SRC plots</u>

TWINSPAN then split the plant list from the 50 ex-cropland plots into two further groups of plants that each characterise plots differing in the age of establishment ($P<0.05$) and the use of a contact (or translocated) herbicide at last cut-back ($P<0.005$). The recently established (on average 3 years ago) ex-cropland plots, contained mostly annuals and short-lived perennials (class 1 and 2 species) and had been recently sprayed. The older ex-cropland plots (n=41) were planted on average six years ago, and most had not had a recent application of a contact herbicide. The plant database for these 41 plots was split into two further groups by TWINSPAN which again differed with the age of establishment ($P<0.05$). The plants characteristic of the oldest ex-cropland plots (n=25, on average eight years) were mostly invasive perennial weeds - common nettle (*Urtica dioica*), rosebay willowherb (*Chamaenerion angustifolium*), dandelion (*Taraxacum officinale*), creeping bent (*A. stolonifera*), creeping buttercup (*R. repens*) and docks (*Rumex* spp.), but included 3 important class 1 weeds - couch grass (*Elymus repens*, propogates vegetatively like an annual), black grass (*A. myosuroides*) and cleavers (*Galium aparine*). High cover (2 or 3) for many of these weeds indicates an increase in their abundance with time, despite the recent use of herbicides in most. Many class 3 perennials were also recorded from these 'old' ex-cropland plots. These included sanicle (*Sanicula europaea*), field buttercup (*R. acris*), St John's-wort (*Hypericum* spp.), wild angelica (*Angelica sylvestris*), ox-eye daisy (*Leucanthemum vulgare*), tormentil (*Potentilla erecta*), plantains (*Plantago* spp.), ground ivy (*Glechoma hederacea*), cock's-foot (*Dactylis glomerata*), Yorkshire fog (*H. lanatus*) and cranesbill species (*Geranium* spp.).

Three class 2 perennials, hogweed (*Heracleum sphondylium*), groundsel (*S. vulgaris*) and creeping cinquefoil (*P. reptans*), were the only species characteristically more common in the young ex-cropland plots (n=16, around four years old). Eighty percent of all species recorded from these plots were annuals or short-lived perennials and included annual grasses, sow thistles (*Sonchus* spp.), oraches (*Chenopodium* spp.), thistles (*Cirsium* spp.), docks (*Rumex* spp.), common nettle (*U. dioica*) and rosebay willowherb (*C. angustifolium*). The results of this analysis are summarised in Figure 1.

Figure 1. Summarising the effect of age and previous land-use on the plant species in SRC. The young ex-cropland plots contained an abundant annual weed flora (class 1 species) which was partly replaced by stable perennial species (class 3) over several years. A small decrease in the presence of invasive perennials (class 2) was also evident. The ex-grassland plots contained few annual weeds. Over half of the plant species recorded from the ex-grassland plots were stable perennials.



DISCUSSION

The TWINSPAN analysis indicated that the ground vegetation recorded from within existing SRC plots in the UK was dependant on the site location and previous land-use, and on the overall age of the plantation. These effects were more important than for example the soil type. There was also evidence that the recent use of contact or translocated herbicides did not lead to a reduction in the occurrence of annual weeds and invasive perennial species a year or two later. It is perhaps more likely that this would reduce the occurrence of slower growing perennials although this was not shown. The importance of age suggests that a stable situation has as yet not been attained in UK SRC plantations. Gustafsson (1988a) also recorded no stabilisation in the ground vegetation in willow SRC planted on peat in Sweden after five years. Invasive perennials became dominant at the expense of most of the originally occurring species. In this study, the class 2 perennials were also found to invade many plots in the early years. Most of these species were also recorded in the older plots.

In another study however, Gustafsson (1988b) did find some stabilisation in the ground flora of a SRC plantation established on meadow land. In this study, many of the class 3 perennials that occurred in the ex-grassland plots were grassland species and it is reasonable to assume that many existed on these sites before the SRC was planted. Some long-lived class 3 perennial grassland species may therefore adjust to the new shadier conditions in SRC and represent the first signs of a stable perennial flora in SRC habitats. It is likely however that many more woodland or hedgerow perennials would be suited to the crop. Relatively few however were recorded, indicating the known slow colonisation rates of this group of species.

The class 1 and 2 species found in the SRC survey plots and listed in Table 2 include most of the competitive weed species which occupy arable crops. However the class 3 stable perennial species in Table 2 are generally not considered to be important weed species. They tend to be slower growing and have lower water and nutrient requirements than the class 1 and 2 species. As a low value and un-intensively managed perennial crop, SRC may be able to tolerate the presence of some of these plants without compromising production considerations. While weed control at establishment is essential in SRC crops (Clay & Dixon, 1995), a covering of slow growing perennial plants beneath the crop may be more cost effective than ongoing weed control by reducing invasion by the larger water demanding weed species and hence the need for herbicides. Such plants may also improve soil structure, enhance natural insect and other pest control mechanisms and provide conservation and landscape spin-offs (Sage *et al.*, 1994).

A succession towards a stable perennial ground flora in SRC crops may therefore be desirable. There is evidence for this succession in this study but over a long period of time. The ex-grassland sites contained many class 3 perennials that probably survived from a previous land-use. The older ex-cropland plots did contain more class 3 perennials than the younger plots but most of the invasive perennial species remained. It may however be possible to introduce a suitable perennial flora and the practicality of such a policy is being investigated.

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PRINCIPLES OF WEED CONTROL IN *MISCANTHUS* SPP. UNDER CONTRASTING FIELD CONDITIONS

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ABSTRACT

Miscanthus is the most promising of a selection of perennial graminaceous species which are currently under assessment as energy crops in the UK. The genus comprises rhizomatous species with the C4 photosynthetic pathway which are capable of exceptionally high annual dry matter yields (*c.* 25-30 t/ha). As a crop which is evenly spaced and planted at relatively low densities (*c.*10,000 plants/ha), it offers unique problems to the agronomist. Whilst inherently high yielding, the principles of energy capture and conversion in these species mean that maximum potential will be achieved only if weed competition is minimised during two critical phases; crop establishment and the early season growth period from March to May each subsequent year. Successful weed control has been achieved with a wide range of products. This paper reviews evidence for yield suppression by weeds and compares and contrasts weed problems and control measures which have been used in Miscanthus crops growing on a range of soil types and locations throughout the UK. An assessment of the long-term implications of perennial energy cropping on weed flora diversity and density is made.

INTRODUCTION

Burning plant material (biomass) to produce heat and light is the oldest form of anthropogenic energy production. In the so called 'developed world', burning biomass has been supplanted as the major source of energy by fossil fuels, nuclear energy and even hydro-power (Scurlock & Hall, 1992). Only recently has interest in the production of energy from farm grown crops been seen once again to have potential. This has been stimulated by the concomitant development of 'set-aside' within the European Union's Common Agricultural Policy, which requires a proportion of agricultural land to be taken out of the production of certain commodities, and the Department of Trade & Industry's Non-Fossil Fuel Obligation (NFFO). Energy crops have been considered in detail by Richards *et al.* (1993), Speller (1993a) and Heath *et al.* (1994). The group of energy species which are currently closest to widescale production are collectively known as arable energy coppice (AEC), and include willow (*Salix* spp.) and poplar (*Populus* spp.). However, the search has been on for some time to develop even more productive species for the UK. One genus which is showing potential as both an energy crop and valuable source of fibre is Miscanthus; a perennial C4 grass with centres of diversity in Asia and Africa. This crop has received a great deal of attention throughout Europe in the last ten years (Rutherford &

Heath, 1992); its performance in the UK is reported by Bullard *et al.* (1995) and Kilpatrick *et al.* (1994). This plant produces cane-like stems from May onwards, which in a mature crop may exceed 4m in height by August. Within-plant competition triggers senescence of the lower canopy layers from late July. Senescence accelerates during autumn as nutrients sequester back to the roots and a deep leaf litter develops. By February, free-standing leafless canes remain, and it is these which are harvested mechanically. ADAS currently has a wide-ranging experimental programme with Miscanthus including complex physiological studies (Bullard *et al.* 1995) and a yield evaluation on seven sites (Kilpatrick *et al.*, 1994), all of which are funded by MAFF. This paper is based on the experience gained at these sites over the preceding four years.

WHY ARE WEEDS IMPORTANT?

In essence, producing energy crops is far more simple than producing food crops or species with other uses where a specific harvestable commodity is desired. Energy crops work on the principle that biomass is accumulated as the plant canopy intercepts radiant energy. A proportion of that intercepted energy is stored as fixed carbon, and it is the oxidation of that carbon (combustion) which yields thermal energy. At any given moisture content the energetic value of one tonne of *any* two crop species will be similar. These working simplifications lead us to identify that the more harvestable biomass a crop can produce, the more successful it will be. On the basis of these criteria one can identify particularly successful energy crops as those which have a full canopy present for as long as possible to intercept as much radiant energy as possible, and which have very efficient photosynthetic mechanisms for converting that energy into fixed carbon. As with any crop the need to reduce competition to maximise yield means that weed control is an important issue - anecdotal evidence suggests that uncontrolled weed growth will seriously reduce yields through competition for light, water and nutrients (and possibly allelopathic interactions). Weed problems associated with Miscanthus were considered in an earlier paper by Speller (1993b). The present paper represents an update on information relating to successful weed control in Miscanthus and it examines some long-term implications for weed occurrence and diversity within a Miscanthus crop.

It has been found that weed control is particularly important in two phases of Miscanthus development:

Crop establishment

Following careful seedbed preparation Miscanthus may be established by planting small rhizome segments, micro-propagated plantlets or by drilling seed. Currently only the first two methods have been employed in the UK because the clones currently under investigation do not produce viable seed (they are thought to be sterile hybrids). Planting (currently by hand but the use of modified vegetable module planters is feasible) at relatively low densities (currently 10-40,000 plants/ha) during April/May provides adequate soil disturbance and large areas of unoccupied space for weed seedling germination and growth. At this stage the young Miscanthus plantlets and newly emerged plants can easily become overwhelmed by weeds. Herbicidal control may not be appropriate for newly transplanted plantlets as they often endure transplanting stress for the first, critical, two weeks. This may necessitate mechanical weed control. In such a widely spaced, evenly distributed crop this is quite feasible. As the Miscanthus sward matures, a range of selective products can be used (Table 1). Although there are no 'on-' or 'off-' label recommendations for herbicides in Miscanthus, any active ingredient which is appropriate for cereals should also be suitable for this energy crop (with the possible exception of some granimicides). In addition, C4 crop-specific herbicides such as atrazine could be used. Once a full canopy has developed (*c.* late May), germination of new weed seedlings is dramatically reduced, and only shade tolerant species such as *Fallopia convolvulus* and *Stellaria media*, or particularly mature individuals, will survive. In post-senescent, low density crops, autumn germinating species like *Poa annua* may also present problems in the establishment years.

Table 1. Herbicides which have been used successfully to control all weeds in Miscanthus

Active ingredient(s)	Data Source[1]	Notes
atrazine	(1)	Gesaprim @ 2.5 l/ha
bromoxynil/ioxynil	(1)	Briotril @ 2.5 l/ha
bromoxynil/fluroxypyr/ioxynil	(1)	Advance @ 2 l/ha
clopyralid	(2)	(100g/l a.i.) 2.4 l/ha
dichlorprop	(2)	(667g/l a.i.) 5 l/ha
diflufenican/isoproturon	(2)	(100:500g/l a.i.) 3 l/ha
fluroxypyr	(1),(2)	Starane 2 @ 2 l/ha
glyphosate[2]	(1),(2)	Roundup @ 3 l/ha
isoproturon	(2)	Tolkan @ 4 l/ha
metsulfuron methyl	(1),(2)	Ally @ 30 g/ha
metsulfuron methyl + bromoxynil/ioxynil[3]	(1)	Ally @ 30g/ha + Deloxil @ 1 l/ha
metsulfuron methyl + fluroxypyr[3]	(1)	Starane 2 + Ally (0.5l + 20g/ha)
MCPA	(2)	(750 g/l a.i.) @ 5 l/ha
MCPA + MCPB	(1)	Trifolex-Tra @ 7.7 l/ha
mecoprop-P	(2)	Duplosan @ 6 l/ha
paraquat[2]	(1)	Gramoxone @ 4 l/ha
tribenuron methyl	(2)	75%

[1](1) ADAS, (2) Georg Noyé Institut of Weedcontrol 'Flakkebjerg', Denmark.
[2]Herbicides for use before Miscanthus emergence.
[3]tank mixtures.

Whilst drilling Miscanthus seed has not yet been attempted in the UK, viable seed sources are available from Asia. It is likely that whilst the use of seed would dramatically reduce the cost of establishing Miscanthus plantations, the yields obtained in the first two or three seasons will be markedly less than those from rhizome-derived plants. However, weed control may be easier if the crop is established from seed, as it will be more analogous to familiar weed control practices for cereals.

Seasonal regrowth

Following the annual harvest during February or March, Miscanthus will undergo a relatively quiescent period while temperatures and net radiation receipts are low. Once again this offers an opportunity for spring germinating and perennial weeds to compete with the grass. The leaf litter layer may provide natural weed suppression. Early emerging weeds have been controlled successfully with pre-emergence applications of glyphosate or paraquat. Paraquat may be applied as late as first shoot emergence. Any shoots that are scorched or killed at this stage will be replaced quickly. Applications at this time are most likely to be necessary to control grass weeds such as *Elymus repens* and *Poa annua*.

Once Miscanthus shoots have emerged, selective herbicides must be used for the control of vigorous annual dicotyledonous weeds. A 'weed wiper' has been used successfully to apply post-emergence gramoxone to the taller, more persistent, weeds such as thistles (S Groves, pers. comm.). Until the end of May for the first three or four years, limited mechanical weed control may also be practical and effective.

SHORT- AND LONG-TERM ECOLOGICAL CONSIDERATIONS

The temporal changes in a weed community may be very different within a perennial crop, and may have important implications for future weed control strategies. An examination of the phenology and ecological strategies of different weed species may provide some insight into how these changes may occur, and what these changes might be.

Grime *et al.* (1988) have defined plant species by their ecological strategies, a strategy being 'a grouping of similar or analogous genetic characteristics which recurs widely among species or populations and causes them to exhibit similarities in ecology'. In addition the primary strategy 'involves more fundamental activities of the organism (resource capture, growth and reproduction) and recurs widely both in animals and plants'. Most agricultural weed species are described by Grime *et al.* (1988), on the basis of their species phenologies, as 'ruderals' (see Table 2). These species are commonly associated with disturbed fertile sites - exhibiting high relative growth rates and a large investment in reproduction and the production of long-term seed banks. Those ruderals in agricultural sites will typically be those which, as annuals, can respond to seasonal disturbances (i.e. ploughing). In long-term Miscanthus plantations, however, the 'stale seedbed' may seriously reduce the options for species regeneration as there will be a lack of soil disturbance through successive years. In addition, as light is restricted from the base of the canopy for the entire period June-March, only those species with spring-germinating seed stand a realistic chance of survival. Under these new conditions it is possible that we shall see a new weed fauna develop, consisting of perennial competitive species, spring-germinating ruderal species and also 'stress tolerators' such as species which are adapted to low light conditions, or opportunistic species which can take advantage of 'gaps' within the canopy. As an example, the species listed in Table 2 were noted on 12 July 1995 within a mature Miscanthus sward growing on an organic (peat) soil with an inherently high weed burden (1400 plants/m^2). These provide the baseline for an assessment of species diversity and frequency change within a Miscanthus canopy. Although these species were found in a plantation in its third year of establishment (i.e. mature), large-scale destructive sampling throughout the lifetime of the sward has given rise to much soil disturbance and areas where much more light penetrates to the base of the canopy. Furthermore, this experiment has allowed us to assess the effect that Miscanthus crop density has on weed diversity, frequency and development. *Miscanthus sinensis* 'Giganteus' were established at 40,000 and 17,777 plants/ha (Bullard *et al.*, 1995). Whilst species diversity was similar at both densities, species abundance was much higher at the wide density where canopy closure occurred later, and consequently weeds had a longer time for development. At this spacing these weeds were also at a more advanced phenological stage, many flowering in June, whereas at the high density the plants were etiolated and still vegetative.

Table 2. Weed species, their general and reproductive strategies (after Grime *et al.*, 1988) and life-cycle, associated with *Miscanthus sinensis* 'Giganteus' growing at two densities in the Cambridgeshire Fens.

Species (common name[1])	General Strategy[2]	Reproductive. startegy[3]	Life- cycle
Aethusa cynapium (Fool's parsley)	R	S,B_S	annual
Anchusa arvensis (bugloss)	R/CR	B_S	annual
Fallopia convolvulus (black bindweed)	R?	B_S?	annual
Capsella bursa-pastoris (shepherd's purse)	R	B_S (all year)	annual
Chenopodium album (fat-hen)	R/CR	B_S (spring)	annual
Cirsium arvense (creeping thistle)	C	V,W,B_S	perennial
Cirsium vulgare (spear thistle)	CR	W,B_S	perennial
Epilobium spp. (willowherbs)	--[4]	--	
Galeopsis tetrahit (hemp nettle)	R/CR	B_S (spring)	annual
Galium aparine (cleavers)	CR	S (spring/autumn)	annual
Matricaria spp. (mayweeds)	--	--	annual
Polygonum aviculare (knotgrass)	R	B_S (spring)	annual
Polygonum persicaria (redshank)	R	B_S (spring)	annual
Sonchus arvensis (perennial sowthistle)	R/CR		
Sonchus oleraceus (annual sowthistle)	R/CR	W,B_S	perennial
Senecio vulgaris (groundsel)	R	W,B_S (spring)	annual
Stellaria media (chickweed)	R	B_S, V spring/ autumn	annual
Urtica urens (small nettle)	R/CR	B_S (spring)	annual
Viola arvensis (field pansy)	R	B_S	annual

[1]Species names according to Stace (1992).
[2]General ecological strategy, after Grime *et al.* (1988); R = ruderal, C = competitor, CR = competitive ruderal.
[3]Reproductive strategy, after Grime *et al.* (1988); V= vegetative expansion, S = seasonal regeneration, B_S = persistent seed bank, W = widely dispersed seed.
[4]Data unavailable.

CONCLUSIONS

The key to successful weed control in Miscanthus would appear to be timely application of post-harvest products combined with early use of selective herbicides to control spring-emerging dicotyledonous and annual weeds. It is possible that, given effective weed control in the first few years, weed problems will become less severe as the crop matures and the seedbed becomes stale. Whilst successful weed control has been demonstrated on a number of sites with differing soil types and weed floras, Miscanthus has only been established on a small scale in the UK. Weed control on a larger, field scale, may present new problems.

All the products used on Miscanthus at ADAS sites have been used under experimental permit as there are no on- or off-label recommendations for Miscanthus. This situation will need to change if Miscanthus is to be grown on a commercial scale.

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RESPONSES OF BRACKEN AND ITS UNDERSTOREY FLORA TO SOME SULFONYLUREA HERBICIDES AND ASULAM

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ABSTRACT

The effects on bracken (*Pteridium aquilinum*) and its understorey flora were investigated in two field experiments after spraying at full frond expansion with the three sulfonylurea herbicides, tribenuron-methyl, metsulfuron-methyl, amidosulfuron or with asulam. One experiment was located on Dartmoor and sprayed in summer 1991, the other was sited on the Quantock Hills and sprayed in summer 1992. Assessments were made at the Dartmoor site in 1991 and 1992, and at the Quantock site in 1992, 1993 and 1994. Most sulfonylurea herbicide treatments and asulam caused a severe reduction of frond regeneration the summer after spraying. However, only the amidosulfuron and asulam treatments gave effective suppression of bracken fronds in the second year after spraying at the Quantock site. There were no differences in the number of plant species in the understorey flora, between treated and untreated plots, one to two years after spraying bracken. The potential of these sulfonylurea herbicides for bracken control is discussed.

INTRODUCTION

Bracken (*Pteridium aquilinum*) is one of the world's most aggressive and opportunist weeds. Agricultural abandonment, reduced grazing pressures and deforestation are among the primary reasons for the increased invasion by this vigorous competitor. The loss of agricultural land and natural habitats through bracken encroachment not only has economic drawbacks but also ecological disadvantages, such as restricting species diversity. There is also concern about the effects of bracken on human and animal health (Taylor, 1990).

Research at IACR-Long Ashton Research Station (LARS) has investigated control stategies for bracken, including studies of potential new herbicide treatments. Recent work has identified the sulfonylurea herbicide, tribenuron-methyl, to have considerable activity against established bracken plants grown in containers and that tank-mixtures with low doses of metsulfuron-methyl can act synergistically against bracken (West & Butler, 1991). Other work at LARS has found that amidosulfuron (a sulfonylurea herbicide for broad-leaved weed control in cereals) is also effective against established bracken grown in containers (West, unpublished data).

Data obtained from a field trial on bracken control started in 1992 on the Quantock Hills (Somerset) are presented here. The objective was to determine the potential for bracken control of tribenuron-methyl, alone and in mixtures with metsulfuron-methyl, and amidosulfuron applied alone. All treatments were compared with asulam, the standard and most selective herbicide approved for bracken control in the UK. Also summarised are results of a collaborative (LARS-ADAS) field trial set up on Dartmoor in 1991, which included some treatments comparable to those in the Quantock experiment but did not include amidosulfuron. Originally, husbandry treatments of cutting and pulling bracken fronds were also included at both sites to compare with herbicide treatments. However, funding for this project was terminated early and the full effects of the husbandry treatments were not realised and are, therefore, not included in this paper.

MATERIALS AND METHODS

Two sites with a uniform, dense population of bracken were selected. The main experimental site was located on Merridge Hill, part of the Quantock hills in Somerset (National Grid Reference ST 203 326). This area of common land has been ungrazed for about 30 years and before that was occasionally cleared of scrub, which consisted mainly of hazel (*Corylus avellana*) and ash (*Fraxinus excelsior*). The other experiment was sited at Coldeast Cross, Dartmoor in Devon (NGR SX 751 738) where bracken had encroached into a grazed area of upland grassland. Both experiments were designed as three randomised blocks with three replicates for each treatment. Each single plot had a treated area of 8m x 8m with a 2m regularly cut, discard-area between plots. For assessment purposes, five 1m^2 permanent quadrats were placed diagonally across the centre 5m x 5m of each plot. The Dartmoor trial was fenced to exclude livestock.

Herbicides were applied at the Quantock site on 29 July 1992 using an Oxford Precision Sprayer with a two person, hand-held 4m boom fitted with 8002 flat fan nozzles delivering 300 litres ha^{-1} at a pressure of 210 kPa (30 psi) at a walking speed of 1m s^{-1}. Similar equipment and volume rates were used at the Dartmoor site, which was sprayed on 6 August 1991. The herbicide formulations used were asulam (400 g AI litre^{-1} SL), tribenuron-methyl (75% AI WG), metsulfuron-methyl (20% AI WG) and amidosulfuron (75% AI WG). The surfactant, Agral (polyoxyethylene nonylphenol) was added at 0.1% v/v to all herbicide treatments. Doses of herbicides used are given in Tables 1-3. At the time of treatment, bracken plants were at full frond expansion with 7-10 pairs of pinnae on fronds which had a mean height of 150 cm (Quantock site) or 105 cm (Dartmoor site). The weather during treatment at both sites was dry and sunny with a light breeze.

At the Quantock site, frond numbers and plant species in the understorey flora were counted within the 1m^2 permanent quadrats in late June 1992, before spraying. Assessments were repeated in late June 1993 and 1994. On 8 September 1994, a final assessment was made on the central 2m x 2m of each plot. This excluded any interference by fronds growing from rhizome which had encroached into the plots from the untreated discards. All fronds in this area were cut off at ground level, counted and weighed. A random sub-sample of 10 fronds from each plot were taken to calculate mean frond height per plot. Assessments of frond numbers at the Dartmoor site were made in late July 1991, before spraying, and again in July 1992. Assessments of the numbers of understorey species within the permanent quadrats were only made in spring 1992 (the year after treatment). Bracken data from both sites were subjected to Analysis of Variance. Data on numbers of species in the understorey flora were statistically analysed for the Quantock experiment but no analysis is available for the results of the Dartmoor experiment.

RESULTS

Effects on bracken

Frond counts on the Quantock experiment (Table 1), taken before the herbicides were applied in 1992, showed no significant difference between plots. The numbers of fronds produced the following year (1993) were severely reduced by all the herbicide treatments tested, whereas the untreated plots showed no significant difference in frond numbers from the previous year. In the second summer after treatment (1994), only the asulam and amidosulfuron treatments were still giving effective suppression of frond regeneration. The numbers of fronds regenerated during 1994 in the plots treated with tribenuron-methyl or metsulfuron-methyl had recovered, and were not significantly different from the numbers regenerated in the untreated plots. An increased number of fronds was also found in the plots treated with the tribenuron-methyl + metsulfuron-methyl mixture, although these were still significantly less than those in the untreated plots.

There were no significant differences in frond numbers between plots on the Dartmoor experiment before herbicides were applied in August 1991 (Table 1). Frond numbers on the untreated plots in July 1992 were similar to the previous year. Frond regeneration was severely reduced by treatments with asulam, tribenuron-methyl at 90g AI ha^{-1} and the mixture of tribenuron-methyl at 60g AI ha^{-1} with metsulfuron-methyl at 5g AI ha^{-1}. Tribenuron-methyl at 60g AI/ha reduced frond numbers by only 50% of the untreated control value.

Table 1. Response of bracken to herbicide treatments.
(Values are means of 3 replicates, each consisting of 5 x $1m^2$ quadrats)

Treatment	Herbicide dose ($g\ AI\ ha^{-1}$)	Frond number / m^2 Quantock June 92	Quantock June 93	Quantock June 94	Dartmoor July 91	Dartmoor July 92
Asulam	4400	22	<1	3	24	1
Tribenuron-methyl	45	19	3	21	-	-
Tribenuron-methyl	60	-	-	-	31	12
Tribenuron-methyl	90	20	6	19	32	7
Metsulfuron-methyl	5	19	3	24	-	-
Tribenuron-methyl +	45 + 5	19	1	14	-	-
metsulfuron-methyl	60 + 5	-	-	-	28	2
Amidosulfuron	45	21	<1	2	-	-
Amidosulfuron	90	19	<1	1	-	-
Untreated	-	18	19	27	29	24
SED (df 239 & *100)		4.1	4.1	4.1	*4.4	*4.4

The final assessment and harvest of bracken fronds at the Quantock trial in September 1994 (Table 2) also showed asulam and amidosulfuron to be the most effective treatments, only a few, weak, fronds being found in these plots. Frond weights and heights were all moderately reduced by tribenuron-methyl or metsulfuron-methyl applied alone, compared with the untreated plots, but frond numbers were not significantly different. The tribenuron-methyl + metsulfuron-methyl mixture reduced frond number and weight compared with the single components, and caused a considerable and significant reduction compared with the untreated.

Table 2. Final assessment of bracken from the central 2m x 2m of each plot on the Quantock experiment in September 1994 (Values are means of 3 replicates)

Treatment	Herbicide dose (g AI ha^{-1})	Fronds / m^2 Weight (g)	Fronds / m^2 Number	Frond height (cm)
Asulam	4400	73	2	60
Tribenuron-methyl	45	1435	20	112
Tribenuron-methyl	90	1542	17	113
Metsulfuron-methyl	5	1526	19	109
Tribenuron-methyl + metsulfuron-methyl	45 + 5	860	12	96
Amidosulfuron	45	37	1	65
Amidosulfuron	90	20	<1	56
Untreated	-	2697	25	159
SED (df 22)		438.2	5.0	18.8

Table 3. Effects on understorey flora from herbicide treatments applied to bracken (Values are mean number of plant species in 3 replicates)

Treatment	Herbicide dose (g AI ha^{-1})	Quantock June 1991 *g	Quantock June 1991 *bl	Quantock June 1993 g	Quantock June 1993 bl	Quantock June 1994 g	Quantock June 1994 bl	Dartmoor July 1992 g	Dartmoor July 1992 bl
Asulam	4400	3.3	7.0	4.0	8.7	3.7	7.3	7.7	5.0
Tribenuron-methyl	45	3.3	6.0	2.3	7.3	3.3	8.3	-	
Tribenuron-methyl	60	-	-	-	-	-	-	8.0	6.3
Tribenuron-methyl	90	4.0	7.7	3.7	8.0	2.7	7.3	8.7	6.3
Metsulfuron-methyl	5	3.7	8.0	4.7	8.3	3.3	9.3	-	-
Tribenuron-methyl +	45 + 5	2.7	7.0	2.7	8.7	4.3	6.7	-	-
metsuluron-methyl	60 + 5	-	-	-	-	-	-	6.0	6.0
Amidosulfuron	45	4.0	7.7	3.3	7.3	2.7	7.0	-	-
Amidosulfuron	90	2.7	8.0	3.3	8.7	3.3	7.7	-	-
Untreated	-	2.3	8.7	4.3	7.7	4.3	7.3	7.0	6.0
SED (df 48) years within treatment		0.9	1.0	0.9	1.0	0.9	1.0	-	-
SED (df 34) treatments within year		0.8	1.0	0.8	1.0	0.8	1.0		

* g and bl are grass and broad-leaved species, respectively.

Effects on understorey flora

At the Quantock site, the number of grass or broad-leaved species found in the understorey flora (Table 3), showed no significant change between treated and untreated plots, either in the same year or between years. At the Dartmoor site, there did not appear to be differences between the number of species found on treated and untreated plots, one year after herbicide treatments. More grass species were present at the Dartmoor site than on the Quantock site.

DISCUSSION

Results from these experiments showed that, of the herbicides tested, only amidosulfuron compared favourably with the standard asulam treatment in its ability to suppress frond regeneration for up to two years after spraying. Experimental work and experience has shown that asulam can effectively suppress bracken for five to seven years after treatment (Pakeman & Marrs, 1993). Further work is needed to determine the potential of amidosulfuron for longer-term control of bracken.

The failure of tribenuron-methyl or metsulfuron-methyl, applied alone or in mixture, to give adequate suppression of frond regeneration in the second year after spraying was surprising, considering the severe suppression achieved in the first year after treatment. Thus, at the doses tested, neither of these sulfonylurea herbicides would be suitable treatments for bracken control in the UK. Higher doses of both these herbicides may give improved control (metsulfuron-methyl is used at 36g AI ha^{-1} for bracken control in Australia) but this would not be economically or environmentally acceptable in the UK.

It was encouraging to find that the understorey flora was not affected by any of the herbicide treatments on bracken. Furthermore, on the Quantock site, there was a trend towards increased ground cover of many of the understorey plant species on the treated plots when the bracken cover was decreased (West, unpublished data). However, some species at this site, such as bramble (*Rubus* spp.) and rosebay willowherb (*Epilobium angustifolium*) can themselves become aggressive opportunists. Therefore, in most situations, a planned programme of after-care for land management is essential and would need to be implemented soon after control treatments have proved successful.

The selective effects of the herbicide treatments are probably associated more with the dense bracken frond canopy, which intercepts most of the herbicide applied, and not the inherent selectivity of the herbicides tested. In areas where the bracken is sparse, overall spraying with herbicides may damage non-target plant species. For example, certain pasture grasses may be susceptible to asulam (West & Standell, 1989), while some wild herbs will be vulnerable to amidosulfuron, a herbicide used for broad-leaved weed control (West, 1994). Other non-target ferns are also likely to be damaged by herbicides which are active against bracken.

In situations where the weed canopy is well above the non-target plants of the understorey, selective application of herbicides using ‘wiping’ methods to place the herbicide directly on to the target without risk to the understorey flora may prove useful. Work in Australia, (Winkworth & Hamilton, 1986), showed that asulam applied using a carpet-wiper could be effective against bracken and that the quantity needed per hectare could be considerably reduced compared with conventional spaying methods. The sulfonylurea herbicide, metsulfuron-methyl, applied using a carpet-wiper is now used successfully in Australia for controlling bracken (Hamilton, 1990). One of the reasons suggested for the success of these carpet-wipers is that the herbicides are wiped on to the underside of the fronds which, according to Kirkwood (1987), is the most effective position for uptake and activity. Because of the relatively high doses of metsulfuron-methyl required for bracken control, and its long residual activity, it may not be a suitable candidate for wiper applications in the UK. However, further investigation of other sulfonylurea herbicides, such as amidosulfuron, may be warranted. This herbicide has low mammalian toxicity, is predominantly foliage-acting, has short residual activity and appears to have a high level of activity against bracken at relatively low doses. These attributes suggest that it may be a suitable herbicide to apply with a carpet-wiper, especially if overall spraying is not environmentally acceptable.

In conclusion, asulam has proved to be a reliable herbicide for bracken control for the past 25 years and will probably remain the only option for 'selective' overall spraying of bracken in the forseeable future. However, for small-scale control or containment of bracken, such as in conservation and amenity areas, the use of selective applicators with asulam or other herbicides active on bracken, possibly amidosulfuron, may be a safer option for control with less risk to other plant species.

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STUDY OF THE LOW DOSE STIMULATION OF BUDS AND RHIZOME GROWTH IN BRACKEN USING A PEAKED LOGISTIC CURVE

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ABSTRACT

A modification of the peaked logistic curve described by Brain & Cousens (1989) was used to show that low doses of thifensulfuron-methyl and tribenuron-methyl can stimulate buds on the bracken rhizome system. However, no comparable low dose stimulation was detected with metsulfuron-methyl at the doses used. Ethephon caused no advantageous stimulation of growth points (developing fronds, lateral and apical buds).

INTRODUCTION

Enhancement of growth by low doses of herbicides has been observed in many cases (Kemp & Caseley, 1987). However, there are few reliable methods for detecting or quantifying such enhancement. One such method has been described previously by Brain & Cousens (1989), and this has been adapted here to examine a particular case where enhancement of growth by low doses of herbicides could be used to beneficial effect in the control of a pernicious weed, bracken (*Pteridium aquilinum*).

Bracken has an extensive rhizome system (Watt, 1940) which has both active and dormant buds, and axillary buds. The dormant and axillary buds do not accumulate the herbicide and are therefore unaffected by herbicide treatment. This problem was also noted by Hinshalwood and Kirkwood (1988). A mechanism is thus required to activate these axillary and dormant buds and to switch on their 'sink'. This may allow increased translocation of herbicide from the fronds into the activated growth points in the rhizome, killing them and leading to the eventual death of the bracken plant.

The glasshouse pot experiment reported here examines the activity of three sulfonylurea herbicides and ethephon at a range of doses, and their effect on bud stimulation and developmental changes in bracken rhizomes. This experiment was set up in late November to permit 'natural' senescence of the fronds and translocation of herbicides into the rhizome. To assist the examination of the response of bracken to low doses of herbicides, a modification of the peaked logistic equation described by Brain & Cousens (1989) was developed.

MATERIALS AND METHODS

Rhizome fragments (3 cm long, with one viable bud) were taken on 17 September 1991 from one stock plant of the Long Ashton (L2) type (Lawrie, 1994). These were planted singly 3 cm deep in 9 cm diameter pots containing a mixture of sand-clay loam, peat and sand (3 : 2 : 2) plus 'Osmocote' fertilizer (18 : 11 : 10, N : P : K) at 2.0g/l. Plants were grown in a glasshouse at 17° to 20 °C with 16h supplementary lighting and were watered from above onto the soil.

Plants were treated on 28 November 1991 when they had two to three fronds each with two to five pinnae pairs, and the rhizome had two to six fronds developing below the soil, two to five buds and 20 to 85 cm of new rhizome. Treatments were applied using a laboratory track sprayer fitted with a 'Lurmark' 80015E flat fan nozzle giving a volume rate of 202 l/ha at 2.1 kPa. Four different chemicals were used. The formulations of the active ingredients and doses (g a.i./ha) of the chemicals were: ethephon, 48% SL, (70, 200, 600, 1800, 5400); metsulfuron-methyl, 20% WG, (0.016, 0.08, 0.4, 2, 10); thifensulfuron-methyl, 75% WG, (0.048, 0.24, 1.2, 6, 30); tribenuron-methyl, 75% WG, (0.024, 0.12, 0.6, 3, 15). Thus there were 20 chemical treatments plus 3 untreated controls, with four replicates. The surfactant `Agral' (Zeneca Plant Protection), a non-ionic alkylphenol ethylene oxide condensate, was added to the spray solutions of the sulfonylurea herbicides at 0.01% v/v.

After spraying, plants were returned to the glasshouse where they were laid out in four complete randomised blocks. On 10 January (six weeks after spraying), plants were transferred to a frost-protected glasshouse (0° to 10 °C), to allow natural senescence of remaining foliage. After one week, the plants were moved back to the 17° to 20 °C glasshouse where they were allowed to regenerate. Eleven weeks after spraying (11 February 1992), fronds were removed and weighed; fresh and dry weights were recorded. Rhizomes were carefully washed and developmental structures (frond and bud numbers) were counted. The length and weight of the rhizomes were also recorded.

Variance stabilising transformations were needed for all variates, as follows:- rhizome length : Log *e* (length+20); rhizome fresh weight : log *e* (weight+0.5); total growth point number : √(number+0.5). Peaked and simple logistic curves were fitted to the means; to detect if there was significant low-dose enhancement by a given herbicide.

The peaked logistic curve presented by Brain & Cousens (1989) was modified to a more useful form as follows:-

$$y = C\frac{1 + \left(\frac{P^{B-1}}{1 - 2P^{B-1}}\right)\frac{Dose}{LD50}}{1 + \left(\frac{1}{1 - 2P^{B-1}}\right)\left(\frac{Dose}{LD50}\right)^{B}} \qquad (1)$$

This curve is an extension of the simple logistic (Striebig, 1980), with a rise in response from the untreated control before the rest of the sigmoid curve. C and LD_{50} retain their meanings (C being the response for the control (zero dose), LD_{50} the dose giving 50% of the control response), and B and P control the steepness of the curve and the size and position of the peak at low doses. P is the dose as a proportion of the LD_{50} at which the response returns to the level of the control. The peaked logistic becomes the simple logistic if P=0, so the model actually fitted was the peaked logistic, with P set to 0 if the simple logistic was required. The difference in lack of fit between a simple model and a more complex one can be used to assess whether the more complex model was a significantly better description of the means, significance indicating low dose enhancement.

For the peaked model, various parameters of low dose enhancement can be obtained. a) DPeak, the dose giving maximum enhancement. At this dose, the slope of the curve against log(dose) equals zero. With some simplication, the equation reduces to solving equation 2 below to find DPeak. This equation cannot be solved explicitly to give DPeak, so was solved iteratively using the function minimisation facilities in Genstat to find the value of DPeak giving the minimum value of the square of the equation.

$$\left(\frac{B-1}{1-2P^{B-1}}\right)\left(\frac{DPeak}{LD50}\right)^{B} - \left(\frac{B}{P^{B-1}}\right)\left(\frac{DPeak}{LD50}\right)^{B-1} - 1 = 0 \qquad \textbf{(2)}$$

b) YMax, the maximum as a percent of the control.
The maximum response (Max) can be found directly from the formula for the peaked logistic, once DPeak has been found and, then, YMax calculated from this.

$$YMax = 100 \times \left(\frac{Max}{Control}\right) \qquad \textbf{(3)}$$

c) Range, the dose at which the response returns to the control response

$$Range = P \times LD50 \qquad (4)$$

All analysis was carried out using Genstat (Payne *et al.*, 1993)

RESULTS

Ethephon had no systematic effect on bracken growth with increasing dose and accordingly the data were not presented. Metsulfuron-methyl, thifensulfuron-methyl and tribenuron-methyl had a significant effect on all measurements; (frond fresh weight, rhizome fresh weight, rhizome length and total growth point number). Visual examination of the means (Figures 1a & b) generally showed systematic changes with increasing dose, with high doses of all three herbicides generally giving significantly lower means than the control. In several cases, the means for low doses appeared to be greater than the control mean, although not strongly significantly so.

Where low dose enhancement was found, using the equations, a substantial increase in growth above the control was indicated (YMax, Table 1), with an estimated maximum of 2½ times the control growth being produced. The range of enhancement (Range) was estimated to be occurring between ¼ to ¾ of the LD_{50} (P). It should be noted that the estimate of the extent of low dose enhancement was not very reliable (as indicated by the large standard errors for YMax) and, as such, should be treated with caution. The position of the maximum enhancement (DPeak) was more accurately estimated, with similar doses producing this for rhizome length and growth point numbers. In contrast, the estimates of LD_{50} indicate that larger doses are required to reduce growth point number by half than are required to reduce rhizome length by a similar amount.

In the case of total growth point number (Fig. 1a), the peaked logistic model gave significantly better descriptions than simpler models of the data for thifensulfuron-methyl and tribenuron-methyl. This suggested enhancement of growth by low doses of both these herbicides. There was no significant evidence for low dose enhancement by metsulfuron-methyl (P,Table 1). None of the herbicides showed significant low dose enhancement of rhizome fresh weight, even though the means for the lower doses were all (non-significantly) greater than the control for both thifensulfuron-methyl and tribenuron-methyl (Fig. 1b).

Table 1. Parameter estimates for fitted curves (Equation 2) to describe the effect of dose of three herbicides on bracken growth. (See text for explanation of parameters).

	Rhizome Fresh Weight	Rhizome Length	Total growth point number
C Control Response	2.02 (0.35)	194.9 (29.6)	17.5 (2.1)
LD50			
Metsulfuron	0.39 (0.06)	0.38 (0.024)	0.49 (0.218)
Thifensulfuron	1.23 (0.42)	1.36 (0.289)	2.16 (0.690)
Tribenuron	2.20 (0.49)	1.01 (0.209)	1.54 (0.429)
B			
Metsulfuron	9.7 (68.0)	11.13 (2.30)	1.92 (1.92)
Thifensulfuron	2.13 (2.62)	2.86 (0.96)	2.10 (0.45)
Tribenuron	8.17 (5.52)	3.35 (0.75)	2.42 (0.44)
P			
Metsulfuron	0	0	0
Thifensulfuron	0	0.661 (0.13)	0.513 (0.131)
Tribenuron	0	0.723 (0.07)	0.595 (0.090)
DPeak			
Thifensulfuron		0.350	0.313
Tribenuron		0.299	0.283
Range			
Thifensulfuron		0.89 (0.26)	1.11 (0.36)
Tribenuron		0.73 (0.14)	0.92 (0.21)
YMax			
Thifensulfuron		202.4 (76.3)	191.3 (4.9)
Tribenuron		245.0 (98.8)	219.6 (5.5)

Note: Standard errors for parameters in brackets have 52 df.

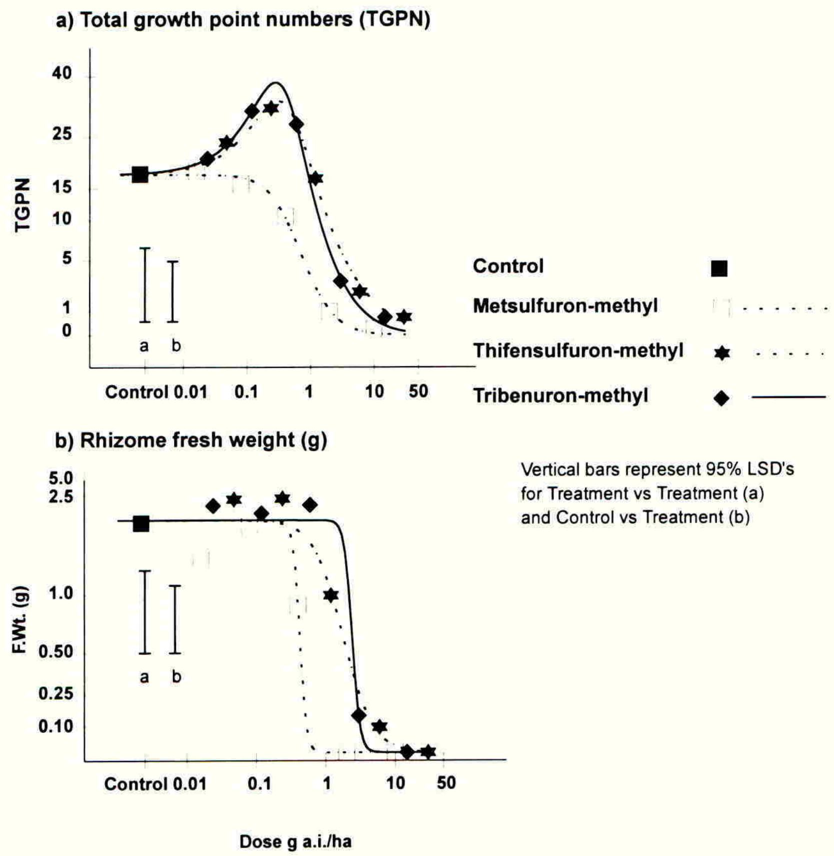
DISCUSSION

There was no evidence of low-dose enhancement for metsulfuron-methyl. This could be because metsulfuron-methyl does not stimulate growth at low doses, or because the doses used were too high. Work by West and Butler (1991) clearly indicated synergism between this herbicide and tribenuron-methyl.

With the use of the peaked logistic equation, it was possible to detect and quantify the low dose stimulation by both tribenuron-methyl and thifensulfuron-methyl of the total number of growth points on the rhizome (Fig. 1a, Table 1), as well as on total rhizome length and frond fresh weight (data not presented). However, no enhancement was detected for rhizome fresh weight (Fig. 1b). As there was an increase of growth and bud numbers, this lack of low dose enhancement for rhizome fresh weight may indicate a redistribution of available resources.

Our experiment would seem to indicate a potential for using low doses of some herbicides, such as tribenuron-methyl and thifensulfuron-methyl, to initiate potential sinks in the rhizome and activate bud growth in order to encourage the translocation of the desired herbicide to useful sites of activity.

Fig. 1 Means of transformed data (symbols) and fitted curves (lines)



Ethephon is usually regarded as a bud stimulator (Caseley, 1970, working on *Elymus repens*). However, in our experiment, ethephon proved to be not very effective as a bud stimulator (data not shown). Similarly, Hinshalwood & Kirkwood (1988) found that ethephon did not increase the uptake of asulam by bracken, when the two components were applied as a mixture.

The equations described in this paper proved to be useful for detecting and summarising low-dose enhancement despite the fact that only five doses were used in our experiment. If more doses had been used a better logistic curve could probably have been fitted. Thus, this method could be a useful tool to examine other cases where low-dose enhancement or related phenomena are anticipated.

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DITHIOPYR WEED CONTROL IN TURFGRASS

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ABSTRACT

Dithiopyr is safe to most established cool and warm season turfgrasses. A single pre-emergence application of the EC formulation of dithiopyr at 560 g ai/ha provides 120 days control of *Digitaria* spp. equivalent to 840 g ai/ha of prodiamine and 3300 g ai/ha pendimethalin. Dithiopyr will also provide control of pre-tillered *Digitaria* spp. at a similar rate. It has been demonstrated in multiple trials over a two year period that split applications of the EC, 45 to 60 days apart, have the potential to lower dithiopyr use rates as much as x 2 without a reduction in efficacy. In addition, new FG (fertilizer granular) formulations have allowed for lower use rates than the EC by reducing volatility and providing more efficient active ingredient transport to the soil surface.

INTRODUCTION

Dithiopyr (Dimension®) was commercially introduced into the U.S. turfgrass market by Monsanto Company in 1991 and purchased by the Rohm and Haas Company on 29 June 1994. Dithiopyr is a highly active pre-emergence turfgrass herbicide that provides consistent control of *Digitaria* spp at 420 to 560 g ai/ha. Dithiopyr's soil half-life (DT_{50} = 40 days), very low solubility in water (1.38ppm) (Adams, 1989) and limited movement in the soil profile (Schleicher *et al.*, 1995) are ideal environmental characteristics for use in turfgrass management. It has been shown that dithiopyr vapors damage *Digitaria* spp. seedlings from emerging up to tillering stage providing early post-emergence control (Rohn *et al.*, 1989).

In 1993 and 1994 field trials were conducted across the eastern half of the U.S. to optimize dithiopyr for long-term *Digitaria* spp.control in turfgrass. This paper summarizes results from trials utilizing split applications to extend control at low use rates and secondly to define efficacy for fertilizer granular formulations having the potential to more efficiently deliver the active ingredient to the soil layer and reduce volatility loss. In addition, the post-emergence control of *Digitaria* spp. was investigated.

MATERIALS AND METHODS

Field studies were conducted in the U.S. during the spring and summer of 1993 and 1994 by university researchers and in-house field personnel. Test sites were selected based on historical knowledge of *Digitaria* spp. infestation or overseeded with *Digitaria* seed. A randomized complete block design was used with three or four replications per site. Individual plots ranged in size from 2-5 m^2. Commercial formulations of dithiopyr evaluated were a 120 g/l EC and fertilizer granular impregnated with dithiopyr. Commercial formulations of pendimethalin and prodiamine evaluated were 60DG and 65WD, respectively. Liquid treatments were applied with a four nozzle CO_2 backpack or tractor mounted boom sprayer, delivering 187-468 l/ha. Granular treatments were weighed for individual plots and applied with a shaker bottle. Pre-emergence applications were made prior to *Digitaria* spp. emergence. A second application was made 45 to 60 days later where split applications were being evaluated. Post-emergence applications were made to *Digitaria* spp. ranging in size from 1 leaf(LF) to 1 tiller(T).

Percent *Digitaria* spp. control was assessed 100-200 days after the initial application. Statistical analysis of data collected from individual test sites was performed. An analysis of data averaged over multiple test sites was not possible.

RESULTS AND DISCUSSION

Dithiopyr comparison with competitive standards

Dithiopyr EC provided long term (106-198 days) *Digitaria* spp. control, in both 1993 and 1994, when applied at 560 g ai/ha (Table 1). Pendimethalin provided comparative control at 3300 g ai/ha while prodiamine at 840 g ai/ha, provided superior control in 1993 but was less effective in 1994. The 420 g ai/ha rate of dithiopyr provided equivalent control to competitive products in 1993 but was less effective in 1994. The variable results between years at the 420 g ai/ha rate was likely a result of variability in soil half-life. Dithiopyr, when applied as an EC formulation, has been shown to dissipate rapidly through volatilization under wet field conditions in effect shortening its soil half-life to as little as 17 days (Rhan *et al.*, 1989).

Table 1. Pre-emergence control of *Digitaria* spp. in turfgrass

		Average % *Digitaria* control(106-198 DAT) (number of trials)	
	Rate (g ai/ha)	1993	1994
dithiopyr	420	85 (6)	59 (2)
dithiopyr	560	81 (7)	79 (6)
pendimethalin	3300	88 (5)	82 (3)
prodiamine	840	97 (7)	69 (5)

Single versus split applications

It was clearly demonstrated over a two year period that the performance of dithiopyr could be improved with split applications. The data showed that split applications of 140 + 140 g ai/ha provided better *Digitaria* spp. control than 560 g ai/ha applied once (Table 2). By splitting the application, the required 180 days of control was achieved at a combined rate x 2 lower than needed from a single application.

Table 2. Single vs. split applications of dithiopyr for control of *Digitaria* spp in turfgrass

Application rate (g ai/ha)	Average % *Digitaria* control (number of trials)	
	1993	1994
140 + 140	97 (3)	89 (3)
230 + 230	97 (3)	89 (3)
420	85 (6)	59 (2)
560	81 (7)	79 (6)

Formulation comparison

Dithiopyr applied as a fertilizer granular (FG) was x 2 more active than the commercialized EC formulation (Table 3). I_{80} for the FG and EC formulations were 0.308 g ai/ha and 0.644 g ai/ha, respectively. Granular formulations have been shown to substantially reduce the volatility of dithiopyr from the soil surface increasing its soil half-life by nearly 4 fold (17 days for EC vs. 63 days for GR) (Adams *et al.*, 1889). The longer soil half-life in conjunction with greater efficiency in delivery of the active ingredient to the soil layer indicate the FG formulation can provide long term *Digitaria* spp. control at lower rates.

Table 3. EC vs. granular formulation of dithiopyr for control of *Digitaria* spp in turfgrass

Application rate (g ai/ha)	Average % *Digitaria* control (number of trials)	
	EC	FG
140	49 (5)	78 (2)
280	63 (8)	79 (4)
420	77 (7)	84 (5)
560	76 (14)	92 (6)
840	89 (10)	93 (2)

Post-emergence *Digitaria* spp. control

Dithiopyr EC averaged greater than 90% control of 1 to 3LF *Digitaria* spp. at 140 g ai/ha, in studies conducted during 1993 and 1994 (Table 4). The granular formulation required a rate of 280 g ai/ha to provide equivalent control. Effective control of 3 to 5LF *Digitaria* spp. was achieved by both formulations at 420 g ai/ha. The EC was consistently more effective on 5LF to 1T *Digitaria* spp. than was the granular formulation.

Table 4. Postemergence control of *Digitaria* spp. with dithiopyr formulations

Application rate (g ai/ha)	Dithiopyr formulation	Average % *Digitaria* control Growth stage at application 1-3 LF	3-5LF	5LF-1T
140	EC	98	57	50
	GR	73	67	5
280	EC	100	73	75
	GR	99	82	20
420	EC	100	93	84
	GR	100	93	53
560	EC	100	95	96
	GR	100	94	82

CONCLUSION

Dithiopyr is an excellent herbicide for *Digitaria* spp. control in turfgrass. It has been demonstrated that use rates can be further lowered by changing the delivery system from an EC to a granular formulation or by utilizing split applications. It is suggested that a reduction in volatility resulting in significantly longer soil half-life is the major contributor to the greater long term weed control of the granular formulation. Repeat application of the EC formulation 45-60 days apart lowered the dithiopyr use rate by distributing the active ingredient over the time period required for 180 days residual control. The post-emergence activity will also contribute to increased residual control by extending the application window from pre-emergence to 5LF stage of *Digitaria* spp. development.

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NEW HEDGEROW ESTABLISHMENT: IMPLICATIONS FOR WEED AND PEST CONTROL

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ABSTRACT

Preliminary data are presented on the colonisation of new hedgerows by plants, invertebrates and small mammals compared with similar observations of established hedgerows in the same location. It is suggested that plant colonisation is influenced by management of the adjacent crop. New and old hedgerows are shown to differ markedly if the adjacent crop was a grass field but not significantly when the adjacent field was in set-aside. In addition, investigations of carabid populations demonstrate that high numbers, found within the new hedgerow, are reduced in adjacent grass crops but not in set-aside. Finally, small mammal colonisation is reported. The findings are discussed in relation to new hedgerow establishment for nature conservation and associated weed and pest problems.

INTRODUCTION

Hedgerows and vascular plants

In Britain, about 500 plant species occur in hedges (Hooper, 1970). The most widespread hedgerow shrubs are hawthorn, blackthorn and elder which are adapted to the colonisation of open lands (Brooks & Agate, 1986). Herbaceous colonisation may occur through seeds transported by birds and small mammals that use the hedgerow as a corridor. Alternatively, plants may use vegetative methods to spread along the structure.

Hedgerows may be rich in remnant woodland plant species (Pollard, 1973) but colonisation may enhance species richness (Hooper, 1970). Hence, the contribution of the seed bank is of great importance in hedgerows adjacent to agricultural fields (Silvertown, 1992).

Weed seed germination may depend on variations in soil type, climate and landscape history although competition between species may be important. The current study examines the development of newly established hedgerows. Thus, comparisons are made between the herbaceous flora in established hedgerows and that developing in new hedgerows during the first year after planting.

Hedgerows and invertebrates

The importance of invertebrates in hedges has been reviewed in numerous studies (Gruttke, 1994). Economically, the most important species are those which prey upon crop pests. Hedgerows may act as refugia for predatory species such as ground beetles (Carabidae) by providing overwintering and shelter habitats (Sotherton, 1985). Ground beetle communities are strongly influenced by the floristic structure of the hedge bottom and margin (Knauer, 1989). Carabids are amongst the first colonisers of many new habitats (Booij 1994) and form a major part of the natural pest control system. Consequently, an understanding of the development of communities is fundamental for management prescription. This preliminary study will investigate early colonisation of hedgerows by carabids.

Hedgerows and small mammals

Research into small mammals in agricultural environments has concentrated on the direct effect of pesticides (Greig-Smith *et al* 1992), population dynamics and behaviour in established hedgerows and adjacent woodland. The response of small mammals to new hedgerows has received little attention despite the new habitats that hedgerows create for rodent species which are still considered to be major agricultural pests (Montgomery & Dowie 1993). Therefore, it is important to understand the mechanisms by which small mammals colonise these habitats with respect to time.

MATERIALS AND METHODS

Establishment of new hedgerows

Hedgerows of *Prunus spinosa* (total length 540m) were established in Cheshire during late 1994. Four management treatments were established randomly along their lengths. Each replicated plot was 15m wide, with a 5m buffer zone between treatments and extended 4m into the field on either side of the hedgerow. The four treatments were: 2m seed mixture (50% *Festuca rubra* and 50% *Dactylis glomerata*) and 2m adjacent crop (H); 4m seed mixture (F); 4m crop (C) or 4m of unseeded (U) area.

Plant sampling

Quadrats were placed 1m from new and established hedges into the adjacent field. In each quadrat, species composition and percentage cover were recorded. Hedges, bordering either grass fields seeded with *Lolium perenne* or set-aside, were monitored every two weeks between March and July 1995. Diversity and similarities between species found in the different hedges and their various treatments were analysed using Shannon's diversity index (Krebs, 1994) and Maximum Likelihood similarity matrices (Cook, 1978) respectively.

Invertebrate sampling

Invertebrates were sampled, within new hedgerows separating *L. perenne* from set-aside, using standard pitfall traps containing $10cm^3$ 4% formaldehyde, set at field level. Each plot contained traps in the centre and at 3 and 5m on either side of the hedge (ie in the hedge margin or in the adjacent crop). Traps were set and collected on four occasions during May 1995 and the number of carabid beetles determined for each occasion.

Mammal trapping

Longworth mammal traps were laid at the centre of the new hedgerow. Traps were set at dawn and dusk daily for a period of five consecutive trap nights in July 1995. A total of 56 traps were placed on each occasion over a hedgerow length of about 500m. Similar trap densities were set in adjacent established hedgerows.

RESULTS

Table 1. Plant species in new and mature hedgerows bordering *L. perenne* and set-aside.

Species Present	Grass								Set-aside							
	New				Mature				New				Mature			
	H	C	F	U	1	2	3	4	H	C	F	U	1	2	3	4
Anagallis arvensis										*	*	*	*			
Capsella bursa pastoris		*		*												
Cirsium arvense		*		*	*	*		*		*	*	*				
Equisetum arvense								*								
Galeopsis segetum		*							*	*	*	*				
Galium aparine													*			*
Heracleum sphondylium						*							*	*		
Hirschfeldia incana	*	*	*	*					*	*						
Matricaria perforata	*	*		*						*	*	*				
Plantago major										*						
Polygonum aviculare	*	*	*	*					*	*	*	*				
Polygonum persicaria	*	*	*	*					*	*	*	*				
Pteridium aquilinum													*	*	*	*
Ranunculus repens									*		*	*				
Rubus fruticosus						*									*	
Rumex obtusifolius					*		*		*		*	*				
Spergula arvensis		*	*	*					*	*	*	*				
Stellaria media	*		*						*							
Urtica dioica	*		*	*	*	*	*		*		*		*	*	*	
Veronica chamaedrys			*							*						
Viola tricolor	*	*	*	*					*	*	*	*				

Table 2. Shannon's diversity indices 1 m into bordering fields of different types.

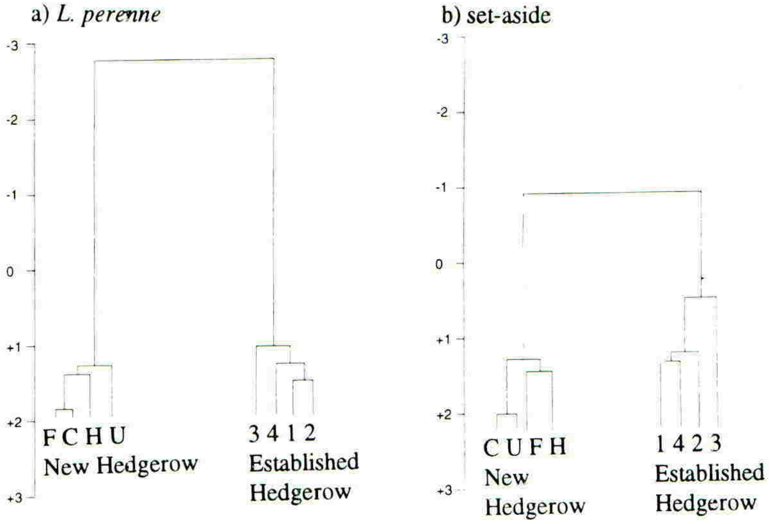
Field type	Hedge	Treatment	Diversity Index
		H	1.31
	New	C	1.39
		F	1.70
		U	1.40
Set-aside		1	0.77
		2	0.74
	Established	3	0.71
		4	0.77
		H	1.87
		C	2.12
	New	F	2.16
		U	2.20
L. perenne		1	0.97
		2	0.96
	Established	3	0.41
		4	0.30

KEY (both tables): H: 2m crop, 2m grass seed mixture; C: 4m crop from adjacent field; F: 4m seed mixture; U: untreated. 1, 2, 3 and 4 are replicate untreated plots in mature hedgerows.

Plant species found in newly planted and established hedgerows during the study period are shown in Table 1. The diversity of plant species was much greater in the new hedgerow plots than in established hedges regardless of the treatment applied to the field margin (Table 2).

Analysis of plant species, using the technique of Maximum Likelihood, demonstrated that the plots within the newly established hedgerows were generally similar to each other regardless of the field margin treatment and were separated by the dendogram from plots adjacent to established hedgerows (Fig.1) regardless of cropping in the adjacent field or the distance away from the hedge.

Figure 1. Dendograms of plants in hedgerows bordering *L. perenne* and set-aside.



KEY: H: 2m crop, 2m grass seed mixture; C: 4m crop from adjacent field; F: 4m seed mixture; U: untreated. 1, 2, 3 and 4 are replicate untreated plots in established hedgerows.

Statistical significance at $P < 0.05$ in the Maximum Likelihood test requires a difference of greater than +1.96 or less than -1.96, the latter indicating significant dissimilarity. Hence, there was no significant difference between any of the new hedgerow treatments bordering either *L. perenne* or set-aside (Fig. 1). Similarly, there was no significant difference between plots in established hedgerows. However, when bordering *L. perenne*, there was a significant difference between plant species in the new hedgerow margin and those in the established hedgerow margin (Fig 1a). In contrast, new and established hedge borders were not significantly different when the field was in set-aside (Fig. 1b).

The numbers of carabids were significantly greater in the hedgerow than in the adjacent grass crop (Fig. 2). Numbers found in the set-aside were reduced although not significantly. However, although the number of carabids was about three times higher in set-aside than in *L. perenne* the difference was not significantly different. Finally, there was no significant difference in carabid numbers between treatments in the new hedgerow.

Figure 2. Number of carabids in hedgerows bordering a set-aside field and a grass crop

```
                                     Individual 95% Confidence Intervals
Trap setting          Captures      ---+---------+---------+---------+--------
                      per trap
Set-aside field          65                  (------*------)
Set-aside margin         68                   (------*------)
Hedge centre            119                               (------*------)
Grass margin            114                              (------*------)
Grass field              20         (------*------)
                                    ---+---------+---------+---------+--------
                                       0        40        80       120
```

Small mammal captures revealed a marked habitat preference of the two most common species captured (Table 3). New hedgerows were preferred by *Apodemus sylvaticus* whilst *Clethrionomys glareolus* remained within established hedgerows nearby.

Table 3. Mammal occurrence in hedgerows of different types.

	Hedgerow type	
	New	Established
Apodemus sylvaticus	20	4
Clethrionomys glareolus	1	46

Chi-squared analysis: $P < 0.001$ ie. species are negatively associated

DISCUSSION

One aim of new hedgerow planting is to replicate the environment existing within established hedgerows. The data presented here indicated that primary establishment produces different plant communities than those in established hedges (Fig 1) with a low degree of overlap between the two habitats (Table 1). The differences were statistically significant only when the adjacent crop was grass rather than set-aside. It is, therefore, suggested that adjacent land management can have a significant effect on plant species development within new hedgerows.

Species diversity was much greater in the new hedgerows than in established ones (Table 2). This probably results from disturbance during the planting of the hedgerow mobilising the seed bank. It is recognised widely that such factors can encourage the emergence of new species (Silvertown, 1992). Undoubtedly, plant diversity is increased considerably in the new hedgerows and many of the newly emergent species are recognisable as potential weeds. Consequently, it is intended that the plots be monitored in the future to document further invasion by annuals, perrenials, shrubs and trees and to record weed infestation.

Data for carabids supported that provided by plants. Numbers were higher in the set-aside and the hedgerow than in the adjacent grass crop. This may demonstrate that management has created differences in numbers in the hedgerow. It is recognised that disturbance may increase carabid populations (Booij, 1994). However, the species inhabiting the *L. perenne* may have been specialist carabids and this is the subject of further analysis. Nonetheless, the high numbers of carabids in the hedgerow are very encouraging for pest control potential.

Small mammal observations indicated that, of the two prominent species, only *A. sylvaticus* was using the new hedgerow. This is consistent with observations which indicate that *C. glareolus* prefers established hedgerows whilst *A. sylvaticus* is more ubiquitous (Pollard & Relton 1970). Nevertheless, it may present a potential pest problem.

To summarise, in the first season after planting the new hedgerows have produced a much more diverse plant community than comparable established hedgerows. Hence, there is a danger of weed infestation under certain cropping regimes. Carabids have been found in large numbers with potential benefits for pest control although possible failure to disperse into adjacent crops may be a concern. Finally, it is apparent that the new hedgerows do not provide shelter for the range of small mammals normally found in established hedgerows.

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AGRONOMIC AND ENVIRONMENTAL EVALUATION OF SET-ASIDE UNDER THE CAP REFORM SCHEME

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ABSTRACT

A programme has been instigated by the Ministry of Agriculture, Fisheries and Food to evaluate the environmental and agronomic impacts of set-aside, considering plants, insect pests, diseases and birds. The evaluation involves both sampling and modelling. A geographically-explicit approach is needed to analyse apparent conflicts, such as that between weed control and scarce arable plant conservation, where the optimum solution may vary between localities. General models of plant species distribution and vegetation dynamics on set-aside are outlined, and extrapolation to the national scale discussed.

INTRODUCTION

Arable land was first set-aside in the UK in 1988. At the time, it was far from certain about the wider costs and benefits of the scheme compared with the alternative approach of encouraging less intensive agriculture on a wider scale (e.g. Potts, 1991). As the five-year set-aside programme progressed, experiments and surveys showed a remarkable variety of agronomic and environmental responses to setting aside land (Clarke, 1992; Clarke *et al.* 1994). Perhaps the worst case was identified by Shield & Godwin (1992), whose set-aside plots on heavy soil developed high levels of couch (*Elytrigia repens*), of little or no environmental benefit and a substantial potential problem for future cropping. More encouraging were those situations where individuals used the opportunity of set-aside to help promote specific environmental objectives, notably the farm on the south coast where a combination of wetland and scrub was created from arable land to become an important area for breeding and migrant birds (Firbank *et al.*, 1993).

Several trends were apparent. In terms of agronomic impact, set-aside could be managed to reduce weed infestations and, in terms of pest and disease problems, set-aside appeared no worse than other sections of the rotation. The ecological impacts were more varied. On the positive side, the winter stubbles created in the first season of set-aside turned out to be very suitable for seed-eating birds, and in some cases scarce plants occurred in large numbers. On the negative side, the practice of weed control in spring and early summer by cultivation destroyed many nests of skylarks and other birds attracted by apparently ideal habitat (Poulsen & Sotherton, 1993).

The set-aside scheme was revised and expanded in 1993 for economic reasons, but by this time there was sufficient experience to improve the rules to reduce the agronomic harm and increase potential environmental benefits. New options were introduced to help specific plant and animal communities, and the Habitat and Countryside Access Schemes were announced to give special incentives for environmental improvements to set-aside or former set-aside land. Since then, the set-aside scheme has been amended to allow for different combinations of short, medium and long-term set-aside, each allowing for different combinations of management. In 1995, it was announced that new farm woodland scheme areas will count towards the set-aside requirements for arable area payments, and other amendments allowing for more types of non-food producing areas to count towards set-aside are being sought from the EC.

AN EVALUATION OF THE IMPACTS OF SET-ASIDE

There is now sufficient knowledge available to suggest the likely impacts of different forms of set-aside management on weeds, pests, diseases and on biodiversity in general. Unfortunately, we are still a long way from being able to quantify the impacts of the scheme as a whole. This is because the national impacts depend upon the take up of different set-aside options and management techniques. Secondly, there is a geographic element, in that the same management will have different impacts depending upon the location of the farm and upon its soils. Thirdly, we are still a long way from having a clear idea of the impacts of the control situation of farming without set-aside.

In 1994, therefore, MAFF announced a tender for a three - year agronomic and environmental evaluation of set-aside. The contract was awarded to a consortium comprising the Institute of Terrestrial Ecology, ADAS and the British Trust for Ornithology. There are several discrete modules within the work, dealing with set-aside management adopted by farmers, changes to the plant communities of set-aside and following crops, insect pests and plant diseases on set-aside land and adjacent and following crops and the use of set-aside land by breeding birds. Wintering birds are already being considered by the Royal Society for the Protection of Birds. What makes the work of the consortium unusual in this area of work is the importance of developing models of the impacts of set-aside management on a national basis.

This work is just beginning, but the rest of the paper will endeavour to give a flavour of the approaches we are adopting, with special reference to plants.

The need for a geographically explicit approach

The impacts of set-aside vary from place to place within the country. One particular example concerns the potential conflict of interest between weed control and the conservation of scarce arable plants. Scarce arable plants are the most threatened section of Britain's flora (Stewart, Pearman & Preston, 1994). Some of these threatened plants have appeared on set-aside because early set-aside is free of herbicides and the competition from volunteers and others plants is often less intense than within a crop. The conflict arises because the cultivation and herbicide applications needed to control problem weeds are also fatal to plants of conservation interest.

In practice, this conflict may not be as serious as may appear at first glance. The recent distribution of scarce arable plants is concentrated on the lighter soils of south-east England (Fig. 1, Firbank & Wilson, 1995), and on such light soils the need for weed control is often less than elsewhere. The use of distribution maps can alert farmers and their advisors of the potential presence of particular species, to help focus on-farm field botanical surveys. Once the farmer is aware of the presence of any scarce plants on the farm, appropriate management can be undertaken.

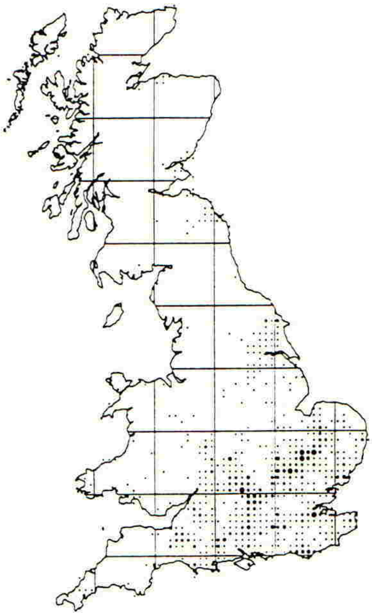

Fig. 1. Distribution of scarce arable plant species from 1970 onwards. 1-2 species ·; 3-4 species •; 5-6 species ●; 7 species ● . From Firbank & Wilson (1995).

Modelling vegetation development on set-aside land

The vegetation succession on set-aside depends upon the plant community in and around the field before set-aside (which in turn depends upon climate, soil type and management history) and upon the management practices adopted during set-aside. If the behaviour of the plant community is known, it should be easier to model the responses of pests, diseases and animal groups to set-aside.The approach of the Consortium is that if these factors can be modelled successfully, then changes to set-aside policy and practices can be explored before they are introduced. The modelling process will be cyclical; model development, validation and continued development. Data are being collected from around 200 farms to feed into this process. The first stage of the modelling is being developed from theoretical principles, however.

The first step is to suggest what species are likely to be present in any given field. The idea is similar to that used in the example of scarce plants above, namely to draw upon knowledge of species distribution. The most valuable data set turns out to be a systematic survey of plants carried out in 1988 by the Botanical Society of the British Isles, who tried to identify all plant species found within a nationwide sample of grid of squares, each 2 km by 2 km. The information can be combined with data on soils in each square to give a smoothed distribution of the probability of occurrence of any given species in any given square. The methods are similar to those described by Hill, Le Duc & Sparks (submitted). The results for couch (*Elytrigia repens*) are shown in Fig. 2. Note that this map shows the probability of finding the species in that square; the likely abundance of the species needs to be estimated separately. Once this has been achieved for all plant species judged important on set-aside land, then a model exists for the initial plant community on any given area of set-aside land.

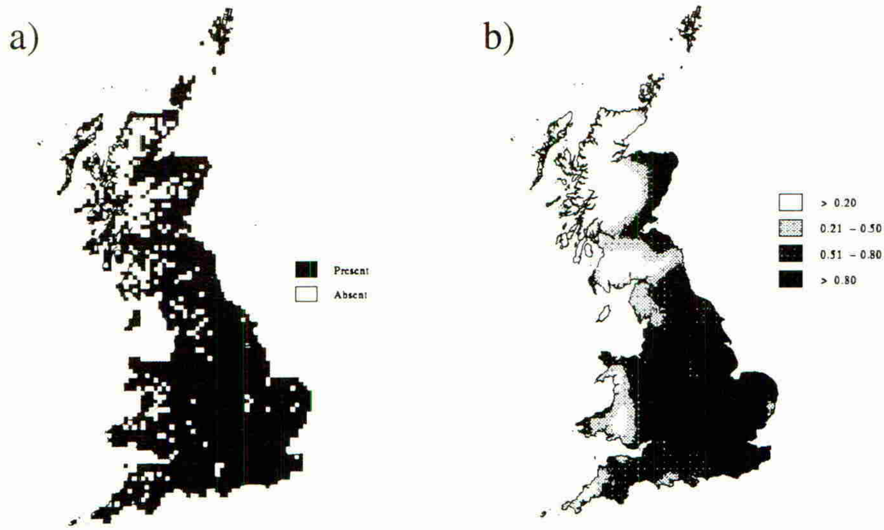

Fig 2. British distribution of *Elytrigia repens*, (a) from Biological Centre Records and (b) smoothed from field survey and soils data.

Community development can be modelled using the succession model SETSARIO (Hill, 1992). This takes into account the growth and reproductive characteristics of each plant species and the management adopted by the farmer, and suggests the trends in vegetation development over as much as ten years. The transition from communities dominated by volunteers, annual weeds, litter and bare ground to those dominated by perennial grasses is well described (Fig. 3). By using SETSARIO along with the model for describing the initial plant communities, it will be possible to suggest the dynamics of plant communities without ever visiting the site. It is unlikely that this approach will prove satisfactory, because of the potential importance of more local factors, and so the models will develop in the light of data from the field. However, it does provide a starting point for modelling the impacts of set-aside on vegetation, and this in turn provides a basis for models concerning pests, diseases and birds.

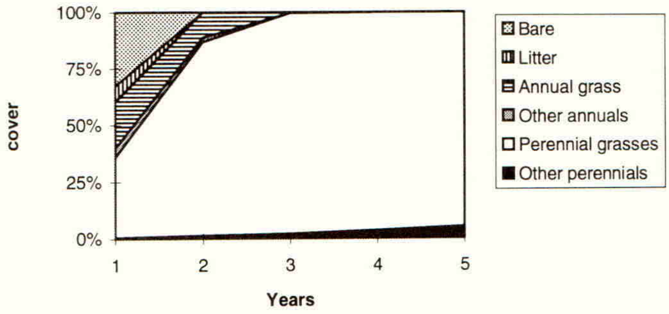

Fig. 3 Example output of SETSARIO, showing potential vegetation changes following one summer cut each year.

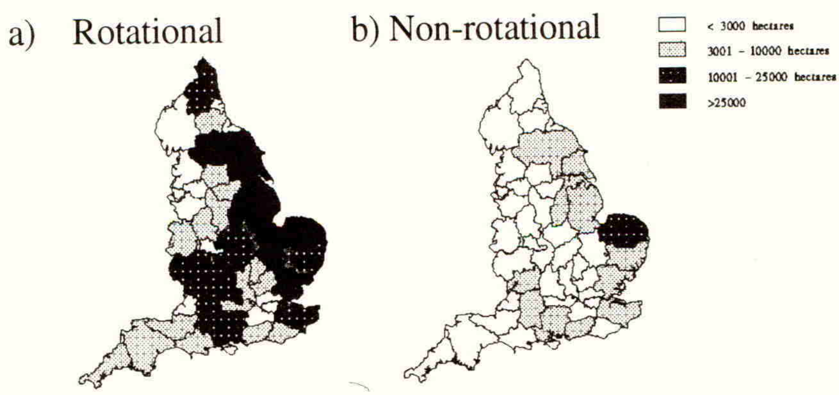

Fig 4. Distribution of rotational and non-rotational set-aside in England in 1993-4. Redrawn from Firbank (1995).

Scaling up from local to national impacts

Just as it is possible to use national data to help suggest what will happen in individual fields, so it is possible to extrapolate from the local to the national situation. In principle, SETSARIO and other models can be applied across the country, taking soils and species distribution into account. However, information is needed about the geographic distribution of patterns of management of set-aside across the country. In England, set-aside is concentrated in the arable areas of the east (Fig. 4), but little is known how set-aside management practices vary. Therefore, we are also undertaking a wider survey of farmers, to identify wider trends of set-aside management which can be built into the analyses.

CONCLUSION

There is little point in assessing agronomic and environmental impacts of set-aside independently from one another. The management of set-aside is central to both. For any given management option, an assessment needs to be made of how well it meets its objectives - whether agronomic or environmental - and what the implications may be for other parts of the agroecosystem. It is impossible to design a survey to deal with all potential combinations of management, soils and species present, and so some form of modelling approach is necessary. If suitable models can be developed which describe the field situation to an acceptable level of accuracy, then the potential impacts of future changes to the set-aside rules can be estimated within days, not years.

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Session 8A

Herbicide Tolerant Crops: Concerns

Chairman	Mr H M Lawson
Session Organiser	Ms C M Knott
Papers	8A-1 to 8A-4

HERBICIDE-TOLERANT CROPS - ENVIRONMENTALISTS' CONCERNS AND REGULATORY RESPONSES

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ABSTRACT

Environmental campaigners are concerned that herbicide tolerant crops will damage the environment, including damage caused by increased use of chemicals and by the spread of genes to cause 'genetic pollution'. They also fear that because of resistance problems, herbicide tolerance will not prove to be a good agricultural strategy, and in general cannot yet be shown to be contributing to more 'sustainable' systems of agriculture. The regulatory response to these concerns has not so far been adequate. The Department of the Environment and the Ministry of Agriculture need to clarify who is responsible for the various types of possible impacts from herbicide-tolerant crops. Further, the companies developing herbicide-tolerant need to present detailed scenarios of the possible patterns of use of the crops together with the herbicides likely to be used.

THE CONCERNS EXPRESSED BY ENVIRONMENTALISTS

Biotechnology's Bitter Harvest

One of the most comprehensive critiques of herbicide tolerance was produced in 1990 by a consortium of U S public interest groups and agencies, including the Department of Agriculture in Texas. The authors (Goldburg *et al*, 1990) started from the viewpoint that agriculture has developed an over-dependence on chemical means of weed control, and the consequences have been harm to human health and to the environment. Biotechnology's Bitter Harvest contended that the first major products of biotechnology 'will not be used to end dependence on toxic chemicals in agriculture. Rather, they will further entrench and extend the pesticide era' (p.5).

The authors drew this conclusion on the basis of the following points, amongst others:

- That chemical companies view herbicide tolerance as a way of expanding market share for particular herbicides (p.9). The authors cited the fact that eight of the world's largest pesticide companies had initiated herbicide-tolerant plant research, and that many major seed companies had been acquired by chemical companies (p.6).

- That increased use of low-dose herbicides may decrease the weight of herbicide used, but will not reduce the 'plant-killing power' of herbicides applied in the environment, and will not decrease the acreage treated.

- That herbicide tolerance is being sought for older, more toxic herbicides as well as newer ones, and that the newer herbicides (they cite imidazolinones, glyphosate, sulfonylureas, glufosinate and bromoxynil) cannot anyway 'be properly considered environmentally benign' (p.43).

- That 'widespread use of herbicide-tolerant crops - with their associated potent herbicides - will exert significant pressure on... populations of weeds to develop resistance to the herbicides. In recent years, weeds have rapidly, and unexpectedly, evolved resistance to the new generation of low-dose herbicides - the sulfonylureas and imidazolinones. Weed resistance problems with these new herbicides threaten their once-touted capacity to replace older, more toxic herbicides' (p.37).

- That 'transfer of herbicide tolerance to weedy species could make weeds even more difficult to control' (p.38).

- That herbicide resistance might accelerate genetic erosion: 'To the extent that herbicide-tolerant varieties are widely marketed and cultivated in the Third World, these products also threaten to displace existing varieties. In some areas, this could contribute to the extinction of traditional landraces and cultivars' (p.42).

The authors argue that there are viable, and more 'sustainable' options for weed management than using chemicals, including mechanical, cultural and biological methods.

Five years on, these arguments remain highly influential amongst the environmental pressure group community.

Views from Europe

In 1992 a statement from the influential Oko-Institute in Germany employed similar arguments and concluded that:

'Herbicide resistant crops would obviously prolong and probably increase the use of herbicides in agriculture. They are not suited to reduce the problems caused by industrialised agriculture. On the contrary they reinforce and accelerate a trend in agriculture that is known to harm the environment and human health and to threaten the basis of nutrition itself'. (Weber, 1991).

Greenpeace UK (1993) gave evidence to The House of Lords Select Committee on Science and Technology enquiry into Regulation of the UK Biotechnology Industry and Global Competitiveness in April 1993. The evidence included the comment:

'[Herbicide resistance] will allow the herbicide to be used on new crops and at times when it was not previously possible to do so. Not only will the use of the herbicide increase, but there may be transfer of the resistance gene to weedy relatives creating a new pest. The increased use of herbicide may also select for the natural emergence of resistant weeds and the crop may itself become a pest, especially if it persists as a 'volunteer' in the next crop and cannot be killed by the herbicide' (p.2) (Greenpeace, 1993).

In addition, as detailed in a Green Alliance briefing document, Greenpeace views the spread of genes in the environment, when they could not have got there by natural means, as environmental damage in itself - in fact, as 'genetic pollution' (p.5) (Green Alliance, 1994).

Crops such as oilseed rape, one of the main target crops for herbicide resistance, have particular potential to spread genes through pollen being transferred long distances, and because there are a number of wild cruciferae that are potential recipients.

Greenpeace and the World Wide Fund for Nature were the two environmental organisations asked to give presentations to a workshop on herbicide tolerance convened jointly by The Ministry of Agriculture, Fisheries and Food (MAFF) and the Department of the Environment (DOE) in January 1995. Their comments divided into three main questions: Will genetically engineered herbicide tolerance lead to additional or exacerbated environmental impacts? Given the potential for resistant volunteers, is herbicide tolerance a good agricultural strategy? Will it be compatible with moves to more 'sustainable agriculture'? On the last point, it is recognised that there is no one definition of sustainable agriculture, but for most environmental groups a key feature of more sustainable systems would be lower inputs of fertilisers and pesticides.

Another opportunity to discuss the possible contribution of biotechnology to sustainable agriculture was provided by a workshop organised by environmental consultancy SustainAbility at Windsor Castle in February 1995. Participants included representatives of environment and consumer groups, farmers, plant breeders, industrialists, regulators and academics. The view of many of the participants was that sustainable agriculture required a variety of conditions, only a few of which were related to innovations in plant breeding, but that genetically-engineered herbicide tolerance did not appear to be a move in the right direction. Others defended the potential for herbicide tolerance to reduce applications of pesticides, but agreed that **there were practically no detailed scenarios or data to show whether this would or would not be the case.** It appears that five years after the publication of 'Biotechnology's Bitter Harvest', the Biotechnology industry is no nearer answering environmentalists' concerns (Jennings, 1995) .

THE REGULATORY RESPONSE TO THESE CONCERNS

From the concerns expressed by environmental groups described above, it can be seen that there are basically three sets of issues for the regulatory system to tackle: the possible **ecological** effects of the insertion of herbicide resistance genes, ie. whether these might themselves alter the behaviour of the plant in the environment, or whether they might transfer to near relatives and cause them to alter their behaviour; the possible **agronomic** effects of the use herbicide resistance ie. the development of resistant volunteers, and ultimately multiple resistances; and the possible environmental impacts from an **increased use** of herbicides, often seen as running counter to aspirations towards more 'sustainable' forms of agriculture. Below is an account of some of the debate that has gone on between different parts of the regulatory system and other key commentators on these issues.

The Role of ACRE and of The Ministry of Agriculture

The Advisory Committee on Release to the Environment (ACRE) was formed in 1990 to advise the Government on the granting of consents for the release of Genetically Modified Organisms (GMOs). ACRE is a statutory committee required by the 1990 Environmental Protection Act, Part VI of which deals with GMOs, and which in turn implements the European Directive 90/220 on Release of GMOs.

Some of the first applications that ACRE dealt with were for trials of herbicide-resistant crops, so the Committee was faced with the question as to how the regulatory system would deal with the issues raised by herbicide resistance very early in its operation. The immediate view of the Chair and the majority of the members of ACRE was that the Committee's remit was to look at the possible **ecological** effects of the insertion of herbicide resistance genes, as outlined above. The effects of growing herbicide-resistant crops on the use of chemicals was judged to be a secondary effect, and also to be the province of the Ministry of Agriculture. ACRE did not have the necessary expertise to consider the environmental impacts of the use of chemicals.

The response of MAFF to this debate (officials from MAFF are present as assessors at ACRE meetings) was to issue a discussion paper in 1991, which was later published in the journal Aspects of Applied Biology (Bainton, 1993). One of the key points of MAFF's assessment of the issues was that:

'It appears impossible to make useful generalisations about such a diverse group of plant varieties in combination with resistance to a varied range of chemicals. Initially, at least, a case-by-case assessment is necessary if any understanding of the implications of a particular proposal is to be gained' (p.47)(Bainton, 1993).

On the possible **agronomic** effects, the assessment judged that herbicide resistance might exacerbate problems with volunteers, although volunteers were said to have 'a significant economic impact on yield in only a small minority of cases...The volunteer problem is not a new one and in practice farmers are able to cope with it (at a certain cost) if they plan flexibly and with foresight' (p.47). MAFF also acknowledged the possibility of transfer of herbicide resistance to some weed species, leading to, in the case of annual weed beet growing in beet fields, a loss of 'much of the benefit of herbicide resistance within the crop itself' (p.47).

The paper stated that 'no other specific threats to the agricultural environment have been identified from information presently available to MAFF' (p.47) although it did raise the possibility of increased herbicide residue levels. This was felt to be the concern of the Advisory Committee on Pesticides, whose approval would be needed for proposed changes of use of herbicides, including their use on transgenic crops: 'the holder of the [pesticide] approval will have to seek specific approval for the use of that herbicide on the new variety. That new approval would, of course, be granted only after assessment of data regarding toxicity and environmental safety' (p.50). The Advisory Committee on Novel Foods and Processes would look at the implications of residues in the human food chain.

On the question of the scale of **use** of herbicides, the MAFF paper made the following tentative conclusion:

'It is ...not possible accurately to predict how levels of herbicide usage would change following the introduction of new resistant crops. There is however no evidence which would suggest that herbicide use would increase. Some crops on which herbicides are not currently used might start to be treated. But for 97% of crops which are already treated, the expectation is that the greater effectiveness of herbicides when used on resistant crops would lead to a decline in overall use. Given their high cost, there would be a strong economic pressure on farmers to take advantage of this greater effectiveness to reduce herbicide inputs' (p.48).

The paper made no firm conclusions as to how MAFF would deal with any anticipated agronomic impacts or the issues surrounding increased or decreased pesticide use. ACRE continued to assess only the possible ecological consequences of releases of herbicide-tolerant crops in trials, although there was increasing discussion of the likelihood of volunteers.

The PGS Application to Market Herbicide Tolerant Rape in the EU

In 1994 the system was faced with the first proposal to market a herbicide resistant rape in the EU. Although Plant Genetic Systems (PGS), the company seeking approval, was a Belgian firm, the application was first made in the UK in February 1994. The 1994/1995 Annual Report from ACRE gives a summary of ACRE's view of the application:

'We concluded that the herbicide tolerance gene was likely spread in the environment through transfer of pollen to other rape crops, thereby giving rise to herbicide resistant volunteers. There was also a small chance that the gene would spread to wild relatives of rape, giving rise to herbicide resistant hybrids. Herbicide resistant volunteers could be a problem in other crops because they would compromise farmers' ability to use the particular broad-spectrum herbicide to which they are tolerant for their control (assuming he would have done so in the normal course of events). However, the Committee was of the opinion that sufficient other herbicides or management practices existed for the control of volunteers, and therefore there would be no harm to man's property arising from this situation. There was also felt to be sufficient means of control should herbicide resistant volunteers spread beyond agricultural land, for instance to disturbed land or road-sides'.

'It was extremely unlikely that the modified rape could cause interference with ecosystems outside the agricultural environment since rape is not known to invade 'natural' habitats, and the herbicide resistance gene would not alter its ability to invade. The likelihood of any hybrids of herbicide resistant rape and wild relatives surviving and establishing was deemed to be very low, and therefore such hybrids would not pose a risk either to ecosystems or to man's property. This was not a unanimous view. A minority in the Committee felt that there were still uncertainties surrounding the extent to which the herbicide genes would spread to wild relatives, and the extent to which this could be regarded as contamination of the gene pool' (p.4-5)(ACRE, 1995).

The import of this judgement is that ACRE had concerned itself with the possibility of resistant volunteers, seeing this as possible 'damage to man's property' under the terms of the 1990 Environmental Protection Act. However, ACRE was still not prepared to consider the indirect effects on the environment of the use of the herbicide tolerant rape, i.e. any changes to the use of the chemical to which the crop is resistant. This was deemed to be outside the scope of the EU Directives which the UK legislation on release of GMOs, part VI of the Environmental Protection Act 1990, was enacted to implement, and thus outside the scope of ACRE as a statutory advisory committee set up by the EPA.

At least one other European country, however, took a different view. In August 1994, the Danish Competent Authority raised the following objections to a consent being issued:

'In this particular case, resistance has ... been introduced to a herbicide (Basta) which is characterised by being effective against practically all weed species of importance. It is therefore to be expected that the transfer of resistant genes to weeds will cause a gradual spreading of resistance to this agent and is thus likely to result in increased and wider use of herbicides. This may constitute an increased environmental impact, and this risk is the essential in the Danish position on this case. The overall problem, that the use of herbicide-resistant plants will affect the use of herbicides, has not been addressed by the notifier, and has not been accounted for in the risk assessment. It is the view of the Danish Competent Authority that an assessment of the secondary environmental impacts is a key component of the directive on the deliberate release into the environment of genetically modified organisms' (Danish Environmental Protection Agency, 1994).

However, at a meeting organised by the Netherlands Government in July 1994 for Non-governmental organisations (NGOs) and regulators from EU member states, it was clear that most countries separated their assessment of the GMO from an assessment of the possible increased use of pesticides. One NGO contributor to the debate commented:

'In the real world herbicide-resistant crops will be grown together with the herbicide...Current institutional arrangements should be revised, so that the environmental risks involved in growing genetically engineered herbicide-resistant crops together with the use of herbicides can be fully evaluated' (p.23) (Netherlands Ministry of Housing, 1994).

On the PGS proposal, a long period of arbitration between the members states ensued. Eventually, a common position was reached . With administrative problems adding to the political delays, the consent was not issued until the summer of 1995.

The lesson of this process is that at least one EU member state government finds the questions raised by environmental groups about the environment impact of herbicide tolerance entirely valid, to the extent that they are prepared to question the scope and appropriateness of Directive 90/220. Other applications to commercialise crops with engineered herbicide tolerance are likely to meet with delay until this question of scope is resolved.

Gaps in the UK System

In the UK, the concern that the consent system for release of GMOs does not take account of the impacts of pesticide use has been countered with the argument that the environmental effects of all pesticides are fully catered for by MAFF. Pesticides to be used in conjunction with herbicide tolerant crops would need permission from MAFF for a change of use (they would not previously have been used on that crop because they would have killed it) and that would be an opportunity to review the environmental impact. This is right, but this side of the system does not take a strategic, or 'in-the-round' view of the quantities of chemical being used or the effects of switching between chemicals. Such a strategic view is, in many NGOs' view, essential to implementing any programme aimed at more 'sustainable' agriculture.

There is also some doubt about the ability of MAFF to take a strategic view of one of the more direct impacts of genetically engineered herbicide tolerance - the possible creation of volunteers with multiple resistances. In rape and beet for instance, if resistance is engineered to a number of different herbicides, there is potential for volunteer plants in successive generations to pick up pollen from these different resistant varieties and be resistant to more than one chemical. In this way the number of chemicals available for control could in theory run out. MAFF's only present way of dealing with this situation is to de-register herbicides that have become ineffective on certain crops as a result of resistance building up. This is a reactive response, rather than a pro-active strategy as demanded by many of the environmental groups in the UK and abroad.

As long ago as 1989, The Royal Commission on Environmental Pollution, discussing the possible need to recover or eradicate GMOs after release, commented: 'Eradication of whole plants, genetically engineered or otherwise, should normally be possible using mechanical methods or herbicides. It will be important when introducing resistance to particular herbicides into plants to ensure that other herbicides which kill the plants remain available' (para 5.39) (Royal Commission on Environmental Pollution, 1989).

A document written by K Harding of the Scottish Crop Research Institute and P S Harris of the Scottish Agricultural Science Agency, and issued by the Chief Scientists' Group of MAFF in July 1994, was titled 'Risk Assessment of the release of genetically modified plants: a review', and made the following comments about the three areas of concern:

'The long term ecological consequences of releasing genetically modified plants which express herbicide resistance are as yet unknown but in the absence of selection pressure exerted by herbicide use could be expected to be neutral' (para 21). 'All three major crops considered here (potato, sugar beet and oilseed rape)..can create in their own right patchy but serious weed problems in following crops in certain rotations. Herbicide-tolerant versions of these crops or their inter-fertile weed relatives are expected to exacerbate volunteer and other weed problems where the herbicide concerned is a major means of their control' (para 22). 'It will not be surprising if deployment of herbicide tolerant transgenics changes herbicide usage both qualitatively and quantitatively (Lawson, 1993). Guidance will be needed to achieve rational herbicide use and to ensure overall compliance with British government policy (Anon, 1990) of minimising pesticide inputs. There may be some danger of less desirable trends in pesticide usage (para 26). (Harding, Harris, 1994).

One of the review's recommendations was:

'Collation of management advice, including industry's packages, relevant to GM crops, wasteland management and decreased pesticide input' (page ii) (Harding, Harris, 1994).

There has as yet been no response from MAFF as to how the recommendations and observations in the Scientists' report will affect MAFF policy on herbicide tolerant crops.

In the meantime, interests other than the environmental pressure groups are becoming concerned that there are gaps in the system. A report of the Biotechnology Working Party of the National Farmers Union (NFU) issued in June 1995 observed, on the issue of volunteers:
'...ACRE does not have a clear obligation to consider the implications of a genetically modified crop becoming an agricultural pest, as a consequence of using the crop in conjunction with an agrochemical. The NFU recognises that ACRE's remit is limited. However, we believe that some wider issues should be formally considered by regulators, and advisory committees with appropriate expertise. An integrated system, applying principles similar to those applied to agrochemical approval, might be appropriate, and deserves further consideration' (para 6.2) (NFU 1995).

CONCLUSIONS AND RECOMMENDATIONS

1. The regulatory system as a whole needs to engage in a wide debate about what constitutes **harm** as a consequence of release of GMOs. To some environmental groups, the spread of herbicide tolerance or other genes to wild relatives is itself 'genetic pollution' and therefore harmful. The present view of harm implies that having spread, the genes have to result in some 'adverse effect' to the ecosystem.
2. It is important that the DOE and MAFF together **clarify who is responsible for the second two areas of concern:** ensuring that herbicide resistant crops do not give rise to problems of multiple resistance in volunteers, and for ensuring that they do not lead to environmentally damaging increases in herbicide use. In both these cases the policy should be pro-active and anticipative - not reactive, as appears to be currently the case.
3. The companies developing herbicide resistance need to present **detailed scenarios** of patterns of use of particular crops, together with probable chemical regimes used on them, in support of any claims about the ability of herbicide tolerance to lessen the impacts of chemicals on the environment.
4. Biotechnology companies together with agricultural and environmental policy makers need to promote a wide debate as to what might characterise **more 'sustainable' systems** of agriculture, and how genetic technologies might fit in.
5. The regulatory system needs to consider the potential for **post-commercialisation monitoring of GMOs**, including herbicide resistant crops. There is at present no means of testing whether the conclusions about risk reached when granting a marketing consent, often granted on the basis of a few large-scale trials, are borne out when the crop is used at commercial scale over a period of years.

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PROBLEMS OF RISK ASSESSMENT WITH GENETICALLY MODIFIED OILSEED RAPE

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ABSTRACT

Much of our present knowledge on gene dispersal from oilseed rape originates from small-scale field experiments. Whilst these works have provided valuable information for the establishment of safe isolation distances for pre-release trials of genetically modified (GM) plants, it is unclear to what extent the results can be extrapolated for use on an agricultural scale. Evidence is presented that suggests pollen dispersal and geneflow from agricultural fields is much greater than had been reported from trial plots. When these data are combined with the abundance and proximity of field and feral populations in an oilseed rape growing area, it is concluded that transgene escape is inevitable following full commercial release of GM cultivars. The importance of transgene escape to the competitiveness of feral populations is discussed with particular reference to the release of herbicide-tolerant cultivars.

INTRODUCTION

Genetic modification (transformation) has enormous potential for the improvement of resistance and quality traits in crop plants. Application of the technology is now routine for a large number of species and this has led to annual rises in the number of field trials of genetically modified (GM) cultivars. Ahl Goy *et al.*, (1994) reported that the number of approved trials worldwide had risen from 5 in 1986 to 244 in 1992. The small size of these trials and the restrictive regulations controlling the manner in which they are conducted has made the likelihood of transgene dispersal from them negligible. The full scale commercial release of GM cultivars, however, such as the launch of the GM tomato (*Lycopersicon esculentum* L.) in May 1994 (Beck & Ulrich, 1993; Fox, 1994), poses a new set of risks.

The annual production of oilseed rape (*Brassica napus* L. ssp. *oleifera*) has grown dramatically in recent years and had risen to a global figure of 232,190 million tonnes in 1992 (Anon, 1993). The crop is amenable to transformation (Ooms *et al.*, 1985) and has accounted for 122 of the 675 field releases during the period 1986-1993. This made it the second most trialled species overall behind potatoes (Ahl Goy *et al.*, 1994). GM plants containing herbicide tolerant transgenes were the most abundant

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category trialled. Trials have been made of GM oilseed rape containing tolerance to the following herbicides: asulam; atrazine; bromoxynil; glufosinate; glyphosate; sulphonylurea and one unspecified. Of these, glufosinate and glyphosate were the most widely used (Rogers & Parkes, 1995). This summer, large-scale field trials of GM oilseed rape possessing tolerance to glufosinate have been conducted over a number of sites in the UK prior to eventual commercial release. This has stimulated continued discussion over the possible implications of commercialisation of such lines. Debate has centred around the possible effects of release on volunteer and feral populations of oilseed rape and on wild relatives of the crop (Crawley & Brown, 1995; Rogers & Parkes, 1995; Crawley *et al.*, 1993; Eber *et al.*, 1994; Scheffler *et al.*, 1993).

Unharvested and spilled seed often gives rise to huge populations of volunteer oilseed rape plants growing in subsequent crops in the rotation. These populations can be controlled in cereal crops by the application of herbicides, although chemical control in dicotyledonous crops is difficult (Lutman, 1993). The presence of significant numbers of herbicide or desiccant-resistant GM individuals in such populations (by geneflow or seed spillage) might reduce the efficiency of weed control and of pre-harvest desiccation. The accumulation of several herbicide-tolerant transgenes could exacerbate the problem (Rogers & Parkes, 1995). It is important, therefore, that factors that might give rise to large populations of transgenic volunteers are well characterised. These include the longevity of seed in the soil and geneflow between oilseed rape fields and between crops in fields and neighbouring volunteer populations.

Seed spillage during transport, planting or harvest can give rise to feral populations of oilseed rape (escapes from cultivation). These populations are seen commonly on road side verges or field margins and are subject to a range of weed management practices, principally mowing and herbicide application. Movement of top soil containing seeds from different arable fields to central soil dumps and thence to road or construction sites is another means by which feral populations of oilseed rape are dispersed and established in both rural and urban locations. It has been suggested that the recruitment of herbicide-tolerant transgenes into these populations by pollen movement, fresh seed spillage or by soil dispersal could reduce the effectiveness of control measures and so enhance the ability of the species to survive outside agriculture. The likelihood of such a transgene affecting the ability of feral populations to survive would be dependent upon several factors but particularly on the rate at which the transgenes are recruited, population longevity and on whether the transgene confers any clear selective advantage.

There have been several reports demonstrating the capacity of oilseed rape to hybridise with various wild *Brassica* species (Kerlan *et al.*, 1992, 1993; Jorgensen & Andersen, 1994). The probability of transgenes becoming transferred and stably incorporated into natural population of these species would depend principally on the gene dispersal rates from oilseed rape fields, the proximity and density of natural populations to those fields and on whether the transgene could confer any direct or indirect selective advantage in the natural environment.

Thus, there is a clear need to determine the gene dispersal characteristics of oilseed rape from agricultural fields; to survey the distribution and abundance of fields, feral populations and wild relatives in established oilseed rape growing areas; to assess the persistence of feral oilseed rape populations and to establish which constructs (if any) are most likely to confer direct selective advantage in the natural environment.

GENE DISPERSAL FROM AGRICULTURAL FIELDS OF OILSEED RAPE

Pollen dispersal

Oilseed rape can be pollinated by both wind and insects. Flowers of the crop are attractive to bees (Free, 1993) but several workers have reported that good yields can be obtained in the absence of insects (Olsson & Persson, 1958; Free & Nutall, 1968; Langridge & Goodman, 1982). The observation that yields are reduced by 33–50% when oilseed rape is grown in the still air of a glasshouse (Harle, 1948; Jenkinson & Glynne-Jones, 1953; Williams, 1978) has led many to believe that wind plays the predominant role in the pollination of the crop (Timmons *et al.*, 1995).

Evidence from small-scale field experiments, however, suggests that the airborne pollen levels produced by the crop are unlikely to be significant. Pollen densities fall rapidly with distance from the margin of trial plots and within 6–10 m levels decrease by 50% (Mesquida & Renard, 1982; McCartney & Lacey, 1991). Extrapolation of these results predicted levels at 100 m to be between 2 and 11% of those at the source (McCartney & Lacey, 1991). Provided pollen emissions are unaffected by plot size, these results suggest that the crop has little capacity for transgene dispersal. Timmons *et al.*, (1995), showed however, that pollen densities around large agricultural fields are very much higher and have dispersal characteristics dissimilar to those of experimental plots. Pollen densities 100 m from the field margin were measured as 27–69% of those recorded at the field margin (as opposed to the expected 2–11%) and low but significant levels of pollen were detected at a distance of 1.5 km. Further work carried out in 1995 supports these findings (Timmons, unpublished data). Clearly then, wind dispersal of oilseed rape pollen from agricultural fields occurs over much greater distances and at higher concentrations than originally predicted.

Geneflow between commercial oilseed rape fields

Manasse & Kareiva (1991) point out that quantification of geneflow is an essential part of risk assessment. Scheffler *et al.*, (1993) used glufosinate-tolerant transgenic oilseed rape to measure geneflow from a small circular plot 9 m in diameter. The number of hybrids declined rapidly from 1.5% at 1 m from the common boundary, to 0.02% at 12 m and to just 0.00033% at 47 m. Geneflow into a 1 m diameter plot of non-transgenic rape in the centre of the 9 m plot of transgenic plants was estimated at 4.8%. Much higher levels of out-crossing (21–36%) had been reported previously in studies using erucic acid content (Rakow & Woods, 1987) and petal colour (Olsson & Persson, 1956) as markers. Manasse & Kareiva (1991) reported levels of geneflow at 50 m (0.022%) almost 95 times higher than that found by Scheffler *et al.*, (1993).

Differences in the size of donor plots and also in the ratio between donor and recipient plot sizes are both likely to have been important contributory factors leading to these large disparities.

At the Scottish Crop Research Institute, vernalization requirement and Randomly Amplified Polymorphic DNA (RAPD) analysis have been used as markers to measure geneflow between neighbouring fields of spring and autumn-sown oilseed rape (cvs Comet and Falcon respectively). A total of 153,351 seeds was collected from the three linear transects in the field of cv. Falcon. When these seeds were sown late in the following year to avoid vernalization, all except 210 (0.14%) failed to flower. The majority (38%) of the flowering plants possessed a RAPD marker diagnostic of cv. Comet and so were identified as hybrids. Control spring and hybrid populations also flowered and possessed the marker, but control plants of cv. Falcon both failed to flower and lacked the marker. Hybrid frequency initially declined rapidly with distance from the shared field margin, but apparently stabilised beyond 32 m at values of between 0.03 to 0.05%. Thus, rates of geneflow at the lower distances appeared similar to those obtained by Scheffler *et al.*, (1993). It should be remembered, however, that flowering of the neighbouring spring-sown and autumn-sown fields coincided for only two of the eight week flowering period of the latter. Moreover, whilst these rates provide a guide to the likely geneflow between neighbouring spring and autumn-sown fields, they are an underestimate (by at least four-fold) of those that could be expected between neighbouring autumn-sown or neighbouring spring-sown fields. Furthermore, geneflow rates at the more distant sampling sites were orders of magnitude higher than previous assessments based on experimental plots. The increased size of the pollen source offers the most likely explanation of the discrepancy. If this were so, it follows that extreme care should be exercised before extrapolating information obtained from trial plots to predict the likely behaviour of crops under standard agricultural conditions. The data suggest also that the levels of geneflow expected between fields, or between a field and a large volunteer population, may be dependent to some extent on the sizes of donor and recipient populations. Whether the levels of geneflow observed could be regarded as significant would depend largely on the nature of the transgene(s) concerned.

Geneflow to artificial feral populations

Differences in size, locality and distribution of feral populations and difficulties in identifying suitable markers to discriminate between selfed and hybrid progeny makes the direct study of geneflow into feral populations difficult. In a further experiment, populations of ten emasculated and de-petalled plants placed along a linear transect were used to study the effect of distance on geneflow. Seed set in the emasculated populations declined with distance from the source field and correlated strongly with the reduction in pollen concentration. Seed set in emasculated populations that had been self-pollinated prior to being placed on the linear transect did not decrease with distance from the field margin. Hybrid seed was recovered from these plants up to a distance of 100 m. Geneflow into the emasculated populations could be taken as representing an extreme case: that of geneflow into a feral population of male-sterile plants. Conversely, the pre-pollinated populations may be taken to represent the opposite extreme, in which the recipient population is large, densely packed and so predominantly self-pollinated. Thus, for most populations, the levels of geneflow expected should fall between these values. The detection of hybrids in the pre-pollinated populations up to a distance of 100 m, therefore, should be viewed as significant and indicates that there is a strong likelihood of wind-mediated geneflow into feral populations at this distance. The presence of hybrids in emasculated populations sited 1.5 km from the nearest field also has importance in demonstrating the capacity of the crop for rare long-range pollination events.

Survey of oilseed rape fields and feral populations

The level of geneflow that can be anticipated following full commercial release of GM oilseed rape is largely dependent on the abundance and distribution of the source fields in relation to those of the recipient (non GM) fields and feral populations. The abundance of oilseed rape fields and feral populations of the crop were monitored over a 2-3 year period in two major oilseed rape-growing districts: Angus, and N.E. Fife in Eastern Scotland. The survey covered an area of 42 km^2 and contained between 263 and 321 fields of autumn-sown rape. Mean distance between fields varied between 390 m and 530 m. In all three years, approximately 20% of fields mapped were within 100 m of the nearest neighbouring field. Spring-sown oilseed rape fields were less numerous than autumn-sown cultivars (between 106 and 153) and mean distances between fields were within the range 800 m to 900 m. In 1993, approximately 12% of fields were situated within 100 m of a neighbouring spring-sown field. This figure rose to 15% in 1994 and 14% in 1995.

Stands of feral oilseed rape varied in size from isolated plants to populations containing more than 3,000 individuals. There were 132 such stands located in the Angus and N.E. Fife survey areas during 1993 and 134 during 1994. Visits were more frequent during the 1995 survey but covered the Angus survey area only. A total of 135 populations were identified in this year. Mean distance between fields and feral populations varied between 600 m and 800 m and the percentage of populations within 100 m of a field margin fell within the range 8% (1993) to 12% (1995).

These results demonstrate that a significant proportion of feral populations found in a major oilseed rape growing area are separated from fields by distances at which geneflow would be expected to occur.

The likelihood of transgene escape

The high concentrations of pollen produced by oilseed rape fields and their capacity for dispersal over large distances would seem to indicate that there is the potential for significant levels of geneflow to populations of volunteers, feral plants and wild relatives as well as to other fields of the crop. The detection of geneflow between neighbouring spring and autumn-sown fields and between isolated fields and artificial feral populations demonstrates that this potential can be realised. Given the close proximity of fields and feral populations within the agricultural environment, it would appear inevitable from these data that significant levels of geneflow will occur from GM oilseed rape fields following their full commercial release. The question that needs to be addressed, therefore, is whether such movement is of any environmental or agricultural importance.

THE PERSISTENCE OF FERAL OILSEED RAPE POPULATIONS

Flowering oilseed rape is a feature of roadside verges and field margins from early spring through to late autumn and non-flowering plants can be found throughout the year. The most direct method of assessing the persistence of feral rape populations is to map their location and size over two or more seasons. The three year survey of feral populations in Angus and N.E. Fife revealed varying levels of population instability. The turnover of populations between years was large, with only 19% (25/132) of the 1993 populations persisting into 1994 and 12% (12/100) of the 1994 Angus populations persisting in 1995. Crawley & Brown (1995) obtained similar results in a shorter survey of feral populations growing along the M25 motorway in Southern England. None of the Scottish populations surveyed were present in all three years but five were found in both 1993 and 1995, having been absent in 1994. The reappearance of such populations may be attributed to fresh seed spillage in the same location or to germination from a viable seedbank. The frequent re-emergence of populations within a season following control measures (mowing) or soil disturbance (Scott, University of Reading, unpublished data) may be indicative that there is a capacity to regenerate feral populations from a soil seedbank. Certainly, there is a large body of circumstantial evidence to suggest that oilseed rape seed can remain viable in the soil for five years or longer (Lutman, 1993). Likewise, evidence from seed burial experiments (Schlink, 1989; Lutman, 1993; Crawley, 1993) and observations of the appearance of oilseed rape volunteers in crop rotations (Talbot, 1993) suggests that oilseed rape seed can remain viable for many years. It is reasonable to suppose, therefore, that seedbanks also exist for feral populations. Certainly, when PCR analysis, using anchored microsatellite primers, was applied to twelve Scottish feral populations, two were found to contain cultivars that are now commercially obsolete. This suggests that either these populations have been self-sustaining or else that the plants contained in them originate from a seedbank which has remained viable since the initial spillage event several years earlier.

In 1993, the size of the seedbank of six feral populations in Angus and N.E. Fife was estimated from soil samples. Seed content of between 10 and 22 soil cores (to 20 cm depth) was assessed from each site before and after pod maturation and seed dispersal. The number of seeds recovered from the populations sampled after seed dispersal were approximately forty-fold higher than those taken beforehand. The quantity of seed recovered had increased in four of the populations and was unchanged in the remaining two. Soil sampled from a further population contained in excess of 1,000 seeds per litre of soil, equivalent to a seedbank of 200,000 seeds/m^2 to 20 cm depth. These preliminary results would seem to suggest that soil around feral populations can contain significant quantities of ungerminated seed, and that the feral plants appear to be able to significantly increase the size of the seed population in the soil after pod dehiscence, despite predation and the presence of vegetative cover.

Evidence from site observations suggest that there is a large turnover in site occupancy by plants between years although the authors feel it would be premature to infer from this that feral populations do not persist beyond two or three years. Further work is required to monitor site occupancy over longer periods, to establish the size and persistence of feral rape seedbanks and also to determine whether there is a genetic influence on seed dormancy in oilseed rape.

SCOPE FOR TRANSGENES AFFECTING POPULATION SURVIVAL

In the absence of definitive proof that feral rape populations are transient in nature, risks presented by particular transgenes must be examined separately. It might be argued that GM feral rape containing insect or disease tolerance might survive and compete more effectively and have a greater chance of returning viable seed to the soil than plants without such a characteristic. Equally, a herbicide tolerance transgene could confer a direct selective advantage over non-GM feral rape populations should that herbicide be applied widely for control. This has been made particularly relevant this year following the sanctioning of large scale replicated field trials in the UK of GM rape containing tolerance to the herbicide glufosinate.

The role of herbicide application in causing population disappearance and in limiting seed return was assessed in feral populations of Angus and N.E. Fife by repeated surveys of the area in 1994 and 1995. Control measures used by the local authorities and farmers were identified as the most significant factors limiting population survivorship. The two main methods of control employed were mowing and herbicide application. In both years, however, approximately half of the populations (55% in 1994; 51.8% in 1995) received no treatment and apparently returned substantial quantities of seed to the soil. In the remaining populations, mowing was by far the most widespread cause of mortality, with 34% of populations in 1994 and 39% of those in 1995 being mowed at least once. In comparison, only 2% of populations in 1994 and 5% in 1995 were sprayed with herbicides. A similar number were subject to both treatments (5% in 1994 and 4% in 1995). The specific herbicide used was identified in 90% of cases. No sites were sprayed with either glufosinate or glyphosate.

More detailed study of fifteen populations in 1995 allowed the scale of losses caused by these control measures to be assessed. Five populations were mowed, one was sprayed with a herbicide, four received both treatments and the remaining five were not subject to control. Plant numbers did not change greatly in populations receiving no control treatments but variable losses were observed in populations that had been mowed and/or sprayed. Avoidance (by position or timing) appeared to be the principal means of survival in treated populations. No population was entirely eliminated by the control measures, although losses were severe in several populations. In most instances, surviving plants were able to flower and set seed, indicating that these 'control' measures would not be 100% effective in preventing pollen transfer or seedbank replenishment by GM plants.

These results would seem to suggest the scope for direct selective advantage, conferred by the possession of herbicide tolerance transgenes, would be limited and stochastic in nature. In the case of glufosinate in particular, there appears to be no evidence that the presence of tolerance transgenes would greatly influence the ability of plants to survive in a feral environment. It should be remembered that this assertion takes no account of any pleiotropic effects of the transgene or of any future increase in the use of this herbicide in non-agricultural situations. Neither does it relate to the agricultural environment where volunteer populations are subject to entirely different control regimes.

In this study, we have presented results on the pollen dispersal and geneflow from oilseed rape fields, on the distribution and persistence of feral populations and on the effectiveness of herbicide application in controlling the spread of feral populations. These data provide a useful contribution enabling preliminary assessments to be made on the risks posed by glufosinate tolerance transgenes to the competitiveness of feral oilseed rape. The work serves also to highlight the volume of information required to anticipate the likely consequences of any given GM release. It follows that the temptation to make sweeping generalisations over the risks (or absence of them) posed by GM crops as a whole should be resisted and that assessments should continue to be made on a case-by-case basis.

Full and careful account should be taken also of the benefits of transgenic plants being released. Again, this should be appraised separately for each GM line.

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ARE CURRENT GMP REGULATIONS "EUROPEAN" OR EFFECTIVE?

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ABSTRACT

Regulation for genetically manipulated plants (GMP's) should have two aims: to ensure the safety of the public, and to give companies a reliable procedure towards market introduction. In Europe, regulation has failed to achieve its goals and there are differences between countries in interpretation and application of 'European' regulation and also in the perception of the public. The contrast with the regulatory approach and acceptance in the USA is highlighted. The effect of European regulation on development of GMP's by seed companies is discussed.

INTRODUCTION

Like any new technology, genetic modification has raised concerns that there could be undesirable consequences as well as all the obvious advantages. These concerns were aggravated by the special characteristic of organisms, their ability to multiply, and all kinds of run-away scenarios were envisaged.

In addition, the issues have an immediate personal impact because of our perceived relationship with living organisms, which differs from our relationship with mineral products. This explains why many people and organisations, even where they lacked background knowledge about the GMP's or current practices, felt the need to take a stand on the issues involved. As a consequence, gene technology was possibly the first new technology for which forms of regulation and limitations were set, even before the research phase was under way.

An immediate obstacle to regulation was the lack of knowledge of exactly what the possible undesirable consequences might be. Therefore, in Europe, the new regulation was not based on specific potential dangers that had to be addressed, but was a kind of umbrella legislation that covered all Genetically Modified Organisms (GMO's), where all possible risks were taken into account. The definition of a GMO according to the EC directive is:-

"an organism in which the genetic material has been altered in a way that does not naturally occur by mating and/or natural recombination."

The UK definition is:-

"an organism is genetically modified if any of the genes or genetic material in the organism: a) have been modified by means of an artificial technique; or b) are inherited or otherwise derived through any number of replications from genes or other genetic material (from any source) which were so modified."

In the USA, attention was focused on pathogen dangers and food quality risks, for which existing legislation could be applied by established agencies. The basic difference between these two approaches is that in Europe regulation is for the technology (sometimes referred as 'horizontal' regulation), whilst in the USA regulation is for the product ('vertical' legislation). Japan is also taking the product regulation approach.

In Europe new developments are evaluated for potential dangers allowing a step-by-step process of release so that procedures can gradually be relaxed where it is judged safe to do so. At the same time it must be possible to terminate an experiment at any stage, if unforeseen dangers occur.

Regulation should have two aims:

- to ensure safety of GMO's to the public
- to give companies a reliable procedure towards market introduction

EXPERIENCE WITH EUROPEAN REGULATIONS

For plants the relevant European regulations are covered in two Directives:-

90/219/EC which regulates contained use of GMO's
90/220/EC which covers deliberate release

In addition there are regulations which cover Novel Food.

90/219 - contained use

This regulation aims to ensure the safe use and handling of GMO's in containment, that is, in conditions intended to limit contact between GMO's and the environment. At the moment, this legislation is under revision and it is the intention to change this from a GMO based approach to one based on the potential risks posed by a specific experiment.

90/220 - deliberate release

This regulation aims to protect human health and the environment when carrying out the deliberate release of GMO's into the environment, and when marketing products containing, or consisting of GMO's.

Although the text of this regulation is the same all over Europe, there are some clear differences between countries in their execution.

- In Holland, the UK and Germany the procedure is fully public and ensures that objections from the public are taken directly into account. As a consequence, the procedure, from the time of application until approval, can take up to six months. In France and Belgium a period of one month is more typical and most of the dossier can be kept confidential.

- The application fee in Germany can be as high as £20,000 (50,000 DM), in the UK, £2,000 and in most other countries there is no charge.

- There is disagreement even within countries about whether any effect on the environment is unacceptable or, whether an adverse effect on the environment equivalent to existing practices is acceptable.

- Holland does not take the actual advantages of the GMP into account in the evaluation, but France and Germany do.

- A comparison of the safety measures taken to achieve containment of an open field experiment is difficult to make, but there are differences in the ease of obtaining permits to allow free-flowering in seed crops.

Novel Food

There is a big debate in Europe about Novel Foods, focused on the question of labelling and 'substantial food equivalence'. At the moment the proposal is to make this only obligatory if there is an actual difference in chemical composition but always if a gene technology process has been used at any production stage. The Food Industry does not want mandatory labelling although it is prepared to label foods for religious, dietary or ethical reasons. Many food products are so far removed from the production process that no analytical technique can prove GMP involvement, for example, cheese from genetically manipulated maize, sugar from genetically manipulated sugar beet. Moreover, in many crops a certain percentage of natural outcrossing is usual, therefore, some degree of GMP presence is always possible. International Trade adds further complications because of differences in agreements, tariffs and barriers between countries. Food may also contain ingredients from several sources and this will also cause problems.

The key difference between countries is, however, the opinion of the public as to whether regulation meets its goal. Consumer groups in Germany and Holland are demanding more stringent legislation than those in France, the UK and Belgium. As a consequence, it is these last three countries that will be selected by seed companies for their first market introductions.

THE USA SYSTEM

The approach in the USA by the authorities and the public is much more pro-active and based on opportunity rather than threat. For many specific crop/trait combinations only a notification procedure is in effect and five of these crop/trait combinations have been declared as outside the scope of regulation. In addition, the USA is taking positive action to make sure that these products can be exported without the imposition of undue regulatory burdens.

The most important aspect is the clear and convincing position that the authorities proclaim in this field which is a considerable help in ensuring public acceptance of these products. The exponential development of field testing in the USA comes, therefore, as no surprise and demonstrates the enormous potential of gene technology.

THE REACTION OF ENVIRONMENTAL ORGANISATIONS

A general weakness in the European system is the lack of coherent policy decision. This gives environmental groups a reason to oppose the outcome of the regulations. The herbicide resistant GMP must pass the 90/220 regulation and the herbicide/crop combination must also pass the pesticide regulatory tests before it can be sold. However, this can be done even if the development is adverse when seen in broad agricultural perspective, for example, if it makes control of volunteers in another crop impossible. Environmental Organisations claim that many of these implications, together with ethical considerations and the effect on the developing world, are not taken into account by the authorities because of these separate limited procedures. As a consequence, they feel it their duty to obstruct these developments in any way possible. Of course this is not unique to GMO's but for this sensitive issue it is extremely important.

The resulting situation is that these organisations focus completely on the potential risks and insist on absolute guarantees of total safety. As a consequence, in Holland, the leading environmental organisation is arguing against a herbicide application to a genetically manipulated herbicide-tolerant crop which is actually a vast improvement over the chemicals presently applied. Provided no new problems materialise, if they are successful in blocking this development, they are in fact working against their (and our) best interests.

COMPANY EXPERIENCES

It came as a shock to my company when we had chosen two herbicide resistant developments, with obvious advantages over current and alternative practices and no new disadvantages, to find our field trials destroyed in Holland and occupied in Germany. It became eminently clear that introduction of GMP's into the market place would be much more than just a technical evaluation together with farmers and authorities. However, seed companies simply do not have the resources to address the public directly and explain the issues in sufficient detail. So, if the authorities do not facilitate this process, long delays can be expected.

CONCLUSION

GMP regulation in Europe is still subject to local differences in interpretation and compliance.

The main shortcomings, however are failure to achieve it's goals:-

- the potential risks which were pre-supposed are not materialising.

- the positive experiences with the safety of GMP are not effectively communicated to the public so that widespread distrust of gene products remains.

- as a result seed companies are proceeding more cautiously with GMP developments, in complete contrast to the USA. The patent position in this field in the USA is the strongest in the world, therefore we can expect the USA to reap the major benefits of this key technology and its vast range of products.

- environmental and other organisations are disappointed in the regulatory process and its achievements, since they perceive it as too narrow in scope and they feel obliged to force the issue.

It is questionable if regulation is the best approach to make the safe application of GMP's accepted, especially if it is perceived to be flawed. The informal discussions between industry and Non Governmental Organisation's in Holland seem an effective means to really evaluate all advantages and disadvantages of each product and achieve effective acceptance. At the least, it makes these groups co-responsible when their actions result in the hindrance of progress.

HERBICIDE-TOLERANT CROPS - THE NEW GREEN REVOLUTION?

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ABSTRACT

The widespread release of herbicide tolerant (HT) crops is imminent as technical, legislative and commercial goals are achieved. Against a background of controversy and debate surrounding the release of HT crops, significant areas of transgenic HT rapeseed cultivars are being grown in Canada this year. This provides a useful example with which to review the integration of HT crops into an existing arable agricultural environment. The utility of these novel cultivars is considered in the light of options for commercial practice, weed control, the management of herbicide resistant weeds and transgene introgression. The subsequent introduction of other non-herbicide related transgenes is important in relation to the need to develop diagnostic tests which will monitor the introgression of genes in the environment.

INTRODUCTION

Herbicides are generally still regarded as essential tools in successful crop production. Selectivity of herbicides and the mechanism of plant resistance to herbicides in crops has been the subject of scientific study for more than 50 years. By contrast, in less than one decade, the production of herbicide-tolerant crops *de novo* via biotechnological methods has become a topic of considerable controversy and debate. Indeed, the point is well made by Gressel (1993) that reviews of various aspects of conferring resistance on crops almost outnumber the actual technical articles describing successes.

This paper is not going to continue these debates specifically but simply record the pros and cons: First the pros; (i) reduced herbicide rates (ii) increased opportunities to use herbicides which are environmentally benign, (Burnside, 1992) (iii) improved weed control options for farmers (iv) opportunity to integrate HR crops in control programmes for HR weeds (v) non-selective herbicides can be used to control hitherto uncontrollable weeds (with selective herbicides) (vi) increased weed management opportunities for minor crops (vii) improved soil conservation via reduced use of residual herbicides (viii) competence to identify new strategies for the use of HR crops (e.g. parasitic weeds, third world crops, forest crops) (Gressel, 1993) (ix) economic advantage to farmers (Singh *et al.*, 1994) (x) improved returns on herbicide discovery to industry. Second the cons; (i) increased use of herbicides (Burnside, 1992) (ii) reduced research effort devoted to the development of new herbicides (iii) unfavourable environmental impact, specifically gene introgression with wild and/or cultivated plants (Darmency, 1994) (iv) opportunities for new volunteer problems (Williamson, 1994) (v) fear/concern over genetic engineering (vi) development of monopolistic seed/chemical companies (vii) political objections (Deo, 1991) (viii) high cost of special seed (ix) poor agronomic performance (x) reduced biodiversity (Fox, 1994).

Rather than focus on the issues listed above which will be well-debated at this conference, this paper will adopt a more fatalistic view to the introduction of herbicide-tolerant crops based upon commercial reality.

HERBICIDE TOLERANT CROPS

General opportunities

A consideration of the future release of herbicide-tolerant crops is presented in Table 1. The present indications are that rapeseed is going to be the first crop in Europe with commercial releases but already, in spite of all the reservations expressed in Europe and elsewhere regarding the prudent use of herbicide-tolerant crops, the fact remains they are already a reality in North America. It is useful to examine the practical implications as they become integrated with an established agronomic system. Canadian crop production can provide such an example. Indeed, Canadian farmers are no strangers to the concept of herbicide-resistant crops since the 1980's saw the adoption of triazine-tolerant rapeseed varieties, bred and selected by conventional breeding methods (Marshall, 1987). The triazine-tolerant canolas are now obsolete, victims of the introduction of a new sulfonylurea herbicide (ethametsulfuron) for wild mustard control (*Sinapis arvensis*) and competition from more modern cultivars. Therefore, even in the brief history of herbicide tolerant crops, it is apparent how vulnerable cultivars can be to improvements in weed control and the genetic improvement of crops.

Table 1. Anticipated commercial availability of herbicide-tolerant crops

Crop	Country	Phosphinothricin	Glyphosate	Imazethapyr	Chlorimuron
Rapeseed	Canada	1995	1995	1995	-
	Europe	1997-98	1999-2000	-	-
Soybeans	USA	1997	1996	1995	1993
Maize	USA	1997-98	2000	1991	-
Cotton	USA	1998	1998	-	-
Sugar Beet	USA	2000	2000	-	-
	Europe	2001	1998	-	-
Wheat	USA/Europe	>2000	>2000	-	-

Herbicide-tolerant rapeseed in 1995

An estimate of the performance characteristics of three herbicide-resistant rapeseed (canola) cultivars is described in Table 2.

Table 2. A summary of the characteristics associated with three herbicide-tolerant spring rapeseed (canola) cultivars

Name/supplier	Roundup Ready® Canola Monsanto	Liberty Link/ Innovator® AgrEvo	Pursuit Smart®/ cv 45A71 American Cyanamid/ Pioneer HiBred
Herbicide	glyphosate	glufosinate	imazethapyr
Rate g/ha	293-445	300-600	480
Crop or weed growth stage	0-6 leaves of crop	Seedling-early bolting of crop	Weeds emerged up to 4 leaf stage
Re-application	Possibly required	Possibly required	Not required
Crop tolerance	Some yellowing	Excellent	Excellent
Weed Control Most effective	Grasses	Broad-leaved	Broad-leaved
Least effective	Broad-leaved weeds Hot dry weather	Perennials Volunteer cereals	Volunteer cereals
Special value	No soil residues	No soil residues	Broad-leaved weed control
Cultivar performance	Below recent cultivars	Approaches current cultivars	Approaches current cultivars
Future cultivars under development	3 for 1996 8 by 1997	3 for 1996 4-5 for 1997	Unknown
Estimated cost as % of standard herbicide/seed (Can $61/ha)	152%	144%	144%

The herbicides involved are the non-selective compounds glyphosate and glufosinate with a legume-selective imidazolinone, imazethapyr. During the 1995 season limited quantities of the Roundup Ready® canola (800 ha) will be grown to create awareness of this new cropping opportunity. A scaling up of the seed supply is envisaged for 1996. Clearly, glyphosate is a herbicide with which growers are very familiar and it will be able to provide effective control particularly of grass weed species. It's main performance limitation will be evident where low application rates are used under conditions of high temperatures and low relative humidities. Recurrent flushes of weed growth may require a second application of glyphosate within the crop development limits permitted (6 leaves). Seed is available for 16,300 ha of Innovator® to be planted in 1995. The attendant herbicide in this package is glufosinate which should prove to be especially effective in the control of broad-leaved weeds. Similar to glyphosate, there may be a need for a follow-up application if there is new weed growth. The expression of the resistance trait appears to be superior in the case of the glufosinate-resistant Innovator® since glyphosate application may cause temporary yellowing in Roundup Ready® canola. The resultant seed produced from both transgenic cultivars cannot be sold for export during the 1995 year. This restriction does not however apply to the non-transgenically produced imazethapyr-resistant trait known as Pursuit Smart® which has been incorporated in the Pioneer® cultivar 45A71. Unlike the glyphosate and glufosinate resistant canola cultivars, imazethapyr has residual and translocated activity thus rendering re-application in one growing season unnecessary. Volunteer cereals are only suppressed by this herbicide therefore the common practice of applying a post-emergence graminicide may still be required.

Beyond the 1995 field trials

The adoption of the herbicide-tolerant rapeseed cultivars from 1996 and beyond will depend upon their economic and technical success. Given present estimates of costs, farmers will be required to pay substantial premiums to adopt this apparently simple, uncomplicated package of cultivar-herbicide. It is difficult to see any immediate economic benefit which would drive farmers on a widespread basis to purchase these crops. Only in situations where inadequate weed control would have prevented a rapeseed crop being grown, is it clear that the use of a herbicide-tolerant cultivar would make growing rapeseed practical and economic again. Therefore just as triazine-tolerant canolas found a niche in the 1980's, these herbicide tolerant canolas offer flexibility of weed control without the burden of sustantial yield penalties conferred by the triazine resistant gene. Another important market consideration is the impact of international opinion on the integrity of Canadian canola if oil produced from transgenic, herbicide-tolerant cultivars is to be exported from North America.

Several technical uncertainties also prevail. The agronomic performance of the herbicide-resistant cultivars is presently inferior to the best non-transgenics. While it is theoretically desirable to move away from soil-applied, residual herbicides in an attempt to preserve soil organic matter and moisture conservation by minimising tillage, it is not always practical. Farmers may have very large areas to spray and windy conditions, spring frosts or rain may greatly limit the available spraying periods available. If however, glyphosate and glufosinate were used more frequently in weed control programmes it is likely that weed spectrum shifts would occur due to the weaknesses of both herbicides where low rates are applied (Table 2). One technical benefit for Canadian farmers with the use of glyphosate or glufosinate will be the ability to control grass weeds which have developed resistance to the selective graminicides which have their primary biochemical site of action as acetyl-coA carboxylase. By contrast it would definitely not be wise to use imidazolinone-resistant rapeseed in areas where broad leaved weeds already show acetolactate synthase resistance e.g. wild mustard (*Sinapis arvensis*).

The potential for gene flow to wild relatives whose hybrid offspring may become more weedy or invasive is studied under the topic of introgression. As listed in the introduction the movement of transgenes into the environment has possible implications for crop species, feral populations (Wilkinson *et al*., 1995) and wild or weedy relatives. B. *napus* plants are know to outcross with other plants of the same species *B. rapa, B. juncea, B. carinater, B. nigra, Diplotaxis muralis, Raphanus raphanistrum* and *Erucastrum gallicum*. In Canada studies have shown that introgression of the herbicide-resistance gene is most likely to occur with *B rapa*, the other major canola species (Anon, 1995). Studies by Agriculture and Agri-Food Canada (AAFC) conclude that gene flow from herbicide resistant canolas (glyphosate and glufosinate) to relatives is possible but would not result in increased weediness or invasiveness of these relatives. However, a longer-term concern is expressed by AAFC that if there is general adoption of several different crop and specific herbicide weed management systems, there may be potential for crop volunteers to develop with a combination of novel resistances to different herbicides. This would result in the loss of the use of these herbicides and any of their benefits. Therefore AAFC cautions extension personnel, in both the private and public sectors to promote careful management practices for growers who use herbicide resistant crops to minimise the development of multiple resistance.

It is likely that growers will swiftly judge their requirements for herbicide-tolerant crops. Given an adequate supply of agronomically productive cultivars and a suitable choice of selective herbicides, there may be no need to pay a premium for a herbicide-tolerant cultivar. From the Canadian experience of 1995 it is clear that the commercial level of support for the individual cultivar/herbicide 'packages' is very high providing a blend of technical, management and economic information. Advisors in the public sector will be keen to observe the integration of these new practices in crop production systems.

Transgenic crops in the UK

There are several reasons why it is unlikely that HT crops in the UK are less likely to be adopted compared to their counter parts in North America. First, spring rapeseed is not such an important crop in the UK as winter-sown rapeseed. The selection of herbicides available for broad-leaved and grass weed control in winter rapeseed is extensive, and with a competitive, long-season crop, reliance on herbicides is less critical than in spring rapeseed. HT winter rapeseed cultivars would simply add one more option for weed control but farmers in the UK are not used to the concept of engineered herbicide resistance, specific to one given herbicide. The care required to match a specific herbicide to a specific cultivar on a large arable farm may be a complication which growers would wish to avoid. By contrast, it is likely that HT sugar beet might be well-received as new option for crop production with the proviso that one effective non-selective herbicide e.g. glyphosate was retained as an option for volunteer HT sugar beet cultivars. The other arable crop which could be targetted for release as a HT cultivar is potato. However, the added value of more weed control options are likely to be more than outweighed by the difficulties attached to controlling a HR volunteer potatoes especially if glyphosate or glufosinate were the target herbicides.

Overall, perhaps it it the transgenic crops which do not involve herbicide tolerance which will provide the greatest impact upon agronomic practise. For example, transgenes to modify crop quality; altered starch content in potato, hybrids in oilseeds, improved nutritional quality in maize and rapeseed, modified fatty acids in rapeseed and stress tolerance (to drought and frost) all provide exciting new opportunities in cultivar choice. Still, these transgenes may also have an impact on the weediness of crop volunteers both in terms of germination behaviour and survival. Clearly, the environmental impact of these transgenes will have to be determined. Similarly, the opportunity for gene introgression involving stress tolerance and herbicide resistance in crop and weedy relatives is an important ecological issue which must be examined in light of proposed field releases of novel transgenic crops.

Monitoring transgenes

Now that we have reached the situation where herbicide-tolerant cultivars will be grown outside the regulatory and short-term monitoring arrangement of an environmental release permit will further monitoring assessments be undertaken? From the growers point of view it might be helpful to be able to identify the volunteers of herbicide-tolerant cultivars as compared to their non-transgenic counterparts. This identification could be marked simply by noting the response of the plants to the application of herbicide on a trial and error basis. Still, this is a rather crude diagnostic test and the whole issue of testing for herbicide-resistant cultivars is one of some complexity (Rogers & Parkes, 1995). These authors report the EU via CEW 23 Working Group 3 is currently developing standards relating to characterisation, sampling and monitoring of genetically modified plants for release in the environment.

The most direct and reliable method for detecting the presence of a transgene is the use of PCR or DNA probes using known sequence data (Goldsbrough, 1992). A DNA-based test requires small quantities of plant material, any part of the plant can be assayed and the test is relatively inexpensive. However, settting up a PCR for 'routine' tests is not particularly rapid by comparison with an immunological-based diagnostic test. A comparison of DNA methods, suitable for microtitre format automation and methods for assessing the proportion of transgenic plants in bulk samples are reviewed by Rogers & Parkes (1994).

Perhaps it is doubtful that research effort will be devoted to developing new diagnostic technologies for the identification of transgenes in practical crop protection when there is no statutory requirement. Beringer *et al.*, (1992) proposed a scaling down of detailed monitoring once genetically modified crops become commercialised, thus farmers should report any problems they detect. While farmers may eventually recognise the development of novel herbicide-tolerant volunteers or new weed problems created by introgression, this diagnosis may arise too late to effect any remedial action.

CONCLUSIONS

Clearly, the development of HT crops is a practical reality, one of the first generation developments from plant biotechnology. This opportunity to broaden systems of weed control has not been universally welcomed principally due to concerns regarding the environmental impact of herbicide tolerance transgenes. Furthermore, a basic mistrust of partnership agreements between the agrochemical industry and plant breeding companies has given rise to concern by those not directly involved in the production and release of HT crops. But at the end of the day it will be farmers who will decide whether or not these novel cultivars have any economic and technical advantages which warrant their adoption. Still, opening the door to the use transgenes in arable agriculture should be undertaken with due regard to their integration in each agro-ecosystem. It would be naive simply to extrapolate examples from one country to another where differences in environment, cropping practices and associated wild flora exist. The impact of the more widespread growing of HT crops and subsequent transgenic cultivars must be effectively monitored at various levels from crop rotation records through to the development of diagnostic tests for the detection of transgenes in the environment. Too great an investment has been made in the development of HT crops for the technology to be commercialised without due regard to its 'after sales' impact.

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