SESSION 5C

HERBICIDES IN THE CONSERVATION MANAGEMENT OF FARMLAND, GRASSLAND, WOODLAND AND THE UPLANDS

SESSION ORGANISER DR N. W. SOTHERTON

POSTERS 5C-1 to 5C-9

THE USE OF HERBICIDES ON NATIONAL NATURE RESERVES

A.S. COOKE

English Nature, Northminster House, Peterborough, PE1 1UA

ABSTRACT

The successor bodies of the former Nature Conservancy Council are responsible for more than two hundred National Nature Reserves (NNRs), about half of which are in England. Management of invasive vegetation is undertaken by physical means whenever practicable. However, there are situations when decisions are made to use herbicides, otherwise the specific wildlife interest of the site may be lost. In 1990, it was estimated that there were 80-90 herbicide treatments on NNRs including 60-70 in England.

The objective is usually to control a single plant species and have a minimal direct toxic impact on the community being invaded. This is often achieved by using relatively selective herbicides (eg asulam) or precise placement techniques (eg directly onto cut stumps). Non-selective herbicides are usually only sprayed on invasive monocultures. Only a few named herbicides may be used routinely; permission to use other products should be sought in advance. Our approach is underpinned by commissioned research on control techniques and on minimising impact on non-target vegetation.

INTRODUCTION

In April 1991, the Nature Conservancy Council (NCC) was reorganised. New agencies were set up in each country: English Nature, the Nature Conservancy Council for Scotland and the Countryside Council for Wales (after amalgamating with the Countryside Commission in Wales). Overseeing the work of these country agencies is the Joint Nature Conservation Committee.

This paper examines the past use of herbicides by the NCC on National Nature Reserves (NNRs). It is unlikely that reorganisation will have a major impact on patterns and techniques of herbicide use on NNRs. Conservation of NNRs is regarded as a means of safeguarding, through appropriate control and management, the most important areas of (semi-)natural vegetation with their characteristic flora and fauna. Reserves are chosen to provide adequate representation of the countryside's range of variation. Most NNRs are owned or leased by one of NCC's successor country agencies or managed under a Nature Reserve Agreement. A few are held and managed by an approved body and declared under Section 35(1)(c) of the Wildlife and Countryside Act, 1981. Details of NNRs, as declared by 31 March 1990, are given in Table 1.

TABLE 1. National Nature Reserves declared March, 1990

Country	Number of NNRs	Total area (ha)
England	121	41,312
Scotland	68	112,241
Wales	46	12,798
Britain	235	166,351

PRINCIPLES OF MANAGEMENT WITH HERBICIDES

Should a herbicide be used?

Nearly all NNRs have to be actively managed if they are to retain their characteristic flora and fauna. Guidelines on herbicide use have been produced for site managers (Cooke, 1986). One of the central recommendations is that the control of unwanted plant species should be achieved by methods other than use of herbicides, wherever this is practicable. The most specific method of eliminating undesirable plants is by removing each individual by hand or machine. Thus pines (*Pinus* spp.) are always best controlled by physical means; seedlings can be pulled up and larger trees will not regenerate if cut down. Physical removal can be used successfully to counter the early colonisation of a site by many invasive plants, eg scrub species. Where numerous individual plants have to be controlled, regular cutting, grazing or burning may provide the solution. However, in some situations, these methods may be unsuccessful or impracticable. Where this is the case and where further inaction would lead to loss of conservation interest, then herbicide use is viewed as an option.

In some situations, control of invasive plants appears to be virtually impossible without recourse to herbicides. For instance, extensive areas of birch (*Betula* spp.) or rhododendron (*Rhododendron ponticum*) can really only be selectively removed with the help of herbicides. Although such practices may be frowned on by some traditional conservationists, (semi-)natural habitat in Britain has declined in area to such an extent over recent decades that the remaining habitat must be safeguarded by the most appropriate means available.

Any herbicide usage should be regarded as a 'one-off' management exercise to aid habitat restoration. A herbicide should not be used to tackle the proximate cause of a problem without the ultimate cause also being tackled, if this is feasible. Thus if a thistle problem stems from poaching caused by over-stocking, the stocking rate should be corrected in order to avoid having to re-spray the thistles in subsequent years.

Guidance on herbicide usage

On NNRs the management aim is often to prevent natural succession from taking place. Herbicides are used to control plant species invading open terrestrial, freshwater and coastal habitats, including:

(i) Bracken (Pteridium aquilinum) on heathland or moorland;

(ii) Thistles (Cirsium spp.), bramble (Rubus fruticosus) and other common weed species in grassland:

(iii) Tree and scrub species on heathland or grassland;

(iv) Common reed (Phragmites australis) in shallow freshwater areas;

(v) Spartina anglica on coastal flats.

The conventional aim of a farmer or forester, when using a herbicide, is to safeguard the single crop species, but control the invading species. The latter may often be a plant community rather than a single invasive weed. In nature conservation, the aim tends to be the opposite, ie to safeguard the (semi-)natural community, but control a single invasive species. There are various means of achieving this much more selective aim. While totally-selective chemical herbicides do not exist, some compounds are much more selective than others. Thus, for bracken control, we would select asulam, not glyphosate, which is a broad spectrum herbicide. For the control of birch on heathland, fosamine-ammonium is recommended, as it has no significant effect on ground flora (Marrs, 1984). Another aid to the targetting of specific plant species is the use of precise placement techniques, eg weedwipers on tall vegetation or paint brush or drench gun application to cut stumps. Broad-spectrum herbicides are only applied from knapsack sprayers to extensive monocultures of, for example, Spartina anglica or Japanese knotweed (Reynoutria japonica). The NCC has commissioned research on the topic of spray drift impact (eg Marrs et al., 1989), so that precautions can be taken to avoid effects on non-target vegetation from such spraying.

The policy for herbicide use on NNRs and other reserve areas is outlined by Cooke (1986). The use and non-target impact of the following seven herbicides is described in detail: ammonium sulphamate, asulam, dalapon, diquat, fosamine-ammonium, glyphosate, triclopyr. Each of these may be used on NNRs provided the guidelines and label instructions are followed. None of these is noted for causing problems relating to persistence or water contamination. Staff were alerted in 1990 by an internal circular to the potential of triclopyr to cause damage by vapour drift; they were advised not to undertake treatment with formulations containing triclopyr if air temperature had exceeded or was likely to exceed 15°C that particular day.

The guidelines (Cooke, 1986) were published prior to enforcement of the Control of Pesticides Regulations (COPR), 1986. In order to be certain of legal and other aspects, the Pesticides Safety Division of MAFF was approached for specific advice. This advice, in the form of two detailed letters, was circulated to regional staff in 1989 and is included with each new copy of the guidelines distributed. In addition, regional staff are updated at roughly annual intervals on approvals of the seven listed herbicides and on newly-approved herbicides that may prove valuable for conservation, eg a mixture of dicamba, triclopyr and 2,4-D ('Broadshot') and another formulation of dicamba ('Tracker') developed for bracken control. If regional staff are considering using unlisted herbicides on NNRs, they are required to consult the Science Directorate.

We endeavour to anticipate problems and undertake research as necessary. Thus, the current general interest in the control of Japanese knotweed, especially on amenity areas, was anticipated by a review commissioned in 1987 (Scott, 1988). This was followed by a review of NCC's views and action over knotweed (Cooke, 1988). Another invasive plant to attract attention in recent years is the alien, aquatic stonecrop Crassula helmsii; an investigation of control techniques has been commissioned (Dawson & Henville, 1991). We may also collaborate with manufacturers over testing a product for conservation use. Thus, NCC and now English Nature have worked with Monsanto plc to determine the efficiency and environmental safety of glyphosate formulations used against Spartina anglica.

DOCUMENTED HERBICIDE USE ON NNRS

Background

From the 1960s up until early 1987, NCC's wardening staff contributed to an Event Record System for NNRs. Information was recorded from notable events on NNRs, eg use of a herbicide. This information was placed on computer centrally. Since 1987, a similar system, the Project and Recording System (latterly the Project Planning and Recording System), has been operating. Records from 1987 to 1989 have been assembled and, at the time of information retrieval, about 75% had been entered on to computer. For these schemes, records are held at Peterborough for Britain for the Event Record System, but for England only for the latter system. It was decided to extract records from the period 1984-6 to represent pre-COPR use and 1987-9 to represent the post-COPR situation. However, two problems are apparent with these schemes:

(i) Not all herbicide events are recorded;

(ii) Many of those that are reported do not contain key-words in their "short descriptions" that allow ready retrieval using a word search.

Therefore, I have attempted to obtain further information directly from regional staff on herbicide usage in 1990. The approach differed somewhat from event recording, where multiple herbicide application on the same NNR may be treated as different records, in that I asked simply how many NNRs had been treated in 1990 with specific herbicides?

Some treatments on NNRs are undertaken by contractors while others may be carried out by graziers or other site occupiers. Most, however, have been undertaken by NCC staff. COPR introduced certificates of competence for pesticide users, and during 1987 and 1988, 75 regional NCC staff received training. Results of testing under the National Proficiency Tests Council are being collected during 1991 and are not available for this paper. Two regions have not had any staff trained; one of these regions (East Midlands) seems to have used no herbicides during the entire period, 1984-9. Although regions have used herbicides according to the national guidelines, the extent of herbicide use has reflected each region's priorities and preferences. In regions where little spraying is done, use of contractors may now be a preferred cost-effective option.

Results

Data on usage for British NNRs, 1984-6, and for English NNRs, 1987-9, are given in Table 2. During 1984-6, triclopyr was the most frequently used herbicide although it should be noted that the majority of its uses were on a single NNR (Bure Marshes). Ammonium sulphamate was the next most frequently used. However, by 1987-9, the use of ammonium sulphamate had decreased considerably, it having been largely replaced for stump treatment by glyphosate and triclopyr. Applications to freshwater or coastal areas decreased from ten records to zero. Most of the earlier aquatic use centred on a control programme at Walberswick NNR. However, an additional reason for the decrease resulted from the fact that no herbicide was approved post-COPR for use against *Spartina anglica*.

TABLE 2. Herbicide treatments on English NNRs with data for Scotland and Wales given in brackets for 1984-6.

Herbicide	Target species				Total treatments
	Trees or scrub	Bracken	Other terrestrial species	Freshwater or coastal species	
1984-6					
ammonium sulphamate	21 (8)	(1)			21 (9)
asulam		9 (3)	(1)		9 (4)
dalapon				4 (1)	4 (1)
fosamine-ammonium	2				2
glyphosate	4 (2)		4 (1)	2	10 (3)
triclopyr	32 (1)		4 (1)		36 (2)
others	(1)		1		1 (1)
unspecified	6	3	1 (1)	4	14 (1)
TOTAL	65(12)	12 (4)	10 (4)	10 (1)	97(21)
1987-9					
ammonium sulphamate	6				6
asulam		9			9
fosamine-ammonium	4				4
glyphosate	9		6		15
triclopyr	18		1		19
others			4		4
unspecified	2	4	2		8
TOTAL	39	13	13	0	65

Information in Table 2 indicates that a significant decrease in herbicide use occurred between the two time periods (chi squared = 6.32, $P<0.05$). Half of the recorded decrease could be accounted for by a reduction in the intensity of the programme at Bure Marshes NNR from 24 treatments during 1984-6 to 8 in 1987-9. Although the decrease in overall use was probably real, one should be cautious about this conclusion for the reasons given in the background to this section. The numbers understate reality and can only be regarded as an index of herbicide use (see below). The records from the 1987-9 data set not yet entered onto computer were searched manually. This revealed only 11 records that would have been retrieved by a key-word search, but 12 others involving herbicide use that lacked key-words in the titles. As all of these records were used in the 1987-9 data set in Table 2, this is an additional reason to support the contention that herbicide use decreased in the late 1980s.

In the separate direct enquiry about herbicide use in 1990, replies were received from 12 of the 15 regions. These reported 49 treatments on NNRs. If these regions were a representative sample, it indicated that there were about 60 treatments in Britain in 1990. However, the author is aware of at least one treatment not reported by one of the regions that responded, so this may be an underestimate. It also takes no account of repeat treatments on the same NNR in the same year. The total of 118 treatments referred to in Table 2 for 1984-6 included 38 instances of repeat treatment in the same year. Applying a conversion factor of 118/80 provides an estimate of 80-90 single treatments on NNRs in 1990. The estimate for England is 60-70 treatments in 1990. This is regarded as a more accurate reflection of recent herbicide use than the figure of 65 for the three year period 1987-9 (Table 2).

More reassuringly, however, the pattern of use in 1990 was similar to that in Table 2 for 1987-9. Thus, glyphosate and triclopyr were the most frequently used herbicides accounting for 15 (31%) and 11 (22%) of the treatments respectively; others on the 1990 list included asulam, 7 (14%), ammonium sulphamate, 6 (12%) and fosamine-ammonium, 2 (4%). So while contributors to the Project Planning and Recording System need further guidance on what and how to record information, the system does seem to give a reasonable indication of the pattern of usage.

Details of tree and scrub species targetted for treatment are given in Table 3. The total numbers of English treatments exceed the numbers quoted for trees and scrub in Table 2, because some applications involved two or more species. Overall, the most frequently treated species was willow (*Salix* spp.) followed by alder (*Alnus glutinosa*) and sycamore (*Acer pseudoplatanus*). However, alder appeared so important because of the previously-mentioned programme of control on the Bure Marshes. Away from this site, the order was sycamore, followed by birch and willow (Table 3). Rhododendron seemed relatively unimportant as an invasive species in English NNRs but assumed greater importance in Scotland and Wales. Of the 116 instances of tree or scrub treatment summarised in Table 2, 99 (85%) involved applications to cut stumps.

The range of other plants treated is given in Table 4. Thistles accounted for about half of the terrestrial applications and were often targetted by the grazier/occupier rather than the NCC.

TABLE 3. Number of treatments of tree and scrub species. Treatments for Bure Marshes NNR are given in brackets.

	Number of treatments			
	England 1984-6	Scotland & Wales 1984-6	England 1987-9	Total
Salix spp.	17(13)	1	7 (3)	25(16)
Alnus glutinosa	18(18)		5 (3)	23(21)
Acer pseudoplatanus	15 (5)	2	5	22 (5)
Betula spp.	10 (5)	3	3 (1)	16 (6)
Fraxinus excelsior	5 (4)		2 (1)	7 (5)
Crataegus monogyna	1		5	6
Rhododendron ponticum	1	5		6
Quercus spp.	2		1	3
Hippophae rhamnoides			2	2
Prunus laurocerasus	2			2
Cornus sanguinea			1	1
Fagus sylvatica			1	1
Ligustrum vulgare			1	1
Unspecified	21 (2)	1	11 (2)	33 (4)

TABLE 4. Number of treatments of miscellaneous species

	Number of treatments			
	England 1984-6	Scotland & Wales 1984-6	England 1987-9	Total
Terrestrial				
Cirsium spp.	6	3	7	16
Urtica dioica	2	2	2	6
Rubus fruticosus	4		1	5
Rumex spp.	1	2		3
Juncus spp.		2		2
Senecio jacobaea		1	1	2
Brachypodium pinnatum			1	1
Freshwater and coastal				
Phragmites australis	6	1		7
Hippuris vulgaris	3			3
Spartina anglica	1			1

CONCLUSIONS

Although the total area of British NNRs exceeds 150,000 ha, there are fewer than 100 herbicide applications to NNRs per annum. Other methods of vegetation control are preferred wherever possible. Invasive tree and scrub species are the principal targets, but non-woody species, especially bracken, are also controlled. In 1990, 80% of recorded applications involved formulations of only four active ingredients: glyphosate, triclopyr, asulam and ammonium sulphamate.

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ENHANCING BOTANICAL DIVERSITY WITH HERBICIDES

R.J. HAGGAR, D. JONES, A.T. JONES

AFRC Institute of Grassland and Environmental Research, Welsh Plant Breeding Station, Aberystwyth, Dyfed, SY23 3EB

ABSTRACT

Herbicides, used traditionally to kill weeds in agricultural crops, may have a role in enhancing biodiversity. Results from a current experiment highlight the potential of certain grass-suppressing herbicides for creating gaps and reducing competition for subsequent recruitment of new species. Also outlined are other potential situations where herbicides can be used as conservation tools.

INTRODUCTION

Selective herbicides have traditionally been used to kill or suppress unwanted weeds in intensively managed swards, with yield and quality improvement as primary aims. A limited number of these herbicides have also been recommended for use in nature reserves to conserve key plant communities, by controlling certain invasive species (Marrs, 1984), provided that care is taken to avoid damaging the understorey plants and associated insects (Cooke, 1989). Less work has been done on the potential use of herbicides as management tools for enhancing botanical diversity, through the deliberate creation of gaps and suppression of competition, to allow subsequent recruitment of new species from soil seed banks or other sources (Haggar, 1985). This paper reports an experiment which evaluated a range of grass-suppressing herbicides on a perennial ryegrass sward, over which seed of various dicotyledonous species was broadcast.

MATERIALS AND METHODS

A permanent pasture, consisting mainly of *Lolium perenne*, *Agrostis tenuis* and *Poa trivialis*, with some *Trifolium repens* and broad-leaved species, was trimmed to 2 cm on 4 March 1988, prior to spraying the following herbicide treatments (chemical dose refers to active ingredient): 2.0 kg/ha alloxydim-sodium; 2.8 kg/ha carbetamide; 6.0 kg/ha dalapon-sodium; 2.0 kg/ha diclofop-methyl; 0.6 kg/ha glyphosate; 1.0 kg/ha paraquat; 1.2 kg/ha propyzamide, together with an untreated control. The herbicides were applied at 300 l/ha on 8 March to 1.5 x 7.5 m plots in a randomised block design, replicated four times. On 16 May the plots were scarified with a tined rake, exposing about 10% bare ground, and the following wild flower seed mixture was broadcast at 0.6 g/m^2: yarrow *(Achillea millefolium)*, black knapweed *(Centaurea nigra)*, meadow cranesbill *(Geranium pratense)*, St. John's wort *(Hypericum perforatum)*, rough hawkbit *(Leontodon hispidus)*, oxeye daisy *(Leucanthemum vulgare)*, birdsfoot trefoil *(Lotus corniculatus)*, ribwort plantain *(Plantago lanceolata)*, cowslip *(Primula veris)*, self heal *(Prunella vulgaris)*, meadow buttercup *(Ranunculus acris)*, goat's beard *(Tragopogon pratensis)* and common vetch *(Vicia sativa)*. Other species which did not establish have been ignored. The area was trimmed to about 7.5 cm at intervals of approximately 2 weeks. Establishment, initially retarded by drought, was favoured by prolonged rainfall in July. Plant counts were made on 14 September. In 1989 and 1990 a single hay cut, harvested in late July from the central 1.8 m^2 of each plot, was oven dried at 80°C for 12 h, separated into component species and weighed.

EXPERIMENT RESULTS

Paraquat and glyphosate caused the greatest initial suppression of grass growth, whilst dalapon and carbetamide caused the least suppression (Haggar & Jones, 1989). Propyzamide gave greatest long-term suppression. Establishment of sown species was inversely related to grass suppression, with the highest density occurring on paraquat and propyzamide treatments. Yarrow, oxeye daisy, ribwort plantain and common vetch established well but meadow cranesbill and St. John's wort only established in trace amounts. Establishment of introduced species was very low on untreated plots.

In 1989 amounts of herbage harvested for the introduced species were greatest on the propyzamide and paraquat-treated plots and least on the untreated plots (Table 1). However, with both these herbicides grass yields were reduced to less than one-fifth of the untreated yields, although total amounts of herbage harvested were significantly greater than untreated.

TABLE 1. Effect of herbicide pre-treatment on herbage harvested, 1989 and 1990 (d.m. kg/ha)

	1989			1990		
Herbicide	Grass	Other spp.	Total	Grass	Other spp.	Total
Propyzamide	854	4361	5215	447	5405	5852
Paraquat	530	5238	5801	1059	3390	4449
Diclofop-methyl	2095	882	2897	1051	3872	4923
Glyphosate	3026	854	3880	1502	3382	4884
Alloxydim-sodium	4001	650	4651	1001	3823	4824
Dalapon-sodium	3644	517	4161	937	3707	4644
Carbetamide	4336	512	4848	3308	2673	5981
Untreated	4259	301	4560	2457	2133	4590
SE	262	275	184	182	220	164

In 1990 the propyzamide treatment produced the highest yield of introduced species (Table 1), although grass yields were still extremely low. The predominant non-grass species were, in descending order: oxeye daisy, ribwort plantain, yarrow, self heal and knapweed.

DISCUSSION

This experiment showed that meaningful numbers and amounts of herbaceous species can be successfully introduced into an all-grass sward following suppression with propyzamide and paraquat. However, levels of grass suppression would probably be unacceptably high, suggesting that further work is needed to determine optimum doses, especially of propyzamide. Measurements of nutritive values of each introduced species would be additionally helpful. Interpretation of the findings would also have been facilitated by measurements of buried seed populations and gap sizes, as influenced by the herbicide treatments, as well as germination percentages for the introduced species. Initial establishment was greatest for species with light seed and thus more seed per gram (Yarrow and oxeye daisy have extremely light seed, respectively 7,000 and 3,000 per gram).

During the second year, when all plots received a common treatment, there was a substantial increases in sown species on the untreated plots. this probably reflected dispersal of seed from adjacent plots. If so, this implies that chemical "knocking" of swards to facilitate initial seed introduction only needs to be done on a limited scale if followed by appropriate management to encourage dispersal and colonisation.

This approach to enhancing botanical diversity is seen as being potentially relevant to low-input swards, especially those having field margins (e.g. hedges, earth banks, ditches etc.) which have a rich seed rain. Current work aims to identify the suitability of a range of grassland field margins for this purpose. Alternatively, seed could be introduced by slot-seeding machinery (Marshall, 1982) or via hay bales harvested from species-rich swards.

Other potential situations for herbicidal enhancement of diversity

Grass monocultures Whereas mosaics of tall grasses, such as *Molinia caerulea* and *Deschampsia caespitosa* can support a high diversity of wildlife, large monocultures of these species can be restrictive to overall diversity. Grass-suppressing herbicides, e.g.low-dose paraquat, can be used to selectively penalise the ranker species and favour the smaller herbs (Green, 1983), or as alternatives to burning and/or grazing to create gaps in these monocultures for buried, or introduced seed, to colonise. Equally, perennial ryegrass swards can be made more botanically diverse by spraying them with low-dose dalapon in July (Haggar & Oswald, 1976). Growth retardants, such as maleic hydrazide, can also be used as tools for maintaining species-rich swards (Marshall, 1982).

Heather Marrs (1984) has demonstrated that certain herbicides can be applied to lowland *Calluna*, to induce regeneration, or to create uneven-aged swards, as an alternative to cutting or burning. Low-dose dalapon might also prove useful for selectively controlling patches of grasses in upland heather, thus facilitating burning and/or mechanical defoliation and subsequent seedling regeneration. Cayford (1988) has used glyphosate to create patches in heather, with benefit to feeding grouse.

Bracken In addition to conserving species-rich communities on an

SSSI, through the selective removal of invading bracken by asulam (Haggar *et al.*, 1988), dense swards of bracken can be broken up with glyphosate and sown with grass or *Calluna* seed, coupled with appropriate management (Lowday, 1984). Similarly, trees planted into dense bracken at wide spacing for agroforestry purposes (and to enhance landscape values, overall biodiversity and provide long-term bracken suppression), require localised bracken control for rapid tree establishment. For instance, spraying bracken with glyphosate in 2 m diameter circles prior to tree planting significantly increased tree establishment (Haggar & Jones, 1991).

CONCLUSIONS

Herbicides can be considered as management tools for enhancing or maintaining botanical diversity in a range of vegetation types and habitats. However, it must always be remembered that herbicide efficiency against the particular target species must be balanced with careful assessment of possible harm to the associated plant and animal/insect communities. Further work is needed to identify a wider range of suitable herbicides (including plant growth regulators) for conserving and enhancing biodiversity in grass-based swards, with due consideration given to the effects on the genetic structure of the remaining species and populations.

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THE EFFECT OF GROUND VEGETATION MANAGEMENT IN AGRI-FORESTRY SYSTEMS ON TREE GROWTH AND ENVIRONMENTAL IMPACT

C.A.WATSON

The Scottish Agricultural College, 581 King Street, Aberdeen, AB9 1UD

C.BODEUX

Faculte des Sciences Agronomiques, Unite des Eaux et Forets, Place Croix du Sud,2, 1348 Louvain-la-Neuve, BELGIUM.

M.A.BIRLEY, P.NEWBOULD

Macaulay Land Use Research Institute, Craigiebuckler, Aberdeen, AB9 2QJ

J.E.HOOKER, D.ATKINSON

University of Aberdeen, 581 King Street, Aberdeen, AB9 1UD

C.J.NIXON

Forestry Commission (NRS), Roslin, Midlothian, EH25 9SY

ABSTRACT

Data on the effects of herbicide use around young trees in farm woodlands and agroforestry plantings are presented. Weed control increased the growth of young trees on ploughed and unploughed land; total control did not benefit growth over spot control. The extent of animal damage to trees in farm woodlands was influenced by the type of animal, the tree species and the presence or absence of weed control. In an agroforestry experiment herbicide treatment around trees increased nitrogen mineralization and potential nitrate leaching from soil.

INTRODUCTION

At a time when many crops are being produced in surplus within the EC, planting trees on farmland is an acceptable long-term alternative to agriculture. It may also result in environmental benefits because of the reduced fertilizer requirements of trees compared with agricultural crops and their value as wildlife habitats (Atkinson, 1991). The extent to which sites satisfy the multiple objectives for planting woodland will depend upon species composition and management. Frequently objectives change in importance during the life of a woodland. Farm woodlands may involve pure tree planting or maintaining trees in parallel with a pastoral or arable enterprise (agroforestry). In both cases in order to maximise the benefits from planting woodlands it is important to understand and manage the whole woodland ecosystem rather than just the trees within it. This is particularly important for agroforestry plantings but also for woodlands planted to enhance conservation potential. There are also economic incentives to plant trees. Apart from timber value grants are available for planting woodland with additional incentives for broadleaved trees, because of their additional value as wildlife habitats. Establishing farm woodlands thus involves consideration of a number of factors with the most suitable management methods depending on the relative importance given to the different objectives.

A management method frequently applied in agri-forestry systems (farm woodlands and agroforestry plantings) is the planting of trees into herbicide treated zones which are maintained weed free for a number of years. The value of this practice for tree establishment, its effects on interactions with wildlife and some of its possible environmental consequences are discussed here.

MATERIALS AND METHODS

Cultivation

This work was carried out on a farm forestry experiment established in 1989 at the Scottish Agricultural College's Tillycorthie Farm, 10 miles north of Aberdeen (grid reference NJ 907209). The effects of cultivation (ploughing and non-ploughing) and weed control on growth of sycamore were studied. There were three levels of weed control; no control, 1m spot where glyphosate (Roundup 90g AI/l applied with a weedwiper) was applied each April, and total control where propyzamide (Kerb 1.5kg AI/ha) was applied in winter and glyphosate applied when necessary during the growing season. The experimental design comprised four replicate plots (16 trees, plot size 8X8m) of each treatment.

Pest damage

At the same site pest damage assessments were carried out. The experimental design comprised four replicate blocks with 8 different tree species with and without 1m spot weed control using propyzamide (as above) annually in winter. The number of trees damaged by either deer, rabbits or voles were recorded in 1991. Tree heights and diameters were measured annually.

Environmental impact

This work, funded by the Commission of the European Communities, was carried out at the Glensaugh Research Station of the Macaulay Land Use Research Institute on part of an Agroforestry Systems experiment; Glensaugh is situated approximately 35 miles south of Aberdeen (grid reference NO 670783). Trees were planted at 400 stems/ha in a mowed pasture. The trees were planted into herbicide treated zones 1m in diameter. A total of 160 kg N/ha was applied in four fertilizer applications in 1989. Prior to each fertilizer application soil inorganic nitrogen was measured at 0-5, 5-15 and 15-30cm depths in the herbicide zones (near trees) and in the adjacent pasture (away from trees). Nitrate-N in 2M KCl extracts was measured using a colorimetric method. Soil moisture was recorded at 10, 30 and 70 cm depth near and away from trees at two weekly intervals through the growing season using a neutron probe.

RESULTS

Cultivation

Results showed that ploughing prior to planting increased both height and diameter increments in the first year (Table 1). Spot vegetation control using herbicides increased both height and diameter of trees in unploughed plots. In ploughed plots both height and diameter were increased by spot application, only diameter was increased by complete control.

TABLE 1. Incremental growth of sycamore under different cultivation and weed control treatments for 1990.

Cultivation	Vegetation control	Height (cm)	Diameter (mm)
Unploughed	None	18.3	1.9
	Spot	20.8	3.0
	Complete	17.8	2.2
	Mean	19.0	2.4
	LSD	1.54	0.64
Ploughed	None	24.7	3.1
	Spot	30.1	5.0
	Complete	25.4	4.4
	Mean	26.8	4.2
	LSD	1.62	0.68

Animal damage

Preferences of specific animals for certain tree species were observed (Figure 1). Deer, for example, had damaged most of the cherry trees (70-90%), but only a very small number of fir trees (0-10%). In general a larger number of broadleaved trees were damaged than conifers. Damage to conifers by voles was particularly low.

For most species weed control increased the proportion of trees damaged by deer and rabbits and decreased damage by voles. The extent to which damage was influenced depended upon both tree species and animal. Weed control in ash for example resulted in over ten times as many trees being damaged by rabbits whilst weed control in fir resulted in no change to the number of trees damaged.

Environmental impact

Nitrate-N levels were generally much higher in the herbicide treated zone than in the pasture away from the trees (Figure 2). Near to trees the nitrate-N levels increased until August (day 213), the highest level was always found in the top 5 cm of the soil profile. By November (day 318) the total amount in the top 30cm of soil was much lower than it had been in August and the highest level was in the 15-30 cm layer. In the pasture nitrate-N levels remained low throughout the year.

Throughout the season the soil water deficit was lower in the herbicide treated zones than in the pasture at both 10cm and 30cm (Figure 3). In the herbicide zone the soil began to dry out later in the season than the soil under grass, the return to field capacity was earlier in the herbicide zones than in the pasture.

DISCUSSION

Weed control increased tree growth, with greatest increases occurring on ploughed land. Ploughing releases nitrogen by stimulating mineralization (Dowdell & Cannell, 1975), and this may have provided nitrogen to support extra tree growth. The effects of vegetation control on tree growth were less clear than have previously been reported for forest and fruit trees (Tuley, 1984, Atkinson & White,1981), this may be due to the smaller trees used in this study or to the more exposed site.

Although damage by voles was reduced, damage to most tree species by rabbits and deer was increased by vegetation control, presumably by influencing animal behaviour and host location. Given the greater degree of damage usually caused by rabbits and deer this would tend to suggest that when aiming to limit damage to trees the preferred management option would be no vegetation control. However although it is usually possible to fence against rabbits and deer this is clearly not a way of controlling voles. This data suggest therefore that in adequately fenced farm woodland plantations overall pest damage may be reduced by vegetation control. Selection of species will also influence the need for protection, for example voles tended not to damage coniferous species. There was also an interaction between tree height and animal damage, taller trees were more likely to be damaged by deer.

The nitrate-N and soil moisture data (Figures 2 & 3) suggested that in herbicide zones nitrate-N accumulated during the period April - October but that as soon as the rainfall was high enough to allow water to move through the soil profile ie from September onwards, nitrate leaching occurred. In the pasture nitrate-N levels remained fairly low throughout the year due to the uptake of N by the actively growing grass. Leaching of nitrate would be restricted to late autumn/winter by the low soil moisture potential which existed until this time. This suggests therefore that the use of herbicides in agri-forestry systems could lead to nitrate loss by leaching, and this has implications for ground water quality. Essentially the potential loss from an area will depend on planting density and the total area which is herbicide treated. However at 400 stems per ha with spot treatments 1m in diameter the total treated area is only around 3% of the ground area. From an environmental point of view sprayed out zones should thus be kept to a minimum size necessary to ensure acceptable tree growth.

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FIGURE 1.Damage to trees by animals(means of four replicates)

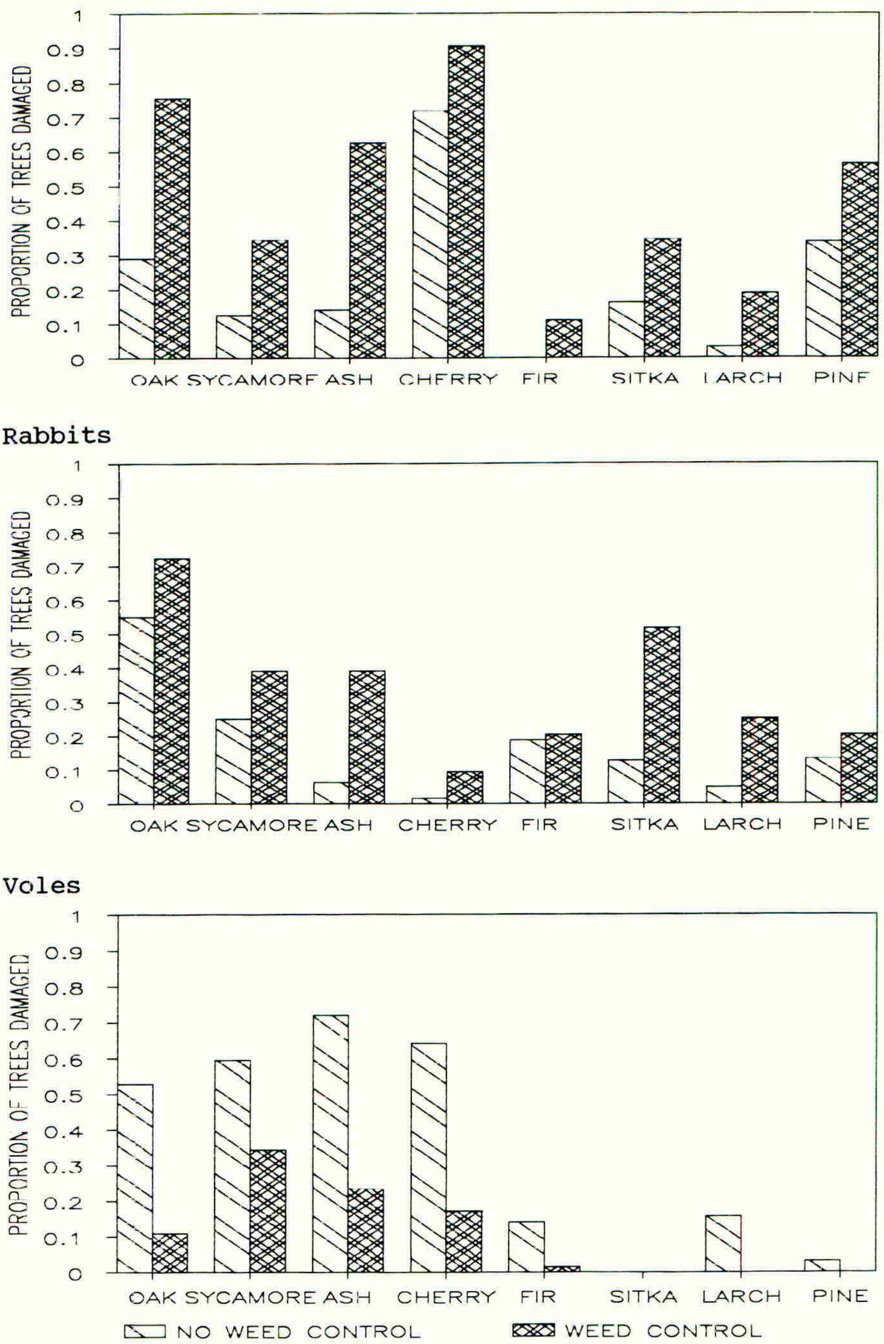
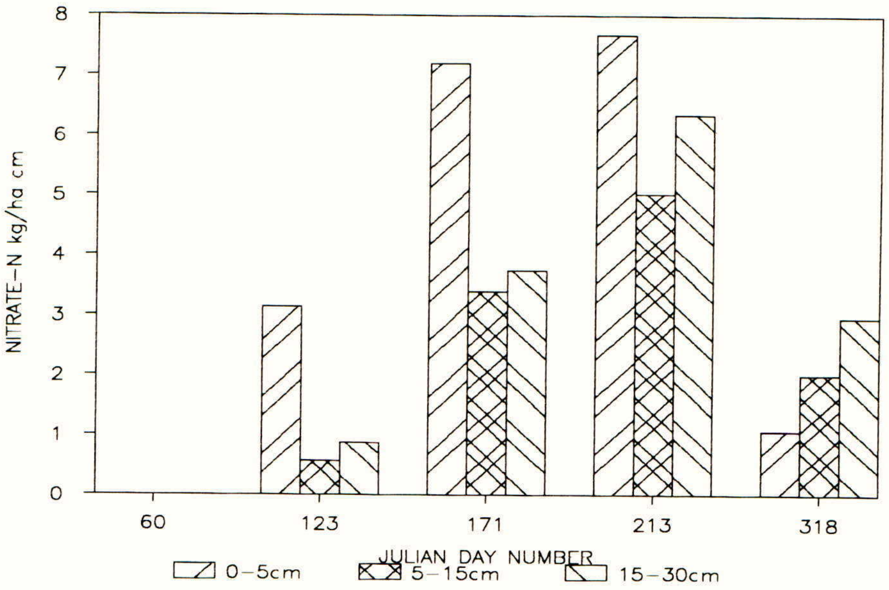


FIGURE 2. Changes in soil nitrate-N with time, 1989.

a) Near trees in herbicide treated zone



b) Away from trees in pasture

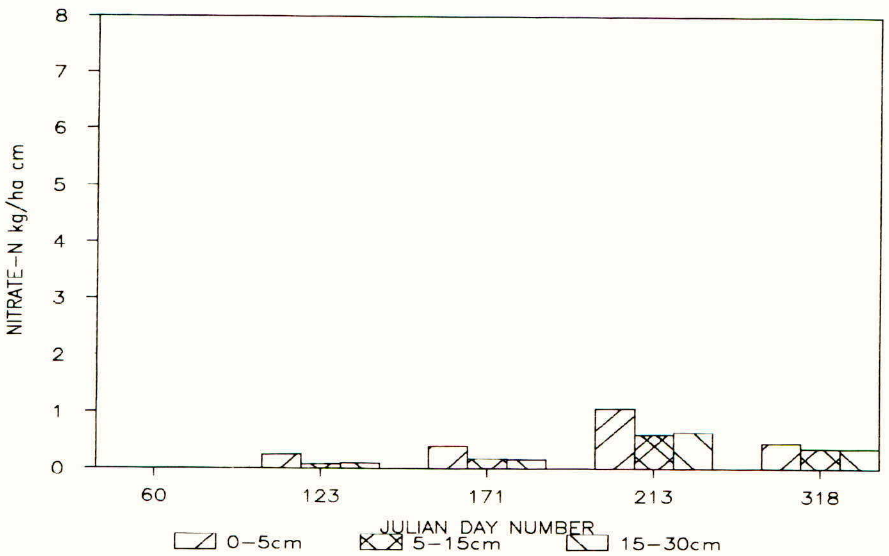
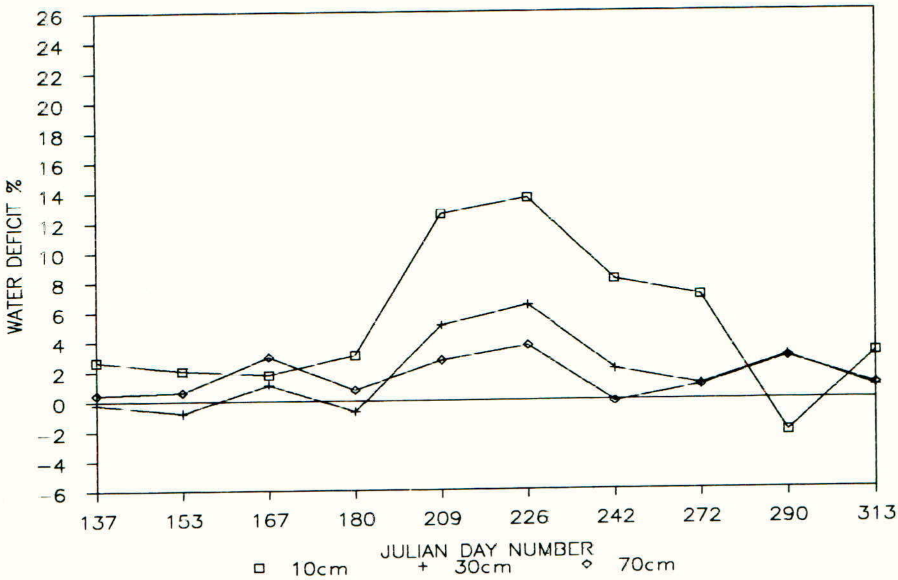
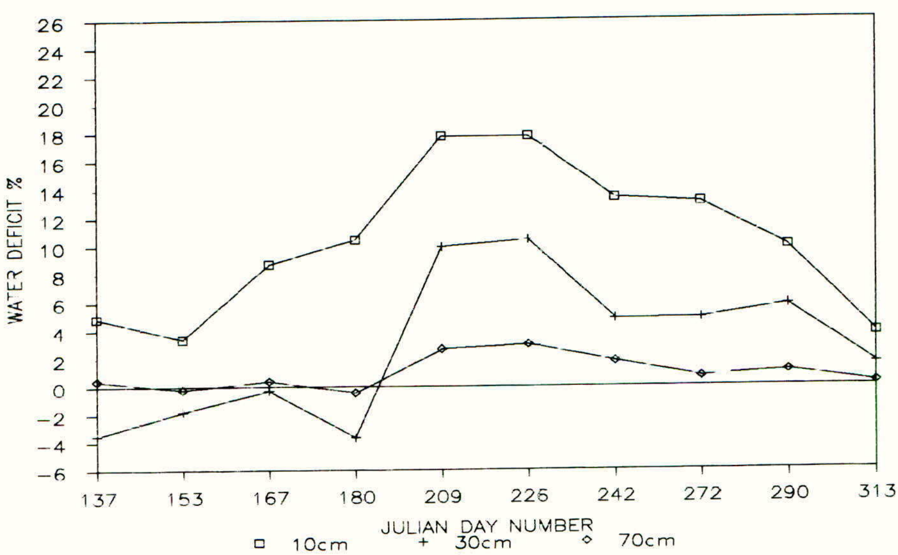


FIGURE 3. Changes in soil water deficit with time, 1989

a) Near trees in herbicide zone



b) Away from trees in pasture



CONSERVATION MANAGEMENT OF DIRECT-SEEDED BROADLEAVED WOODLAND USING HERBICIDES

P.D. PUTWAIN, A.M. MORTIMER

PlanTech Research, Department of Environmental and Evolutionary Biology, The University of Liverpool, P.O. Box 147, Liverpool L69 3BX

B.E. EVANS

Planning Department, Gwent County Council, County Hall, Cwmbran, Gwent, NP44 2XF

ABSTRACT

The creation of naturalistic broadleaved woodland using the technique of direct-seeding is critically dependent on the application of graminicides during the early establishment phase. The establishment and subsequent growth of tree seedlings was considerably enhanced by the application of propyzamide to suppress competitive grasses. The impact of the herbicide on the herbaceous plant community has been to create greater ecological diversity and a correlated increase in the number of butterfly species feeding as adults in the recently created young woodland.

INTRODUCTION

The creation of ecologically diverse amenity woodland - an approach

Losses of native woodland in England have been occurring steadily since the first survey was undertaken in the Domesday Book, 1086 (Rackham, 1980). In almost all English counties (with the exception of Cornwall, Devon and Herefordshire) losses of woodland between 1086 and 1924 were greater than 25% of the total woodland area and in some counties more than 75% of woodland has disappeared (Forestry Commission, 1928 census statistics). During the present century, although the total woodland area has almost doubled from less than 5% of the land surface in 1905 to 9% in 1980, almost all of this increase has resulted from the planting of coniferous high forest. For example, ecologically valuable coppice and coppice-with-standards broadleaved woodland reduced from 209 kha in 1905 to just 38 kha in 1980 (Peterken & Allison, 1989).

In recent times attempts have been made by local authorities, central government departments and Non-Governmental Organisations such as the Countryside Commission, the Woodland Trust and the Forestry Commission, to increase the area of amenity broadleaved woodland, through a variety of schemes for grant-aid.

Landscape schemes in urban and rural areas have involved extensive tree planting (of transplanted nursery stock) on derelict land, roadside verges, cuttings and embankments, urban parks, country parks, school grounds etc. Generally a limited ranged of tree species (some nonnative) have been planted without any attempt to create and manage a semi-natural community that has worthwhile wildlife and conservation value. At some sites this would not be appropriate, but nevertheless many valuable opportunities have been ignored to deliberately create woodland landscapes with greater structural diversity and greater species richness of the fauna and flora, at a modest economic cost.

The Planning Department of Gwent County Council and Liverpool University have undertaken a collaborative research programme which demonstrates that establishment of woodland by direct seeding will produce natural woodland landscapes that also have a worthwhile conservation value. The objective of the research was to develop methods of direct seeding and aftercare that would give reliable establishment of tree seedlings and predictable species composition of woodland plant communities.

The role of herbicides in the creation of amenity woodland

Young tree seedlings are generally very sensitive to competition from grassland vegetation (Buckley, 1984). Similarly, transplanted trees will be greatly retarded in their growth unless a substantial area (0.5m - 1.0m diameter) around the base of the tree is kept weedfree for several years after planting. Competition for mineral nutrients and for soil moisture are the most important factors that determine the success of tree establishment and subsequent growth (Davies, 1987). Paraquat and glyphosate have been mainly used to produce a vegetation-free area around the base of individual transplanted trees. However for a direct-seeded area where seedling emergence is patchy and seedling density may reach 5 to 8 individuals per m^2, a soil-acting residual herbicide may be more appropriate. Visual appearance of amenity woodland is important and therefore it would not be appropriate to attempt elimination of all herbaceous plants and grasses. Application of propyzamide provides a compromise since competitive grasses are severely checked but annual plants and herbaceous perennials provide some ground cover and a habitat for the invertebrate fauna.

MATERIALS AND METHODS

Site preparation

An experiment was established on sloping ground adjacent to a new road (A467) from Crumlin to Aberbeeg in Gwent (NGR ST 214995). The experiment was set-up in September 1983 on a substrate consisting of colliery waste and boulder clay subsoil including industrial debris and some large stones. The site (0.43ha) was sprayed with paraquat and glyphosate on separate occasions and was cultivated with several passes of a disc harrow followed by several more passes of a chain harrow. Stones and industrial debris at the surface were collected mechanically and were removed from the site. A compound fertilizer (5,24,10) was applied at a rate of 37.7g/m^2.

Seed mixtures

On 26 September 1983 a seed mixture was sown (broadcast by hand) over the entire experimental area. This consisted of herbage grasses and legumes, winter barley and tree and shrub seed. Tree and shrub seed were not pre-treated to break deep dormancy. Full details of the site preparation and the seed mixture are given in Putwain et al. (1988); a summary is given here.

The tree and shrub seed mixture consisted of the following species with the number of seeds sown per m^2 also given; Alnus glutinosa (common alder, 404), Acer campestre (field maple, 8.5), Betula pendula (silver birch, 808), Corylus avellana (hazel, 0.28), Crataegus monogyna (hawthorn, 20), Cytisus scoparius (broom, 70), Fagus sylvatica (beech, 0.28), Fraxinus excelsior (ash, 32.5), Quercus petraea (sessile oak, 0.28), Quercus robur (pedunculate oak, 0.28), Rosa canina (dog rose, 65), and Sorbus aucuparia (rowan, $154/m^2$).

The split-split-plot randomized experimental design comprised of four main plots (65.0m x 16.6m) two of which were sown with Lupinus arboreus (tree lupin) and Lupinus perennis (perennial lupin) $0.22g/m^2$). The main-plots were subdivided into two sub-plots (65.0m x 8.3m) with either plus or minus propyzamide granules ($0.06g/m^2$AI) applied annually in December/January 1984-1988. In the period 1989-1990 the application rate was increased to $0.12g/m^2$AI.

The sub-sub-plots (21.6m x 8.3m) consisted of three fertilizer regimes (control, low, high fertilizer). The rates of fertilizer addition were a) control (no fertilizer added), b) low fertilizer ($5g/m^2$ Enmag (6:20:10) and $10g/m^2$ ICI No 5 (17:17:17) and c) high fertilizer ($15g/m^2$ Enmag and $30g/m^2$ ICI No 5). Fertilizer was applied in July 1984 and biennially thereafter in July.

Monitoring tree seedling numbers and growth

Tree seedlings were censused in two separate $4m^2$ permanent sampling areas which were randomly located in each treatment sub-sub plot in two out of a possible 40 positions. Individual tree seedlings were marked using a numbered tag attached to a wire ring. The height, extension growth and stem diameter (measured using callipers at 20mm above the ground) of individual trees was measured annually. Sample size varied but was invariably greater than 10 individuals per treatment sub-sub plot.

In April 1988 the entire experimental site was thoroughly and systematically searched (along 2m width strips) to provide evidence of the number of established tree seedlings per unit area.

Monitoring impacts on grass/herb plant communities and butterfly populations

An assessment was made in July 1990 of the plant species composition of each treatment sub-sub-plot. Three sampling areas (2m x 2m) selected using random numbers for their location were assessed for species abundance using the Domin Scale of abundance. A measure of species diversity (Shannon & Weiner) was calculated for each sampling area to provide an objective measure of species richness.

Butterfly species and numbers of individuals were recorded on the experimental area and also on the same day at nearby stands (within 400m) of Alder (Alnus spp.) and Poplar (Poplar spp.) of comparable area also located alongside the A467 road. Recording effort was the same at all three sites. Counting was undertaken by walking a regular transect across each sub-sub plot (replicated three times). This was difficult to achieve in the plots with lupins since tree and shrub density was greater. The number of butterflies were recorded on three separate dates (20 July, 23 August and 23 September) during summer 1989.

RESULTS

Tree numbers and growth

The number of established tree seedlings per unit area (adjusted to a per hectare basis) in the various experimental treatments is given in Table 1. The census was made three years after the majority of the seedlings had emerged and thus surviving individuals were well-established. It is clear that there were consistently higher populations of seedlings (total number) on the propyzamide treated plots and also that the presence of lupins was beneficial to the establishment of tree seedlings. The influence of the herbicide treatment was greater in the "plus lupins" treatment and was somewhat more consistent in the case of ash than it was with hawthorn (two of the most abundant tree species present).

TABLE 1. The mean number of established trees and shrubs per hectare in the propyzamide treatments with three levels of fertilizer, with or without lupins, at Crumlin, April 1988.

Treatment	Ash	Hawthorn	Total Number
With lupins			
none minus propyzamide	3,125	3,625	8,656
none plus propyzamide	7,438	3,313	12,219
low minus propyzamide	2,875	1,875	6,688
low plus propyzamide	12,125	4,500	18,969
high minus propyzamide	6,750	1,625	10,406
high plus propyzamide	12,688	2,188	17,563
No lupins			
none minus propyzamide	4,625	1,063	6,469
none plus propyzamide	8,938	1,688	12,562
low minus propyzamide	6,250	1,033	8,031
low plus propyzamide	5,625	1,938	9,031
high minus propyzamide	7,500	1,063	9,531
high plus propyzamide	8,125	813	10,125

none - no fertilizer
low - low fertilizer treatment
high - high fertilizer treatment

The total number of established trees per unit area was greater than required for conventional amenity woodland in all treatments, since a total tree population between 3,500 and 5,000 per hectare is rarely exceeded in traditional amenity planting. However the more dense tree population established in the plus propyzamide, high fertilizer treatment would allow greater flexibility in the selection of robust, straight, well-proportioned trees at first thinning. At Crumlin there was poor establishment of some species, in particular alder, beech, birch and rowan. These species were represented by small populations. However at other direct seeded sites in Gwent, birch and rowan have established successfully.

Using ash and hawthorn as indicator species, it was clear (Table 2) that the direct effect of propyzamide on the height growth of the young trees was relatively pronounced, and was statistically significant in the majority of comparisons. Ash and hawthorn responded to the herbicide treatment in a similar way although growth of hawthorn was less influenced by the presence of lupins. Growth of ash was generally consistently greater in the plus lupins treatment whereas the response of hawthorn was less consistent. In both species the growth response to increased input of fertilizer was very substantial. Although data for other species such as field maple and oak is not presented, these species responded to the herbicide and fertilizer treatments in a very similar way to ash and hawthorn.

TABLE 2. Mean height (±SE) of Fraxinus excelsior (ash) and Crateagus monogyna (hawthorn) in the propyzamide treatments with three levels of fertilizer, with or without lupins, July 1990.

Treatment	Ash	Hawthorn
With lupins		
none minus propyzamide	50.9 ± 7.3	58.1 ± 3.4
none plus propyzamide	81.4 ± 3.5	93.6 ± 5.2
low minus propyzamide	83.8 ± 14.5	99.8 ± 5.7
low plus propyzamide	120.9 ± 11.6	131.9 ± 9.7
high minus propyzamide	107.0 ± 8.7	123.4 ± 18.8
high plus propyzamide	138.2 ± 8.3	133.8 ± 25.5
No lupins		
none minus propyzamide	58.7 ± 5.5	70.5 ± 6.7
none plus propyzamide	63.5 ± 9.6	108.9 ± 12.3
low minus propyzamide	55.6 ± 6.5	77.6 ± 14.9
low plus propyzamide	82.5 ± 8.7	99.8 ± 8.2
high minus propyzamide	65.8 ± 6.9	112.2 ± 14.0
high plus propyzamide	109.3 ± 5.5	134.7 ± 6.6

Plant communities and associated butterfly populations

An additional important impact of the propyzamide treatment was to create more diverse ground flora communities that contain a greater number and abundance of herbaceous species. This effect was described quantitatively by the Shannon-Weiner measure of information content (Table 3). Species diversity was consistently greater in the plus propyzamide treatment in all combinations except the high fertilizer, plus herbicide with lupins treatment. This treatment had a high density of well-grown trees that cast considerable shade and therefore had suppressed the growth of herbs and grasses. An apparent consequence of the presence of a more diverse ground flora was a greater number of butterfly species and more individuals per species (Table 4). The cumulative numbers of individuals recorded on three occasions during summer 1989 was substantially greater in the experimental area in comparison with other areas of transplanted woodland.

TABLE 3. Shannon's species diversity measure of information content (±SE) calculated for the grass and herb plant communities in the propyzamide/fertilizer treatment combinations with or without lupins.

Experimental treatment	With lupins	No lupins
none minus propyzamide	3.11 ± 0.11	3.13 ± 0.14
none plus propyzamide	3.44 ± 0.18	3.51 ± 0.09
low minus propyzamide	2.91 ± 0.20	3.08 ± 0.08
low plus propyzamide	3.02 ± 0.30	3.70 ± 0.11
high minus propyzamide	2.96 ± 0.25	2.91 ± 0.25
high plus propyzamide	2.82 ± 0.16	3.37 ± 0.16

TABLE 4. Total numbers of butterflies (individuals) recorded on the area of direct-seeded trees and shrubs at Crumlin compared with nearby stands of transplanted alder and poplar (July, August, September, 1989).

Butterfly species	Direct-seeded tree experiment Crumlin	transplanted Poplar spp.	transplanted Alder spp.
Common blue	2	-	-
Dark green fritillary	1	-	-
Gatekeeper	1	-	-
Grayling	3	-	-
Green-veined white	1	-	-
Large white	6	-	-
Meadow brown	11	-	3
Peacock	1	-	-
Small copper	33	2	3
Small skipper	6	2	-
Small tortoiseshell	3	1	-
Small white	2	-	-

DISCUSSION

The total established tree population after five growing seasons was more than adequate for amenity woodland in all treatments. Nevertheless the tree population was considerably enhanced in the majority of treatment combinations that involved the application of propyzamide. Populations of individual species (ash, hawthorn) tended to reflect the pattern demonstrated by the total tree population. It appears that the suppression of the growth of grasses was critical in enhancing the early establishment of tree seedlings. Other advantages of the use of propyzamide are a) that a smaller quantity of tree seed can be sown initially thus providing a capital cost-saving and b) that a larger established population of tree seedlings allows greater flexibility in the selection of well-grown individuals when thinning is carried out. Recent research on direct-seeded woodland at two other sites in Gwent demonstrated that tree population density may be considerably enhanced by sowing 50% pre-treated seed (i.e. seed that has experienced a temperature regime designed to break deep dormancy and increase percentage germination, often described as 'stratification'). Species populations of rowan and hawthorn may be enhanced using pre-treated seed.

The mean height growth of ash and hawthorn over seven growing seasons had responded considerably to the annual application of propyzamide. In the plots with lupins (where there was also a denser population of broom) the height of ash in the most favourable treatment (high fertilizer plus propyzamide) was 2.7 times the height in the control treatment. The height of hawthorn was 2.3 times for the same comparison. Clearly the use of propyzamide was very advantageous in promoting the development of woodland vegetation both in terms of population size and tree growth. The differential was less in the plots without lupins. This difference in tree performance may reflect an interaction between a more favourable microclimate (particularly winter shelter) and/or nitrogen fixation provided by the experimental treatments that included lupins, and the presumed reduction in competition from grasses, caused by the application of propyzamide.

The successful establishment and low mortality of tree seedlings was considerably enhanced by the application of propyzamide. Putwain et al. (1988) demonstrated that there was a relatively consistent beneficial effect on seedling survivorship up to two years after emergence due to the application of propyzamide, particularly in the high fertilizer treatment in which competition from grasses was probably considerable. Further evidence of the importance of grass competition in preventing the establishment of tree seedlings was given by Buckley (1984). Once established, young trees remain sensitive to competition for mineral nutrients and water. This was clearly demonstrated by Davies (1987) in extensive experiments at the Alice Holt Research Station. Therefore a herbicide such as propyzamide is an essential part of the management of direct-seeded woodland during the establishment phase; five years or more.

The impact of propyzamide on the species composition of the grassland and herbaceous flora was substantial. The more diverse flora in the propyzamide treated plots, combined with an open vegetation, probably provided a much more suitable habitat for butterflies than the more densely shaded conventionally planted blocks of alder and poplar that occurred near to the experimental site at Crumlin. Species that provided a source of nectar for butterflies and were much more abundant on the propyzamide treated plots included Cirsium arvense and C. vulgare, Lotus corniculatus, Vicia sepium and Trifolium pratense.

Future management of the woodland at the experimental site will seek to maintain open, lightly shaded glades containing a herb-rich grassland vegetation. Such management may involve the further use of selected herbicides.

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THE USE OF A GRAMINICIDE IN CONSERVATION MANAGEMENT

K. PORTER

Nature Conservancy Council for England (English Nature), South Region, Foxhold House, Thornford Road, Crookham Common, Newbury, Berkshire RG15 8EL

M. NOWAKOWSKI

Willmot Industries (Conservation Department), West Yoke, Ash, Wrotham, Kent TN15 7HU

ABSTRACT

A trial was set up to investigate the effectiveness of graminicides to control coarse grasses in woodland. The primary objective was to control Calamagrostis epigejos and Deschampsia caespitosa and increase the numbers of Viola spp. and their growth in a short, open sward. Considerable success was achieved using the graminicide fluazifop-P-butyl, ('Fusilade 5') with an increase in Viola riviniana and V.riechenbachiana and other herbs at the expense of some grasses.

INTRODUCTION

The management of vegetation is an essential principle of nature conservation and each semi-natural vegetation type has its traditional management prescription. Problems arise when we try to reverse natural trends and restore habitats against the process of succession. The problems of restoring herb-rich grasslands on arable land are well known and documented by many researchers (Wells, et al. 1989), but the problems of optimising the nature conservation potential of coniferous woodland are rarely addressed.

In native, semi-natural woodland most species in the ground flora are adapted to maintaining their populations by flowering and setting seed in the spring, before the tree canopy reduces light levels. Traditional practices such as rotational coppicing and small-scale clearance (Peterken, 1981) give a few years in which some species can set copious amounts of seed and grow rapidly in conditions of high light intensity and high ground temperatures. In this latter scenario several plant species can create a colourful, attractive habitat which supports characteristic insects, such as the pearl-bordered fritillary (Boloria euphrosyne) (Warren & Fuller, 1991). The replacement of semi-natural, broadleaved woodland by alien coniferous species destroys the cycle of spring release for the native ground flora and as a consequence, the indigenous ground flora may not recover or be severely modified after clearance of the conifers (Kirby, 1988).

In Bernwood Forest, a semi-natural woodland complex east of Oxford that has been extensively coniferised in the last four decades, the indigenous ground flora is being depleted. This site supported in excess of 40 species of butterfly in the 1970's, when plantations were still open enough to support many elements of the woodland ground flora. In the last two decades this site has lost three of its four species of fritillary and the fourth, B. euphrosyne, has been greatly depleted. This rate of extinction, related to a series of factors including changes in woodland management, is not unusual amongst this group of butterflies, indeed the same species are now extinct over the majority of eastern England and the east Midlands (Emmet & Heath, 1989). These butterflies depend upon the early successional stages of coppice, or other woodland clearance, when violets (Viola spp.) proliferate in warm, open-ground conditions. The two essential elements are the larval foodplant (Viola spp.) and open, bare ground in which the violets grow.

The removal of conifers usually provides suitable conditions for B. euphrosyne for a few years until the sward begins to close in when grasses and sedges shade out the violets. This is acceptable in a nature conservation sense provided that sufficient areas are being felled to maintain open habitats in suitable condition. In many areas of the wood, particularly where the Oxford Clay is present, the removal of conifers rapidly leads to a tall, dense sward of coarse grasses and sedges. Of particular concern are wood small-reed (Calamagrostis epigejos) and tufted hair-grass (Deschampsia caespitosa) which dominate the structure of the grassland within two or three years of clearance. The growth form of these species does allow violets to persist in the sward, but as shaded plants totally unsuitable for B. euphrosyne. Control of these grasses by grazing is not possible and mowing has been found to have little effect in the short to medium term. The trial described here is an attempt to recreate open, herb-rich woodland habitat using specific graminicides with the objective of influencing the composition and structure of the sward to allow breeding by B. euphrosyne.

METHODS

Three replicated blocks were laid out in January 1989 in an area cleared of Norway spruce in 1986. The plots were arranged in three staggered rows comprising plots 1-7, 8-14 and 15-24. Each plot was 3m x 3m with no discards between them. This gave a trial of three replicates, each of eight treatments. The treatments included combinations of vegetation cutting and removal, cutting and leaving the vegetation, five combinations of herbicides, two non-chemical treatments, and control plots (Table 1). The purpose of cutting in February was to encourage sufficient grass growth to provide a good target for later applications of a contact herbicide. Cutting was done using a clearing saw down to height of 5 to 8 cm and the cuttings raked clear.

An AZO plot sprayer with a 3m boom was used to apply the herbicides at a volume rate of 300 l/ha using Lurmark orange 110° fan jets at a pressure of 3 bars. The treatments were first applied in April, 1989 and repeated in 1990 and 1991, with the exception of plots treated with 2,2-dichloropropionic acid 'Dalapon' which were monitored but not treated after 1989.

Botanical assessments were made in February, 1989 (pre-treatment); May, 1989; August, 1989; August, 1990 (limited to three species); and May, 1991. The assessments involve two levels of detail: in 1989 and 1900 each main plot (3m x 3m) was divided into 25 sub-plots (each 60cm x60cm). The rooted presence of an individual species in a sub-plot was scored as one, giving a maximum score of 25 per main plot. In 1990 and 1991 a 1m x 1m quadrat was placed centrally in each main plot and rooted presence was recorded in each of 25 sub-plots (20cm x 20cm). This change was made to accommodate the sparse distribution of some key species in the treated plots. Both methods were used in 1990 in an attempt to correlate the two scales of quadrat assessment. The sward height was measured in June 1989, and by using a dropped disc technique (20cm diameter, 100g disc dropped from 1m)) in 1990 and 1991 assessments. The use of a dropped disc enabled the integration of sward height and density data. The results for Viola spp., C. epigejos and D. caespitosa were analysed using analysis of variance with a simple randomised block analysis treating sub-plots as "main" plots. The data had a highly skewed distribution and were transformed (square root + 0.5).

TABLE 1. Details of treatments applied to coarse grass plots over three years.

Treatment		Rate	Cut/Vegetation removed	Application dates
A	Control	(no management)	No/No	
B	Cut vegetation		Yes/Yes	
C	Cut vegetation		Yes/No	
D	fluazifop-P-butyl + Agral (0.5% vol)	375g AI/ha	Yes/Yes	20.4.89; 12.4.90; 22.4.91
E	fluazifop-P-butyl + Galion (0.5% vol)	375g AI/ha	Yes/Yes	20.4.89; 12.4.90; 22.4.91
F	fluazifop-P-butyl + Galion (0.5% vol)	375g AI/ha	No/No	20.4.89; 12.4.90; 22.4.91
G	mefluidide	960g AI/ha	Yes/Yes	20.4.89; 12.4.90; 22.4.91
H	2,2-dichloroproprionic acid	5 kg AI/ha	Yes/Yes	20.4.89.

RESULTS

The effect on key species

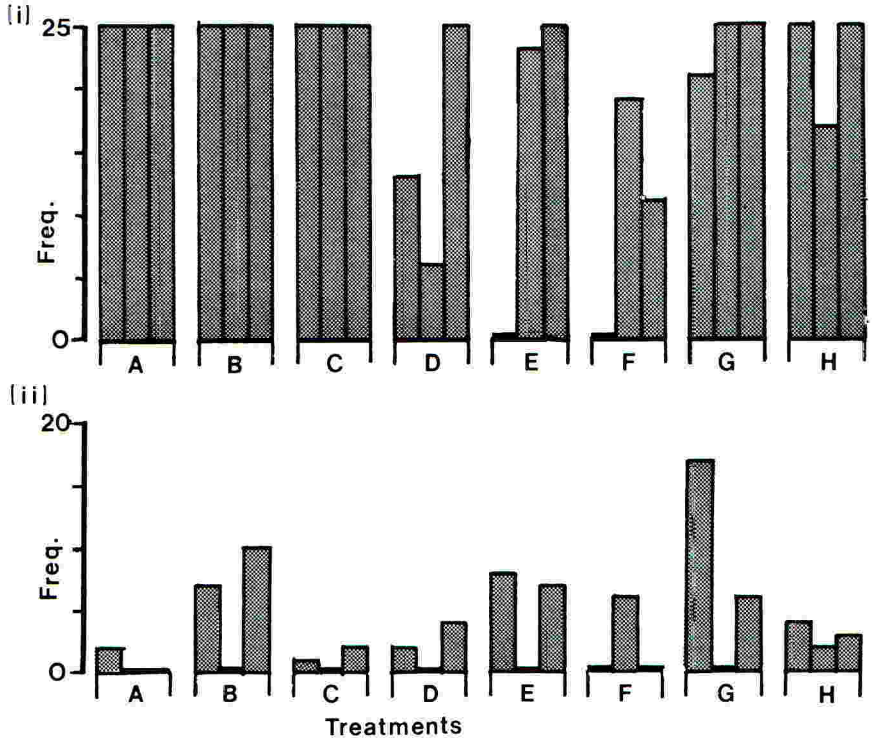
Viola spp. frequencies were significantly greater in some treatments when compared to the control levels (Table 2). The only consistent significant increase in Viola spp. was in the two fluazifop-P-butyl treatments (D & E). However, cut & remove and mefluidide treatments (B & G) also gave significant differences compared to the controls, but in 1989 only. Similarly, although not strictly significant, there was a detectable difference in the frequency of C. epigejos in treatment F compared to the control (Table 2). No significant effects were demonstrated using the current assessment method for D. caespitosa.

TABLE 2. Mean rooted plant frequencies in 25 sub-plots (with SED). Data for Viola spp. in 60cm x 60cm sub-plots (Aug, 1989 & 1990) and C. epigejos in 20cm x 20cm sub-plots (Aug, 1990). degrees of freedom =14, significant result = *

	Treatments									
	A	B	C	D	E	F	G	H	SED	P level
Viola spp.										
1989	1.00	2.83*	2.41	2.98*	3.35*	2.64*	2.78*	2.46	0.668	0.13
1990	1.00	2.31	2.08	2.79*	3.97*	2.18	1.94	1.35	0.801	0.064
C. epigejos										
1990	5.05	5.05	5.05	3.76	3.53	2.84*	4.91	4.76	0.925	0.175

The trends for C. epigejos and D. caespitosa in the treated plots in August, 1990 showed that reductions were apparent in plots treated with fluazifop-P-butyl (Figure 1). As the dominant species it was also reasonable to equate this trend with the reduction in sward height and "structure" as detected by the dropped disc technique (Figure 2). This trend reinforced the visual inspection of the plots whereby the two grass species, although present in all sub-plots were growing sparingly when compared with control and "non-herbicide" plots. In appearance the cut & remove; cut & leave, and control plots were virtually undistinguishable, although differences did exist in species composition. The trends for Viola spp. showed a clear increase in frequency in fluazifop-P-butyl treated plots (Figure 3), when comparing initial levels (May, 1989) with later (August, 1990) results. These dates were used to reflect the lead time needed for Viola spp. to colonise new "space". The initial increase of violets in "non-chemical" plots (Figure 3) in May and August 1989 were reversed by 1990, presumably as the sward closed in. The initial good response in Viola spp. increasing in these latter plots was of little conservation significance as these plants were too shaded to be of value to B. euphrosyne.

FIGURE 1. Frequency of (i) C. epigejos and (ii) D. caespitosa in the three individual plots, August, 1990.



The effect on general flora

An outstanding effect of the fluazifop-P-butyl treatments was to produce a much more diverse herb sward. Using simple analysis of presence in treatment plots species diversity of the sward was increased after use of the graminicide. In the plots treated with fluazifop-P-butyl no species were lost and a further 23 species were gained, compared to the control. The detail of the species changes and occurence provides some indication of the scale of change (Table 3).

FIGURE 2. Sward density measured by the dropped disc technique (August, 1990 (shaded) and May, 1991 (unshaded) (SE's indicated by bar.)

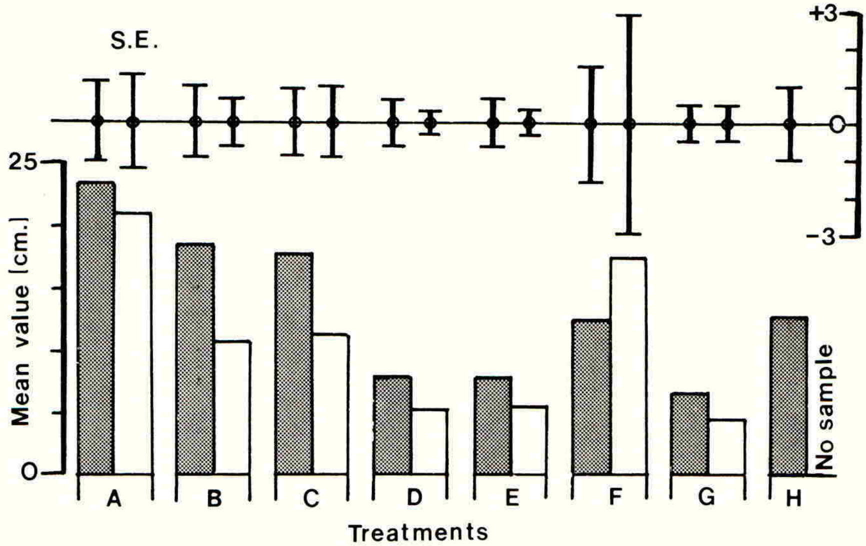


FIGURE 3. Frequency of Viola spp. for the three plots in each treatment. Data show changes from May, 1989 (shaded), August, 1989 (stippled) and August, 1990 (unshaded).

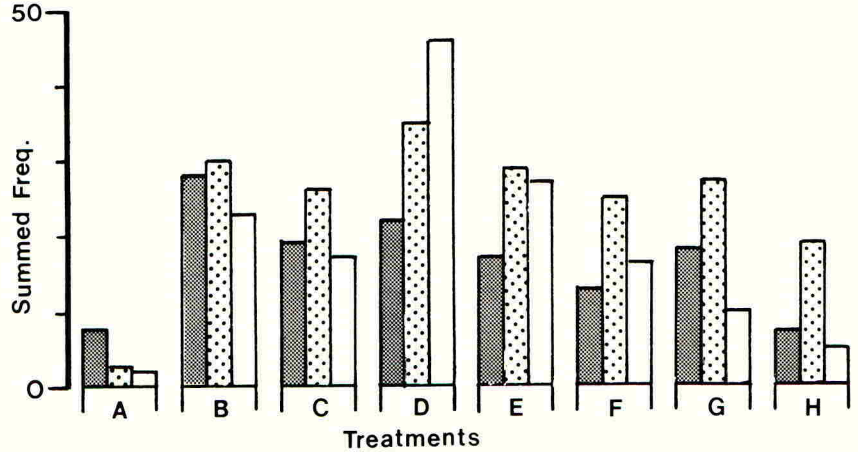


TABLE 3. The distribution of plant species in trial plots. Presence is measured as constant (● = present in all three years) or present (o = occuring at least once in the three years). Categories: 1 = Control (A); 2 = fluazifop-P-butyl (D, E & F); 3 = mefluidide (G); 4 = Cuts only (B & C).

Categories / Species	1	2	3	4
Ajuga reptans	●	●	●	●
Anemone nemorosa	●	●	●	●
Calamagrostis epigejos	●	●	●	●
Carex flacca	●	●	o	●
Carex riparia	●	●	●	●
Deschampsia caespitosa	●	●	●	●
Filipendula ulmaria	●	●	●	●
Galium uliginosum	●	●	●	●
Hypericum humifusum	●	●	●	●
Juncus effusus	●	●	o	●
Lonicera periclymenum	●	●	●	●
Lotus uliginosus	●	●	●	●
Luzula pilosa	●	●	o	●
Potentilla erecta	●	●	●	●
Rosa spp.	●	●	o	●
Stachys officinalis	●	●		●
Stellaria holostea	●	o	●	o
Agrostis canina/tenuis	o	●	●	●
Angelica sylvestris	o	●	o	o
Carex pallescens	o	●	o	o
Carex sylvatica	o	●	o	o
Chamaenerion angustifol.	o	●		o
Cirsium arvense	o	●		●
Cirsium palustre	o	●	●	●
Corylus avellana	o	●		o
Dactylorhiza fuschii	o	●		
Euphorbia amygdaloides	o	●	o	o
Fragaria vesca	o	●	●	
Holcus spp.	o	●	●	●
Hyacinthoides non-script.	o	●	●	o
Juncus conglomeratus	o	●	o	o
Populus tremula	o	●	o	o
Prunella vulgaris	o	●	●	●
Rubus fruticosus agg.	o	●	●	●
Succisa pratensis	o	●	●	●
Vicia cracca	o	●	o	o
Viola spp.	o	●	●	●
Centaurium erythraea		●		●
Lysimachia nummularia		●		●
Poa spp.		●		
Primula vulgaris		●	●	●
Betula pendula		o	o	
Brachypodium sylvaticum		o		
Circaea lutetiana		o		o
Cirsium vulgare		o		
Crataegus monogyna		o	o	o
Dactylis glomerata		o	●	●
Epilobium spp.		o	o	
Hypericum hirsutum		o	o	
Juncus articulatus		o		
Juncus inflexus		o		o
Odontites verna		o		
Plantago major		o	o	
Potentilla reptans		o		o
Potentilla sterilis		o		
Senecio jacobea		o		
Ranunculus repens		o	●	o
Scrophularia nodosa		o		
Sonchus spp.		o		
Veronica officinale		o		

An interesting effect was seen in the mefluidide treated plots where 16 species were judged to have declined over the three years of the trial whilst 18 appeared to be maintaining their frequency levels or increasing. The effect of mefluidide was essentially to stunt the grasses and to delay or prevent flowering in herbs. The progressive loss of species from the mefluidide plots could be due to failure to reproduce or competition from the stunted but prevalent grasses, sedges and rushes. The 2,2-dichloropropionic acid treatment was severe on most species in the first year of application and created up to 30% bare ground in the first year.

CONCLUSION

The trial demonstrated that fluazifop-P-butyl had no measurable, deleterious effect on the majority of woodland herbs present at the study site, whilst it had a profound effect upon the abundance and growth form of grasses and sedges. The beneficial effect on herbs was due largely to a reduction of shading and litter mulching and an increase in the area of bare ground. This effect was in contrast to the impact of mefluidide, a growth retardant, and 2,2-dichloropropionic acid, a control for grass weed species in some broadleaved crops. Both had a deleterious effect upon broadleaved herbs but mefluidide plots took two seasons for the full effect to be seen.

DISCUSSION

In forestry practice in the UK many herbicides are approved for use, some specifically for grass and "weed" control (Williamson & Lane, 1989), yet fluazifop-P-butyl has only clearance for use in new woodlands on 'new' sites. In some European countries this graminicide is extensively used in weed control around tree transplants. For general weed control many of the recommended herbicides strive for total control of grasses and broadleaved species (eg. propyzamide). Unfortunately one of the two key "problem" species in the present trial, C. epigejos, is resistant to several of the most commonly used herbicides. The result of such "control" is to take out the woodland herbs and characteristic non-aggressive grasses and allow C. epigejos to dominate (Kirby, 1987).

In the present trial it appeared that a similar effect resulted from the suppression of natural ground flora by coniferous plantation; grasses such as C. epigejos and D. caespitosa rapidly dominated the ground flora after plantations were felled. This is a common feature of coniferous woodland on the clay belt of the Midlands and if left to natural forces this grassland would ultimately succeed to woodland. The previously rich ground flora of the ancient coppice-with-standards woodland would rarely reappear following conifer removal.

In nature conservation terms the answer to this problem is to control the coarse grass species and encourage a sward which permits the woodland species to grow. How to achieve this is at the heart of the problem which encouraged the trial described here. The traditional answer is to crop the grassland by cutting or grazing. The latter option is rarely available in conservation woodland, whilst mowing and removal of cuttings is labour intensive and often fraught with practical problems in woodlands. This would be the classic response of a nature conservationist. Experience of mowing regimes in such coarse grasslands suggests that control is limited to reducing the stature of the problem grasses, but encouraging their density; essentially creating a grass dominated sward.

We have demonstrated that the use of a selective herbicide fluazifop-P-butyl, can achieve a degree of control over these "problem" grasses and thus allow woodland herbs to recolonise. In this trial we have targeted a specific herb, related to a current problem in nature conservation, but the results have wider implications. We see the "surgical" use of targeted graminicides as a tool to redress the natural balance and, once the problem species are checked, to allow natural succession and management techniques to take over. We hope that this approach will encourage further research into ecologically acceptable uses for herbicides in natural ecosystems.

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THE USE OF HERBICIDES IN THE CREATION OF A HERB-RICH FIELD MARGIN

E.J.P. MARSHALL

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

M. NOWAKOWSKI

Willmot Industries (Conservation Department), West Yoke, Ash, Wrotham, Kent, TN15 7HU.

ABSTRACT

An experiment was conducted on the introduction of a mixed grass and wildflower seed mixture in a strip along the edge of an arable field. For successful establishment, the need for adequate control of arable weed species in the first year was demonstrated. Fluazifop-P-butyl did not affect Festuca species, but reduced the frequencies of weed grasses, thus encouraging the establishment of sown dicotyledonous species. Ameliorative applications of herbicides in the second year, after weed grasses had become dominant, were not effective in encouraging further germination of the sown mixture.

INTRODUCTION

Field boundaries are an integral part of agricultural landscapes in Britain. As well as influencing regional landscapes, field margins affect adjacent arable land (Marshall, 1988). Although the dispersal of pests, weeds and disease from field margins is a common perception, Marshall (1989) showed that only a small proportion of boundary plant species are capable of successful ingress into cereal crops. Studies are demonstrating that uncultivated areas on farms, particularly hedge bottoms, can harbour sufficient polyphagous predators to limit populations of crop pests (Wratten, 1988). Such areas often serve as refugia for plant and animal species typical of local semi-natural habitats. Thus, field boundaries may serve both conservation and agricultural functions.

Increasingly, arable farmers may need to establish areas of semi-natural vegetation on previously cultivated land. As well as fulfilling the requirements for Set-aside, such areas can provide access and shooting, horse-riding and conservation areas for landowners. Sown strips of perennial vegetation may also reduce the ingress of competitive weed species (Marshall, 1990). By encouraging a diverse perennial flora, weed species within a hedge may be reduced and crop pollination and natural control of anthropod pests may be improved. Under arable conditions, with high soil fertility, it is likely that weeds in the seed bank will pose a threat to the establishment of herb-rich vegetation. Methods of creating and managing botanically-diverse grass strips in arable land need to be developed, expanding on the information available for amenity use (Wells et al., 1989). An experiment was, therefore, set up to examine the establishment of sown grasses and dicotyledonous species at the edge of an arable field and included a range of herbicide and cutting treatments aimed at reducing weed growth.

METHODS

Fifteen plots 3 m wide and 15 m long, along the edge of a field of oilseed rape, near Faringdon, Oxfordshire, were sown on 10 October 1988 with a seed mixture (Table 1) dominated by Festuca species, which show some tolerance to fluazifop-P-butyl (Fusilade 5, ICI) (Richardson et al., 1981). The sowing rate was 31.6 kg/ha mixed with 400 kg/ha of silver sand. In 1989, the first year, five chemical treatments (Table 2) were applied to plots selected at random from each of three replicate blocks. Each treatment was applied to three plots. In 1990, the plots were sub-divided and either left unmanaged (subplot 1) or re-treated (subplot 2) (Table 2). An AZO sprayer with a 3 m boom was used to apply the chemicals at a volume rate of 200 l/ha (orange Lurmark jets at 3 bars pressure). In autumn 1989, the vegetation on all of the plots was cut to a height of 2.5 cm with a forage harvester with clippings blown off the plots. Other cutting treatments (Table 2) were made with a pedestrian-operated rotary mower and clippings were removed.

TABLE 1. Seeds mixture used to establish a grass and wild flower strip. Proportions : 70% grass to 30% herb seed by weight.

Species	% in mixture	Species	% in mixture
GRASSES			
Festuca rubra subsp. commutata	12.6	Festuca ovina	14.0
Festuca tenuifolia	12.6	Festuca rubra subsp. rubra	16.8
Festuca longifolia	14.0		
ANNUAL DICOTYLEDONOUS SPECIES			
Anthemis arvensis	0.3	Centaurea cyanus	1.0
Agrostemma githago	3.2	Silene alba	0.8
Rhinanthus minor	1.3		
PERENNIAL DICOTYLEDONOUS SPECIES			
Hypochaeris radicata	0.8	Geranium pratense	1.2
Lotus corniculatus	1.0	Malva moschata	1.2
Centaurea nigra	1.0	Leucanthemum vulgare	0.3
Cerastium fontanum	0.2	Silene dioica	0.5
Rumex acetosa	0.8	Leontodon hispidus	0.8
Primula veris	0.8	Onobrychis viciifolia	2.7
Knautia arvensis	1.9	Sanguisorba minor	2.1
Centaurea scabiosa	1.5	Prunella vulgaris	0.8
Plantago media	0.5	Daucus carota	0.8
Anthyllis vulneraria	1.4	Achillea millefolium	0.2
Galium verum	0.8		
Ranunculus acris	1.0		

TABLE 2. Details of treatments applied to sown grass and wildflower strips over two years.

Year 1 - 1989	Year 2 - 1990	
	Subplot 1	Subplot 2
no treatment	unmanaged	cut on 11/4/90
fluazifop-P-butyl 0.25 kg (AI)/ha on 1/4/89	unmanaged	fluazifop-P-butyl + quinmerac 0.25 + 1.5 kg (AI)/ha on 17/11/89
mefluidide (low rate) 0.48 kg(AI)/ha on 1/4/89	unmanaged	mefluidide 0.48 kg (AI)/ha on 6/4/90
mefluidide (high rate) 0.96 kg(AI)/ha on 1/4/89	unmanaged	mefluidide 0.48 kg (AI)/ha on 6/4/90
quinmerac 1.5 kg (AI)/ha on 24/11/88	cut on 11/4/90	fluazifop-P-butyl 0.25 kg (AI)/ha on 17/11/89

During April and July 1989, rooted frequencies of species were estimated by recording presence or absence in ten 0.1 m^{-2} quadrats per plot. In July 1990, vegetative presence of species was recorded in five 0.1 m^{-2} quadrats in each subplot. Mean vegetation height was measured and the percentage cover of grasses, dicotyledonous species and bare ground were estimated by eye each year. Results were analysed using analysis of variance. Initially a split-plot design was used, with Year 2 treatments split into their subplot treatments (Table 2), using plot number as a covariate for position along the hedge. Subsequently, a simple randomised block analysis was used, treating subplots as 'main' plots. Where necessary, data were transformed (square root or log) before analysis.

RESULTS

Visually, there were marked differences between plots. Untreated and quinmerac-treated plots became dominated by tall grasses, notably Bromus sterilis, Lolium multiflorum and Poa trivialis. Mefluidide-treated plots had more open canopies, while fluazifop-P-butyl controlled most grasses other

TABLE 3. Mean vegetation height (cm) and percentage ground cover in sown strips in July 1989. (SED = standard error of the difference between means; df = 9).

	untreated	fluazifop -P-butyl	mefluidide		quinmerac	SED
			low rate	high rate		
Height	90	11	62	71	88	14.3
COVER						
Grass	85	33	75	75	95	6.5
Dicotyledons	5	37	10	7	5	4.5
Bare ground	10	30	15	18	0	4.0

than sown Festuca spp. Plots treated with fluazifop-P-butyl were significantly shorter than others and the marked reduction in grass cover was accompanied by significant increases in the cover of dicotyledonous species and bare ground (Table 3).

By July, 1989, data on rooted frequencies indicated no treatment effects on Festuca spp. (Table 4). The frequency of individual sown dicotyledonous species was also not significantly affected, with the exception of Leucanthemum vulgare, which was encouraged by treatment with fluazifop-P-butyl. When the sum of occurrences of sown dicotyledonous species was analysed, a weakly significant effect ($P<0.10$) was noted, with fluazifop-P-butyl encouraging sown dicotyledonous species. Analyses indicated a marked difference along the field margin in the amounts of Agrostis spp. and Elymus repens unconnected to the imposed treatments. Bromus sterilis was eliminated by fluazifop-P-butyl, but maintained frequencies of about 70% on the remaining plots. Poa trivialis was also significantly reduced by fluazifop-P-butyl and by mefluidide (Table 4). Significantly lower mean numbers of grass species per quadrat were found on those treated with fluazifop-P-butyl and high rate mefluidide, compared with untreated plots. Only small amounts of unsown annual species were recorded in the plots. The exception was Sonchus asper, which was promoted on fluazifop-P-butyl plots. Unsown biennial and perennial dicotyledonous species were not significantly affected by the treatments.

TABLE 4. Rooted frequencies (%) of sown and unsown species in July 1989 and the mean number of species per quadrat. (N.S. = not significant; df = 9)

	untreated	fluazifop -P-butyl	mefluidide low rate	mefluidide high rate	quinmerac	SED
SOWN SPECIES						
Festuca spp.	100	100	100	94	93	N.S.
D. carota	37	40	52	24	13	N.S.
L. vulgare	8	40	3	7	13	6.6
P. vulgaris	20	43	17	17	13	N.S.
R. acetosa	23	27	37	43	27	N.S.
UNSOWN GRASSES						
Agrostis spp.	60	3	58	45	53	24.9
B. sterilis	80	0	80	74	70	17.1
E. repens	50	83	59	61	57	19.9
L. multiflorum	70	27	65	85	67	17.4
P. trivialis	93	10	60	33	100	9.2
Mean number of sown dicotyledonous species per quadrat	2.0	3.9	2.4	1.9	1.8	0.7
Mean number of unsown grass species per quadrat	4.0	1.3	3.5	3.2	4.0	0.31

In the second year, analyses, where significant, indicated that first year treatments had the greatest influence on vegetative frequencies. Highest frequencies of D. carota, L. vulgare, P. vulgaris and R. acetosa were found on plots treated with fluazifop-P-butyl in the first year (Table 5.). Among the unsown species, both L. multiflorum and Agrostis spp. remained at lowest frequencies on plots treated with fluazifop-P-butyl in 1989 (Table 5.). There was no evidence of significant effects of the subplot treatments made in 1990. Among the dicotyledonous species, Plantago major was significantly encouraged on fluazifop-P-butyl-treated main plots, while there was a weak trend for greater amounts of Heracleum sphondylium on plots previously treated with mefluidide at 0.48 kg (AI)/ha.

TABLE 5. Frequencies (%) of sown and unsown species in July 1990. Data are averaged over both subplots for each treatment.

Year 1	untreated	fluazifop -P-butyl	mefluidide low rate	mefluidide high rate	quinmerac	SED
SOWN SPECIES						
D. carota	33	87	64	36	30	11.8
L. vulgare	7	37	5	5	13	8.6
P. vulgaris	13	70	27	17	37	10.8
R. acetosa	10	43	4	9	33	11.8
UNSOWN SPECIES						
Agrostis spp.	77	3	84	56	80	12.4
L. multiflorum	100	27	69	81	57	18.4
P. major	3	67	11	T	10	11.3
H. sphondylium	17	3	24	6	7	7.1

There were significantly more sown species per plot after treatment with fluazifop-P-butyl in 1989. In addition, there were fewer unsown grass species, but more unsown annual dicotyledonous species (weeds) (Table 6). Despite a significant covariate effect, indicating differences along the field margin in the total number of species, unrelated to the treatments, fluazifop-P-butyl-treated plots still supported the greatest species diversity. Comparing the results in 1990 with those from 1989, it was apparent that fewer sown and unsown species were recorded in the second year (Table 6).

TABLE 6. Mean numbers of sown and unsown species in 1989 and 1990 on main plots of sown strips.

Year 1	untreated	fluazifop -P-butyl	mefluidide low rate	mefluidide high rate	quinmerac	SED
SOWN SPECIES						
1989	10.0	17.7	10.5	11.2	10.7	2.30
1990	4.8	10.8	5.1	5.1	6.2	1.11
UNSOWN SPECIES						
1989	11.9	13.9	12.7	12.7	10.9	N.S.
1990	6.5	6.7	7.3	6.2	8.3	N.S.

DISCUSSION

Weed species pose a threat to the establishment of sown wildflower and grass areas on border strips and redundant arable land, as well as to adjacent areas which continue in arable production. The most striking effects on the diversity of sown strips were produced by fluazifop-P-butyl, which eliminated B. sterilis and reduced amounts of other unsown grasses, notably P. trivialis and probably Agrostis spp. and L. multiflorum. This promoted a significant increase in the frequency of some annual and perennial dicotyledonous species and E. repens. Overall, species diversity was enhanced by fluazifop-P-butyl. The occurrence of P. trivialis was also significantly reduced by mefluidide treatments, which did little to L. multiflorum, perhaps reflecting poorer growth suppression of ryegrasses, noted by Price (1984) on Lolium perenne.

The experiment highlighted the continuing effect of weed control in the season of establishment into the second year. In the first year, the site became dominated by L. multiflorum, Agrostis spp., and B. sterilis. Sown dicotyledonous species did best where these grasses were controlled with fluazifop-P-butyl in the first year. There was little evidence to show that remedial treatments in the second season, on plots which were dominated by grass weeds in the first year, resulted in increased numbers of sown species. There was evidence of declining diversity on all the plots from the first year, partly due to reduced numbers of annual plant species. Nevertheless, further changes in composition might be expected to occur through time and further management may be required to maintain a diverse sward. Initial data from a further experiment established in a different year and location, has confirmed the above effect of fluazifop-P-butyl on weed grasses. Further experiments on the effects of graminicides and cutting treatments on different grass species mixtures are in progress.

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POTENTIAL NEW HERBICIDE TREATMENTS FOR BRACKEN CONTROL IN GRASSLAND AND HILL PASTURES

T.M. WEST, R.C. BUTLER

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

ABSTRACT

Herbicides were tested in an outdoor experiment to investigate their activity against established, container-grown bracken (Pteridium aquilinum) and to determine the tolerance of perennial ryegrass. Treatments were applied during 1989 to bracken at 50% and 100% frond expansion and to well tillered perennial ryegrass. Asulam severely inhibited bracken frond regeneration during 1990. Tribenuron-methyl and metsulfuron-methyl, applied alone, suppressed frond regrowth more effectively when applied at full frond expansion. Thifensulfuron-methyl was ineffective. Low dose mixtures of tribenuron-methyl with metsulfuron-methyl applied at either growth stage were synergistic. Perennial ryegrass showed moderate initial suppression by asulam, metsulfuron-methyl and tribenuron-methyl but regrowth in 1990 was unaffected by any treatment. The potential of these herbicides for bracken control is discussed.

INTRODUCTION

Bracken (Pteridium aquilinum) is one of the world's most successful weeds (Taylor, 1990). There has been much concern in recent years of the effects of bracken on human and animal health (Taylor, 1989) and the loss through encroachment of agricultural land and natural habitats. Upland areas of the UK are particularly vulnerable to bracken infestation, often caused by reduced grazing pressures and deforestation.

Research at Long Ashton Research Station continues to investigate control strategies for bracken. Recent work has shown considerable activity from some sulfonylurea herbicides against bracken while several pasture grasses have exhibited good tolerance to these herbicides (West & Standell, 1989). This suggests a potential use in grassland situations.

This paper presents data from experiments in which three sulfonylurea herbicides applied alone and in mixtures were compared with the 'standard' asulam treatment and tested to determine their activity on bracken and perennial ryegrass. Ryegrass is often one of the least tolerant to sulfonylurea herbicides and therefore acts as a good indicator species for grass tolerance.

MATERIALS AND METHODS

Plant propagation

In April the year before treatment, bracken rhizome fragments with viable frond buds were collected from a natural population near Long Ashton. Three 20 cm fragments were planted 8 cm deep in 25 cm diameter pots containing a soil/sand/peat mixture (3:2:1) plus fertiliser, Osmocote 18.11.10 at 3.3 g/l.

Seeds of perennial ryegrass (Lolium perenne) cv. Melle were sown in early April 1989 into seed trays of Levington compost, watered lightly and kept in a glasshouse. At the 1-2 leaf stage 30 plants/pot were pricked out into 20 cm diameter pots containing the same soil mixture used for bracken.

For both species, pots were kept outdoors and watered using trickle irrigation to supplement natural rainfall. During winter they were plunged into ashes to protect them from frost.

Herbicide treatments

The formulations used were asulam 400g AI/litre SL; metsulfuron-methyl 20% AI WG; thifensulfuron-methyl (DPX-M6316) 75% AI WG; tribenuron-methyl (DPX-L5300) 75% AI WG. A surfactant (Agral 90) was added to all spray solutions at 0.1% v/v. The treatments (Tables 1-3) were applied using a laboratory track sprayer fitted with a Lurmark 80015 flat fan nozzle at a pressure of 210 kPa and giving a volume rate of 262 l/ha.

Bracken was treated at two growth stages. The early application was made on the 26 May, 1989 when fronds were up to 45 cm high with six pinnae not completely unfurled. The later application was made on 12 July, 1989 when fronds were up to 80 cm with twelve pinnae fully expanded. All plants had extensive rhizome systems.

Perennial ryegrass was sprayed on 12 July, 1989. There were 30 plants per pot with a mean height of 28 cm and having 8-16 tillers per plant. The mean shoot fresh weight per pot was 230g.

Pots were kept under cover for 24 h after spraying. Prior to placing outdoors, they were watered overhead using a rose attached to a water line to simulate heavy rainfall. Plants were then returned outdoors and set out in three randomised blocks.

Assesssments

Vigour scores of bracken fronds and records of the degree of sporulation were made in late August, 1989. In late August 1990 fronds were cut off at soil level and the number and fresh weights per pot were recorded. Soil was removed and rhizome development assessed. All viable buds on the rhizome, that is, developing frond buds and apical rhizome buds were counted. Rhizomes were then oven dried at 90°C for 48 h and dry weights recorded.

Shoots of perennial ryegrass were cut off 1 cm above the soil surface on 6 August, 1989 and fresh weights recorded. Shoot regrowth was assessed similarly on 13 June, 1990.

Statistical analysis

Analysis of variance was carried out on the bracken and perennial ryegrass data. Data from bracken assessments were also subjected to a regression analysis using a simple-similar action model for herbicide dose (Finney, 1971), with two dose response curves, the logistic and the modified logistic (Brain & Cousens, 1989) which allows for low dose enhancement. Lack of Fit was used to assess the results of the analyses.

RESULTS

Effects on bracken growth in the season of spraying (1989)

When sprayed at the early growth stage with asulam and the three sulfonylurea herbicides, fronds made little or no growth after spraying. When sprayed at full expansion, fronds showed scorch from asulam and yellowing from the sulfonylureas.

While untreated plants sporulated prolifically in late summer, 1989, all plants treated with herbicides at the early growth stage did not sporulate. Similarly, plants treated with sulfonylurea herbicides at full frond expansion failed to produce spores. Close examination showed that plants treated with thifensulfuron-methyl had developed malformed sporing bodies but no spores were produced. Asulam applied at full frond expansion did not affect spore production.

Effects on bracken regrowth one year after spraying (1990)

Asulam severely suppressed frond regeneration and the amount of suppression did not vary significantly between application dates (Table 1). Early application had significantly greater effects than later applications on rhizome dry weights (Table 2).

The sulfonylurea herbicides produced various significant interactions between herbicides (three single herbicides + three mixtures), doses and application dates for all four types of assessment.

Frond numbers (Table 1)

Low doses (3 and 6g AI/ha) of metsulfuron-methyl and all six treatments of thifensulfuron-methyl enhanced production of new fronds. Metsulfuron-methyl at 12g AI/ha and tribenuron-methyl at 60g AI/ha each applied alone considerably reduced frond numbers and were most effective at the late application. Early application of the higher doses of metsulfuron-methyl in mixtures with thifensulfuron-methyl reduced frond numbers significantly compared with the two herbicides alone. Similarly, low dose mixtures of metsulfuron-methyl with tribenuron-methyl applied early or at full frond expansion also reduced frond numbers significantly compared with the single herbicide treatments. Mixtures of thifensulfuron-methyl with tribenuron-methyl were no more effective than tribenuron-methyl applied alone.

Frond fresh weights (Table 1)

The results for frond fresh weights were similar to those for frond numbers. The most notable effect was the significant reduction of frond fresh weight by the low dose metsulfuron-methyl/tribenuron-methyl mixture, compared with the small effect produced by the individual herbicides.

TABLE 1. Response of bracken to herbicides applied 26 May or 12 July, 1989 assessed in late August, 1990. (Values are means of three replicates)

Herbicide	Dose (g AI/ha)	Frond Assessments: Number May	Number July	Fresh weight (g) May	Fresh weight (g) July
asulam	4400	5.7	1.7	23	6
metsulfuron-methyl	3	45.3	48.3	471	400
	6	56.7	25.3	480	188
	12	15.0	5.0	143	20
thifensulfuron-methyl	30	51.3	39.7	551	453
	60	52.7	41.7	616	465
	120	50.0	47.0	489	538
tribenuron-methyl	15	39.3	36.0	311	350
	30	37.0	26.0	185	156
	60	10.3	0.7	64	1
metsulfuron-methyl	3 + 30	61.3	38.3	544	491
+	6 + 60	15.0	40.7	57	307
thifensulfuron-methyl	12 + 120	0	10.3	0	33
metsulfuron-methyl	3 + 15	11.0	0.7	42	3
+	6 + 30	3.0	2.7	28	5
tribenuron-methyl	12 + 60	3.3	0	57	0
thifensulfuron-methyl	30 + 15	33.0	34.0	224	401
+	60 + 30	11.3	21.7	56	184
tribenuron	120 + 60	9.7	2.3	33	16
untreated	-	28.5		397	
SED (df 94) untreated vs treated		6.46		55.5	
treated vs treated		8.61		74.0	

Number of viable buds on rhizomes (Table 2)

Numbers of viable buds were affected in the same way as frond numbers and fresh weights. Metsulfuron-methyl and tribenuron-methyl applied alone at the highest doses caused large reductions in the numbers of viable buds. Lower doses of these herbicides in mixtures gave significant reductions compared with the single treatments. Two treatments of thifensulfuron-methyl (60 and 120g AI/ha) applied alone at full frond expansion significantly increased the number of buds produced.

Rhizome dry weights (Table 2)

No treatment increased rhizome weights. All early herbicide treatments lowered weights significantly more than the late applications except for metsulfuron-methyl which, although reducing rhizome weights, showed no significant difference between application dates. Thifensulfuron-methyl caused significant reductions of rhizome dry weights from early applications whereas late applications had no effect. Tribenuron-methyl and all herbicide mixtures reduced dry weights, early applications usually giving significantly greater effects. The low dose tribenuron-methyl/metsulfuron-methyl mixture reduced rhizome dry weight more than the single treatments.

TABLE 2. Response of bracken to herbicides applied 26 May or 12 July, 1989 assessed late August, 1990. (Values are means of three replicates)

Herbicide	Dose (g AI/ha)	Rhizome Assessments No. viable buds		Dry weight (g)	
		May	July	May	July
asulam	4400	36	10	135.6	289.6
metsulfuron-methyl	3	435	319	301.2	336.1
	6	347	204	221.1	229.9
	12	168	31	111.4	166.0
thifensulfuron-methyl	30	448	458	227.2	334.1
	60	374	740	248.0	275.5
	120	447	583	221.3	341.6
tribenuron-methyl	15	384	274	183.5	280.7
	30	298	97	127.5	195.5
	60	42	4	91.5	194.0
metsulfuron-methyl	3 + 30	356	446	221.9	346.9
+	6 + 60	37	346	73.0	233.1
thifensulfuron-methyl	12 + 120	0	29	45.9	169.9
metsulfuron-methyl	3 + 15	90	9	99.4	175.8
+	6 + 30	47	4	78.4	192.1
tribenuron-methyl	12 + 60	7	0	47.8	111.1
thifensulfuron-methyl	30 + 15	155	284	132.3	247.0
+	60 + 30	86	48	73.3	196.7
tribenuron-methyl	120 + 60	26	2	75.8	175.0
untreated	-	378		336.8	
SED (df 94) untreated vs treated		51.5		26.5	
treated vs treated		68.7		35.4	

Regression analysis

Lack of Fit was not significant when just the single herbicide treatments were included, except for rhizome bud numbers and dry weights with late application; thus in all other cases synergism or antagonism for two herbicides was supported when Lack of Fit was significant on including data for their mixture, and also when it was reduced on excluding data for that mixture.

There was strong evidence from the data on frond number and fresh weight and number of viable buds on rhizomes of synergistic activity between metsulfuron-methyl and tribenuron-methyl when applied in mixture. The data also indicated marked low-dose enhancement of frond numbers and fresh weights by metsulfuron-methyl and, more notably, by thifensulfuron-methyl.

Effects on perennial ryegrass (Table 3)

Initially, growth was moderately suppressed by treatments containing asulam, metsulfuron-methyl or tribenuron-methyl. There was no increased damage from herbicide mixtures compared with the single treatments. Plants were unaffected by thifensulfuron-methyl treatments. Regrowth during 1990 was healthy and vigorous following all herbicide treatments.

TABLE 3. Response of perennial ryegrass to herbicides applied 12 July, 1989 assessed August, 1989 and June, 1990. (Values are means of three replicates)

Herbicide	Dose (g AI/ha)	Shoot fresh weight (g) August 1989	Shoot fresh weight (g) June 1990
asulam	4400	198	214
metsulfuron-methyl	3	211	247
	6	187	269
	12	172	256
thifensulfuron-methyl	30	280	227
	60	214	220
	120	231	219
tribenuron-methyl	15	208	230
	30	210	226
	60	183	198
metsulfuron-methyl	3 + 30	229	241
+	6 + 60	189	235
thifensulfuron-methyl	12 + 120	189	260
metsulfuron-methyl	3 + 15	191	227
+	6 + 30	192	256
tribenuron-methyl	12 + 60	173	234
thifensulfuron-methyl	30 + 15	200	252
+	60 + 30	204	260
tribenuron-methyl	120 + 60	192	226
untreated	-	288	229
SED (df 43)	untreated vs asulam	17.9	24.0
	untreated vs others	19.5	26.1

DISCUSSION

Previous experiments on plants grown in containers has shown that tribenuron-methyl at 30-60g AI/ha (West & Richardson, 1987; West & Standell, 1989) or metsulfuron-methyl at 3.75-7.5g AI/ha (Oswald et al., 1986) could give effective control of bracken. The work reported here also shows that tribenuron-methyl and metsulfuron-methyl applied alone at 60g AI/ha and 12g AI/ha respectively are effective treatments.

In contrast to these pot experiments, both these herbicides have shown somewhat less activity in field experiments. Recent trials including tribenuron-methyl at 60g AI/ha (West, 1991) caused considerable reductions of frond regrowth but did not give adequate control of bracken. The extremely hot and dry weather in 1989 after spraying was probably the main adverse factor. It could have reduced herbicide uptake and translocation or decreased soil activity because of the short degradation period of the herbicides. Even asulam at 4400g AI/ha was only marginally better than tribenuron-methyl under these conditions. Past field trials in the UK (Oswald et al., 1985) with metsulfuron-methyl at 2.5 to 10g AI/ha also gave appreciable reductions of frond regrowth but not effective control. However, a low dose mixture with chlorsulfuron (a sulfonylurea now withdrawn from use in the UK) was significantly more active than the single components and gave excellent control. Recent Australian field trials (Arends & Velthuis, 1990) also showed good control of a bracken (*Pteridium esculentum*) by metsulfuron-methyl which led to approval for use at 36g AI/ha. In the UK climate, the degradation period, soil mobility and grass tolerance of metsulfuron-methyl would clearly be unfavourable at such a high dose.

The synergistic activity found in our experiments between low doses of tribenuron-methyl (15g AI/ha) and metsulfuron-methyl (3g AI/ha) suggest a promising new treatment for bracken control. Although higher doses will probably be needed in the field, the mixture offers the potential to reduce significantly the overall amount of active ingredient required for effective control. This result seems even more encouraging when considering the lack of activity from this mixture on perennial ryegrass. In fact, a mixture with doses four times greater than that which controlled bracken was initially no more damaging to perennial ryegrass than asulam, and the regrowth showed a full recovery. Other studies (West, unpublished data) have shown that several useful grasses associated with upland pastures exhibited good tolerance to mixtures of tribenuron-methyl with metsulfuron-methyl but they were generally more sensitive to asulam.

The observed enhancement of frond regrowth, emergence and of frond bud development with no increase of rhizome growth, particularly from thifensulfuron-methyl, was an interesting feature which cannot be explained at present. The stimulation of frond number and hence increase in subsequent target area offers the potential to improve uptake and translocation of herbicides into the rhizome system and may warrant further investigation.

In conclusion, tribenuron-methyl applied alone or more particularly in a mixture with metsulfuron-methyl, showed good potential for bracken control in grassland. The tolerance of grass species, together with low mammalian toxicity, relatively short soil persistence and low dose rates may make them environmentally acceptable treatments.

Further field experiments are in progress to verify the early promise of these herbicides for bracken control and to study, in detail, the effects on non-target plant species in pastures.

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SELECTIVE CONTROL OF CLEAVERS (Galium aparine) IN CONSERVATION HEADLANDS WITH QUINMERAC

N.D. BOATMAN

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

ABSTRACT

Trials were carried out with quinmerac applied at different rates and timings, to confirm its efficacy in controlling *Galium aparine* in a headland situation, and to investigate its degree of selectivity with respect to other weed species. Eleven small plot trials were carried out in 1989 using a backpack sprayer with hand held boom, and a further two in 1990 involving larger plots with herbicide applied by full width farm sprayers. Good control of *G. aparine* was achieved in all trials. *Veronica* spp., *Papaver rhoeas* and *Lamium purpureum* were also susceptible, but all other species were resistant. It is concluded that quinmerac has potential for selective control of *G. aparine* in Conservation Headlands.

INTRODUCTION

The term 'Conservation Headland' refers to a system of modified pesticide use whereby the use of herbicides affecting broadleaved weeds is minimised and summer insecticides are avoided, on the outermost few metres of cereal crops. This allows the survival of the less damaging components of the arable flora typically found in cereals, along with the associated phytophagous invertebrate fauna. These provide food sources for other faunal groups, including gamebirds (Potts, 1986) and predatory arthropods important in biological pest control (Chiverton & Sotherton, in press). Details of the technique, the agronomic consequences and the benefits for farmland wildlife have been described elsewhere (Boatman & Sotherton, 1988; Boatman, 1989; Sotherton *et al.*, 1989).

Herbicide use on Conservation Headlands is restricted to those with specific activity against species most damaging to crop production, and which are therefore not tolerable to farmers (Boatman, 1987; 1989). Surveys of farmer opinion have shown that the species which causes greatest concern to farmers in field margins is cleavers (*Galium aparine*) (Boatman, 1989). It is a very competitive weed which can cause large losses of yield (Wilson & Wright, 1987).

There is at present no herbicide approved for use on cereals which gives truly selective control of *G. aparine*. Quinmerac (BAS 518H; Wuerzer *et al.*, 1985) has been reported to be effective against *G. aparine* with activity against only a very limited range of other species (Nuyken *et al.*, 1985; Bond & Burch, 1987; Boatman, 1989).

The experiments reported here were carried out to confirm the efficacy of quinmerac against *G. aparine* at the crop edge (where *G. aparine* is often more abundant then in the rest of the field and crop competition is often lower), to determine the optimum dose and timing for use in this situation, and to provide further information on its spectrum of activity. Results on the use of quinmerac in field boundary vegetation, have been reported elsewhere (Bain & Boatman, 1989).

MATERIALS AND METHODS

Field experiments were carried out in headlands of cereal fields, selected for the presence of *G. aparine* and a range of other broadleaved species at sites throughout the south of England (Table 1). Soil types were: calcareous silt (sites 1, 6, 9, 12, 13), loam (2, 5, 7, 8), clay loam (4), calcareous clay (10, 11) and silty clay with flints (3).

Eleven experiments were carried out in 1988/89 (three main sites, eight subsidiary sites) and two in 1989/90. Treatment details were as follows:

quinmerac dose (kg AI/ha)	timing	1988/89 main	1988/89 subsidiary	1989/90
0.5	Oct/Nov	√		√
0.75	"	√		√
1.0	"	√		
0.5	Dec	√		√
0.75	"	√	√	√
1.0	"	√		
0.5 + 0.5	Oct/Dec	√		
0.75 + 1.14 kg AI/ha diclofop-methyl	Dec	√		
0 (untreated)		√	√	√

1988/89 experiments

The full range of treatments were applied to the main sites in 1988/89. The mixture with diclofop-methyl was included to test for compatibility, since this herbicide is recommended for selective grass weed control in Conservation Headlands (Boatman, 1987). Only one spray treatment, intermediate in dose, was applied to the eight subsidiary sites, to determine the range of between-site variation in levels of control.

Herbicides were applied with an Oxford Precision Sprayer fitted with Lurmark 02-F80 nozzles at a pressure of 2.5 bars and a volume rate of 218 l/ha. Application dates are given in Table 2. Plots were positioned with their long axis running from the crop edge to the first tramline, a distance which varied between 6 and 12 m. They were 3 m wide in all cases. There were four replicates of each treatment, arranged in a randomised block design.

Growth stages of crop plants, *G. aparine* and other species present were recorded at spraying (Table 1). Crop and *G. aparine* % cover, weed density and vigour scores were recorded from ten 0.25 m^2 quadrats in each plot four and eight weeks after spraying. Percentage cover of crop, and all weed species were recorded post-ear emergence, in late June, in ten 0.25 m^2 quadrats per plot.

1989/90 experiments

Treatments were similar to those applied in the previous year, but using farm sprayers instead of a backpack sprayer. Spray pressure was 2.5-3 bars and volume rate 250 l/ha. Individual plots were 20 m long and plot width varied between 6-12 metres, according to the distance between crop edge and tramline. Each treatment was replicated twice, in a randomised block design. Dates of herbicide application, crop and *G. aparine* growth stages are presented in Table 1.

TABLE 1. Dates of herbicide application and growth stages of crop and *G. aparine* at spraying.

Year	Site	Date of spraying	Mean crop growth stage[1]	*G. aparine* growth stage range[2]
1988/89	1. Hants	20 Oct	11	expanded cots - 1 whorl
		7 Dec	14/20	expanded cots - 25 mm
	2. Cambs	28 Oct	12	expanded cots - 1 whorl
		21 Dec	13/22	expanded cots - 6 whorls
	3. Dorset	22 Oct	11	expanded cotyledons
		12 Dec	13/21	expanded cots - 100 mm
	4. Berks	10 Nov	13/22	expanded cots - 2 whorls
	5. Oxon	11 Nov	11	expanded cots - 2 whorls
	6. Hants	10 Nov	13/21	expanded cots - 2 whorls
	7. Berks	24 Jan	13/21	expanded cots - 1 whorl
	8. Hants	23 Nov	10	expanded cots - 4 whorls
	9. Hants	21 Nov	11	expanded cots - 2 whorls
	10. Glos	11 Nov	14/22	expanded cots - 4 whorls
	11. Cambs	21 Dec	14/22	1 whorl - 25 cm
1989/90	12. Wilts	17 Nov	-[3]	expanded cots - 150 mm
		19 Dec	-	150-250 mm
	13. Hants	13 Nov	-	100-250 mm
		5 Jan	-	100-250 mm

1 after Tottman, 1987, *Ann. Appl. Biol.* **110**, 441-454
2 after Lutman & Tucker, 1987, *Ann. Appl. Biol.* **110**, 683-678
3 not recorded

The appearance of plants of *G. aparine* and other broadleaved species present in sprayed plots was assessed eight weeks after spraying, in comparison with untreated plots, as in the previous year. Because some species had senesced by the time of the June assessment in 1989, an earlier assessment was made in 1990. Broadleaved weeds were assessed in experiment 13 by counting numbers in ten randomly placed 0.25 m^2 quadrats in each plot in April and early May. In experiment 12, poor growth of the crop and abundance of species with a prostrate, spreading habit, particularly chickweed, precluded the separation of individual plants. Headland quadrats in these plots were therefore scored on the 'Domin Scale'. For the purposes of analysis, Domin scores were transformed into percentage cover using the method of Currall (1987). Percentage cover of *G. aparine* was assessed in July in ten 0.25 m^2 quadrats in each plot.

RESULTS

Only results from the later assessments, in June 1989 and in May and July 1990 are presented.

1988/89 experiments

Very high levels of control of *G. aparine* were achieved: control by 0.75 kg AI/ha was greater than 92% in all experiments, and greater than 99% in six of the eleven experiments (Tables 2 & 3). There was no significant difference between any of the herbicide treatments in the main sites (Table 2).

TABLE 2. Percentage cover of *G. aparine* in late June 1989 following treatment with quinmerac in autumn 1988 at main sites. (Figures in parentheses are arcsine transformed data. Standard errors refer to transformed data. Figures in bold type are percentage control).

Site	Treatment (dose kg AI/ha and timing) 0	0.5 Oct	0.75 Oct	1.00 Oct	0.5 Dec	0.75 Dec	1.00 Dec	0.5 Oct + 0.5 Dec	0.75 Dec + diclofop-methyl	SE
1	1.3 (6.3)	0 (0) **100**	<0.1 (0.3) **99.2**	0 (0) **100**	0 (0) **100**	<0.1 (0.5) **97.7**	0 (0) **100**	0 (0) **100**	0 (0) **100**	0.4***
2	24.0 (29.3)	0.2 (2.4) **99.0**	<0.1 (0.3) **>99.9**	0 (0) **100**	<0.1 (0.3) **>99.9**	0 (0) **100**	0 (0) **100**	0 (0) **100**	1.3 (3.2) **94.8**	1.2***
3	3.4 (10.0)	0.5 (2.6) **86.6**	0.2 (1.7) **94.8**	<0.1 (0.5) **99.1**	0.1 (1.4) **96.2**	0.1 (0.9) **97.1**	0 (0) **100**	<0.1 (0.3) **99.7**	0.1 (1.1) **97.5**	1.0***

TABLE 3. Percentage cover of *G. aparine* in late June 1989 following treatment with quinmerac in autumn 1988 at subsidiary sites. (Figures in parentheses are arcsine transformed data. Standard errors refer to transformed data. Figures in bold type are percentage control)

Dose (kg AI/ha)	Site 4	5	6	7	8	9	10	11
0	32.3 (34.6)	30.2 (33.0)	7.1 (15.0)	4.9 (12.6)	9.9 (16.6)	40.9 (39.7)	1.0 (5.5)	21.6 (27.6)
0.75	0 (0) **100**	0.3 (2.8) **99.0**	0.4 (2.9) **94.4**	0.1 (1.0) **98.0**	0.7 (4.1) **92.9**	0.4 (3.4) **99.0**	0 (0) **100**	0 (0) **100**

SE Treatment = 0.7***; SE Site = 1.4***; SE Treatment x site = 1.9***

Papaver rhoeas and *Veronica persica* were also susceptible to quinmerac, high levels of control resulting from all treatments where these species were present. Once again there was little difference between treatments (Table 4). Earlier assessments indicated that *Veronica hederifolia* and *L. purpureum* were also susceptible, but these species had senesced by the time of the later assessment.

Species present at one or more sites in sufficient quantities to permit statistical analysis, but for which no significant effects of the herbicide were detected, included *Geranium molle*, *Myosotis arvensis*, *Stellaria media*, *Tripleurospermum inodorum* and *Viola arvensis*. Other species present at levels too low for statistical analysis, but for which no obvious treatment effects were detected, included *Aphanes arvensis*, *Fallopia convolvulus* and *Senecio vulgaris*.

TABLE 4. Percentage cover in late June 1989 following treatment with quinmerac in autumn 1988 at main sites. (Figures in parentheses are arcsine transformed data. Standard errors refer to transformed data).

Site	Treatment (dose kg AI/ha and timing)									SE
	0	0.5 Oct	0.75 Oct	1.00 Oct	0.5 Dec	0.75 Dec	1.00 Dec	0.5 Oct + 0.5 Dec	0.75 Dec + diclofop-methyl	
Papaver rhoeas										
1	5.3	<0.1	<0.1	0	0.3	0.1	<0.1	0	0.1	
	(12.9)	(0.6)	(0.8)	(0)	(1.9)	(1.4)	(0.5)	(0)	(1.2)	0.9***
2	1.7	<0.1	0	0	0	0	<0.1	0	0	
	(7.0)	(0.5)	(0)	(0)	(0)	(0)	(0.3)	(0)	(0)	0.6***
3	2.6	1.0	0	<0.1	0.5	0.2	0.2	0	0.1	
	(8.4)	(3.0)	(0)	0.5)	(3.3)	(1.5)	(1.7)	(0)	(0.9)	1.3**
Veronica persica										
1	0.9	<0.1	<0.1	<0.1	<0.1	<0.1	0	<0.1	0.1	
	(5.5)	(0.3)	(0.5)	(0.5	(0.3)	(0.8)	(0)	(0.3)	0.6	0.4***
2	5.6	0.1	0.1	0	0.1	0.1	0	0	0.2	
	(13.1)	(1.7)	(1.1)	(0)	(1.0)	(1.6)	(0)	(0)	(1.4)	1.0***

<u>1989/90 experiments</u>

Levels of *G. aparine* control (measured as percentage cover in July) in experiments 12 and 13 were comparable with those measured in the previous year at a similar time, ranging from 89 to 98 %, with little difference between treatments (Table 5).

The only other species to show significant effects of herbicide use was *V. persica*. This was completely controlled by both doses at the earlier timing in experiment 12, with the low and high doses giving 78 and 93% control respectively at the later timing (Table 6). In experiment 13, there was a similar effect of timing (through not significant at $P<0.05$), but levels of control were markedly lower (Table 6). Numbers of *L. purpureum* were lower in treated plots in experiment 13, though the difference was not statistically significant. In contrast, *Legousia hybrida* was present in significantly greater numbers in experiment 13, where herbicide was used

(Table 6). This may be a result of reduced competition from *G. aparine* and/or *V. persica* in treated plots.

TABLE 5. Percentage cover of *G. aparine* in July 1990, following treatment in autumn 1989. (Figures in parentheses are arcsine transformed data; standard errors refer to transformed values. Standard errors only given for differences significant at P<0.05. Figures in bold type are percentage control).

Experiment	Treatment (dose, kg AI/ha and timing) 0	0.5 Nov	0.75 Nov	0.5 Dec/Jan	0.75 Dec/Jan	SED* UH	UDT	DT
12	50.2	1.8	2.7	5.3	4.1			
	(45.1)	(7.5)	(9.4)	(13.3)	(11.1)	3.9	(NS)	(NS)
		96.4	**94.6**	**89.4**	**91.8**			
13	6.3	0.2	0.1	0.5	0.1			
	(12.6)	(2.7)	(2.0)	(2.9)	(1.9)	3.6	(NS)	(NS)
		96.8	**98.4**	**92.1**	**98.4**			

* UH = SED for comparing untreated with herbicide treated; UDT = SED for comparing untreated with each level of dose <u>or</u> timing; DT = SED for comparing levels of dose <u>or</u> timing.

TABLE 6. Percentage cover, derived from Domin Scores (Expt. 12, see text) or numbers per 0.25 m^2 (Expt. 13) of broadleaved weeds in May 1990, following treatment in autumn 1989. (Figures in parentheses are arcsine transformed data; standard errors for these data refer to transformed values. Standard errors only given for differences significant at P<0.05).

	Treatment (dose, kg AI/ha and timing) 0	0.5 Nov	0.75 Nov	0.5 Dec/Jan	0.75 Dec/Jan	SED*	
<u>Experiment 12</u> (% cover)							
Veronica persica	4.76	0.0	0.0	1.03	0.33	UH	0.91
	(12.56)	(0.0)	(0.0)	(5.75)	(3.22)	UT	1.00
						T	0.81
<u>Experiment 13</u> (plant numbers)							
V. persica (13)	5.40	2.85	1.60	3.50	4.75	UH	0.79
Legousia hybrida (13)	4.15	7.70	5.75	5.50	7.15	UH	0.85

* UH = SED for comparing untreated with herbicide treated; UT = SED for comparing unsprayed with each level of timing; T = SED for comparing levels of timing; UD = SED for comparing untreated with each level of dose; D = SED for comparing levels of dose; (NS) = no significant differences.

Other species sufficiently abundant at one or more sites to permit statistical analysis, but which showed no treatment effects, were *A. arvensis*, *Capsella bursa-pastoris*, *Fumaria officialis*, *S. media*, *T. inodorum*, and *V. arvensis*.

DISCUSSION

A high degree of control of *G. aparine* was achieved at all sites in both years.

The only other species effectively controlled by quinmerac in these experiments were *V. persica*, *V hederifolia* and *P. rhoeas*. *L. purpureum* showed susceptibility but levels of control were variable. These species are not thought to be important as insect host plants. All other weed species present appeared to be resistant, including *F. convolvulus*, *T. inodorum* which are important insect food plants, and *S. media*, the seeds of which (along with *F. convolvulus*) are eaten by adult partridges (Potts, 1986). It is concluded that quinmerac is an appropriate herbicide for us in Conservation Headlands.

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THE USE OF SELECTIVE HERBICIDES TO CONTROL WEED GRASSES IN HEATHER MOORLAND

A.C. Wakeham, R.C. Kirkwood

Department of Bioscience and Biotechnology, University of Strathclyde, Glasgow G4 0NR

ABSTRACT

The overgrazing of heather moorlands, by sheep and to a lesser extent red deer, has reduced the coverage of Calluna vulgaris leading to an increase of coverage of Molinia caerulea and other grazing resistant species, reducing the productivity of the moorland. In order to promote the heather regeneration the use of selective herbicides to control the grass species has been considered.

In this paper the preliminary results of field and laboratory studies using carbetamide, diuron and sethoxydim, for the control of grass species present on heather moorland are presented. Of the three compounds sethoxydim appears to be the most appropriate in selectivity and mode of action. In addition the effectiveness of the compounds at a range of soil organic contents will be discussed.

INTRODUCTION

Much of the heather (Calluna vulgaris) moorland in this country is overgrazed by sheep and, to a lesser extent in Scotland, by red deer. The effect of the excessive grazing is to reduce the numbers of broadleaved species, and to favour the grazing-resistant grasses, particularly purple moor grass (Molinia caerulae). Together with bad burning practices which further weakens C. vulgaris, and the introduction of fothering (feeding concentrates to the sheep on the hill in the winter), the invasion of heather moorland by M. caerulae and other 'weed' grasses has greatly increased in recent years (Welch, 1984).

Methods of regenerating C. vulgaris stands, such as cessation or reduction of the grazing levels, are used. In cases of prolonged and or severe overgrazing, however, these methods of regeneration have failed, often caused by the growth habit of M. caerulea.

The effect of M. caerulea development is to prevent seed germination and growth of heather plants. The build up of dead leaf material from previous seasons tends to smother existing heather plants which have already been suppressed through grazing pressure, further reducing the stand of C. vulgaris. This coupled with the aggressive, tussocky nature of M. caerulea and the reduced vigour of the C. vulgaris has allowed the M. caerulea to flourish.

In some instances, the regeneration of heather may be achieved by the removal of excess M. caerulea leaf litter and selective suppression of the grass plants. Previous use of herbicides on heather moorland was aimed at total kill of all plant species (Williams, 1979). In this project, however, selective herbicides were used to control the M. caerulea and other grass species, enabling the C. vulgaris plants to develop with the reduction of grass competition.

The herbicidal compounds selected for study were:-

diuron, a substituted urea which inhibits cyclic photophosphorylation in susceptible species, killing a wide range of plant species including grasses and broadleaved species (Stranger & Appleby, 1972).

carbetamide, a carbamate which kills many grasses and a few selected broadleaved species by disrupting the growth zones of the plant.

sethoxydim, an oxy phenoxypropionic acid graminicide which inhibits lipid synthesis (Burton et al., 1987).

The suitability of each compound were tested in laboratory studies and a field trial, using formulated herbicides (diuron 500g AI/kg; carbetamide 700g AI/kg; sethoxydim 193g AI/1).

MATERIALS AND METHODS

Laboratory Studies

The laboratory studies were conducted on eight test species:-

C. vulgaris, the major food plant for adult grouse, M. caerulae, an aggressive tussock forming grass species, which is beginning to dominate heather moorlands. Deschampsia flexuosa, a tussock forming needle grass, Nardus stricta, a species which tends to replace overgrazed C. vulgaris in drier areas in the absence of M. caerulea, Festuca ovina and Agrostis tenuis which are both useful species palatable to sheep, Eriophorum vaginatum, the seed heads of which are the main source of energy and calcium for the female grouse during egg production and Juncus squarrosus, an important food plant for grouse feeding on the seeds in the autumn.

M. caerulea has not been included in the laboratory studies to date due to propagation difficulties.

Grass plants were grown until the tillering stage or at 6 cm height in the case of C. vulgaris. The herbicide treatments were applied using a laboratory bench sprayer with 'T' jet-flat fan nozzles with a pressure of 2.5 bar at the following rates:-

sethoxydim 0, 0.25, 0.5, 1.0 and 2.0 kg AI/ha
diuron 0, 1.0, 2.0, 4.0 and 8.0 kg AI/ha
carbetamide 0, 0.5, 1.0, 2.0 and 4.0 kg AI/ha

After spraying the plants were left to grow for a further four weeks (sethoxydim and diuron) or eight weeks (carbetamide) in the greenhouse. The variation in treatment period was based on the mode of action of the compounds. The effect of each herbicide was evaluated using the following methods:-

The chlorophyll content of leaf material was measured by homogenising the tissue in 80% acetone, followed by centrifugation at 2000 G. Supernatant absorption at 663 nm and 645 nm was read and chlorophyll content calculated.

Membrane leakage of treated leaf material was determined by shaking 0.1g leaf material in distilled water at 100 rev/min for 24h after which conductance was measured using a conductivity meter. The samples were then boiled and conductance re-measured. The readings were expressed as percentage of total conductivity of the sample.

Field Trials

The field trials were carried out at Milngavie (near Glasgow) and the island of Islay (both Strathclyde Region), and Keld (Yorkshire). At Milngavie, the driest of the three sites, the trial area contained a patchwork of N. stricta, M. caerulea, C. vulgaris, Erica tetralix and E. cineraria as the predominant species. The site on the island of Islay was typical of most overgrazed Scottish heather moorlands, being grazed by red deer as well as sheep. The dominant species was M. caerulea with little or no C. vulgaris. Keld in Yorkshire was typical of overgrazed Yorkshire heather moorland with well established tussocks of M. caerulea and D. flexuosa which have smothered the previously dominant C. vulgaris.

The plot size at Keld and Islay was 4m x 5m and 4m x 4m at Milngavie. At each site, plots were treated with two rates of sethoxydim (1.0 and 2.0 AI kg/ha), or fluazifop-P-butyl (0.375 AI kg/ha). Control plots were left untreated. For each treatment there were three replicates. The treatments were made using a hand held boom at pressure 2.5 bar. Applications were made as follows:-

Late spring - April/May 1991
Early summer - June/July 1991
Autumn - August /September 1991 (not reported here)

All treated and control plots were assessed using a vigour score for each major species of zero to five.

- Zero - a healthy growing plant.
- One - little affect on plant growth on whole plant or one or two leaves affected.
- Two - whole or part of plant affected and plant growth slightly stunted.
- Three - still growing but whole plant affected and growth significantly stunted.
- Four - plant severely affected, no seed production and plant growth minimal.
- Five - plant dead.

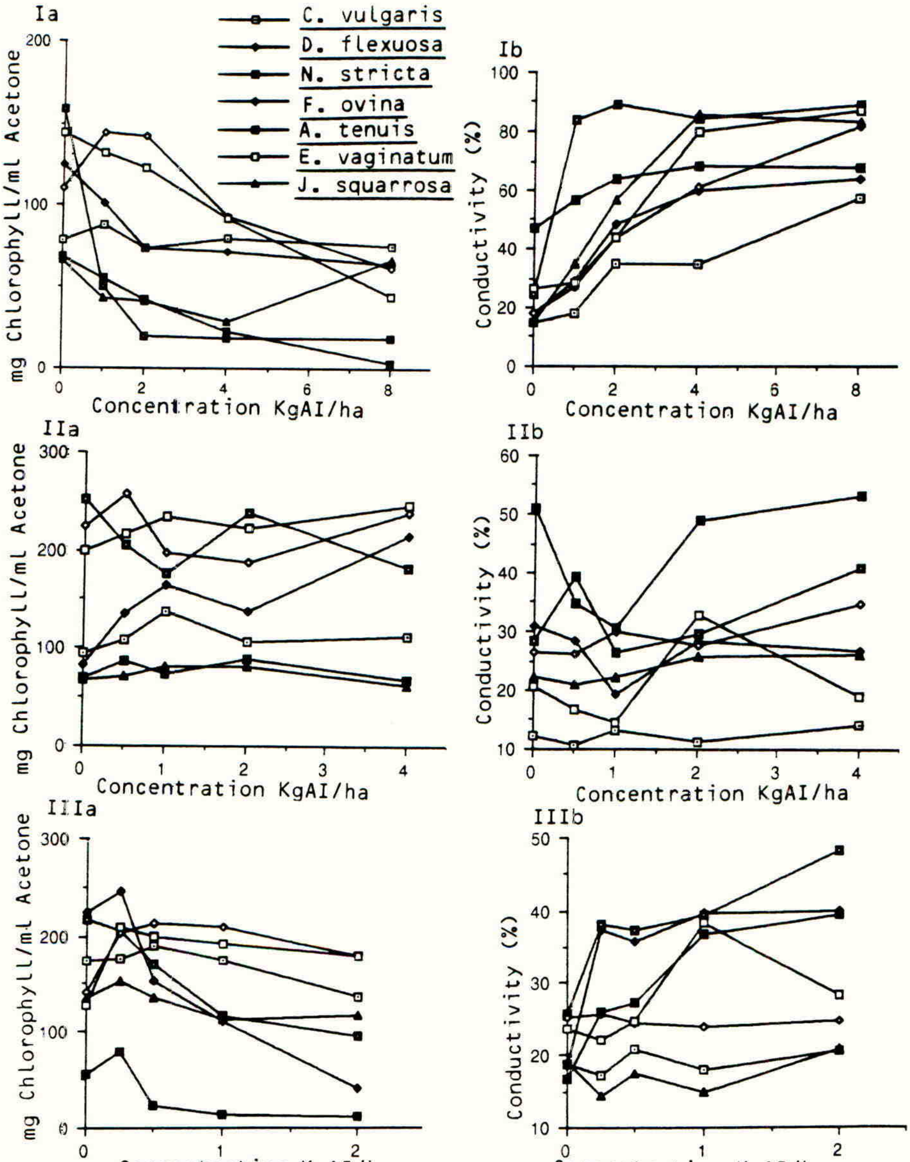
RESULTS

Laboratory Studies

The effects of herbicide treatment on chlorophyll content and membrane leakage are shown in Figure 1. In all experiments carbetamide produced no significant visual effects and membrane leakage, and chlorophyll content was not significantly altered.

In all species diuron significantly increased membrane leakage, and reduced chlorophyll; treatments caused a reduction in growth or death of the plants.

Figure 1 The effect of I) diuron II) carbetamide and III) sethoxydim on a) chlorophyll content and b) membrane permeability of selected species in the laboratory.



Sethoxydim produced more variable results. In D. flexuosa, N. stricta and A. tenuis, chlorophyll content was greatly reduced and conductivity greatly increased. In other species there was little or no effect. The lack of control of F. ovina was unexpected, but may reflect the relatively small receptive leaf surface area of this grass which can receive the spray.

Since sethoxydim controlled the required range of species with little side effects on C. vulgaris or F. ovina, it was regarded as the major candidate for field trials. This was confirmed by a preliminary assessment of a field trial sprayed in October 1990 at Milngavie. Visual assessment indicated that diuron and carbetamide were relatively less suitable for field use in grass-invaded heather moorland than sethoxydim. Accordingly the major trials sprayed in 1991 have concentrated on the effect of sethoxydim.

FIELD STUDIES

Spring Treatment

Results showing the visual effects of sethoxydim treatments are presented in Table 1. At all three sites C. vulgaris and M. caerulea appeared to be totally unaffected, and only slight effects were seen on E. vaginatum and Polytrichum spp. (Keld). However, as the Molinia was still visibly dormant at the time of application the plant appeared unable to take up sufficient herbicide to have any affect.

Table 1. Vigour scores of selected species one month after spring spraying with sethoxydim and fluazifop-P-butyl applied post-emergence at Milngavie (M), Islay (I) and Keld (K).

Dose (Kg AI/ha)		sethoxydim		fluazifop-P-butyl	control
Species		1.0	2.0	0.375	
N. stricta	M	4.0	5.0	2.6	0.0
D. flexuosa	I	3.0	4.3	3.3	0.0
	M	3.0	4.3	3.3	0.0
	K	3.3	4.0	3.3	0.0
E. vaginatum	K	0.2	0.0	0.0	0.0
Polytrichum	K	0.0	1.0	1.3	0.0

D. flexuosa produced red pigments (anthocyanins) in all green leaves and shoots, and seed head production was suppressed. The affect was particularly marked at Keld where there was a high proportion of D.

flexuosa in the sward. At Islay and Milngavie, similar effects on D. flexuosa were obtained, but the effects were less striking as there was a smaller content in the sward.

At Milngavie, N. stricta was affected and the plant turned brown with no seed head production. Three months after application there appeared to be no visual recovery of the Nardus and in certain cases the treated plots were colonised by Potentilla erecta and Galium saxatile.

Sethoxydim (2.0 kg AI/ha) and fluazifop-P-butyl caused some scorching of Polytrichum moss at Keld, though this effect may reflect the drought conditions, which prevailed during the treatment period.

Fluazifop-P-butyl caused similar but less effective control of the named species. The lower activity could be due to the lower rate of application (0.375 kg AI/ha) compared to the sethoxydim (1.0 and 2.0 kg AI/ha).

The apparent lack of control of M. caerulea in all cases was disappointing but it is assumed that herbicide uptake was inadequate since the grass had not started to grow at the time of application.

Summer Spraying

Results showing the visual effects of sethoxydim treatments are presented in Table 2. At Keld and Islay sethoxydim produced good control of M. caerulea, with all treated plants being stunted and the actively growing leaves turning red or brown, there was no seed head production; fluazifop-P-butyl showed a similar rate of control compared to sethoxydim. D. flexuosa appeared unaffected except that panicle maturation was suppressed.

Table 2. Vigour scores of M. caerulea one month after summer spraying treated with sethoxydim and fluazifop-P-butyl applied post-emergence at Islay (I) and Keld (K).

Dose (Kg AI/ha) Species		sethoxydim 1.0	sethoxydim 2.0	fluazifop-P-butyl 0.375	control
M.caerulae	I	4.0	4.0	3.0	0.0
	K	4.0	4.0	3.0	0.0

On Islay there appeared to be an increase in the amount of Vaccinium myrtilis and P. erecta on the sethoxydim-treated sites, reflecting the suppressed undergrowth of these species on the untreated plots.

At Keld there was not such a strong undergrowth of other plant species, but where there was such growth, the plants had expanded to fill part of the opened canopy. In one such plot there was a large growth of Empetrum nigrum and V. myrtilis; C. vulgaris was recorded in the plot for the first time. In another plot P. erecta was greatly increased as a large clump had grown in a cleared area. The recovery of Keld to a large stand of C. vulgaris is expected to be slow as there was little or no heather present in the sward.

Milngavie plots were not treated with herbicide, due to weather conditions, until mid August, and currently results are not available.

DISCUSSION

The laboratory results were quite clear cut, there was little or no effect of diuron or carmetamide whereas sethoxydim successfully controlled a selected range of grasses. The limited range of control of diuron and carbetamide, even when used at rates three or four-fold higher than for normal agricultural use, could be attributed to the wrong timing of application. Ideally the herbicides should be applied when the plant is beginning active growth or just before the onset of dormancy. Unpublished field trial data from Milngavie showed that even when these herbicides were applied at the correct timing there was a lack of activity. This may be due to several factors. For example, it may be attributed to the adsorption of active ingredient to the organic content of the soil; root absorption would be affected and foliar uptake restricted due to leaf senescence. Experiments are planned to calculate the mobility of diuron and carbetamide in ericaceous compost and their activity in varying soil organic matter contents.

The selectivity of sethoxydim to date was satisfactory. While M. caerulea was not included in the laboratory trials, a preliminary trial at Keld in 1989 showed that sethoxydim was able to retard the growth of M. caerulea significantly (D. Newborn, pers. comm.). The field trial results have shown that sethoxydim (1.0 and 2.0 kg AI/ha) has a greater activity on the weed grass population than fluazifop-P-butyl, but the results may reflect the different application rates as sethoxydim was applied at 1.0 and 2.0 kg AI/ha and fluazifop-P-butyl at 0.375 kg AI/ha. The range of species varied from the laboratory trials in that there was an effect on E. vaginatum and Polytrichum spp. The latter species were only affected at Keld, a site which was suffering from drought conditions.

While control of D. flexuosa and N. stricta was evident from the results of the spring spraying, control of M. caerulea was disappointing, doubtless reflecting the relative dormancy of these plants at that time; the summer spraying produced much more satisfactory results.

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