PART 3

WEEDS OF ESTABLISHED GRASSLAND — IMPORTANCE AND CONTROL

Incidence of Weeds in Permanent Grassland

A. HOPKINS and
S. PEEL
The Animal and Grassland Research Institute, North Wyke, Okehampton, Devon

ABSTRACT

The incidence of weeds in permanent grassland is reviewed with reference to three Grassland Research Institute surveys conducted between 1970 and 1983, and other surveys in Scotland and N. Ireland. Collectively these surveys covered over 100,000 ha of grassland. Assessments of serious infestations of Rumex obtusifolius *or* R. crispus *ranged from 4 to 8% of swards; intensive dairy farms were worst affected. Assessments of serious infestations of* Cirsium *spp. (mainly* C. arvense*) ranged from 7 to 27% of swards.* Cirsium *spp. were more frequent on older swards, especially grazed fields on beef/sheep farms.* Ranunculus *spp infest about 5% of swards, but* Senecio jacobaea *only 1%.* Juncus *spp. are widespread.* Holcus mollis, Bromis hordeaceus, Hordeum murinum *and* Deschampsia caespitosa *are the most undesirable graminaceous weeds; 3% of swards are infested by one or other of these species.*

Introduction

Permanent grassland constitutes the majority of the 8 m. ha of enclosed grassland in the UK. Not all permanent grassland is old grass as about 20% of the grassland in England and Wales is less than 5 years old, though about 50% of the total is over 20 years old. In recent years there has been a trend away from short-term leys (Peel *et al.* 1985).

Once established a sward seldom remains free of unsown species. In the average old sward (> 20 years old) sown species, principally *Lolium perenne*, contribute only 30–35% to the ground cover. Indigenous grasses, rushes (*Juncus* spp) and broad-leaved weeds contribute the balance. In other crops volunteer species are invariably regarded as weeds, but in grassland the concept of a weed is less clear-cut since most species contribute to the crop. Nevertheless, about 8% of the grassland area is reseeded annually and many broad-leaved weeds in long-term swards are regularly controlled by spraying or other means: 66% of farmers claimed to take action of some kind in the study of Peel & Hopkins (1980).

This paper seeks to update an earlier review (Peel & Hopkins 1980) in the light of recent surveys and other research. Consideration is restricted to those broad-leaved and grass species which farmers actively seek to discourage, either for aesthetic reasons, or because economic response to treatment is anticipated.

Methods

The results presented are mainly from Grassland Research Institute (GRI) surveys. The most detailed of these was the National Farm Study (NFS) carried out between 1974 and 1977 on 502 predominantly permanent grassland farms (Forbes *et al.* 1980). We have also drawn extensively on the major random survey of grassland in England and Wales in 1970–72 (Green 1982) and a smaller survey in South West England in 1983 (Hopkins *et al.* 1985; Peel *et al.* 1985). In these surveys the percentage cover of the main grasses was recorded visually and broad-leaved weeds (*i.e.* dicotyledonous species other than cultivated legumes) were assessed collectively on the basis of their contribution to the sward. Additionally, specific infestations were recorded using the following criteria: (i) weed well distributed across the field, *and* (ii) at least one plant/16 m^2 in the case of thistles, docks and ragwort, or >5% of the sward in the case of buttercups. Incipient or partial infestations, where the weed was sparser or localised but nevertheless was a potential problem were also recorded. Occasional plants or patches were ignored. These assessments were purely visual, but decisions were seldom problematical since if the weed was well distributed it invariably exceeded the required density.

Surveys carried out by other organisations have adopted similar field methods and levels of assessments. These include a survey of 5,300 ha of enclosed grassland in E. Scotland in 1976–78 (Swift *et al.* 1983) and a survey of 7,600 ha of grassland on hill farms in N. Ireland (McAdam 1983). Together with the three GRI surveys they represent a total of approximately 112,000 ha of grassland, of which 5,000 ha was surveyed in both the 1970–72 survey and the 1983 SW England survey. Reference is also made to weed surveys in N. Ireland in 1969 (Courtney 1973), to a postal survey of dock infestations in Britain in 1972 involving 343 farms (Haggar 1980) and to research from outside the UK.

Results

1. Broad-leaved species collectively

In the NFS broad-leaved species (other than sown legumes) made a minor contribution (2–5% of cover) in 64% of the swards and were present at 5–15% of cover in 18% of swards. A further 5% of swards had more serious contributions. They were more frequent in older swards and on beef/sheep farms. Soil factors were also related to the incidence of broad-leaved weeds with a higher incidence where drainage was impeded or where there was a low soil P or K index, but no overall relationship was noted with variation in pH. Higher levels of broad-leaved weeds were recorded in the 1970–72 survey (Green 1982) and in Eastern Scotland (Swift 1983). In N. Ireland, McAdam (1983) found that broad-leaved weeds constituted 11% of the herbage cover in 9–20 year old swards but only 4% in older swards and rough grazing.

2. *Major broad-leaved weed species*

The major broad-leaved weeds of established grassland are docks, thistles and buttercup. Ragwort and certain other species are of interest in some situations and these are also considered separately. Levels of infestation are summarised in Table 1 and trends over time for an identical group of farms are shown in Table 2.

DOCKS *Rumex obtusifolius*

The broad-leaved dock, and *R. crispus*, the curled dock, are both widely distributed (Cavers & Harper 1964). In the NFS docks were perceived as a weed problem by 40% of farmers but serious infestations were recorded, mainly in younger swards, on 6% of fields on dairy farms and on 3% of fields on beef farms (Forbes *et al.* 1980). Slightly higher figures were recorded in the 1970–72 survey and in N. Ireland where they were 'a problem' in 11% of the grassland (Courtney 1973). Considerably higher levels of dock infestation were recorded by Haggar (1980), but this survey involved individual farmer assessments. Relationships between docks and high soil P, and low K, were reported for the NFS (Peel & Hopkins 1980). Several studies have noted that docks are associated with intensive management including cutting for silage and the application of organic manure and fertilizer N (Courtney 1973; Haggar 1980; Hopkins, 1982; Hopkins *et al.* 1985). Factors which appear not to encourage docks include flooding, cutting for hay and sheep grazing (Haggar 1980).

THISTLES

Several species of thistle occur in grassland including *Cirsium vulgare*, *C. acaule*, *C. palustre*, *Carduus acanthoides* and *Carduus nutans*, but the perennial *Cirsium arvense* is the main thistle species of permanent grassland.

In the 1970–72 survey infestations of *Cirsium* spp (predominantly *C. arvense*) were more frequent in older grass (33% of swards >20 years) than in younger grass (13% of swards) (Green 1982). Corresponding figures for the 1983 SW England survey were 12 and 3%. In the NFS infestations were recorded in 10% of swards on beef farms and almost 5% of swards on dairy farms, with partial infestations in an additional 15 and 11% of swards, respectively. These percentages were considerably higher in older swards. In this study 50% of farmers mentioned thistles as being a weed problem on their grassland. In N. Ireland, *C. arvense* was recorded as being 'a problem' on 20% of the grassland (Courtney 1973).

Table 1: Summary of weed infestations found in grassland surveys, 1970–83

Location	Area, ha	Date of survey	Author(s)	Propn. (%) of sward infested* by: Docks	Thistles	Butter-cups	Ragwort	Rushes
Eng. & Wales	68,000	70–72	Green	8	22	15	2	NA
Eng. & Wales	28,000	74–78	Forbes *et al.*	4(9)	8(13)	5(11)	1	3(9)
E. Scotland	5,300	76–78	Swift *et al.*	5	27	NA	1	NA
SW England	8,000	83	Hopkins/ Peel *et al.*	6(12)	7(16)	5(10)	<1	4(8)

NA Not available. *Figures in parenthesis are the proportions of swards partly infested, in addition to those infested.

Table 2: Trends in weed infestation from 1970–72 to 1983 on an identical sample of 59 farms (Honiton, Truro and Totnes districts)

	1970–72 % of swards infested	1983 % of swards infested	1983 % of swards partly infested
Thistles (*Cirsium* spp)	13	7	15
Buttercups (*Ranunculus* spp)	22	3	12
Docks (*Rumex* spp)	14	8	10

The data collected for the NFS have been used to relate creeping thistle infestation to soil factors. Thistles were more frequent where soil P indices were >2 and on sites with higher levels of soil K. These relationships were most pronounced in older swards. There was no apparent association between creeping thistle and soil pH, but the species was more frequent on soils having satisfactory drainage (Peel & Hopkins 1980). In the NFS some 6% of farms had severe thistle infestations on over 40% of their grassland. These farms were mainly upland beef (+ sheep) using little fertilizer N (mean 37 kg ha^{-1}). In subsequent analyses of the NFS data Hopkins (1982) used cluster analysis to identify fields having similar botanical composition and identified a group comprising *Agrostis-Lolium* associations with *Cirsium arvense*. On livestock farms these were associated with low fertilizer N, absence of mowing, and relatively intensive grazing which usually included sheep over a long grazing season but with a rest period in late summer. This rest period seems crucial in permitting *Cirsium* to spread.

BUTTERCUPS

Three species of buttercup are common in British grassland: *Ranunculus repens* (creeping buttercup), *R. bulbosus* (bulbous buttercup) and *R. acris* (meadow buttercup). All three species are reported to be poisonous but tend to be avoided by stock (Williams 984). The ecology of these species in relation to drainage and management has been described by Harper (1957) and Harper & Sagar (1953). In grassland surveys the incidence of the various buttercup species has been recorded collectively. In the 1970–72 survey buttercup infestations were more frequent in swards aged >20 years (20% of swards) than in younger grass (10% of swards). Swift *et al.* (1983) found that heavy infestations (>5% of herbage cover) affected one-third of fields aged >9 years.

In the NFS buttercup infestations were more frequent in the older lowland swards especially where drainage was poor. Subsequent analyses of these data have shown buttercup to be associated with grassland containing *Poa trivialis, Holcus lanatus* and docks, and on some beef/sheep farms with *Agrostis-Festuca* grassland. The management of this association of *Agrostis-Festuca* plus *Ranunculus* spp. was 'traditional': with <70 kg N/ha, some fields being mown for late hay but more usually grazed over a long season at a low stocking rate. With a high proportion of grazing days in the winter this inevitably leads to seasonal overgrazing (Hopkins 1982).

Results from identical farms in 1970–72 and 1983 in SW England show that there has been a sharp decline in the incidence of buttercup infestations (Table 2). Some of this demise may be associated with the high levels of fertilizer N now being used; e.g. on grassland aged >20 years in SW England in 1983 buttercup infestations were recorded in 9% of that which received <200 kg N/ha as compared with only 3% of the grassland which received more than this amount.

RAGWORT

Although only occasional weeds of grassland both common ragwort (*Senecio jacobaea*) and the less frequent marsh ragwort (*S. aquaticus*) are of interest on account of their toxicity particularly in hay or silage. Ragwort is typically a problem of poorer grassland (Courtney 1973). It can be prevalent in swards receiving low inputs of fertilizer N, including some where legumes may be important (Forbes 1982). In the NFS fields with ragwort infestations were concentrated on a few farms (mainly dairy) on sandy or light-textured soils. Ragwort is reported to be one of the most problematic weeds in New Zealand dairy pastures (Thompson & Makepeace 1983) which rely on clover for N but are intensively stocked and receive P and K.

3. *Other Dicotyledonous Species*

Stinging nettle (*Urtica dioica*) is an occasional weed of grassland, but although some fields, particularly those in high fertility situations near buildings, contain patches of nettles they are very seldom distributed across whole fields.

Rosette-forming species such as plantains (*Plantago* spp), daisy (*Bellis perennis*) and dandelions (*Taraxacum* spp. and related genera) are frequent constituents of grassland, especially older pastures. Plantain and daisy are commonly associated with over-grazing and are frequent weeds in heavily-grazed horse paddocks. Dandelions are a frequent constituent of traditionally managed hay meadows but their status as a weed in these circumstances is doubtful. Another frequent component of hay meadows is cow parsley (*Anthriscus sylvestris*). Although a biennial it may behave as a perennial if prevented from flowering, and is resistant to most herbicides (Williams 1984).

4. *Undesirable Grasses*

Several grass species can be regarded as undesirable in most agricultural grasslands, either because of their low productivity, low palatability or low feed value, or because they are hazardous to stock in some way. Many other constituents of permanent grassland swards may be less productive or desirable than sown grasses or legumes, but cannot necessarily be regarded as weeds in all circumstances. The grasses shown in Table 3 are the main undesirable species and potential candidates for active control by farmers. The proportion of fields in the NFS having infestations, *i.e.* a contribution to vegetation cover of >10% by any one of these grasses, is shown in the table. A total of 3.2% of the grassland surveyed was so affected.

Table 3: Proportion of fields with 'undesirable' grass infestations

	Fields affected, %
Bromus hordeaceus (Soft brome)	1.2
Elymus repens (Couch)	1.1
Deschampsia caespitosa (Tufted hair-grass)	0.8
Holcus mollis (Creeping soft-grass)	0.2
Hordeum murinum and *H. secalinum* (Barley grasses)	0.1

Bromus hordeaceus is an annual which thrives in traditionally managed hay fields, mainly on beef/sheep farms rather than dairy farms, where it has the chance to shed seeds before being harvested. Although potentially high yielding it is unattractive to stock (Williams 1984). The incidence of soft brome has increased in upland hay meadows in recent years, especially on sheep farms (Cooper 1982).

Elymus repens and *Holcus mollis* are rhizomatous species and are serious weeds in an arable situation and hence of leys in rotation; they may be less imortant in permanent swards. Neuteboom (1981) has reported that couch (*E. repens*) is associated with late or infrequent defoliation, especially under high N. Other evidence (Smith 1979; Courtney 1980) has shown that the proportion of couch can increase with age under conditions of cutting and high N. The higher incidence of couch in E. England may also be associated with climatic factors (dry summers and cold winters) as well as management practices. The grass is very common in the Netherlands (Hoogerkamp 1975) where the climate is similar to East Anglia, and also in Finland (Pulli 1983). In Britain it is also a common constituent of grasslands which have been subjected to marine inundation such as the East Anglian 'marshes'; similar findings were noted for inundated fields in the Netherlands (Hoogerkamp 1975). *Holcus mollis* rarely contributes significantly in agricultural grassland but we have recorded occasional infestations on extensively-managed swards on dry sandy soils, in 'tumble-down' swards on reclaimed *Calluna* moorland and even on badly drained clay soils.

5. *Other Indigenous Grass Species*

In addition to the grass species described above there are many other species of grassland, which although unsown cannot necessarily be regarded as weeds. The most common of these are *Agrostis* spp. (chiefly *A. capillaris* and *A. stolonifera*), *Holcus lanatus*, *Poa trivialis*, *Festuca rubra* and *Poa annua*. Of grassland in England and Wales aged over 20 years they collectively account for about 55% of the herbage cover. *Poa annua* is the only one likely to be subject to specific control measures. It is found in small quantities in a high proportion of swards of all ages and is particularly evident on disturbed ground around gateways or troughs. Confined to these small areas it is of little consequence. In the NFS it was present in appreciable quantities (>15% of ground cover) in only 2% of old swards and 7% of swards of <20 years old. Other surveys (Swift *et al.* 1983; McAdam 1983; Hopkins *et al.* 1985) have also shown *Poa annua* to be of relatively minor importance in established grassland.

6. *Other Weed Species*

Other species which may present weed problems in grassland include rushes, bracken and horsetails. The field horsetail (*Equisetum arvense*) may occasionally be a troublesome weed in both old and young grassland. It is poisonous to stock (Williams 1984). Rushes and bracken are much more widespread.

RUSHES (*Juncus* spp.)

Soft rush (*J. effusus*) is most common and affects much wet land, especially in upland areas. Its unpalatability and consequent competitiveness under grazing, together with the long viability of its seed, can make it a particularly persistent weed (Lazenby 1955). Hard rush (*J. inflexus*) and jointed rush (*J. articulatus*) are also widespread. The incidence of rushes in two surveys is included in Table 1. They are more frequent in older grassland (20% of swards >20 years old in the NFS were affected to some extent). Rushes are also associated with low soil K status and low pH (Hopkins 1982). There are many instances, especially on dairy farms, where poor or bad drainage conditions are not associated with rushes; however such swards are often subject to more intensive management.

BRACKEN (*Pteridium aquilinum*)

Bracken is an aggressive vigorous plant widespread on light, well drained, neutral-to-acid soils ascending to 600 m elevation, particularly in sheltered areas. It affects 160,000 ha of hill and enclosed grassland in England and Wales and a further 200,000 ha of hill land in Scotland (MAFF 1978; Holroyd & Thornton 1978; SAC 1979). Increases in herbage dry matter yield of up to 47% have been reported from controlling medium-density bracken infestations (Davies *et al.* 1979). Bracken is associated with set-stocking by sheep and the presence of even a small proportion of cattle can markedly reduce the regrowth of fronds (Williams 1980).

Discussion

The likelihood of a particular weed affecting grassland can be related to environment and management. A schematic representation of the effect of these factors is shown in Fig. 1. The results of the surveys reported here indicate the incidence of the various species commonly designated as weeds. What they do not show is the extent to which weeds are an *economic* problem of permanent grassland. Grass is grown to feed livestock; most pasture species are consumed either *in situ* or as conserved forage, and animal output on farms is dependent more on sward management and fertilizer inputs than on the species present (Peel & Green 1984).

Most people would agree that the species considered here are undesirable constituents of long-term swards and their presence should be minimised. Nevertheless, not all so-called weeds are undesirable in all situations. Rhizomatous grasses such as couch (*E. repens*) are less of a problem in long-term swards than in arable grassland. Pulli (1983) has noted that for Scandinavia, couch has a good feed value, equal to that of Timothy (*Phleum pratense*). Research in Switzerland has shown dandelions to be particularly beneficial in terms of intake and nutrient content; milk production from zero-grazed herbage was just as high with 9% clover and 35% weeds (mainly dandelions) as when it contained 20% clover and no weeds (Jans 1982). Even docks have a digestibility

80%, and an *intake* by cattle 85% of that of grasses (Courtney & Johnson 1978).

The incidence of the major broad-leaved weed species may be declining. Table 2 shows that in SW England at least buttercups are now far less abundant than they were; this may be due as much to increasing fertility and stocking rate as to specific control measures. The decline in thistles and docks is less clear-cut since there are a large number of fields with 'partial infestations', a category not recorded in the 1970–72 survey. It may be that selective herbicides have enabled farmers to reduce weed levels substantially in the worst fields, but that they regard it as uneconomic to tackle the remaining lesser infestations.

The best estimate of the situation on established grassland in England and Wales as a whole is still made from the 1974–78 NFS. Using these data we suggest that of the 5.0 m. ha of enclosed grassland there are serious infestations of thistles on 400,000 ha, docks on 200,000 ha and buttercups on 250,000 ha. Since some fields have more than one serious weed these values are not strictly additive. Oswald (1982) has suggested that up to 1 m. ha of grassland in England and Wales could be treated using techniques to exploit height differential between weed and grazed grass.

Experimental evidence on the effects of weed control on grassland productivity is still rather limited. These figures should be seen as a guide to the relative importance of each species and the areas which might be subject to control measures, rather than an indication that the productivity of all such areas could be improved by removal of weed species.

References

CAVERS, P.B.; HARPER, J.L. (1964) Biological flora of the British Isles: *Rumex obtusifolius L.* and *R. Crispus* L. *Journal of Ecology,* **52**, 737–766.

COOPER, F.B. (1982) Experiences in controlling *Bromus mollis* L. in permanent swards. *British Crop Protection Conference – Weeds 1982*. 381–385.

COURTNEY, A.D. (1973) Noxious weeds in grassland – docks, thistles and ragwort. *Agriculture in Northern Ireland,* **48**, 22–25.

COURTNEY, A.D. (1980) A comparative study of management factors likely to influence rhizome production by *Agropyron repens* and *Agrostis gigantea* in perennial ryegrass swards. *British Crop Protection Conference – Weeds 1980,* **3**, 469–476.

COURTNEY, A.D.; JOHNSON, R. (1978) A consideration of the contribution to production of *Rumex obtusifolius* in a grazing regime. *1978 British Crop Protection Conference – Weeds,* 325–331.

DAVIES, G.E.; NEWBOULD, P.; BAILLIE, G.J. (1979) The effect of controlling bracken (*Pteridium aquilinum* L. Kuhn) on pasture production. *Grass and Forage Science* **34**, 163–172.

FORBES, J.C. (1982) Evaluating herbicides for selective control of *Senecio jacobaea* in grass/clover swards. *British Crop Protection Conference – Weeds 1982*, 375–379.

FORBES, T.J.; DIBB, C.; GREEN, J.O.; HOPKINS, A.; PEEL, S. (1980) *Factors affecting the productivity of permanent grassland.* Joint Permanent Pasture Group, Hurley.

GREEN, J.O. (1982) *A sample survey of grassland in England and Wales, 1970–72*. Hurley: Grassland Research Institute.

HAGGAR, R.J. (1980) Survey of the incidence of docks (*Rumex* spp.) in grassland in ten districts in the UK in 1972. *ADAS Quarterly Review* **39**, 256–263.

HARPER, J.L. (1957) Biological flora of the British Isles: *Ranunculus acris* L., *Ranunculus repens* L. and *Ranunculus bulbosus* L. *Journal of Ecology* **45**, 289–342.

HARPER, J.L.; SAGAR, G.R. (1953) Some aspects of the ecology of buttercups in permanent grassland. *Proceedings British Weed Control Conference* 256–263.

HOLROYD, J.; THORNTON, M.E. (1978) Factors influencing the control of bracken (*Pteridium aquilinum* L. Kuhn) with asulam. *Weed Research* **18**, 181–186.

HOOGERKAMP, M. (1975) *Elytrigia repens* and its control in leys. *Proc. European Weed Research Society Symposium. Status, Biology and Control of Grass Weeds in Europe* 322–239.

HOPKINS, A. (1982) *An investigation of relationships between the composition of swards and their environment and management.* M. Phil. Thesis, University of Reading.

HOPKINS, A.; MATKIN, ELIZABETH A.; ELLIS, JULIA A.; PEEL, S. (1985) SW England Grassland Survey 1983: 1. Age structure and sward composition of permanent and arable grassland and their relation to manageability, fertilizer N and other management features. *Grass and Forage Science.* (In press).

JANS F. (1982) Sommerfütterung. Die bedentung der botanischen zusammensetzung des grünfuttters. *UFA Revue* **3**, 1–5.

LAZENBY, A. (1955) Germination and establishment of *Juncus effusus* L. II. The interaction effects of moisture and competition. *Journal of Ecology* **43**, 595–605.

MAFF (1978) Bracken and its control. *Ministry of Agriculture, Fisheries and Fool (Publications). Advisory Leaflet 190.*

MCADAM, J.H. (1983) *Characteristics of grassland on hill farms in N. Ireland – physical features, botanical composition and productivity.* Department of Agricultural Botany, Queen's University of Belfast.

NEUTEBOOM, J.H. (1981) Effect of different mowing regimes on the growth and development of four clones of couch (*Elytrigia repens*) (L). Desv.; Syn. *Agropyron repens* (L) Beauv.). In monocultures and in mixtures with perennial ryegrass (*Lolium perenne* L.). Mededlingen Lanbouwhoge-school, Wageningen 81–115.

OSWALD, A.K. (1982). Two surveys of the potential use of a technique for controlling tall weeds in grassland. *British Crop Protection Conference – Weeds 1982* 387–393.

PEEL, S.; GREEN, J.O. (1984). Sward composition and output on grassland farms. *Grass and Forage Science* **39**, 107–110.

PEEL, S.; HOPKINS, A. (1980). The incidence of weeds in grassland. *British Crop Protection Conference – Weeds 1980*, 877–890.

PEEL, S.; MATKIN, ELIZABETH A.; ELLIS, JULIA A.; HOPKINS, A. (1985) SW England Grassland Survey 1983: 2. Trends in cropping pattern, reseeding and sward composition, 1970–83. *Grass and Forage Science* (In press).

PULLI, S. (1983). Productivity and forage quality of couch grass (*Agropyron repens*). *Proc. 9th General Meeting European Grassland Federation.* 263–268.

SCOTTISH AGRICULTURAL COLLEGES (1979). *Bracken control in grassland.* Publication No. 39.

SMITH, A. (1979). Changes in botanical composition and yield in a long-term experiment. *British Grassland Society Occasional Symposium No.* **10**, 69–75.

SWIFT, G.; HOLMES, J.C.; CLELAND, A.T.; FORTUNE, D.; WOOD, J. (1983). *The grassland of East Scotland – a survey 1976–78.* East of Scotland College of Agriculture, Bulletin No. 29.

THOMPSON, A.; MAKEPEACE, W. (1983). Longevity of buried ragwort (*Senecio jacobea* L. seed. *New Zealand Journal of Experimental Agriculture* **11**, 89–90.

WILLIAMS, G.H. (1980). Follow-up treatments for control of *Pteridium aquilinum. British Crop Protection Conference – Weeds 1980*, 423–428.

WILLIAMS, R.D. (1984). *Crop Protection Handbook – Grass and Clover Swards.* Croydon: British Crop Protection Council.

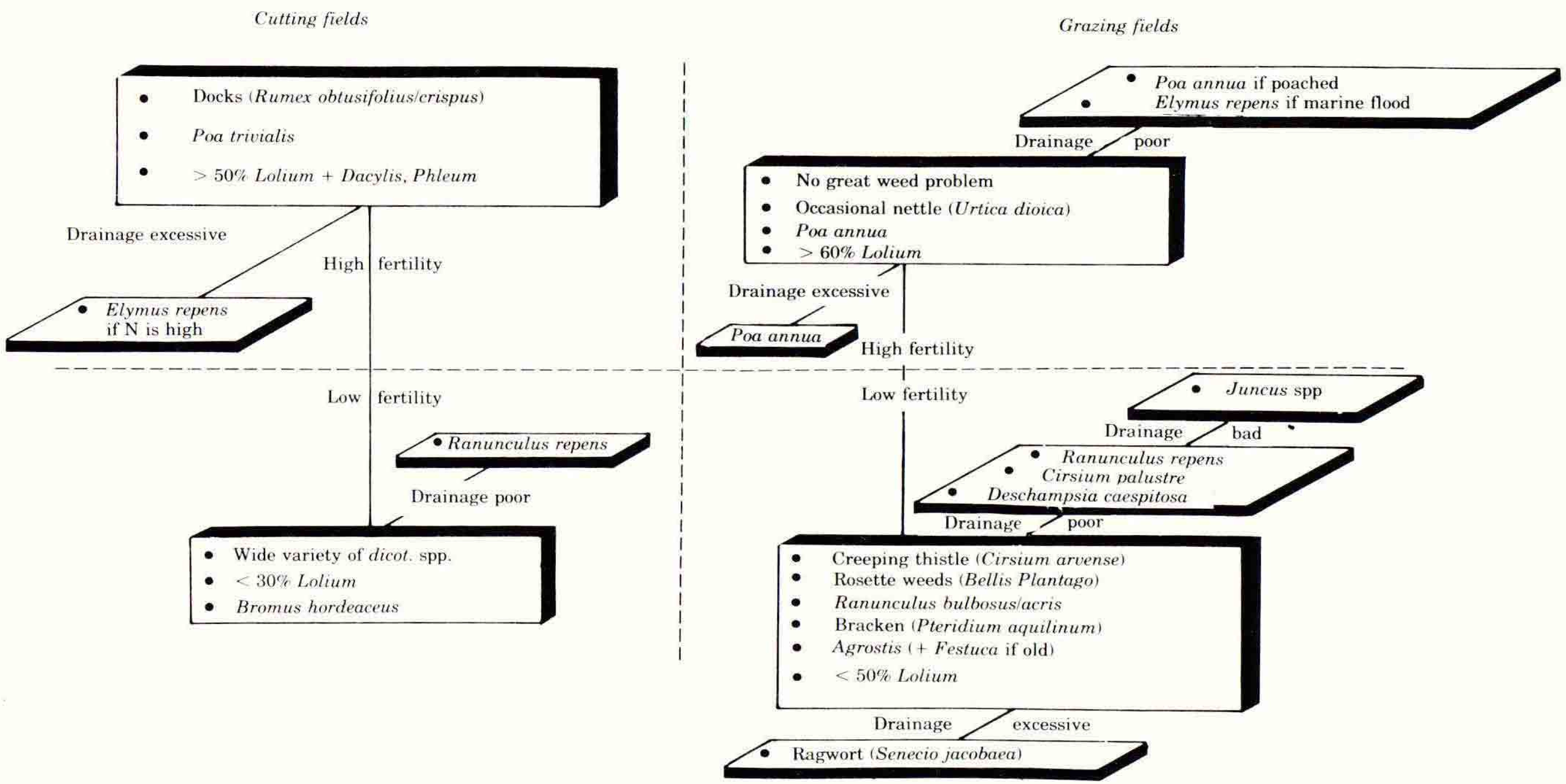

Figure 1: Simple 3-dimensional representation of impact of environment and management on weed incidence in established swards

The Nutritional Value of Common Weeds

W.P. BARBER
MAFF,
ADAS,
Newcastle upon Tyne

ABSTRACT

Whilst it is clear that weeds are not wanted on horticultural land and arable land in general, some agronomists believe that the presence of weeds in a pasture is nutritionally advantageous for grazing animals. Reference to published data on the nutritional value of some common weeds has shown them to be useful sources of energy, protein and minerals for ruminants. It is unlikely, however, that they could fully replace the need for mineral supplements at grass. Some weeds contribute to the green material available during summer months. More work needs to be done on the value of weeds grown under intensive grassland management systems or continuous grazing regimes. The possible toxic nature of some of the weeds should always be borne in mind.

Introduction

In agricultural and horticultural terminology, unwanted plants growing alongside useful plants on cultivated land are collectively referred to as 'weeds' or 'wild grasses'. They are wild plants whose spread and mode of existence have become adapted to the changing conditions of cultivated ground. In fact, in a botanical sense there are no such things as weeds or grass weeds.

The definition of the term 'weed' makes it clear that they are plants growing in cultivated crops (cereals, root and vegetable crops, fruit, grassland and forest) on agricultural or horticultural land, which are not wanted on such sites because they are more harmful than useful, and because if sufficiently widespread they seriously reduce the production value of the crop.

This definition may apply well enough to horticultural land and, indeed, to arable land in general; whether it is valid in the case of grassland is much less certain. Some agronomists believe that the presence of weeds in a pasture is nutritionally advantageous for grazing animals. Others believe that a productive ley consisting of stimulated herbage of only a few selected species, all at comparable stages of maturity, provides at least an equally effective diet for grazing stock.

During summer months pastures of selected swards are often severely depleted in the quantity and quality of grass available for grazing. At this time of the year, however, a number of weed species grow actively and could make a substantial contribution to the green matter on offer.

In response to the introduction of quotas on milk production, many dairy farmers are not seeking larger proportions of milk from forage. In many cases, little or no purchased compounds will be fed to cows at grass. For high yielding cows, however, grass cannot supply all of their mineral requirements. Can the essential mineral supplements that compounds once supplied be obtained from weeds?

This paper attempts to pull together published information on the nutritional value of some weeds to see if they can be effective sources of energy, protein and minerals for ruminants.

Weed Species

The main problems with the published data on the nutritional value of weeds are that few relate to UK climate and conditions and the majority of the information available is on chemical composition only. There is little information on *in vitro* digestibility, palatability or *in vivo* studies and only a few observations have been made on the performance of animals grazing weedy pastures. Tribe *et al.* (1952) for example reported similar liveweight gains from cattle grazing weedy and weed-free pastures. They also reported that continued grazing changed the weed populations both in species and density. This point should be borne in mind when considering the value of weeds and the stage of growth at which various workers have analysed them.

Table 1 lists the common weeds considered in this paper. Although information was available, those known to be poisonous to stock have, for obvious reasons, been excluded. Also excluded are those where only one sample has been analysed.

Nutritional Value of Weeds

In preparing the data for this section the following papers were consulted:– Fairbairn & Thomas (1959), Hughes *et al.* (1980), Jones *et al.* (1971), Martin & Anderson (1975), Trinder (1974) and Vengris *et al.* (1953). Table 2 illustrates some of the published values for dry matter (dm), total ash (TA), crude protein (CP), crude fibre (CF) and ether extract (EE) for samples of some of the weeds listed in Table 1 taken at various stages of growth. Table 3 illustrates the corresponding values of *in vitro* digestible organic matter in the dry matter (IV DOMD), chemically determined digestible crude protein (DCM) and calculated metabolisable energy (ME).

Because of limited information on nutritional value by stage of growth, data on creeping thistle, nettle and spear thistle have not been included in Tables 2 and 3 (refer to text).

Table 1: Weed species analysed for nutritional value

Common name	Botanical name
Birds-foot trefoil	*Lotus corniculatus*
Broad-leaved dock	*Rumex obtusifolius*
Coltsfoot	*Tussilago farfara*
Creeping thistle	*Cirsium arvense*
Dandelion	*Taraxacum officinale*
Nettle	*Urtica dioica*
Ribwort plantain	*Plantago lanceolata*
Rose bay willow herb	*Epilobium angustifolium*
Sorrel	*Rumex acetosa*
Spear thistle	*Cirsium vulgare*
Tufted vetch	*Vicia cracca*
Yarrow	*Achillea millefolium*

Table 2: Chemical analysis of weed species at various stages of growth expressed as a per cent of dry matter

Species	Date cut	d.m.	TA	CP	CF	EE
L. corniculatus	June	17.8	7.8	20.0	18.7	3.0
	July	24.2	7.9	18.2	19.6	3.3
R. obtusifolius	May	16.1	10.3	25.6	–	2.9
	June	19.8	7.5	16.6	15.5	2.1
	July	20.0	7.4	12.0	22.6	1.6
T. farfara	May	15.5	15.4	15.4	–	2.7
	June	13.8	18.2	13.3	11.2	2.7
	July	14.2	18.8	10.9	12.0	2.6
T. officinale	May	15.0	11.4	23.1	–	4.9
	June	14.8	14.1	16.6	13.4	3.6
	July	14.2	14.5	15.4	11.6	4.2
	August	–	16.8	13.7	11.2	5.0
P. lanceolata	May	18.3	9.9	15.8	–	2.5
	June	20.4	7.9	10.3	22.5	2.2
	July	21.6	8.5	8.3	20.4	2.9
E. angustifolium	June	15.8	8.2	17.5	14.7	2.7
	July	21.7	7.1	12.6	16.9	2.8
R. acetosa	May	13.0	9.4	25.5	–	3.3
	June	15.7	8.5	16.8	17.6	2.6
	July	21.7	6.0	8.2	28.5	1.6
V. cracca	May	18.4	8.9	30.1	–	2.0
	June	22.2	7.0	21.9	22.0	2.2
	July	22.2	8.5	19.3	24.5	2.0
A. millefolium	May	19.5	12.1	15.7	–	2.3
	June	18.4	11.8	14.9	15.4	2.0
	July	19.4	12.5	13.0	13.2	2.5

Table 3: *In vitro* digestibility and calculated ME value of weed species at various stages of growth expressed on a dry matter basis

Species	Date cut	IV DOMD, %	DCP, g/kg	ME, MJ/kg
L. corniculatus	June	63.6	139	9.8
	July	59.8	135	9.3
R. obtusifolius	May	63.4	166	10.0
	June	53.6	61	8.3
	July	40.6	51	6.2
T. farfara	May	56.3	66	8.7
	June	59.8	53	9.2
	July	57.4	43	8.9
T. officinale	May	64.5	137	10.1
	June	62.5	88	9.7
	July	58.9	50	9.2
	August	–	72	–
P. lanceolata	May	64.4	70	9.9
	June	57.8	58	8.9
	July	54.6	37	8.3
E. angustifolium	June	54.3	120	8.4
	July	53.1	76	8.2
R. acetosa	May	67.0	171	10.3
	June	58.5	107	9.0
	July	43.0	33	6.6
V. cracca	May	65.2	228	10.2
	June	69.1	188	10.6
	July	61.8	162	9.5
A. millefolium	May	63.6	76	9.8
	June	61.7	71	9.5
	July	60.5	53	9.3

Table 4 illustrates the major mineral and trace element composition of samples of the weed species taken in late May to early June.

Table 4: Major mineral and trace element composition of weed species expressed on a dry matter basis

Species	Ca	P	Mg %	Na	Mn	Zn	Cu mg/kg	Co
L. corniculatus	1.04	0.24	0.27	0.76	–	–	–	–
R. obtusifolius	0.72	0.45	0.32	0.20	34	128	9	0.15
T. farfara	1.72	0.31	0.28	0.16	25	111	13	0.07
C. arvense	2.13	0.51	0.24	0.27	59	–	29	0.06
T. officinale	1.84	0.36	0.36	0.46	42	117	16	0.13
U. dioica	2.76	0.68	0.31	0.23	81	–	22	0.13
P. lanceolata	1.26	0.33	0.23	0.28	96	122	12	–
E. angustifolium	0.83	0.40	0.35	0.25	331	–	11	0.22
R. acetosa	0.39	0.45	0.29	0.06	221	134	8	–
C. vulgare	1.84	0.40	0.20	0.35	36	–	24	0.15
V. cracca	0.80	0.48	0.23	0.10	64	131	13	0.24
A. millefolium	1.13	0.40	0.22	0.13	48	106	21	–

Discussion

The analytical data in Tables 2, 3 and 4 represent those of a small number of samples grown on a limited range of soil types under a limited range of climatic conditions. Single values are recorded but obviously the published data indicates a range of results for all parametres measured. Only in a few cases do the data refer to weeds grown under intensive grassland management systems or continuous grazing regimes. More information is required to cover these points. It can be expected that the recorded rapid falls in digestibility with stage of growth for some of the weeds will be reduced if the plants were being continuously eaten down and forced to renew leafy material.

Birds-foot trefoil, *L. corniculatus* appears to be reasonably digestible with good energy and protein content. It has useful levels of calcium and sodium but from a dietary point of view is low in phosphorus. It is questionable if it should be regarded as a weed as it has in the past been included in seed mixtures and grown for hay. Unfortunately, it can contain variable amounts of a cyanogenic glycoside (50–500 mg-kg) which hydrolyses to hydrocyanic acid when the plant is crushed or broken down in the rumen. The wide range may well account for the contradictory reports that exist about its toxicity. In general, the seeds contain the least and leaves the most glycoside, the amount increasing with age of leaf.

Broad-leaved dock, *R. obtusifolius* and Sorrel, *R. acetosa* when young are digestible with good protein contents. Their nutritional value, however, falls off rapidly with stage of maturity. Both are useful sources of phosphorus and trace elements. *R. acetosa* has been shown to contain varying amounts of oxalic acid and it is possible that *R. obtusifolius* may also contain it. Experimental feeding of housed bullocks up to 100 kg of *R. acetosa* over a 6 week period was shown to have no adverse effect (Craig & Kehoe 1921). The main problem, however, lies with lactating animals. If consumed in large enough quantities, oxalates could be absorbed directly from the rumen into the blood stream where they would combine with calcium and so induce symptoms of milk fever.

Coltsfoot, *T. farfara* is primarily a weed of damp and heavy arable soils but it can occur in pastures and meadows. It is reasonably digestible with only moderate protein content. Although reported to have medicinal properties, its mineral analysis shows only a good copper content. Perhaps its most useful feature is that it appears to be of fairly constant nutritional value over a long growing period.

Creeping thistle, *C. arvense* and spear thistle, *C. vulgare* have both been reported (Fairbairn & Thomas 1959) to have high protein and copper contents, up to 30% and 30 mg/kg respectively. They are also said to be most palatable in their earlier stages of growth. In a mature state *C. arvense* can be spinous. Calcium content is very high in both species. This could cause problems if intakes were high, it would be very difficult to create a mineral balance.

Dandelion, *T. officinale* appears to hold its digestibility very well. Protein content, however, falls with stage of maturity. Major and trace element contents are good. The figures included in the tables agree very well with some very early reports on the nutritional value of this plant (Schneider 1947; Fagan & Watkins 1932). Dandelions are noted for their diuretic quality which would only be a problem for housed animals. There is some evidence, however, to suggest that the property is lost on ensiling.

Nettle, *U. dioica* favours good soils where the calcium status is high. It can be regarded as a weed of grassland where it often occurs in patches. Crude protein levels up to 28% and crude fibre levels as low as 13.7% have been reported for this plant (Fagan & Watkins 1932; Fairbairn & Thomas 1959). Although phosphorus and copper levels can be considered to be high they are spoilt by the extremely high calcium content, levels up to 4.3% have been recorded (Fagan & Watkins 1932). Nettles have also been shown to be a good source of vitamins (Hughes *et al.* 1980).

Ribswort plantain, *P. lanceolata* has a good initial digestibility value but only moderate protein content which falls off rapidly with increasing stage of maturity. Its mineral balance can also only be considered as moderate.

Rose bay willow herb, *E. angustifolium* appears to be only moderately digestible with an initial reasonable protein content. It is, however a useful source of phosphorus and trace elements.

Tufted vetch, *V. cracca* is potentially a very good energy and protein source. Digestibility remains high over a long growing period. It appears also to be a good source of phosphorus and trace elements. Some vetches have been reported to be poisonous but there have been no recorded cases in the UK.

Yarrow, *A. millefolium* has only a moderate crude protein content but a good and persistant digestibility value. It is also a good source of phosphorus and copper.

Conclusion

Analytical data on some weed species to date indicates that they could be useful sources of energy, protein and minerals for ruminant livestock. Bearing in mind palatability problems and possible low intakes it is doubtful if major and trace element intakes from weeds could fully replace the need for a mineral supplement at grass.

More work is required to measure the nutritional value of weed species grown under intensive grassland management systems or continuous grazing regimes. It is still a possibility that weeds could usefully contribute to available green matter supplies during the summer months. The possible toxic nature of some of the weed species must, however, always be borne in mind.

References

CRAIG, J.F.; KEHOE, D. (1921) Investigation as to the poisonous nature of common sorrel (*Rumex acetosa linn*) for cattle. *Journal of Comparative Pathology and Therapeutics* **34**, 27–47.

FAGAN, T.W.; WATKINS, H.T. (1932) The chemical composition of miscellaneous herbs of pastures. *Welsh Journal of Agriculture* **8**, 144–151.

FAIRBAIRN, C.B.; THOMAS, B. (1959) The potential nutritive value of some weeds common to north-eastern England. *Journal of the British Grassland Society* **14**, 36–46.

HUGHES, R.E.; ELLERY, P.; HARRY, T.; JENKINS, V.; JONES, E. (1980) The dietary potential of the common nettle. *Journal of the Science of Food and Agriculture* **31**, 1279–1286.

JONES, D.B.; CHRISTIAN, K.R.; SNAYDON, R.W. (1971) Chemical composition and *in vitro* digestibility of some weed species during summer. *Australian Journal of Experimental Agriculture and Animal Husbandry* **11**, 403–406.

MARTEN, G.C.; ANDERSON, R.N. (1975) Forage nutritive value and palatability of 12 common annual weeds. *Crop Science* **15**, 821–827.

SCHNEIDER, B.H. (1947) *Feeds of the World.* Charleston: Jarret & Co.

TRIBE, D.E.; GORDON, J.G.; GIMINGHAM, C.H. (1952) The nutritive value of weeds and coarse herbage (Browse) for young cattle grazing a temporary pasture. *Empire Journal of Experimental Agriculture* **20**, 240–248.

TRINDER, N. (1974) The feeding value of common weeds. Ministry of Agriculture, Fisheries and Food, *ADAS Nutrition Chemistry Annual Report* 1973/74. 19–22.

VENGRIS, J.; DRAKE, M.; COLBY, W.G.; BART, J. (1953) Chemical composition of weeds and accompanying crop plants. *Agronomy Journal* **45**, 213–218.

Problems and Benefits of Grass Weeds

C. DIBB
MAFF,
ADAS
Coley Park, Reading,
Berks

ABSTRACT

Recent work in the UK on yields and quality of major weed grasses as monocultures and in mixed swards is reviewed. Characteristics of Holcus lanatus, Agrostis stolonifera, Agrostis capillaris, Festucs rubra, Poa trivialis *and* Poa pratensis *are given. Amongst the minor weed grasses* Alopecurus pratensis *and* Cynosurus cristatus *are classed as useful species. Undesirable species include* Deschampsia cespitosa, Brachypodium pinnatum, Holcus mollis, Hordeum murinum *and* Bromus mollis. *Tolerable species within limits include* Anthoxanthum odoratum, Elymus repens, Arrhenatherum elatius, Trisetum flavescens *and* Poa annua. *The problems of extra cost, loss of production and risk when reseeding are balanced against the extra DM production and quality from perennial ryegrass to arrive at a break-even point expressed as extra production required from the ley. It is concluded that reseeding to obtain a ryegrass sward for grassland conservation as silage is justified.*

Introduction

Grass weeds in the widest definition are grass species not normally sown in current agricultural seed mixtures for lowland conditions i.e. species other than Italian, hybrid and perennial ryegrass, meadow and tall fescue, Timothy and cocksfoot. These sown or 'preferred' species are in a minority in terms of ground cover in the enclosed grassland of England and Wales particularly on non-dairy farms and in older swards (Forbes *et al.* 1980). The balance of ground cover is provided by weed grasses together with other mono and di-cotyledenous plants. The commonest weed rasses in enclosed land are the various species of bents, fine leaved fescues, meadow grasses and Yorkshire fog.

A feature of some grassland over 20 years old, which comprises 50% of all grass, is the diversity of the grassland component of the sward with many species co-existing under conditions of low intensity of inputs. For example, Garstang

(1981) has described the botanical changes over 16 years of an old upland sward at the former Great House EHF containing 22 species. Fertiliser nitrogen induced fairly rapid changes in favour of increases in perennial ryegrass and cocksfoot.

Other swards can be dominated by a single species. The remnants of the sheep grazd turf of the southern chalklands of England are dominated by red fescue and Dibb *et al.* (1981) have commented on the difficulties of introducing other species in this situation without first killing the fescue. Swards reflect environment and fertility and there has been an increase over the past 40 years in the 'preferred' species content of older swards commensurate with increases in nitrogen fertiliser applications and stocking rates (Forbes *et al.* 1980). There are now many more swards dominated by perennial ryegrass to rival the old examples of the Leicester bullock fattening pastures (Davies & Williams 1954) and the best sheep swards of Romney Marsh (Hall &Russell 1912).

There is an increasing amount of data on yield and quality of the major weed grasses either as separate species or as major components of mixed swards. Much of the information prior to 1978 was reviewed by Dibb & Haggar (1979) and the following summary concentrates on more recent work.

Dry Matter Yields from Weed Grasses

Frame (1983) compared a number of weed grasses with perennial ryegrass (cv. Perma) over 3 years from 1979–81 at 6 cuts annually. Without fertiliser nitrogen, *Holcus lanatus, Festuca rubra, Poa trivialis* and *Agrostis stolonifera* outyielded perennial ryegrass. At 240 kg/ha of nitrogen, *P. trivialis* produced only 70% of the yield of perennial ryegrass with the other grasses at above the 90% level. At 480 kg/ha, *P. trivialis* declined to 66%, *F. Rubra* and *A. stolonifera* to about 80% but *H. lanatus* maintained its position at 87% of the ryegrass yield of 13.2 t/ha DM. At this highest level of nitrogen, *Poa pratensis* was the highest yielding weed grass with 89% of the ryegrass yield.

Charles *et al.* (1979) showed that perennial ryegrass established quicker than *P. trivialis, Agrostis capillaris, A. stolonifera* and *H. lanatus*. Similarly the perennial ryegrass was superior in spring and autumn production. In mid-season, however, the weed grasses produced between 80 and 90% of the best ryegrass cultivar. Overall two ryegrass and three *H. lanatus* cultivars produced over 90% of the yield of the best ryegrass cultivar with two ryegrass species at above 80% and the two *P. trivialis* populations at 77 and 68%.

Sheldrick (1985) has compared a self-sown established sward composed largely of *A. stolonifera* with a perennial ryegrass reseed. In the first harvest year, the perennial ryegrass outyielded the *A. stolonifera* by some 50% at all nitrogen levels from nil to 800 kg/ha. In the second harvest year in 1984, differences widened at 400 and 800 kg/ha, but at lower levels of nitrogen the swards did not differ significantly in output.

Results from experiments where weed grasses have been sown with perennial ryegrass indicate that admixture does not necessarily lead to yield reduction. For example Charles *et al.* (1979) found that a 2/3 ryegrass: 1/3 *P. trivialis* mixture yielded similarly to a ryegrass monoculture in the first year after sowing.

Mixtures of perennial ryegrass and *H. lanatus* yielded more than calculated from the yields of these grasses in monoculture. Harvey *et al.* (1984) found that the presence of a high proportion of *H. lanatus* in mixture with perennial ryegrass had little detrimental effect on amount of herbage harvested. Wells & Haggar (1974) observed that d.m. yields were not significantly less from swards composed of half *P. trivialis* and half perennial ryegrass than from pure swards of the latter. Smith (1983) has pointed out that the presence of areas of lower yielding species and of bare ground may not lower overall yield due to the capacity of a heterogenous sward to be buffered against small scale variability by compensatory growth.

There are still very few experiments where heterogenous swards have been compared with ryegrass monocultures. Garstang (1981) has commented that under high summer rainfall conditions and generous application of fertiliser nitrogen a permanent grass sward produced high yields over 15 years similar to those obtainable from either mixed or single species leys. Scott *et al.* (1984) have compared an indigenous sward of 29% perennial ryegrass, 30% *H. lanatus*, 16% *Poa* spp. and 13% *Agrostis* spp. with an adjacent reseeded ley of perennial ryegrass (cv. Melle) together with a small amount of Timothy (cv. S48). The older grass yielded as well or better than the ley in its second and third years. In the third year of comparison in 1984 (ADAS 1985) the ley was superior in yield but taking the 3 years together the mean yields at all levels of fertiliser nitrogen up to 500 kg/ha were almost identical.

An interesting feature was that the ley consistently outyielded the older sward at the first 2 cuts but the difference was made up at the remaining 2 cuts. Harvey *et al.* (1984) have shown a much greater yield from perennial ryegrass compared with *H. lanatus* at first cut in May. Haggar (1976) calculated relative d.m. yields at 65 D for primary spring growth for 5 species. Taking the yield of ryegrass (cv. S23) as 100 the ranking became *H. lanatus* at 79, *P. trivialis* at 65, *A. stolonifera* at 50 and *F. rubra* at 21. At the end of May, however, *H. lanatus, F. rubra* and *A. stolonifera* had higher yields of digestibel organic matter than perennial ryegrass and *P. trivialis*.

Quality of Major Weed Grasses

Frame (1983) has shown that a wide range of weed grasses are higher in mean annual crude protein percentage than perennial ryegrass (cv. Perma). Conversely the ryegrass was superior in mean annual percentage organic matter in the dry matter. Phosphorus content was higher, and potassium and magnesium contents were similar in the weed grasses compared with the perennial ryegrass.

Harvey *et al.* (1984) determined dry matter digestibility (DMD) of *H. lanatus* and perennial ryegrass and found no difference between the species at the first cut. At the second cut the DMD of *H. lanatus* was significantly lower. Nitrogen, phosphorus and potassium concentrations were greatest for monocultures of *H. lanatus* and decreased with increasing proportions of perennial ryegrass in the mixture.

Scott *et al.* (1984) showed that a perennial ryegrass ley was more digestible than permanent grass at first, third and fourth cuts in each of two years with differences up to 4 units of D value. At the second cut, the higher digestibility of the permanent grass was attributed to the good performance of the *H. lanatus* component.

Water soluble carbohydrate content is generally found to be lower in permanent grass of a high grass weed content than in perennial ryegrass (ADAS 1984).

Generalised statements about production from species mask the variation which exists between cultivars or populations from widely differing environments. Subject to this proviso, the problems of the major weed grasses using perennial ryegrass as the comparison can be summarised.

H. lanatus may approach or exceed the d.m. yield of perennial ryegrass at all levels of nitrogen but with a greater proportion later in the season. Digestibility is slightly lower. It is acceptable to grazing stock except when running to head (Watt 1978).

A. stolonifera is a high yielding grass at lower levels of nitrogen but responds less well to higher levels. *A. capillaris* is a very variable but probably responds better to nitrogen. Both species are readily grazed but digestibility is rather lower. *Agrostis* spp. tend to be replaced by perennial ryegrass at higher levels of nitrogen (Hopkins *et al.* 1984).

F. rubra is capable of high yields and good spring production but digestibility is consistently lower than other major grasses. In spite of this it is acceptable to grazing stock. Owing to its rhizomatous nature it forms dense swards resistant to changes in management.

P. trivialis has many similarities to perennial ryegrass under good grass growing conditions but suffers badly from summer drought when it behaves as a biennial. *P. pratensis* tolerates drought and is productive under fertile conditions but is of lower digestibility. Both species are readily grazed.

Minor Weed Grasses

Much less scientific information is available on yield and quality of the individual species which form this numerically large group. There is however a general fund of knowledge about their agricultural merits or drawbacks partly arising from the inclusion of some of them in seed mixtures (Hubbard 1968; Armstrong 1950).

Useful Species

Alopecurus pratensis is prominent and occasionally dominant in older swards on moist soils and is conspicuous by its early flowering habit. It is generally regarded as a useful species being early growing in spring and palatable to stock but with lower digestibility in conserved grass. It is dominant in some of the higher yielding plots at Rothamsted (Williams 1978).

Cynosurus cristatus is best known for wiry stems, but this contrasts with its leafiness and value as a grazing plant particularly in winter and spring for sheep. Frame (1983) showed that it improved its yield rankings at high levels of nitrogen.

Undesirable Species

Deschampsia cespitosa is a worthless grass of badly drained or periodically flooded soils. Its presence can be overstated because of visual impact.

Brachypodium pinnatum can dominate large areas of dry calcareous grassland and it is not grazed by stock except when nothing else is available.

Holcus mollis has a poor reputation because of its vigorous rhizomes which at one time allowed it to perpetuate as a weed throughout a ley/arable rotation. In grassland it forms dense clumps which are likely to be resistant to changes in management.

Hordeum murinum is an uncommon annual largely ignored by grazing stock (Griffiths *et al.* 1978). It causes problems by the long awns contaminating wool and causing eye injury when hay is fed out of elevated racks.

Bromus mollis is the commonest of a group of annual or biennial brome species which reseed in grassland and particularly in hay meadows where they can be dominant. Cooper (1984) has noted a small improvement in the digestibility of the herbage of a Dales meadow after the herbicidal control of *B. mollis*. Whether its removal is desirable will depend on replacement species and sward density.

Tolerable Species

The inclusion of a number of grasses in this section is dependant on their presence in swards to only a limited extent. If they become dominant then they may become undesirable.

Anthoxanthum odoratum was amongst the lower yielders in the comparison by Frame (1983). As a grazing plant, it can be unpalatable to stock presumably because of its rather bitter taste. Its fragrance in hay is attractive but stemminess can lead to rejection. Morris & Thomas (1972) have shown that it can yield well at higher altitudes.

Elymus repens is generally regarded as undesirable (Peel & Hopkins 1980) because of its reputation as a rhizomatous weed of arable land. It persists in grassland, particularly under high nitrogen and infrequent cutting regimes. Neuteboom (1981) has compared *E. repens* and perennial ryegrass (cv. Cropper) in monocultures on sandy soil. One particular clone was at least equal in d.m. yield to the perennial ryegrass under a range of managements. Now that herbicidal control of *E. repens* is feasible before reseeding or arable cropping, the status of couch in grassland may be more open to debate.

Arrhenatherum elatius is commonly found on dry soils where its deep rooting habit enables it to persist under cutting conditions but is much less suited to grazing. It is dominant in some of the higher yielding plots at Rothamsted (Williams 1978).

Trisetum flavescens is found in a variety of situations but grows best on moist calcareous soils. It is very palatable under grazing and useful as a later heading hay grass but overall its yield is only moderate.

Poa annua is a prolific coloniser of swards that have become open through damage by treading, weakened by intensive management or thinned by dying out of less persistent components. As such it is an indicator of problems rather than a causal agent. Over short periods it can produce as much d.m. as perennial ryegrass (Wells & Haggar 1984). It is unlikely that its presence up to 15% of ground cover is reducing the yield of the sward overall as at that level it will only be filling in spaces that would otherwise be bare ground.

Weighing up Problems and Benefits

The problem of grass weed species is that individually or collectively they are unlikely to exceed perennial ryegrass in yield and may be inferior in various aspects of quality, palatability or durability.

Against this, old grassland, containing an average 70% of weed species (Forbes *et al.* 1980) does not incur the costs or risks of reseeding and this together with resistance to treading (Green 1982) are the benefits.

Reseeding in the grass to grass situation entails a loss of production. This has been minimised in recent years by the introduction of herbicides to destroy swards before reseeding giving a shortened time interval between the old and new swards (Monsanto 1985).

Reseeding also carries a bonus in that ryegrass swards in their first harvest year are higher yielding than subsequently (NIAB 1985). A GRI/ADAS comparison of permanent grass of a low perennial ryegrass content with a reseeded sward of perennial ryegrass (cv. Melle) both at 2 cutting frequencies is currently being conducted at 16 sites in England and Wales (Hopkins *et al.* 1984). This is one of the few examples where loss of production during reseeding, increased yield of the ley in the first harvest year and subsequent production of both old and new swards over 3 years is being directly measured in the same experiment. In 1984, the first harvest year ley outyielded the old sward by 44% at the 4 weekly cut and by 30% at the 8 weekly cut, both at the 300 kg/ha level of fertiliser nitrogen (Hopkins 1985).

The Break Even Point

Problems

The extra cost of reseeding will depend on farm circumstances but may amount to £200/ha which is £40/ha over a 5 year length of life of the ley without allowing for interest on money invested.

The loss of production may amount to 40% of the annual yield of 10 t/ha d.m. on an average grass growing site class three. If this 4 t/ha d.m. is valued at £40/t then the annual cost over 5 years is £32 making a total of £72/ha/annum.

A further debit is the risk factor and although this has been discounted by allowing the costs of pest and weed control in the reseeding cost, there are climatic and management factors which can jeopardise the operation.

Benefits

The extra production required annually at £40/t to break even is 1.8 t-ha d.m. If the herbage is valued at £100/t d.m. and allowing for the d.m. lost, 1.2 t/ha d.m. extra production is required annually. On the average grass growing site class three, these quantities amount to 18 and 12% respectively extra production/annum for each of 5 years after reseeding.

Applying a mean figure of 15% adjusted upwards where sward life is less than 5 years to the yields of a range of swards calculated by Wilkins (1984) suggests very little scope for reseeding in the grazing situation particularly when treading problems are taken into account. Reseeding to high yielding ryegrasses would however seem to be economically viable for grassland conservation as silage. The improved herbage quality of the reseed could also be a considerable incentive, particularly if the cost of silage aids could be avoided. Reseeding would also give the opportunity to switch to the highest yielding cultivars which would help to compensate for renewal costs.

References

ADAS (1984) *National herbage quality monitoring scheme 1984*. ADAS Liaison Officer, Grassland Research Institute, Hurley: Unpublished data.

ADAS (1985) The effect of fertiliser nitrogen on the yield and botanical composition of a permanent grass sward 1984. Reading: Unpublished data.

ARMSTRONG, S.F. (1950) *British grasses and their employment in agriculture* 3rd Edn. Cambridge:University Press.

CHARLES, A.H.; JONES, J.L.; THORNTON, M.S.; THOMAS, T.A. (1979) Comparison of ryegrass with some common unsown grasses sown separately and in mixtures. (Eds A.H. Charles and R.J. Haggar) In: *Changes in Sward Composition and Productiviey. BGS Occasional Symposium No. 10* pp. 25–29. Hurley: British Grassland Society.

COOPER, F.B. (1984) Soft brome control in Dales meadows. ADAS Agronomy Newcastle: Unpublished data.

DAVIES, W.; WILLIAMS, T.E. (1954) Cattle fattening on permanent grass and leys. *Journal of the Royal Agricultural Society of England* **115** 98–111.

DIBB, C.; EDWARDS, R.V.; HAGGAR, R.J.; JACKSON, M.V.; ALDRICH, D.T.A. (1981) The British Grassland Society Dorset site. *Grass and Forage Science* **36**, 135–137.

DIBB, C.; HAGGAR, R.J. (1979) Evidence of effect of sward changes on yield. In *Changes in Sward Composition and Productivity, BGS Occasional Symposium No. 10*. (Eds A.H. Charles and R.J. Haggar) pp.11–20.

FORBES, T.J.; DIBB, C.; GREEN, J.O.; HOPKINS, A.; PEEL, S. (1980) *Factors affecting the productivity of permanent grassland. A National Farm Study*. Hurley: Grassland Research Institute and Agricultural Development and Advisory Service Joint Permanent Pasture Group.

FRAME, J. (1983) Yield and quality response of secondary grasses to fertiliser nitrogen. In *Efficient Grassland Farming. BGS Occasional Symposium No. 14* (Ed. A.J. Corrall) pp. 292–294. Hurley: British Grassland Society.

GARSTANG, J. (1981) The long term effects of the application of different amounts of nitrogenous fertiliser on dry matter yield, sward composition and chemical composition of a permanent grass sward. *Experimental Husbandry* **37**, 117–132.

GREEN, J.O. (1982) *A sample survey of grassland in England and Wales, 1970–1972*. Hurley: The Grassland Research Institute.

GRIFFITHS, W.; HAMMOND, C.H.; EDWARDS, C.J. (1978) Weed control in new leys and established pastures with ethofumesate. *1978 British Crop Protection Conference – Weeds* **1**, 309–316.

HAGGAR, R.J. (1976) The seasonal productivity, quality and response to nitrogen of four indigenous grasses compared with *Lolium perenne*. *Journal of the British Grassland Society* **31**, 197–207.

HALL, A.D.; RUSSELL, E.J. (1912) On the causes of the high nutritive value and fertility of the fattening pastures of Romney Marsh and other marshes in the S.E. of England. *Journal of Agricultural Science* **IV** 339–370.

HARVEY, B.M.R.; CROTHERS, S.H.; HAYES, P. (1984) Dry matter and quality of herbage harvested from *Holcus lanatus* and *Lolium perenne* grown in monocultures and in mixtures. *Grass and Forage Science* **39**, 159–165.

HOPKINS, A. (1985) GRI/ADAS comparison of permanent and reseeded swards. North Wyke: Unpublished data.

HOPKINS, A.; DIBB, C.; BOWLING, P.J.;GILBEY, J.; MURRAY, P.J.; WILSON, I.A.N. (1984) Production and response to nitrogen from permanent and reseeded grassland in England and Wales. *British Grassland Society Winter Meeting, 1984*, pp.7.8–7.9.

HOPKINS, A.; GILBEY, J.; DIBB, C. (1984) The response of upland permanent pasture to fertilisr nitrogen. *Proceedings of the Hill Land Symposium, Galway.* (In press)

HUBBARD, C.E. (1968) *Grasses.* Second Edn, Harmondsworth: Penguin Books Ltd.

MONSANTO (1985) Roundup herbicide in grassland. Precut recommendations. Leicester: Monsanto p.l.c.

MORRIS, R.M.; THOMAS, J.G. (1972) The seasonal pattern of dry matter production of grasses in the north Pennines. *Journal of the British Grassland Society* **27**, 163–172.

NEUTEBOOM, J.H. (1981) Effect of different mowing regimes on the growth and development of four clones of couch in monocultures and in mixtures with perennial ryegrass. Mededelingen Landbouwhogeschool Wageningen. Nederland. 81–15 (1981).

NIAB (1985) Recommended varieties of grasses. *Farmers Leaflet No. 16, 1985.* Cambridge: National Institute of Agricultural Botany.

PEEL, S.; HOPKINS, A. (1980) The incidence of weeds in grassland. *British Crop Protection Conference – Weeds 1980* **3**, 877–890.

SCOTT, JOYCE L.; JOHNSON, J.; DIBB, C. (1984) The effect of fertiliser nitrogen on the yield and botanical composition of a permanent grass sward. *Paper presented at FAO Lowland Grassland Meeting, Ås, Norway, 1984.*

SHELDRICK, R.D. (1985) Nitrogen response by an *Agrostis* sward. North Wyke: Unpublished data.

SMITH, A. (1983) The influence of sward variability on the efficiency of herbage production. In *Efficient Grasssland Farming. BGS Occasional Symposium No. 14* (Ed. A.J. Corrall) p. 294. Hurley: British Grassland Society.

WATT, T.A. (1978) The biology of *Holcus lanatus* L. (Yorkshire fog) and its significance in grassland. *Herbage Abstracts* **48**, 195–204.

WELLS, G.J.; HAGGAR, R.J. (1974) Herbage yields of ryegrass swards invaded by *Poa* species. *Journal of the British Grassland Society* **29**, 109–111.

WELLS, G.J.; HAGGAR, R.J. (1984). The ingress of *Poa annua* into perennial ryegrass swards. *Grass and Forage Science* **39**, 297–303.

WILKINS, R.J. (1984) Leys? *Paper presented at the NIAB Crop Conference 'The Place of the Ley Today'*. Cambridge: National Institute of Agricultural Botany.

WILLIAMS, E.D. (1978) *Botanical composition of the Park Grass plots at Rothamsted, 1856–1976.* Harpenden: Rothamsted Experimental Station.

Impact and Control of Docks in Grassland

A.D. COURTNEY
Agricultural Botany Research Division, Department of Agriculture for Northern Ireland. Newforge Lane, Belfast, Northern Ireland

ABSTRACT

The extent to which docks reduce grass yield is much greater when swards are cut only 3–4 times/annum than is the case when they are cut 5–7 times each year. The effect on grass yield is directly related to the percentage ground cover of the docks with an approximately 1% decline in grass d.m. for each per cent ground cover of docks. This relationship may not hold at low dock densities under more frequent defoliation regimes. The application of herbicides to swards containing a high proportion of docks usually increases grass yields, but more information is needed upon yield responses to herbicides applied to swards containing only a low proportion of docks.

Introduction

The survey data of Peel & Hopkins (1980) identified some 0.7×10^6 ha of grassland in England and Wales as being infested with *Rumex* spp. Haggar (1980) had previously recorded its widespread importance in grassland regions throughout the UK.

Information on the role of docks in reducing production from grassland has been gathered over the years in a piecemeal fashion. Most often this has been as part of a programme to investigate the efficacy of herbicides used for dock control (Courtney 1970; Oswald & Elliott 1970; Savory &Soper 1968, 1970; Frame & Harkness 1972). These data have perhaps a tendency to overemphasise reductions in grass yields at high levels of dock infestation. Savory & Soper (1973) were able to provide some information about the response of swards with a range of infestation levels to the herbicide asulam and to demonstrate a relationship between dock ground cover and grass yields. There remains a deficiency of information on the significance of docks over a wide range of infestation levels and on the response of such swards to the application of herbicides.

More recent studies by Oswald & Haggar (1983) have gone some way to quantifying the effect of docks on perennial ryegrass production for either a 6-cut or a 3-cut system with added N levels in the range 120–240 kg ha^{-1}. These experiments provided information that demonstrated the relatively greater effect of docks on production later in the season and the relationship between the depression in grass yields and the % cover of docks in the sward. These data have recently been complemented by a systematic attempt by Doyle, *et al.* (1984) to develop a model which allows the prediction of the effects of various control strategies with the herbicide asulam, on the productivity of swards infested with *Rumex obtusifolius*. The model highlighted the need for additional information about the population dynamics and the factors which influence the susceptibility of docks to chemical control. A further unknown factor appears to be the nutritive value of docks. Data from N. Ireland (Courtney & Johnston 1978) suggests that the palatability of docks is, on average, about 80% of that of grass. In addition, the digestibility of docks, measured both *in vitro* and *in vivo*, is about 80% of that of perennial ryegrass. Taken together, it may be estimated that docks are only about 65% as valuable as grass to the grazing animal. More precise information on the feeding value of docks is not yet available.

In N. Ireland over the past 10 years the initial aim of the programme was to compare the relative efficiency of herbicides in controlling docks. (Courtney 1970; Courtney 1972; Courtney & Johnston 1974). Emphasis has now shifted to a more detailed study of the dynamics of dock infestations under a range of conditions and a large amount of new information has been gathered from a long term experiment begun in 1977 at the Agriculture and Food Science Centre, Newforge Lane, Belfast. Dock infestations were planted at a range of densities (0.5–32 plants m^{-2}) both alone and in association with perennial ryegrass. Nitrogenous fertiliser was applied at rates equivalent to 50, 100, 200 and 400 kg ha^{-1}. Two different defoliation regimes were used: simulated grazing where plots were cut 5–7 times/annum and a simulated silage conservation regime where the plots were cut 3–4 times/annum.

Production Potential in Monoculture

As a preliminary to considering the mixed dock/grass association it is appropriate to discuss the productive potential of *Rumex obtusifolius* in monoculture. In Table 1, production from a dock population equivalent to 32 plants m^{-2} is compared to that from pure perennial ryegrass sward when fertiliser is applied at annual rates equivalent to either 50 kg ha^{-1} or 400 kg ha^{-1}. Under the less frequent defoliation regime, dock d.m. production ranged between 55 and 80% of that of the perennial ryegrass sward. It remained relatively constant throughout the 3 year period. Under a more frequent defoliation and at the higher level of nitrogenous fertiliser application dock production rapidly declined until it yielded only about 20% of that of the ryegrass sward. These data illustrate the lower potential productivity of *R. obtusifolius* compared with that of perennial ryegrass. The lower palatability and digestibility have already been mentioned.

Table 1: Effect of cutting frequency and N level on dock yields in monoculture relative to perennial ryegrass

	(dock yield as % of grass yield)					
Defoliation regimes	3–4 cuts/annum			5–7 cuts/annum		
N regime	1978	1979	1980	1978	1979	1980
50 kg ha^{-1}	72.1 (9.7)	66.5 (7.6)	79.5 (9.8)	71.6 (4.7)	35.7 (5.3)	20.7 (8.3)
400 kg ha^{-1}	55.3 (16.8)	58.1 (14.6)	69.2 (15.8)	33.5 (13.1)	21.1 (10.4)	18.6 (12.5)

Grass d.m. yield t ha^{-1} in parenthesis

Influence on Production in Grassland

From an agricultural point of view the competitive influence of docks on the productivity of swards in terms of grass and total d.m. yields is of most importance. Fig. 1 illustrates the combined effects of defoliation frequency and initial dock density on the yield of d.m. derived solely from grass. Defoliation frequency clearly had a major affect in the extent to which docks reduced grass yields. With 5–7 cuts/annum, grass yields were reduced by a maximum of 16% whereas where only 3–4 cuts were made each year, grass yields were reduced by up to 70%. The changing relationships of dock, grass and total yields is further depicted in Fig. 2. Again, it can be seen that when the sward was subject to frequent cutting, the presence of docks had little effect on total yield and that the contribution of docks was small and rather stable from year to year. In contrast, when the sward was cut infrequently, total yields were reduced and a high proportion of that yield was composed of dock foliage. Under both defoliation regimes the association is a dynamic one. reflecting a constantly changing balance within the sward.

There has, throughout the experiment, been little invasion of the sward by new dock seedlings. The original planted docks have tended to slowly decline in number, but after 6 years, 50–60% were still present (Courtney 1983).

Savory & Soper (1973) and Oswald & Haggar (1983) recorded a relationship between % ground cover of docks and grass yields. Using point quadrat counts taken before each clip the relationship between grass d.m. and the *Rumex* % counts, meaned over all clips each year, was established and is shown in Fig. 3 for the 4 years 1981–1984. These data confirm a relationship between dock % cover and declining grass yields. In swards cut only 3–4 times / annum, simulating a conservation regime, the equation of 1% dock ground cover and a 1% decline in grass yield observed by Oswald & Haggar (1983) was generally confirmed. In 1981 and 1982 there was little or no evidence of yield depression by dock ground cover percentages less than 15% under the conservation regime. However, in 1983 and 1984 competition by docks appeared more pronounced and results

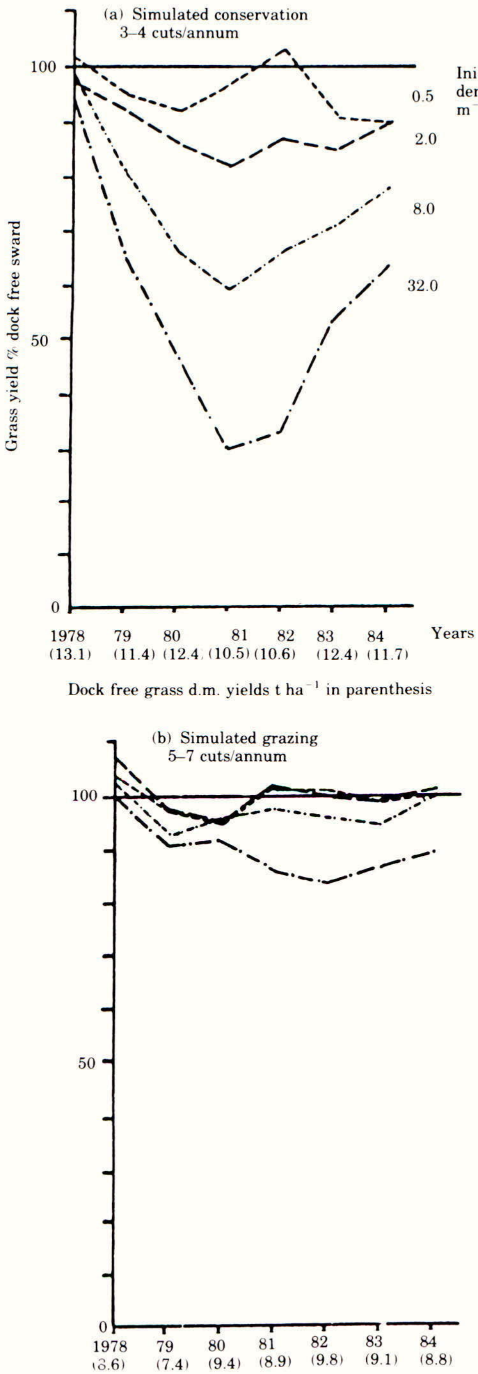

Figure 1: The effect of defoliation frequency and dock density (plants m^{-2}) on grass d.m. yield (%) dock free *Lolium perenne*

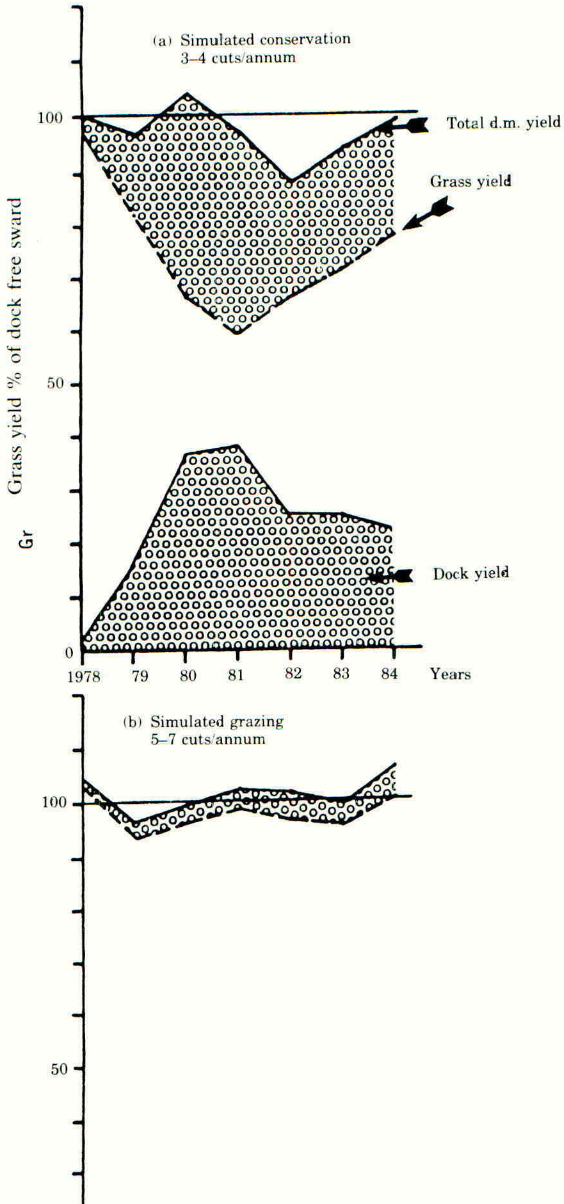

Figure 2: Changing dock, grass and total d.m. yields according to defoliation regime for an initial dock infestation of 8 plants m^{-2} relative to dock free *Lolium perenne* sward.

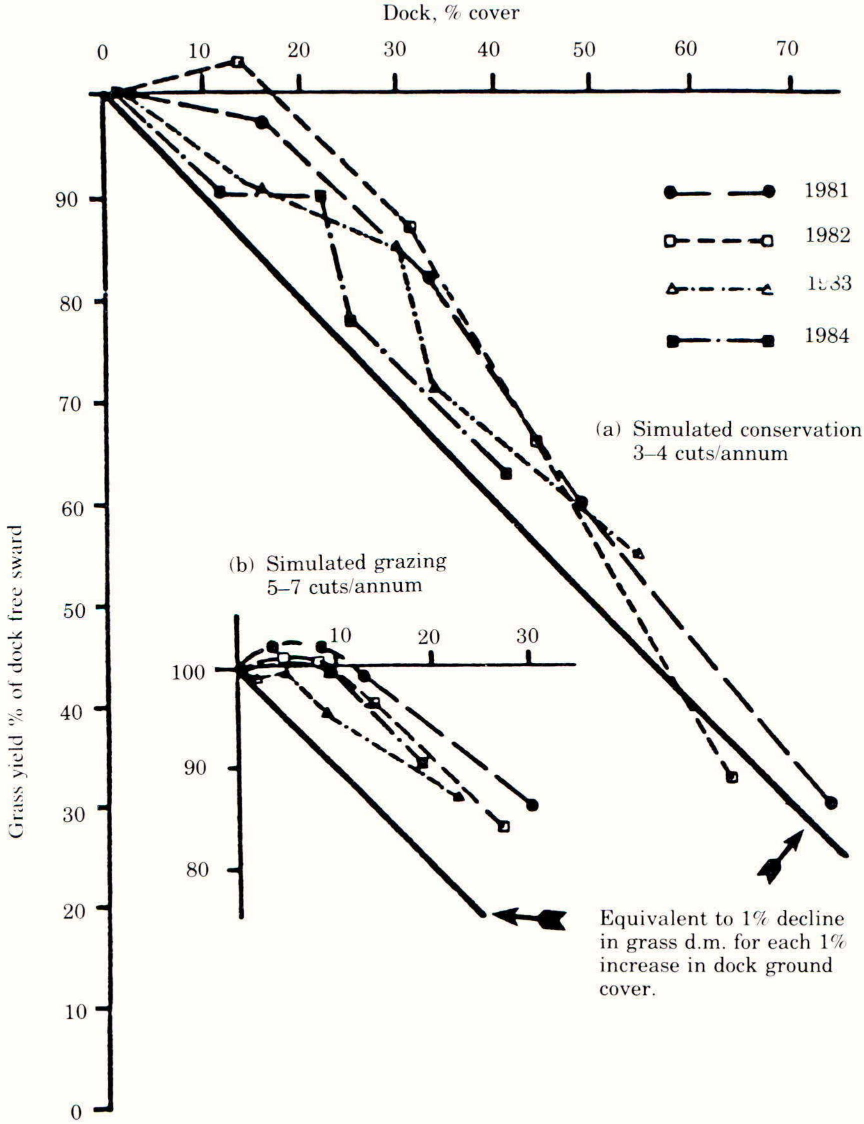

Figure 3: The relationship between dock % cover and % decline in grass yield

approximated more closely to those reported by Oswals and Haggar (1983) even at low ground cover percentages.

In contrast, under the frequent defoliation used in the simulated grazing system the dock plants were less competitive. There was no reduction in yield at below 10% ground cover of dock. Above this level, the % decline of grass also approaches a 1% decline for each addition 1% of dock ground cover.

Control with Herbicides

Whilst defoliation and sward competition clearly influence the degree of dominance achieved by docks in a sward, herbicides may also be used to assist in their control. Most of the published information relates to control by asulam, dicamba/mecoprop and mecoprop. More recently products including triclopyr are being marketed for the selective control of docks in grassland. There is also an interest in the selective application of herbicides such as glyphosate by wiper applicators (Oswald 1980). Reported grass yield increases resulting from the application of herbicides have often been large where dock infestations were severe, but total d.m. yields do not normally increase and may even decline in the short term (Courtney 1972; Savory & Soper 1973).

In N. Ireland, having recorded the pattern of dock development over a period of 4 years and studied how this had limited grass production the experimental area was then split into two. Two blocks were sprayed with dicamba/mecoprop at 1.9 kg a.i. ha^{-1} in May 1982 and again in May 1983 (Courtney 1983). Fertiliser levels and cutting frequencies remained unchanged. Yield responses were then measured in both 1982 and 1983 as well as in 1984 when no herbicide was applied.

Whilst it is not possible to present the data in this paper, the general effect of herbicide treatment has been to increase the yields of herbage other than docks where docks were present at levels of more than 20% ground cover under the grazing system and at over 25–30% ground cover under the less frequently defoliated silage system. At lower levels of dock cover the yields of dock free herbage declined after herbicides were applied. There is evidence of an interaction of several experimental factors including N level and dock density in determining the response to herbicide application. As dock density increases it becomes the primary constraint on grass production. At lower levels of infestation, other factors are important:whilst there has been an increase of clover and other broad-leaved weeds in some of the swards it appears that these are not solely responsible for the decline in yields of herbage, other than docks, after the use of a herbicide. The data may also reflect the effects of moisture stress during the dry summers of 1983 and 1984. Previous studies in N. Ireland (Courtney & Johnston 1980) reported further evidence that herbicides based on mecoprop and dicamba/mecoprop also have some short and medium term effects on grass growth although they did not significantly reduce annual yields.

Erratic or unpredictable control of dock infestations is often attributed mainly to meteorological factors influencing either the development of the docks or the activity of the herbicide. As Doyle *et al.* 1984) have indicated more information is needed on the factors that influence herbicide efficacy. Studies on the seasonal pattern of dock development (Oswald & Haggar 1983) and studies in N. Ireland (Courtney & Johnston 1972) have identified the advantages of herbicide application to the regrowth after a first silage cut, when dock shoot numbers and competition are both increasing in the sward. Further information on the reaction of sward components to herbicides, including the importance of both intra- and inter-specific competition is required to allow the successful adoption of herbicides in long and short term strategies for the control of docks.

References

COURTNEY, A.D. (1970) Control *Rumex* spp. in N. Ireland and the influence of herbicidal treatment on herbage yield and composition. *10th British Weed Control Conference* 488–494.

COURTNEY, A.D. (1972) Docks in grassland – their influence on herbage productivity. *11th British Weed Control Conference* 315–322.

COURTNEY, A.D. (1983) *Department of Agriculture, Northern Ireland, Annual Report on Research and Technical work* 137–138.

COURTNEY, A.D.; JOHNSTON, R.T. (1974) Time of herbicide application for the control of docks (*Rumex obtusifolius*) in a grassland conservation system. *12th British Weed Control Conference* 751–760.

COURTNEY, A.D.; JOHNSTON, R.T. (1978) A consideration of the contribution of production of *Rumex obtusifolius* in a grazing system. *1978 British Crop Protection Conference – Weeds* 325–332.

COURTNEY, A.D.; JOHNSTON, R.T. (1980) The effect of herbicides on the dry matter yield and regrowth elongation of an established *Lolium perenne* (ryegrass) sward. *British Crop Protection Conference – Weeds 1980* 589–594.

DOYLE, C.J.; OSWALD, A.K.; HAGGAR, R.J.; KIRKHAM, F.W. (1984) A mathematical modelling approach to the study of the economics of controlling *Rumex obtusifolius* in grassland. *Weed Research* **24**, 183–193.

FRAME, J.; HARKNESS, R.D. (1972) Herbicides for control of docks (*Rumex* spp.) in grassland. *11th British Weed Control Conference* 315–322.

HAGGAR, R.J. (1980) Survey of the incidence of docks (*Rumex* spp.) in grassland in ten districts in the UK in 1972. *ADAS Quarterly Review* **39**, 256–270.

OSWALD, A.KK. (1980) Progress in the development of the selective application of herbicides to control *Rumex obtusifolius* in grassland. *British Crop Protection Conference – Weeds 1980* 209–215.

OSWALD, A.K.; ELLIOTT, J.G. (1970) The toxicity of three herbicides to the docks (*Rumex* spp.) and grasses growing in a mainly ryegrass pasture. *10th British Weed Control Conference* 481–487.

OSWALD, A.K.; HAGGAR, R.J. (1983) The effects of *Rumex obtusifolius* on the seasonal yield of two mainly perennial ryegrass swards. *Grass and Forage Science* **38**, 187–191.

PEEL, S.; HOPKINS, A. (198;) The incidence of weeds in grassland. *British Crop Protection Conference – Weeds 1980* 877–890.

SAVORY, B.M.; SOPER, D. (1968) Asulam for the control of docks in grassland. *9th British Weed Control Conference* 508–514.

SAVORY, B.M.; SOPER, D. (1970) Factors affecting the control of docks (*Rumex* spp.) with asulam. *10th British Weed Control Conference* 358–365.

SAVORY, B.M.; SOPER, D. (1973) Response of dock infested pasture to asulam. *Weed Research* **13**, 224–230.

Impact and Control of Thistles in Grassland

A.K. OSWALD
Weed Research Division
Long Ashton Research Station
Yarnton, Oxford

ABSTRACT

Cirsium arvense *(Creeping thistle) infests about 1 million ha of grassland in England and Wales. Current studies indicate that the species reduces grass growth and grazing utilisation (including the rejection of contaminated hay), thus leading to a reduction in liveweight productivity. Cultural control is difficult in grassland because of the regenerative ability of the extensive underground root system which also reduces the effectiveness of translocated herbicides. Repeated treatment and appropriate management are therefore essential. Recently, improved chemical control has been achieved using mixtures of bentazone, clopyralid, dicamba and triclopyr and there are new highly active compounds still under test. Promising results are also being obtained from the combined use of biological agents and low dose of herbicide. More detailed studies are required to confirm preliminary results on the influence on pasture productivity and to investigate further the potential of integrated biological-chemical control systems.*

Introduction

Several species of thistle occur in grassland in the UK and up to 25% of such land is infested (Morrison & Idle 1972; Green 1974). However, the perennial creeping thistle (*Cirsium arvense* (L.) Scop.) is the most widespread, being ubiquitous in both arable and grassland, which is unusual among weeds (Sagar & Rawson 1964). It was the commonest weed in British agriculture (Brenchley 1920) until the advent of herbicides when it began to decline,although still listed as an injurious weed under the Weeds Act, 1977.

It is prickly and unsightly and is traditionally thought to reduce the amount of grass present and the area grazeable.

Reproduction of the weed relies heavily on vegetative spread from creeping underground roots and this renders chemical control uncertain, if not unlikely, because a complete kill of the ramifying underground system is virtually impossible (Chancellor 1970).

This paper assesses the current status of *C. arvense* as a weed in UK grassland and reviews the control means available and in prospect.

Impact of Cirsium Arvense

Extent of the Problem

The National Farm Study carried out by the Grassland Research Institute and the Agricultural Development and Advisory Service showed that 8% of the fields surveyed were infested with *C. arvense* at levels above one plant m^2 with lower infestations on a further 13% of fields (Forbes *et al.* 1980). Heavy infestations have also been reported in Scotland where up to 50% of swards over 10 years old were affected (Swift *et al.* 1978). In Northern Ireland, *C. arvense* was a problem in 20% of grassland surveyed in the late 1960's (Courtney 1973).

From the evidence of the National Farm Study and assuming that there are 5.3 m. ha of permanent grassland in England and Wales (Peel & Hopkins 1980) it can be concluded that *C. arvense* seriously infests 0.4 m. ha or 1.1 m. ha if moderate and incipient infestations are included (Haggar *et al.* 1984).

C. arvense is more plentiful in old swards and in swards between 9 and 20 years old than in younger grassland (Forbes *et al.* 1980). It is prevalent where soil phosphate and nitrogen are below average and potash is at a relatively high level. The weed is also more frequent in grass utilized by beef animals in lowland areas and sheep in the uplands rather than swards grazed by dairy cattle.

Effects on Grass Productivity

There has been little quantitative research on the extent to which *C. arvense* affects grass production. Stapledon & Davies (1948), implied that thistles were of value when ensiled with grass, possibly because of their high crude protein and mineral content (Fairbairn & Thomas 1958). Although it is possible that some young shoots may be eaten along with the grass, the chief objection to the species has been that it occupies ground which should provide grazing. The prickly nature of the mature plants prevent stock from eating close up to the base of isolated plants and they may be excluded entirely from patches of ground occupied by colonies of plants (Bates 1955). Contact can result in painful skin eruptions on the mouth and lips.

Pasture studies in New Zealand have given a more accurate indication of the effects of *C. arvense* on grassland productivity. Experiments in sheep pastures showed that as weed density increased in the summer (January–April) the sheep did not graze amongst them and utilization declined (Table 1, Harley & James 1979). Following the decline in utilization there was a sharp drop in pasture production, confirming that *C. arvense* does affect pasture production indirectly via impaired utilization by sheep. Trials on dairy pastures, also in New Zealand, have indicated that cattle are less affected than sheep because they are more prepared to move into weedy areas and thin the *C. arvense* clumps by trampling new shoots (Hartley & Thompson 1982).

Work in the USA has indicated that where *C. arvense* was controlled effectively by herbicides, average grass production increased by 110–314% compared to untreated areas (Reece & Wilson 1983).

Current investigations at the Weed Research Organization (WRO) are aimed at identifying ways in which *C. arvense* may affect grass production and utilization by: (1) direct competition; (2) impeding utilization by grazing beef animals; (3) impeding hay feeding by beef animals.

Preliminary results for 1984 suggest that the amount of grass d.m. harvested during the period May–October was not affected by *C. arvense* populations of up to 9 plants m^2 (Table 2). Although the size of weed plants increased during the season, yields were not affected at any of the monthly harvests.

Table 1: Percentage dry matter production and utilization of untreated plots compared to plots treated with MCPB to control *Cirsium arvense* in pasture (Hartley & James 1979)

Date	Utilization, %	d.m. Production, %
November 1977	124	129
December 1977	136	127
January 1978	32	99
February 1978	60	14
April 1978	62	57
July 1978	94	56
October 1978	100	105
November 1978	89	95
January 1979	94	90
March 1979	85	75

Sward measurements are indicating that *C. arvense* does impede grazing by beef animals. A steady increase in sward height has been recorded at monthly intervals from May to October 1984 from a position 1 m distant to the site of a single plant, 1.4 m to the centre of clumps of 5 plants and 1.8 m to the centre of clumps of 10–15 plants (Fig. 1). Although potential yields have not been calculated, this rejection of palatable material on a field scale could lead to a significant reduction in liveweight gain and ultimate beef production.

An initial experiment measuring the rejection of contaminated hay over a 20-d period by beef animals, housed indoors during the winter, showed that 80–86% of *C. arvense* herbage was rejected (Table 3). Although some of the 14–20% not accounted for may have been eaten, most was observed to be trampled or buried in straw bedding. Twenty percent of the grass component of the contaminated hay fed at a high rate was also rejected, indicating that over a 20-d period, 20 animals would waste about 235 kg grass (13–14 bales). There was no difference in the amount of rejected grass at the lower feed rate, probably suggesting more careful selection by the animals.

Table 2: Effect of *Cirsium arvense* density on total grass yield during 1984

Plants m^{-2}	Grass d.m., t ha^{-1}
0	6.0
1	6.3
2	6.7
4	5.8
9	6.2

Table 3: The percentage rejection of *Cirsium arvense* and grass hay by animals fed on different rations

Rations (herbage $animal^{-1}$ d^{-1})	% herbage rejected $animal^{-1}$ d^{-1}	
	C. arvense	Grass
10 kg grass only	–	12
10 kg grass + *C. arvense* (89 + 11%)	80	20
7.5 kg grass only	–	13
7.5 kg grass + *C. arvense* (89 + 11%)	86	13

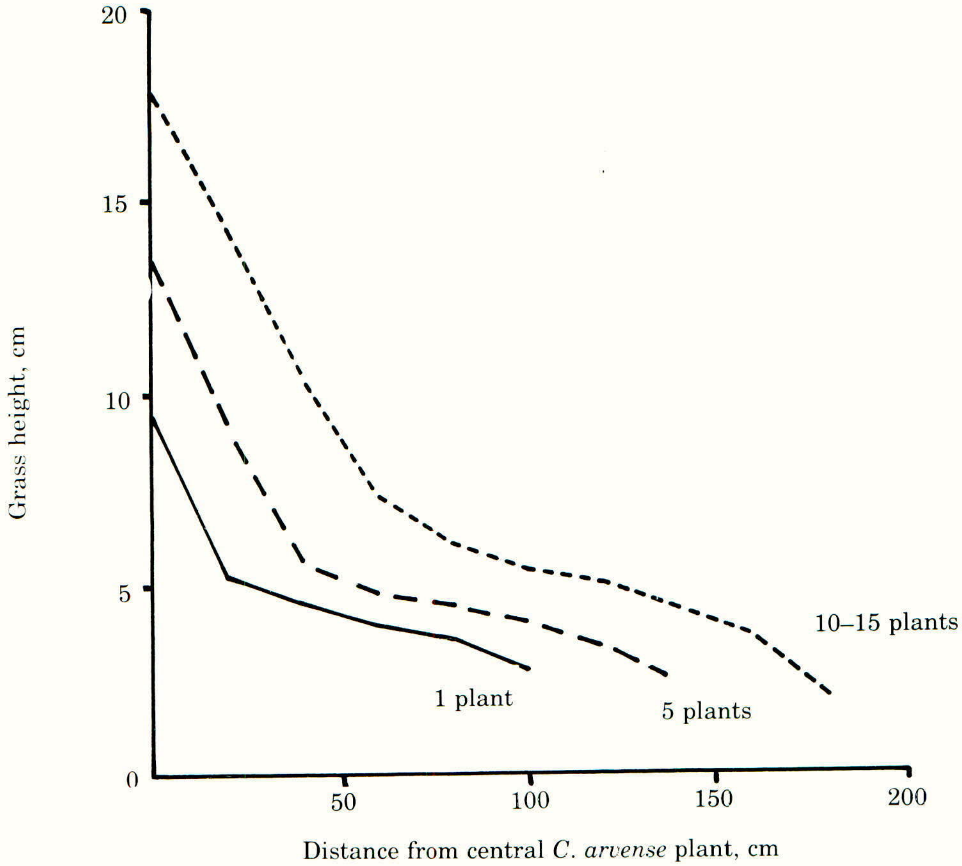

Figure 1: The height of grass at different distances from a single *Cirsium arvense* plant or groups of plants present in a pasture grazed by beef animals.

Control of *Cirsium arvense*

Cultural Control

Mowing can prevent seeding and seed dispersal and the removal of the flowering shoot in mid-summer can also be effective at the time when food resources in the roots are lowest (Bakker 1960). After cutting, the plant can make little further growth that year and may remain dormant for several seasons. Competition from the grass sward following weed topping can also reduce infestations as young plants in particular are strongly affected by shading from other plants, and stand little chance of survival in dense swards of permanent grass (Koch & Volf 1982). The best time for cutting is shortly before the first flowers open, noting however, that there is only a 6-day period between flowers opening and viable seed set (Kinch & Termunde 1957). Uneven maturation may therefore require more than one cut per season and long-term control depends upon sound grassland management (Roberts 1982). Overgrazing should be avoided in winter and early spring and deficiencies in soil nutrients corrected. Rotational grazing, rather than set stocking should also be practised.

Cultivation and desiccation of roots as a means of control can be effective in arable systems but is not practical in grassland (Anon 1977).

Chemical Control

The use of MCPA and 2,4-D, applied just before flower buds open, is well-established and treatment can prevent seeding. However, dense, mature stands are often only partly affected and if mown too late seeding will not be checked (Chancellor 1970). Spraying can also reduce infestations by altering the competitive balance in favour of the grasses which can then cover the area more densely and keep the remaining weed roots dormant.

Other herbicides including dicamba, dichlorprop, mecoprop, picloram, clopyralid and for clover/based swards, bentazone, MCPB and 2, 4-DB can also be used (Williams 1984). Control is easiest in newly sown leys where roots are close to the soil surface. In old grassland the extensive root system means that repeat spraying is necessary, coupled with improved sward management (Haggar *et al.* 1984).

Single herbicide applications do not usually give effective control so work at the WRO has concentrated on the evaluation of mixtures of herbicides.

Treatment with bentazone alone has given 77% reduction in the shoot weight of *C. arvense* grown in pots with clopyralid and triclopyr less effective (Richardson *et al.* 1984). However, mixtures of bentazone with either of the two other herbicides increased activity and reduced shoot gowth by up to 90%. In a second experiment a bentazone + triclopyr + clopyralid mixture eradicated shoots and reduced root growth by 99%. Unfortunately this mixture also damages white clover. An associated field experiment on permanent pasture has also indicated the weed control efficacy and grass safety of mixtures of triclopyr with bentazone or clopyralid (Table 4). The bentazone + MCPB mixture would have been clover-safe. Other related trials with mixtures including dicamba and triclopyr have indicated promising control of *C. arvense*, but without clover safety. Current work is concerned with the evaluation of new sulphonyl urea type herbicides, which look promising at this early stage.

Table 4: Effect of various herbicides on d.m. yield (g/30 cm^{-2}) of *Cirsium arvense* in grass, recorded in October, 3 months after spraying (Richardson *et al.* 1984)

Treatment	Rate, kg a.i./ha	*C. arvense*	Grass
Untreated control	–	11.6	14.9
Bentazone	1.5	8.9	13.6
Bentazone	3.0	5.8	17.1
Bentazone	4.5	3.4*	12.6
Bentazone + triclopyr	2.5 + 0.5	2.6*	14.9
Clopyralid + triclopyr	0.2 + 0.75	3.8*	14.4
Bentazone + MCPB	1.5 + 1.5	3.4*	18.7
MCPA + MCPB	0.56 + 1.4	3.4*	14.0
	s.e. ±	1.12	1.35

* Statistically significant from control (*P* 0.05)

The WRO has played an important role in developing the technique of smearing translocated herbicides onto tall-growing perennial weeds, including *C. arvense* in grassland (Oswald 1982). Useful control without grass damage has been achieved using dicamba applied through a rope wick applicator especially when lowered into the grass canopy (Oswald 1985).

Biological Control

The need for sequential and costly herbicide treatment to control *C. arvense* has promoted interest in alternative techniques. In North America a number of thistle-eating insects have been released to complement the use of low doses of 2,4-D (Trumble & Kok 1982). Studies on the efficacy of weevil (Peschken & Wilkinson 1981) and gall fly (Peschken *et al.* 1982) released as control agents have also been carried out in Canada. A feasibility study has recently started at the WRO based on the use of the indigenous rust fungus *Puccinia punctiformis* (M.P. Greaves, personal communication). Preliminary investigations suggest that a combination of the pathogen and a low dose of 2,4-D can produce severe effects on the host, indicating the possibility of economic and lasting control.

Conclusions

Preliminary studies are now confirming the traditional view that *C. arvense* is an important weed of grassland in the UK. It is the most widespread weed of permanent pasture, being most prevalent in old, grazed swards. Animals avoid grazing grass in close proximity to growing weed plants, thus leaving palatable grass uneaten which leads to losses in pasture productivity. The presence of *C. arvense* in hay not only leads to rejection of the weed but also of the grass itself.

Control is difficult because of the weed's complex creeping underground root system which has great regenerative capacity following cutting (Hamdoun 1972) and which makes the translocation of herbicides difficult. At present, sequential treatment with herbicides, including mixtures, plus improved sward management, offer the best means of control. However, new and very active compounds are being tested and more effective control may soon be possible.

Future work should continue to measure the effects of *C. arvense* on grass production. More detailed investigations are required on the competition between the weed and the grass crop with different managements and further studies are needed on the problems caused in grazing and hay feeding systems. Herbicide evaluation should emphasise clover-safety at a time when clover is an important constituent in grassland (Doyle & Morrison 1983). The use of integrated control measures involving herbicides and biological control agents should also be persued as this may provide an opportunity to achieve long-term control of this troublesome grassland weed.

References

ANONYMOUS (1977) *Weed Control – thistles: Ministry of Agriculture, Fisheries and Food, Advisory Leaflet* No. 51, pp. 6.

BAKKER, D. (1960) A comparative life-history study of *Cirsium arvense* (L.) Scop. and *Tussilago farfara* L. the most troublesome weeds in the newly reclaimed polders of the former Zuiderzee. *Symposium on biology of weeds. British Ecological Society* 205–222.

BATES, G.H.(1955) *Weed Control.* London: Farmer and Stockbreeder.

BRENCHLEY, W.E. (1920) Weeds of Farm Land. *London: Longmans, Green & Co.*, pp. 239.

CHANCELLOR, R.J. (1970) Biological background to the control of three perennial broad-leaved weeds. *10th British Weed Control Conference* 1114–1120.

COURTNEY, A.D. (1973) Noxious weeds in grassland-docks, thistles and ragwort. *Agriculture in Northern Ireland* **48**, 22–25.

DOYLE, C.J.; MORRISON, J. (1983) An economic assessment of the potential benefits of replacing grass by grass-clover mixtures for 18 month beef systems. *Grass and Forage Science* **38**, 272–282.

FAIRBAIRN, C.B.; THOMAS, B. (1958) The potential nutritive value of some weeds common to North-eastern England. *Journal of the British Grassland Society* **14**, 36–46.

FORBES, T.J.; DIBB, C.; GREEN, J.D.; HOPKINS, A.; PEEL, S. (1980) Factors affecting the productivity of permanent grassland. *Joint Permanent Pasture Group, Hurley*, pp. 141.

GREEN, J.O. (1974) Preliminary report on a sample survey of grassland in England and Wales, 1970–72. *Grassland Research Institute, Internal Report* No. 310.

HAGGAR, R.J.; OSWALD, A.K.; RICHARDSON, W.G. (1984) Importance and control of creeping thistle (*Cirsium arvense*) in grassland. *Crop Protection.* (In press).

HAMDOUN, A.M. (1972) Regenerative capacity of root fragments of *Cirsium arvense* (L.) Scop. *Weed Research* **12**, 128–136.

HARTLEY, M.J.; JAMES, T.K. (1979) Cost benefit of selective control of californian thistle in pasture. *Proceedings thirty-second New Zealand Weed and Pest Control Conference* 245–249.

HARTLEY,M.J.; THOMPSON, N.A. (1982) Effect and control of Californian thistle in dairy pasture. *Proceedings of the New Zealand Grassland Association* **43**, 104–107.

KINCH, R.C.; TERMUNDE, D. (1957) Germination of perennial sowthistle and Canada thistle at various stages of maturity. *Proceedings Association of Official Seed Analysts North America* **47**, 165–166.

KOCH, W.; VOLF, F. (1982) *Cirsium arvense* (L.) Scop. *Journal of University of Agriculture, Prague* **36**, 65–75.

MORRISON, J.; IDLE, A.A. (1972) A pilot survey of grassland in S.E. England. *Grassland Research Institute Technical Report No. 10*. Hurley: Grassland Research Institute.

OSWALD, A.K. (1982) Two surveys of the potential use of a technique for controlling tall weeds in grassland. *British Crop Protection Conference – Weeds 1982*, 387–393.

OSWALD, A.K. (1985) The height-directed application of dicamba for controlling *Rumex obtusifolius* and *Cirsium arvense* in grassland. *British Crop Protection Council Monograph No. 28, Application and Biology*, 55–61.

PEEL, S.; HOPKINS, A. (1980) The incidence of weeds in grassland. *British Crop Protection Conference – Weeds 1980*, 877–890.

PESCHKEN, D.P.; WILKINSON, A.T.S. (1981) Control of Canada thistle (*Cirsium arvense*): release and effectiveness of *Ceutorhynchus litura* in Canada. *Canadian Entomologist* **113**, 777–785.

PESCHKEN, D.P.; FINNAMORE, D.B.; WATSON, A.K. (1982) Biocontrol of the weed Canada thistle (*Cirsium arvense*) in Canada. *Canadian Entomologist* **114**, 349–357.

REECE, P.E.; WILSON, R.G. (1983) Effect of Canada Thistle (*Cirsium arvense*) and Musk Thistle (*Carduus nutans*) control on grass herbage. *Weed Science* **36**, 488–492.

RICHARDSON, W.G.; OSWALD, A.K.; WEST, T.M. (1984) The use of bentazone and pyridyl herbicides alone and in mixture for the control of creeping thistle (*Cirsium arvense* L.) in grassland. *Technical Report, Weed Research Organization* (In press).

ROBERTS, H.A. (1982) *Weed Control Handbook: Principles*. Oxford: Blackwell Scientific Publications.

SAGAR, G.R.; RAWSON, H.M. (1964) The biology of *Cirsium arvense* (L.) Scop. *7th British Weed Control Conference* 553–562.

STAPLEDON, R.G.; DAVIES, W. (1948) Ley Farming, London, Faber and Faber.

SWIFT, G.; HOLMES, J.C.; CLELAND, A.T.; FORTUNE, D.; WOOD, J. (1983) The grassland of East Scotland – a survey 1976–78. *Bulletin No. 29 East of Scotland College of Agriculture*, pp. 43.

TRUMBLE, J.T.; KOK, L.T. (1982) Integrated pest management techniques in thistle suppression in pastures in North America. *Weed Research* **22**, 345–359.

WILLIAMS, R.D. (1984) *Crop Protection Handbook – grass and clover swards*. pp. 105. Croydon: British Crop Protection Council.

The Chemical Control of Bracken (*Pteridium Aquilinum*) – A Review of some Agricultural Development and Advisory Service Field Experiments

C.E. FLINT
MAFF, ADAS,
Weed Research Division,
Long Ashton Research Station, Yarnton,
Oxford
and
H.V. LEA
MAFF,
ADAS,
Leeds

ABSTRACT

During 1969–1971 the National Agricultural and Advisory Service, (NAAS) investigated the use of dicamba, MCPA, asulam and aminotriazole for Pteridium aquilinum *(bracken) control. Applications of dicamba at 3.3 kg a.i./ha were found to be very effective and they could be made in the winter at the* P. aquilinum *dormant stage, when the vegetation had died back and the ground was visible. However, dicamba proved to be too expensive for agricultural use.*

Asulam applied at 4.4 kg a.i./ha during the full frond emergence stage was found to be the most cost effective material and this was commercially recommended in 1971. Also at that time glyphosate was evaluated. Although very effective it was more expensive than asulam.

In 1984, a trial programme to evaluate chlorsulfuron plus metsulfuron-methyl and metsulfuron-methyl alone was started. Both these materials cost much less than the standard asulam treatment. It is too early to report precisely how effective these materials are: initial observations suggest chlorsulfuron plus methsulfuron-methyl is the more active material.

Introduction

P. aquilinum has been and continues to be a problem of upland and hill farming. The need to control *P. aquilinum* in extensive livestock farming has been well documented (Anon 1983). It was towards the end of the 1960's and early 1970's that several new chemicals were identified as having activity against *P.*

aquilinum. The NAAS (now ADAS) started a programme of research to investigate in field experiments, the efficacy of materials such as dicamba, aminotriazole, MCPA, asulam and glyphosate for control.

In this paper the work carried out in the West Riding of Yorshire, between 1969 and 1974 in particular, is reviewed. The paper concentrates on the chemicals used to control *P. aquilinum* and does not consider other methods such as ploughing or mechanical control. Also omitted from the paper is a discussion of the follow up treatments, which are often an essential part of successful *P. aquilinum* control (Anon 1983).

In 1983, the new sulfonyl-urea compound chlorsulfuron was identified at the Weed Research Organization as having a useful degree of control on *P. aquilinum* (West 1985). In 1984, ADAS started a 2–3 year programme of evaluation of 2 sulfonyl-urea materials, *i.e.* a mixture of chlorsulfuron plus methsulfuron-methyl and metsulfuron-methyl alone. Although it is too early to report fully on the current work, the treatments and timings used are reported, along with the early visual reports from the 1984 experiments.

Materials and Methods

Experiment 1

Location – West Riding, Yorkshire
Soil type and herbage – a coarse sandy loam overlaid by *P. aquilinum* deep litter, with some surface peat. Occasionally in patches *Deschampsia flexuosa* and *Calluna* spp. were present.

Table 1: Treatments used for *Pteridium aquilinum* control

Active ingredients	%	Rate of a.i., kg/ha	Application dates 1	2	3	4
Dicamba	40	3.4	/	/	/	/
Dicamba (granules)	10	3.4	/		/	
MCPA amine salt	32	13.4	/	/	/	/
MCPA acid crystals	90	13.4	/		/	
Dicamba followed	40	1.7		/		
by dicamba	40	1.7				/
MCPA amine salt	32	6.7		/		
followed by MCPA amine salt	32	6.7				/

Application dates
1. 10 December 1968 – *P. aquilinum* dormant stage
2. 2 April 1969 – *P. aquilinum* dormant stage
3. 24 June 1969 – Early post-emergence
4. 27 August 1969 – Full frond emergence

The liquid formulations were applied through a PK2 sprayer at a volume rate equivalent to 1359 l/ha. The granules were applied by hand.

Plot size – 3.8 × 2.4 m

Experiment 2

Location – West Riding, Yorkshire
Soil type and herbage – a coarse sandy loam, with deep *P. aquilinum* litter and some surface peat. In places were the litter was less deep patchy sward existed and consisted of the following species:– *Holcus mollis, Agrostis* spp. *D. flexuosa, Nardus stricta* and *Cynosurus cristatus.*

Table 2: Treatments for *Pteridium aquilinum* control

Active ingredients	Form	%	Rate of a.i., kg/ha	Application dates 1	2
1. Dicamba	granules	10	3.4	/	
2. Dicamba	liquid	40	3.4	/	
3. MCPA acid	crystals	90	16.8	/	
4. Aminotriazole (+ ammonium thiocyonate)	liquid	25	9.0		
5. MCPA amine	salt	32	16.8		/

Application dates
1. 10 June 1969 early post-emergence
2. 21 August 1969 full frond emergence

Plot size – 10 × 30 m or 9 × 47 m. Treatment 1–3 had 3 replications but 4 and 5 were applied to single plots only.

Experiment 3

Location – West Riding, Yorkshire
Soil type and herbage – deep *P. aquilinum* litter overlying a coarse sandy loam, with some local areas of surface peat and scattered surface boulders.
Treatments and Dates
i. 29 September 1969 – full frond emergence; the *P. aquilinum* was still completely green. However 9 d later it was observed that the *P. aquilinum* on the fell land on the whole of the experimental area had started to bronze and die back.
ii. 5 December 1969 – *P. aquilinum* dormant. Two 'reference' plots were also sprayed with dicamba (3.3 kg a.i./ha) on this date.
iii. 28 May 1970 – early frond emergence, with fronds ranging from 5 to 60 cm long, the latter having 2 expanded bottom leaves.
iv. 29 July 1970 – full frond emergence with the *P. aquilinum* growing vigorously.

At each date the material asulam (40% wt/wt) was applied at 2.2 kg a.i./ha and 4.4 kg a.i./ha. The materials were applied using an Oxford Precision Sprayer in a volume equivalent to 500 l water/ha.

The plots were 3.8 × 9.6 m in size.

Experiment 4 (1973)

Location – West Riding, Yorkshire
Site – as for experiment 3

Table 3: Treatments for *Pteridium aquilinum* control

Active ingredients	%	Rate of a.i., g/ha
1. Glyphosate	36	1.1 kg
2. Glyphosate	36	2.2 kg
3. Glyphosate	36	4.5 kg
4. Asulam	40	3.3 kg
5. Asulam	40	4.4 kg

All the treatments applied at full frond emergence on 2 August 1973 and were applied through an Oxford Precision Sprayer in a volume equivalent to 400 l/ha.

Experiment 5 (1984)

Location – 2 sites West Riding, Yorkshire, 1 site South Wales
Soil types and herbage – West Riding: 1 site deep litter: 1 site on a coarse sandy loam with various grasses including Agrostis, Fescue and Holcus. Wales: 1 deep litter site.

Both the sulfonyl-urea materials were applied at two different timings. The earlies timing was when the *P. aquilinum* fronds were 30–40 cm tall. It was intended that the first application should be applied at the crozier stage (15 cm high). However this was not possible in 1984. The second application timing was at the full frond emergence stage, generally in mid to late July. Asulam was also applied at this timing. The complete randomised block design was used with 3 replicates per treatment and the plots were a minimum of 5 × 2.5 m in size.

Table 4: Treatments for *Pteridium aquilinum* control

Active ingredient	Rate a.i., g/ha
Chlorsulfuron + methsulfuron-methyl	7.5 + 2.5
	15.0 + 5.0
	30.0 + 10.0
Metsulfuron-methyl	2.5
	5.0
	10.0
Asulam	4.4 kg a.i./ha

Results

Experiment 1

DICAMBA 1968–71

Treatments 1 and 2 applied in the dormant period of 1968 and 1969, became apparent as soon as active growth commenced in the spring. Emerging fronds exhibited severe twisting and a chlorotic green colouration. The stems were thicker and shorter compared with the control. The pinnae on the stems resembled fleshy stubs and failed to develop. After emergence, a much reduced density of the *P. aquilinum* was apparent and a steady reduction in density occurred as the season developed. By 5 September 1969, up to 100% control of *P. aquilinum* was recorded with only a few chlorotic plants surviving about 7.5–10 cm high.

Application to emerging and full frond stage *P. aquilinum* (treatments 3 and 4) had a less dramatic effect and symptoms took time to develop. Initially stems exhibited some yellowing and slight twisting. By early September on treatment 3 plots the *P. aquilinum* cover was still approximately 80%, but showing symptoms of chlorosis and development of necrotic lesions and stunting of younger growth. By the same time in treatment 4 plots the *P. aquilinum* was showing only a slight yellowing of the foliage and slight stem twisting without any reduction in ground cover relative to the control plots.

The split treatment dicamba plots (2 April and 24 June 1969), reduced the *P. aquilinum* cover by 90–95% with only a few spindly chlorotic plants evident.

Treatments 1 and 2 continued to show a very high degree of control with 95–100% kill sustained throughout the 1970 growing season (some 21 months after application) with the few plants still in these areas, showing signs of residual dicamba symptoms, *i.e.* stunted growth, distorted pinnae and some chlorosis.

Emergence in the spring on treatment 3 and 4 plots showed the characteristic stem twisting and dwarfing effects but marginally less severe than treatments 1 and 2. The control of *P. aquilinum* achieved was between 80–90%. The level of control in the split treatment was also between 80–90%.

Observations on the 1 October 1971 found little distortion of *P. aquilinum* present on the treated plots but plants were slightly stunted although normal in colour. (Table 5)

Table 5: 1971 Assessments of the percent *Pteridium aquilinum* cover

Treatment date	% *P. aquilinum* cover	Effect on *P. aquilinum*
December 1968	10–15	stunted
April 1969	20	stunted
June 1969	15–30	stunted
August 1969	20–25	stunted
Split treatment	25–30	stunted

MCPA 1968–1969

Treatments 1 and 2 applied during the dormant period caused a very slight twisting of some fronds evident during the early emergence phase but with normal foliage colour and growth. Applied at timing 3 some yellowing of the foliage was observed accompanied by slight stem twisting. Applied at timing 4 a very marked foliar scorch was noted. The split treatment produced foliar scorch following the second application but with symptoms less severe than a single application at timing 4. An assessment of the *P. aquilinum* control on 5 September 1969 is summarised in Table 6.

Table 6: Assessment of *Pteridium aquilinum* control on 5 September 1969

Application date	% *P. aquilinum* control	Effect on *P. aquilinum*
10 December 1968	40–50	30 cm shorter in height than control
2 April 1969	60–70	30 cm shorter in height than control
24 June 1969	80–100	normal height with some yellowing and necrosis
27 August 1969	80–90	normal height, marked foliage scorch
Split treatment	70–80	15 cm shorter in height, marked foliar scorch

Observations continued in 1970 and showed that MCPA applied on all dates was continuing to have an effect on the *P. aquilinum* density along with a slight reduction in height of about 15–30 cm compared with the control (Table 7).

Table 7: Assessment of *Pteridium aquilinum* density on 17 September 1970

Application date	*P. aquilinum* density as a % of control
10 December 1968	70–90
2 April 1969	80–90
24 June 1969	40–80
27 August 1969	40–60
2 April and 27 August 1969	40–80

The single application on 27 August 1969 had caused the largest reduction in *P. aquilinum* density. From assessments made in September 1971 no residual effects of MCPA were observed. The *P. aquilinum* have made a complete recovery from all the 1968–1969 treatments.

Experiment 2

DICAMBA 1969–1971

Both spray and granular treatment produced the characteristic stem twisting accompanied by chlorosis and development of necrotic lesions. The dicamba had no apparent effect on the grasses found on the site of the experiment. At the end of 1969 growing season, *P. aquilinum* cover was reduced to less than 10 percent of the control.

A continued residual effect from dicamba was observed during emergence in 1970 with very stunted growth, some yellowing and pinnae distortion. On 3 July the ground cover of *P. aquilinum* was estimated at 10 percent of the control with stunted plants still evident. This level of control was maintained through to the 6 October 1970.

The residual dicamba symptoms on *P. aquilinum* growth were no longer evident in 1971 and *P. aquilinum* density was observed to increase during the season and by the final assessment in October, *P. aquilinum* cover was estimated at 20 percent of the control. The patchy sward under the dicamba treatments had been encouraged to fill in due to cattle and sheep grazing at intervals during the experiment. At the end of the year a sward type of *Holcus* spp., *Agrostis* spp. and *D. flexuosa* existed in greater density than was apparent at the beginning of the experiment.

MCPA 1969–1971

The 10 June 1969 (early) treatment with 16.8 kg a.i./ha MCPA crystals had only a very mild effect on the developing bracken, foliage with some slight twisting observed and no effect on leaf colour. Growth for the remainder of the year appeared normal. The MCPA amine applied on 21 August (full frond stage) produced a very severe foliar scorch with the bulk of the foliage turning a predominantly reddish brown. At the end of the season the *P. aquilinum* density on both treatments was still 100%.

In the early emergence stage of 1970 it was noticed that growth appeared normal following the early application, but a reduction in density from late treatment. By October 1970, the *P. aquilinum* density had not been reduced by the early treatment but was reduced by 40% from the late treatment. There were no obvious effects from either timing on the sward.

At the end of the growing season of 1971 the *P. aquilinum* on the June treatment was back to the normal density and height. Whereas the *P. aquilinum* on the August treatment area averaged about 50% of the control density with a patchy degree of control recorded.

AMINOTRIAZOLE 1969–1971

The 21 August application of 9 kg a.i./ha of aminotriazole produced a slight scorch to the *P. aquilinum* foliage, which was also a much paler colour. A severe chlorosis of the sward area in the plots was observed. By the end of the season the *P. aquilinum* density was unaffected but was a very pale colour.

Emergence in 1970 revealed good control of *P. aquilinum* with reduced density and very pale foliage. At the end of July the estimated ground cover was 25% of the control with the *P. aquilinum* still very yellow and death continuing. The end of the season observations confirmed a density estimated at 20% of the control with an accelerated death of the plots with the onset of cold weather. The aminotriazole had a very severe effect on the sward which never really recovered from the treatment and finished up at about 40–50% of its pre-treatment density, with ingress of weed species.

In the early part of the 1971 season the *P. aquilinum* continued to produce pale foliage and was stunted and reduced in density. The damaged sward did not recover and most of the area became colonised by heath bedstraw (*Galium saxatile*). At the end of the season nearly all the *P. aquilinum* had recovered its normal colour and the density of the *P. aquilinum* was about 50% of the control but still reduced in height.

Experiment 3

ASULAM 1970–71

Early in June there as a transient mottling on some pinnae on the older fronds from the 28 May applications but subsequent observations recorded normal growth and density. Earlier observations on the 15 and 28 May and 1 June recorded normal emergence and density following the 29 September and 5 December 1969 treatments with no treatment effect obvious.

The first positive effect of asulam was noted on 3 July from the 29 September treatment, some 9 months after application. The older fronds were showing a slight yellowing with reduced pinnae size. The effect was more noticeable at the 4.4 kg a.i./ha rate. It also became evident that the *P. aquilinum* density was reducing particularly, at the higher rate. By the end of the season further degeneration of pinnae was noted with some yellowing and *P. aquilinum* cover on the higher rate was only 20% of the control and 30–40 on the lower rate. The two dicamba 'reference' plots were 100% clear of *P. aquilinum*.

No effect on *P. aquilinum* growth or density was recorded during 1970 from the 5 December 1969 asulam treatments. Normal growth and density were also recorded for the balance of the season for the 28 May and 29 July treatments.

It was known that asulam was slow to act and normally enters the growing plant via the leaf and stems during periods of active growth of herbage. It was surprising that the 29 September 1969 treatment gave the best results as there were only about 9 days of 'active growth', before normal die back on the fell occurred. Also the long delay of 9 months before results were apparant, was longer than expected. It was noted that asulam had an adverse effect on certain grass species including *D. flexuosa* and *H. mollis*.

From the 29 September 1969 treatments the reduced *P. aquilinum* densities observed during 1970 were reflected in a slightly less dense emergence in 1971. However, a gradual increase in density occurred as the season progressed with the *P. aquilinum* showing complete recovery by the end of the season. Although this treatment date was the only one to show any effect in 1970, it was not sufficiently severe to prevent complete recovery.

The 5 December 1969 and 28 May 1970 treatments resulted in no control as in 1970 and it could be seen that asulam had no activity when applied at the dormant or early post-emergence stage. The 29 July 1970 treatments restricted emergence and any fronds coming through were stunted and slightly paler in colour. By the end of the 1971 season the treatments had achieved 95% control of the *P. aquilinum* and this excellent degree of control was apparant at both 2.2 and 4.4 kg a.i./ha. The degree of control for both rates from this treatment date was as effective as any control method using 3.3 kg a.i./ha dicamba.

Experiment 4

GLYPHOSATE AND ASULAM

The results achieved with 2.2 and 4.5 kg a.i./ha were very good at 91–96% control. A similar level of control was achieved with 3.4–4.4 kg a.i./ha of asulam. Glyphosate at 1.1 kg a.i./ha proved to be inferior. The experiment also showed the damaging effect of glyphosate on grasses and heather. When glyphosate came onto the market in 1974 its cost was 3–4 times greater than for asulam.

Experiment 5

CHLORSULFURON PLUS METSULFURON-METHYL

Of the two sulfonyl-urea materials tested in 1984 this gave the more marked foliar effects and a greater reduction in *P. aquilinum* height. The highest rate produced the greatest degree of fern scorching and reduction in *P. aquilinum* cover. Although there was scorching from the lowest rate, the reduction in cover was less.

Due to several reasons, at none of the sites was chlorsulfuron plus metsulfuron-methyl applied at the crozier stage (the target stage), the earliest stage achieved was when the fronds were between 30–45 cm high. The *P. aquilinum* remained at that height until the end of the season. When sprayed at full frond emergence, there was less fern scorch from any of the rates. There was some suggestion that grasses under the canopy were slightly affected by chlorsulfuron plus metsulfuron-methyl as they appeared paler in colour.

METSULFURON-METHYL

This material produced much less marked foliar effects than chlorsul-furon plus metsulfuron-methyl. There was little reduction in *P. aquilinum* cover or stem height even from the highest rate.

It is too early to say how successful these new materials will be for *P.*

aquilinum control and further detailed assessments will be made during the summer of 1985 and 1986. From the early visual assessments chlorsulfuron plus metsulfuron/methyl appears to be the more active product.

Discussion

The cost of the chemicals for *P. aquilinum* control is one of the overriding factors influencing whether they are used or not. In 1970 the cost of dicamba was £32/ha. This was considered too expensive and therefore a recommendation was never made for its use in *P. aquilinum* on farmland. It is a pity that dicamba is an expensive chemical as it gave very good *P. aquilinum* control and could be applied at a very convenient stage, *i.e.* at the *P. aquilinum* dormant stage, when the vegetation had died back and the ground visible.

Asulam was approved for use in *P. aquilinum* in 1971 at 4.4 kg a.i./ha and at that time cost approximately £20/ha. At current recommended retail prices, asulam costs approximately £66/ha. The wheel has almost gone full circle as the cost of the sulfonyl-ureas is much less. For example 100 gram of product chlorsulfuron plus metsulfuron-methyl retails for approximately £13.50/ha. At this chemical cost it is not surprising that there is considerable interest in whether or not the sulfonyl-urea herbicides can give effective control of *P. aquilinum*.

References

ANON (1983) *Bracken and its Control*. Ministry of Agriculture Fisheries and Food, **190,** pp. 1–8.

WEST, T.M. & RICHARDSON, W.G. (1985) Response of bracken (*Pteridium aquilinum* L.) in pots to various herbicide treatments. *Tests of Agrochemicals and Cultivars* **6**, 108.

The Impact and Control of Ragwort (*Senecio Jacobaea* and *S. Aquaticus*) in Grassland

J.C. FORBES [1]
Monsanto Europe SA
Rue Laid Burniat, 1348
Louvain-la-Neuve,
Belgium

ABSTRACT

Though poisoning of cattle by ragwort is now rare, serious financial loss can still result from the constraint imposed by ragwort on the conservation of grass for winter keep. Data on the occurrence of ragwort in various parts of Great Britain and overseas are reviewed. Analysis of factors affecting ragwort distribution and studies of population dynamics have assisted development of control strategies. Biological control by insects has so far been only locally successful in Australia and North America.

Spraying with 2,4-D or MCPA during stem elongation is now known to give less reliable control than application at the rosette stage in spring. These herbicides make ragwort more palatable to grazing cattle, which must therefore be excluded from recently sprayed pastures. Autumn spraying makes this less inconvenient, but gives only one year's control of ragwort whereas spring spraying gives two. MCPA and 2,4-D damage clover, but this effect can be minimised by spraying after the natural die-back of clover in late autumn. Application of glyphosate or dicamba through a rope wick applicator gives more selective control of flowering ragwort but misses seedlings and rosette plants.

Cases of poor control in commercial practice are usually due to bad spraying technique or to application after the commencement of stem elongation. Good control requires weather, plant and application factors to be close to optimal. Survey data suggest that 22–23% of the grassland area infested with ragwort must each year receive effective control measures just to maintain the frequency of infestation at a constant level.

[1] All of the author's own work referred to in this paper was carried out at the North of Scotland College of Agriculture, 581 King Street, Aberdeen, UK.

Losses Caused by Ragwort

Common ragwort (*Senecio jacobaea*) is one of the most widespread and abundant weeds of grassland in the British Isles. When present at high desnity it can reduce herbage yield by competition with grass and in this way restrict animal output, but this effect is of negligible importance by comparison with losses associated with its poisonous properties.

Nine different pyrrolizidine alkaloids have been identified in *S. jacobaea* (Segall & Krick 1979), all of them hepatotoxic. Cases of ragwort poisoning of cattle and horses are well documented in the veterinary literature (e.g. Donald & Shanks 1956), and the locally common marsh ragwort (*S. aquaticus*) is apparently as dangerous as *S. jacobaea* (Evans & Evans 1949). The effects on the liver are cumulative and there is no known antidote; once cattle develop the symptoms they invariably die. The greatest danger lies in silage, in which animals are unable to discriminate between ragwort and grass, and to a lesser extent in hay, because of the increased palatability of ragwort after drying. Under certain circumstances cattle may eat ragwort in pasture, for example when grass is scarce due to drought, cold or over-stocking. There may be a correlation between ragwort poisoning and mineral imbalance in cattle (Palfrey *et al.* 1967) which is probably due to increased intake of ragwort in response to appetite changes rather than lowered resistance to toxicosis (Johnson 1982). Though ragwort is still one of the most common causes of poisoning of farm animals in Great Britain, this form of economic loss is less important than formerly because of greater awareness by farmers of the danger.

The economic impact of sublethal ragwort poisoning is completely unknown. At intake levels which do not cause mortality it is probable that cattle suffer reduced appetite and consequently become less productive. Contrary to common belief, sheep are not immune to ragwort poisoning, though they tolerate much higher intakes than cattle or horses. Ragwort is believed to reduce sheep productivity in New Zealand.

Probably the most significant form of economic loss due to ragwort, though impossible to quantify, is the constraint it imposes on grassland management. If the grassland area which is safe for the making of silage or hay is restricted, winter keep may have to be bought in at great cost. Infested fields have to be ploughed up and resown long before the end of their productive life. These are some of the more obvious constraints; others, even less easily quantifiable, include the necessity to replace silage with hay, in which the stalks of ragwort can be removed before feeding, the restriction of choice of fields which can be used for conservation, and the exclusion of cattle from pastures which have recently been sprayed with herbicides for ragwort control.

The direct cost of control measures is not here considered part of the economic cost of ragwort, but there are indirect costs which arise as a result of side effects of herbicides, including the restrictions on grazing mentioned above. Herbicide damage, both to clover and to young grass, can be severe (Courtney & Johnson 1980; Forbes 1977a 1982).

Ragwort causes other losses which may be locally important. In Oregon, for example, the tainting of honey by ragwort alkaloids renders it unsaleable (Isaacson 1975).

Incidence of Ragwort Infestation

Davies (1953) reported that about 20% of the grassland area around Fishguard in south-west Wales and 4% of that in north-west Anglesey was 'fairly severely' infested with ragwort. However, in England and Wales as a whole, only 1% of grass swards are now seriously affected (Peel & Hopkins 1980). A survey by Forbes (1974a) in Orkney revealed that ragwort occurred in 54% of the grassland area and that 26% could be described as 'infested', having a density greater than 1 plant/100 m^2. Orkney is unusual in having *S. Aquaticus* as the predominant species; in the survey *S. jacobaea* was found in only 6% of fields.

More recently, Forbes (1984) reported a roadside survey of ragwort, conducted annually for four years in north-east Scotland, with a sample size of 4749 fields. In 1979 the proportion of fields infested at a density greater than 1 plant/100 m^2 was 19.1%, representing a total of 47000 ha of ragwort-infested grassland, but by 1982 this had fallen to 13.5% (32000 ha). The downward trend continued in 1983 (North of Scotland College of Agriculture 1984). The incidence of ragwort differed greatly from area to area. For example in 1979 the proportion of grass fields infested ranged from under 7% in south Kincardine to over 36% in Moray and Nairn. More than 99% of infestations in 1980 were of *S. jacobaea* and less than 1% of *S. aquaticus* (Forbes 1984).

A survey by Curley (1983) in Prince Edward Island, Canada revealed a situation remarkably similar to that in north-east Scotland. Overall 18.7% of the grassland area, or a total of 6600 ha, were infested at a density exceeding 1 plant/100 m^2. The incidence of infestation ranged from 8% in Queens County to 62% in Kings County. *S. jacobaea* is also a serious weed problem in the Pacific Northwest of the USA. In western Oregon approximately 40% of the grassland area contains ragwort, in addition to more than 45000 ha in western Washington (Bedell *et al.* 1981).

Ecology of Ragwort

Various aspects of the ecology of ragwort have contributed to the development of control strategies. Forbes (1976) used multiple regression analysis to relate the occurrence of *S. aquaticus* in Orkney to 22 environmental and management factors. Of these, five factors were associated with high *S. aquaticus* densities: soil surface wetness, light soil texture, absence of sheep, sward openness and sward age. In subsequent extension work the importance was stressed of avoiding sward damage, especially by poaching on wet soils, and encouraging the development of a close, vigorous sward (Forbes 1978b). The use of sheep as a means of control has been advocated not only for *S. aquaticus* but also for *S. jacobaea* in Great Britain (MAFF 1982), North America (Sharrow & Mosher 1982) and Australis (Amor *et al.* 1983). Sheep weaken ragwort by eating the leaves in early spring, but should not be used to control heavy infestations because of the danger of poisoning.

Much research has gone into the potential of various insects as biological control agents for *S. jacobaea* in Australia, New Zealand and North America where the weed is not indigenous. Of a large number of species evaluated, three have shown promose: the cinnabar moth *Tyria jacobaeae*, the ragwort flea-beetle *Longitarsus jacobaeae* and the ragwort seed fly *Hylemyia seneciella*. Release of these species has so far met with only limited and local success (Schroeder 1983) and it is doubtful whether insects could ever contribute usefully to ragwort control in Europe where the plant, the insects that feed on it and the natural predators and pathogens of these insects live in a dynamic equilibrium (van der Meijden 1979; Lakhani & Dempster 1981). Disease has severely limited the establishment of *T. jacobaeae* in Australia (Schmidl 1981), while in North America adaptation of insects to the local climate has proved a problem (Hawkes 1981).

However, one of the greatest difficulties has been the resilience of the weed itself. Even severely defoliated *S. jacobaea* plants are capable of substantial compensatory seed production (Islam & Crawley 1983). In Oregon compensatory growth following attack by *T. jacobaeae* is considerably greater in wet years or sites than in dry ones, with a corresponding reduction in the efficacy of biological control (Cox & McEvoy 1983). In Canada the time available between defoliation and the onset of frost is critical; biological control by *T. jacobaeae* is more successful in eastern Canada than in British Columbia because the time available for recovery is less (Harris *et al.* 1977).

S. jacobaea is characterised by violent fluctuations in population density from year to year (Goodman & Gillham 1954; Forbes 1974b). A study of *S. jacobaea* population dynamics by Forbes (1977b) revealed that about three quarters of plants which reached the rosette stage died without going on to flower, but that by far the greatest losses occurred at the seed stage, only 1% of viable seeds returned giving rise to established seedlings. Surprisingly for a species often described as a biennial, 53% of plants regenerated rosettes from the crown after flowering.

There are implications here for control strategies. Control measures relying on the prevention of seed return or seedling establishment are unlikely to be successful if they take no account of vegetative regeneration. Evan a 90% reduction in viable seed production, as might be achieved by 'successful' biological control or by application of herbicides, still allows the return of ten times more seeds than are required to maintain population density. Control strategies also need to take account of the longevity of ragwort seeds in soil. Thompson & Makepeace (1983) have estimated that the time taken for seed viability in the soil to fall to 1% is 4–5 years near the surface and 10–16 years at depths greater than 4 cm.

No studies have been reported of the competitive ability of ragwort against a grass sward, but it is clear from casual observation that ragwort is not a vigorous competitor in intensively managed grassland. In an experiment in Orkney Forbes (1976) achieved complete elimination of *S. aquaticus* from pasture within two seasons by increasing cattle stocking rate and nitrogen fertiliser application, without recourse to herbicides.

Herbicides for Control of Ragwort

The phenoxyalkanoic acid herbicides 2,4-D and MCPA have long been advocated for ragwort control (Lynch 1949; Holly *et al.* 1952; Fryer 1953; Fryer &

Chancellor 1956). Early recommendations were to spray around the flower-bud stage in late June or early July, though it was already known that spraying at this stage gave extremely variable results (Fryer 1953). Forbes (1974b) demonstrated, at least for northern Scotland, that spraying much earlier, at the rosette stage, was more effective and this has been confirmed repeatedly (Forbes 1978b; Forbes *et al.* 1980). Recommendations for April or May application, first made for Scotland (Scottish Agricultural Colleges 1979) have now been adopted in England and Wales (MAFF 1982). *S. aquaticus* responds similarly to *S. jacobaea* (Forbes 1974b, 1977a). Where direct comparisons have been made, 2,4-D has generally been found to be slightly more effective than MCPA on both species (Holly *et al.* 1952; Forbes 1974b, 1977a; Forbes *et al.* 1980).

Reference has already been made to the increased palatability of ragwort following treatment with these herbicides. Irvine *et al.* (1977) measured water-soluble carbohydrate (WSC) content in *S. jacobaea* plants sprayed and unsprayed with 2,4-D. They observed a rapid increase in WSC in sprayed plants, reaching a maximum around 9 days after treatment. Inasmuch as WSC is a measure of palatability, it was concluded that to minimise poisoning risk cattle should be kept out of sprayed pastures for at least 3–4 weeks. An increase was also seen in pyrrolizidine alkaloid content of *S. jacobaea* leaves with application of 2,4-D.

The necessity to exclude cattle from sprayed pastures is a strong disincentive to spring spraying, for this is often the time when it is most difficult to accommodate the loss of grazing. A useful alternative is to spray in autumn, when very good results can be achieved (Courtney & Johnston 1976; Forbes 1978a, 1982). Autumn spraying has other advantages too: it allows more time for ragwort to die prior to cutting for silage, and the timing is less critical than for spring spraying. However, disadvantages are that weather is often less favourable for spraying in autumn, and control of flowering ragwort can be expected for only one year whereas spring spraying gives control for 2 years.

Both 2,4-D and MCPA are damaging to clover, a particularly important sward component in the very situations where ragwort tends to become a problem (Forbes 1982). Some other, more expensive, herbicides which have been shown to control ragwort are even more damaging; these include mecoprop and mecoprop-containing mixtures (Forbes 1978a), clopyralid and triclopyr (Richards *et al.* 1983).

Improving Clover Safety

Perhaps the most obvious approach to reducing clover damage is to seek more clover-selective herbicides that will control ragwort at least as well as 2,4-D or MCPA. Forbes (1977a) found that April or May application of asulam was far less effective against *S. aquaticus* than 2,4-D, though much safer on clover. Later, Forbes (1982) applied a wide range of clover-safe herbicides to a *S. jacobaea* infestation in autumn. Herbicides based on benazolin, 2,4-DB or MCPB all did little damage to clover, even at twice the rate recommended for dock (*Rumex* spp.) control, but gave only around 80% ragwort control, by comparison with 99% for MCPA and 100% for 2,4-D. Only asulam looked promising, giving 92% control at the single rate and 96% control at the double rate. The following year, *S. jacobaea* control by asulam was again acceptable, though only in the absence of rain; at one site where rain fell shortly after application 2,4-D ester still gave 82%, but asulam only 10% control. Subsequent user trials confirmed the relative unreliability of asulam for control of ragwort.

Another approach to improving clover safety is to apply 2,4-D or MCPA when clover leaf area is minimal. A good practice to achieve this is to graze a pasture down hard with cattle immediately before spraying. Forbes (1982) found that delaying autumn application until after clover die-back reduced clover damage, though ragwort control was maintained.

Recently rope wick applicators, which exploit the height difference between flowering ragwort and the grass/clover sward, have been evaluated, principally in New Zealand (Makepeace & Thompson 1982; Thompson 1983). In general glyphosate has given the best control and has actually increased the clover content of the sward. Dicamba has also given good results. However, this technique cannot control seedlings and rosettes of ragwort.

Getting the Message Across

The control of ragwort is now more a problem of extension than of research and development. Appropriate control measures exist for most situations and the need now is to persuade farmers to use them. By 1979, the reliability of herbicide application had been greatly improved by advocating treatment at the rosette stage, and autumn spraying was available as an alternative to spring spraying. Yet many farmers continued to report poor results, mainly with spring application. Out of 24 case studies in 1979, 14 showed poor control (Forbes *et al.* 1982). In 11 cases this was wholly or partly due to spraying too late, after the onset of stem elongation. Six showed evidence of bad spraying technique, with substantial missed or underdosed strips. Clearly ragwort is only moderately susceptible to 2,4-D and MCPA and any plant, application or weather factor which is not optimal can reduce the reliability of control.

In 1979–80 an advisory campaign was mounted in Scotland to stress the importance of following published recommendations, and this was accompanied by a roadside survey (Forbes 1984). Changes in ragwort density (estimated on a 0–5 logarithmic scale) were followed from year to year in individual fields. A decrease of 2 or more points on the scale was considered as indicative of control action, though natural fluctuations could also have been responsible. In both 1979–80 and 1980–81, the higher the estimated frequency of control measures in an area, the greater was the fall in incidence of infestation. The two areas showing the greatest decrease had received particular attention during the advisory campaign. In both years it was apparently necessary for 22–23% of all infested fields in an area to receive successful control measures just to maintain the overall incidence of ragwort infestation unchanged.

References

AMOR, R.L.; LANE, D.W.; JACKSON, K.W. (1983) Observations on the influence of grazing by sheep or cattle on the density and cover of ragwort. *Australian Weeds* **2**(3), 94–95.

BEDELL, T.E.; WHITESIDES, R.E.; HAWKES, R.B. (1981) Pasture management for control of tansy ragwort. *Pacific Northwest Cooperative Extension Publication 210.*

COURTNEY, A.D.; JOHNSTON, R. (1976) An extended season of herbicies application for the control of *Senecio jacobaea. 1976 British Crop Protection Conference – Weeds*, 611–618.

COURTNEY, A.D.; JOHNSON, R.M. (1980) The effect of herbicides on the dry matter yield and regrowth elongation of an established *Lolium perenne* (ryegrass) sward. *British Crop Protection Conference – Weeds, 1980* 589–599.

COX, C.S.; MCEVOY, P.B. (1983) Effect of summer moisture stress on the capacity of tansy ragwort (*Senecio jacobaea*) to compensate for defoliation by cinnabar moth (*Tyria jacobaeae*). *Journal of Applied Ecology* **20**, 225–234.

CURLEY, R. (1983) Tansy ragwort awareness and eradication demonstration 1983. Project Report, Productivity Enhancement Program, Prince Edward Island. *Agriculture Canada.*

DAVIES, A.J. (1953) The ragwort problem in Wales. *1st British Weed Control Conference*, 204–210.

DONALD, L.G.; SHANKS, P.C. (1956) Ragwort poisoning from silage. *British Veterinary Journal* **112**, 307–311.

EVANS, W.C.; EVANS, E.T.R. (1949) Poisoning of farm animals by the marsh ragwort (*Senecio aquaticus*). *Nature* 164, 30–31.

FORBES, J.C. (1974b) Spraying and cutting experiments on ragwort (*Senecio jacobaea* and *S. aquaticus*). *12th British Weed Control Conference*, 743–750.

FORBES, J.C. (1976) Influence of management and environmental factors on the distribution of the marsh ragwort (*Senecio aquaticus*) in agricultural grassland in Orkney. *Journal of Applied Ecology* **13**, 985–990.

FORBES, J.C. (1977a) Chemical control of marsh ragwort (*Senecio aquaticus*) in established grassland. *Weed Research* **17**, 247–250.

FORBES, J.C. (1977b) Population flux and mortality in a ragwort (*Senecio jacobaea*) infestation. *Weed Research* **17**, 387–391.

FORBES, J.C. (1978a) Control of *Senecio jacobaea* (ragwort) by autumn or spring herbicide application. *Weed Research* **18**, 109–110.

FORBES, J.C. (1978b) Ragwort – making control more reliable. *North of Scotland College of Agriculture Digest 1978*, 24–27.

FORBES, J.C. (1982) Evaluating herbicides for selective control of *Senecio jacobaea* in grass/clover swards. *British Crop Protection Conference – Weeds 1982*, 375–379.

FORBES, J.C. (1984) Changes in the incidence of ragwort (*Senecio jacobaea*) infestation of grassland over a 4-year period in NE Scotland. *Weed Research* **24**, 431–438.

FORBES, J.C.; KILGOUR, D.W.; CARNEGIE, H.M. (1980) Some causes of poor control of *Senecio jacobaea* by herbicides. *British Crop Protection Conference – Weeds 1980*, 461–468.

FRYER, J.D. (1953) The use of 2,4-D for the control of ragwort. *1st British Weed Control Conference* 211–224.

FRYER, J.D.; CHANCELLOR, R.J. (1956) Ragwort and its control. *Agriculture* **63**, 65–69.

GOODMAN, G.T.; GILLHAM, M.E. (1954) Ecology of the Pembrokeshire islands. II. Skokholm, environment and vegetation. *Journal of Ecology* **42**, 296–327.

HARRIS, P.; THOMPSON, L.S.; WILKINSON, A.T.S.; NEARY, M.E. (1977) Reproductive biology of tansy ragwort, climate and biological control by the cinnabar moth in Canada. *Proceedings 4th International Symposium on Biological Control of Weeds* 163–173.

HAWKES, R.B. (1981) Biological control of tansy ragwort in the state of Oregon, USA. *Proceedings 5th International Symposium on Biological Control of Weeds* 623–626.

HOLLY, K.; WOODFORD, E.K.; BLACKMAN, G.E. (1952) The control of some perennial weeds in permanent grassland by selective herbicides. *Agriculture* **59**, 19–23.

IRVINE, A.M.; FORBES, J.C.; DRAPER, S.R. (1977) Effect of 2,4-D on the water-soluble carbohydrate content of ragwort (*Senecio jacobaea*) leaves. *Weed Research* **17**, 169–172.

ISAASON, D.L. (1975) Economic losses to tansy ragwort. *Proceedings 24th Annual Oregon Weed Conference* 1–3.

ISLAM, Z.; CRAWLEY, M.J. (1983) Compensation and regrowth in ragwort (*Senecio jacobaea*) attacked by cinnabar moth (*Tyria jacobaeae*). *Journal of Ecology* **71**, 829–843.

JOHNSON, A.E. (1982)Failure of mineral-vitamin supplements to prevent tansy ragwort (*Senecio jacobaea*) toxicosis in cattle. *American Journal of Veterinary Research* **43**, 718–723.

LAKHANI, K.H.; DEMPSTER, J.P. (1981) Cinnabar moth and its food plant, ragwort: further analysis of a simple interaction model. *Journal of Animal Ecology* **50**, 231–249.

LYNCH, P.B. (1949) Experiments with chemical control of ragwort. *New Zealand Journal of Agriculture* **78**, 575.

MAKEPEACE, W.; THOMPSON, A. (1982) Ragwort control using a rope wick applicator. *Proceedings 35th New Zealand Weed and Pest Control Conference*, 256–260.

MEIJDEN, E. VAN DER (1979) Herbivore exploitation of a fugitive plant species: local survival and extinction of the cinnabar moth (*Tyria jacobaeae*) and ragwort (*Senecio jacobaea*) in a heterogeneous environment. *Oecologia* **42**, 307–323.

MINISTRY OF AGRICULTURE, FISHERIES AND FOOD (1982) Ragwort. *Leaflet 280*.

NORTH OF SCOTLAND COLLEGE OF AGRICULTURE (1984) Weed control in grassland. *Research Investigations and Field Trials 1982–83*, 88–90.

PALFREY, G.D.; MACLEAN, K.S.; LANGILLE, W.M. (1967) Correlation between incidence of ragwort (*Senecio jacobaea*) poisoning and lack of mineral in cattle. *Weed Research* **7**, 171–175.

PEEL, S.; HOPKINS, A. (1980) The incidence of weeds in grassland. *British Crop Protection Conference – Weeds 1980*, 877–890.

RICHARDS, M.C.; SWIFT, G.; CLELAND, A.T.; DAVIES, D.H.K. (1983) Evaluation of 3,6-dichloropicolinic acid, triclopyr, 2,4-D ester and MCPA, alone and in mixtures, for *Senecio jacobaea* control in grassland. *Annals of Applied Biology* **102**, Supplement (*Tests of Agrochemicals and Cultivars* 4), 104–105.

SCHMIDL, L. (1981) Ragwort, *Senecio jacobaea*, in Victoria and renewed attempts to establish the cinnabar moth, *Tyria jacobaeae*, for its control. *Proceedings 5th International Symposium on Biological Control of Weeds* 603–607.

SCHROEDER, D. (1983) Biological Control of Weeds. In: *Recent Advances in Weed Research* (Ed. W.W. Fletcher) pp. 41–78. Farnham Royal: Commonwealth Agricultural Bureaux.

SCOTTISH AGRICULTURAL COLLEGES (1979) The control of ragwort. *Publication 38*.

SEGAL, H.J.; KRICK, T.P. (1979) Pyrrolizidine alkaloids: organohalogen derivative isolated from *Senecio jacobaea* (tansy ragwort). *Toxicology Letters* **4**, 193–198.

SHARROW, S.H.; MOSHER, W.D. (1982) Sheep as a biological control agent for tansy ragwort. *Journal of Range Management* **35**, 480–482.

THOMPSON, A. (1983) Pasture weed control by rope wick applicator. *Proceedings 36th New Zealand Weed and Pest Control Conference*, 96–98.

THOMPSON, A.; MAKEPEACE, W. (1983) Longevity of buried ragwort (*Senecio jacobaea*) seed. *New Zealand Journal of Experimental Agriculture* **11**, 89–90.

Developments in Biological Control

M.P. GREAVES
Weed Research Division,
Long Ashton Research
Station, Yarnton, Oxford

ABSTRACT

Classical techniques of biological control of weeds have been studied and used for many years. These are particularly suited to use where weeds dominate the vegetation in relatively stable environments, such as prairies. It is in such situations that notable successes have been achieved in N. America and Australia. Recently, increasing attention has been given to the control of weeds by inundative inoculation with indigenous pathogens. This paper concentrates on this 'mycoherbicide' or 'microbial pesticide' approach. Examples of successful commercialization of 'microbial herbicides' are given and current research into their development for the control of some grassland weeds (docks, thistles, ragwort and bracken) discussed.

Introduction

Despite the dominance of weed control by chemical herbicides, a considerable increase in the number of biological weed control projects has occurred since about 1960. This has arisen as a result of factors such as increasing development, production and registration costs of chemicals, fear of adverse environmental effects from chemical use, increasing incidence of weed resistance and development of weed populations which are more difficult to control (Watson 1981).

The greatest emphasis in biological control research has been placed on the use of insects via the classical approach. This work has achieved notable successes, such as the control of prickly pear cactus (*Opuntia* spp.) with the cactus-feeding moth, *Cactoblastis cactorum*. The work has been exhaustively reviewed (Schroeder 1982) and will not be dealt with here in any detail. Suffice it to say, this approach is especially suited to the control of a weed species which dominates a relatively stable environment, such as prairies. In this context, it is interesting to note the current research by Lawton at York University which is examining the use of insects to control bracken (*Pteridium aquilinum*). It is worth speculating whether this work will succeed in developing a biocontrol agent or whether it might require an additional input, such as the pathogenic fungus being investigated for control of the same weed at Strathclyde University (see later). Certainly, experience in the USA suggests that, for at least some pernicious weeds, a combination of control agents will be necessary to achieve economic levels of control (Charudattan & Walker 1982).

Perhaps the greatest increase in interest and effort has arisen, during the last decade, in the use of pathogens, particularly fungi, as biological control agents. Thus, in 1974 only 5 weed species in N. America were noted as targets for plant pathogens (Goeden *et al.* 1974). Four years later 23 weed species were being investigated. By 1982, 83 pathogens, including 71 fungi, were being considered as control agents (Templeton 1982). This research has been sufficiently intensive in the last decade to identify two principal strategies of use. This paper will consider both these strategies, the classical and inundative, but will deal mainly with the latter. In addition, some very recent work on techniques for increasing the efficacy of biological control pathogens will be considered. Space constraints mean that only a very superficial cover of the subject can be given.

The Classical Approach

In this strategy, the fungus is introduced or released into an established weed population. In time, the fungus also becomes established and requires no further manipulation. Perhaps, the best known example of this approach, is the introduction of the rust *Puccinia chondrillina* into Australia from Europe to control *Chondrilla juncea* (rush skeleton weed). After release in 1971, the fungus spread very rapidly reaching 320 km from the release point after only 12 generations (Cullen 1974). It has been estimated that the resultant decline in the narrow-leaved form of *C. juncea* represented ultimately an annual saving of $26 m. (Cullen 1978). However, where this narrow-leaved form has declined, it is being replaced with intermediate- and broad-leaved forms which are resistant to the fungus. Consequently forms of the pathogen which are virulent to these forms of the weed are being sought. *P. chondrillina* has also been released in 1981 in four western states of the USA and seems to have established effectively. Schroeder (1982) cites references to several studies of other pathogens for potential as classical biological control agents.

The Inundative Approach

Templeton (1982) describes this strategy as being designed to control indigenous weed species with indigenous plant pathogens. In normal circumstance these pathogens do not control their hosts for a variety of reasons. For example, their dissemination may be severely restricted or their life-cycle may be disrupted or eliminated by the use of pesticides in agriculture. Essentially, highly virulent strains of fungus which are specific for one weed, or a very restricted group of weed species, are mass produced using fermentation techniques. Massive inoculations of the target weed are made, usually annually, using suspensions of spores or mycelia. Thus, the target weed can be infected, and eliminated, at an early growth stage using the fungus in the same way as a chemical herbicide. It is for this reason that such preparations have been called 'mycoherbicides'. There are already two successful commercial preparations on the market in the USA. These are Collego, a formulation of *Colletotrichum gloeosporioides* f. sp. *aeschynomene* which controls *Aeschynomene virginica* (northern jointvetch) in rice and soybean, and Devine, a mycelial preparation of *Phytophthora palmivora* which controls *Morrenia odorata* (strangler vine) in citrus. Aspects of the research, development and use of these products have been reviewed recently by Templeton & Greaves (1984) and TeBeest & Templeton (1985).

Mycoherbicides and Weeds of Grassland

Understandably, the largest proportion of research effort into mycoherbicides is, at present, focussed on weeds of arable crops. However, several of the pathogens being considered for release in the classical strategy to control weeds of the prairies and rangelands of the USA. Canada and Australia, may have potential as mycoherbicides in the UK and the rest of Europe. They will be considered here for some of the more serious grassland weeds. It has to be appreciated that research findings in this area are not yet published, particularly if patent applications are a possibility.

Pteridium Aquilinum (Bracken)

Research in California (Lindow 1983) has centred on two pathogenic fungi. A leaf spotting fungus, *Ascochyta pteridis*, has been examined in field trials where up to 98% necrosis of fronds was observed within two weeks of inoculation with 10^5 or 10^6 spores ml^{-1}. Another fungus, tentatively identified as *Cryptomycina* sp, is also being studied. It causes a systemic infection and greatly reduces both the number and size of fronds produced. In the UK, Dr M. Burge, University of Strathclyde, is studying the fungi causing curl tip (*Phoma aquilina* and *Ascochyta pteridis*) as this disease is found on open, exposed hillsides where bracken control is most desirable (Burge, personal communication). Findings so far indicate a possible synergism between these two fungi in disease development. Field trials have been instituted, but those in 1983 and 1984 have been largely inconclusive due to exceptionally hot dry weather.

The success of individual fungal agents against bracken may be limited. A particular problem is that the croziers of this weed emerge over a long period, thus requiring a persistent soil-applied agent or repeat spraying. It is, perhaps, an example of a weed where a combination of several agents may be necessary to achieve lasting effective control.

Cirsium Arvense (Creeping Thistle)

Probably more research has centred on fungal control of this weed than on any other. In particular, attention has focussed on the rust fungus *Puccinia punctiformis*. A wealth of literature has accumulated since early this century. It is not possible to review it here but the results from one of the most recent studies, by Dr V. Leth, (The Royal Veterinary and Agricultural University, Copenhagen, Denmark) reflect the overall findings (Leth, personal communication). Repeated inoculations with urediospores during a 3-week period, giving moderate to high levels of infection, did not kill the plants. The dry matter production of shoots was reduced by 20–30% but roots were unaffected. However, shoot reduction may ultimately affect root dry matter production. Dr Leth concludes that rapid control cannot be achieved by urediospore inoculation.

Rumex spp. (Docks)

Sedlar *et al.* (1983) have listed 20 species of fungal pathogens on docks which have potential as biocontrol agents. Of particular interest are the rust fungus *Uromyces rumicis* and species of *Phoma, Colletotrichum, Cercospora* and *Septoria*. As yet this research is at a comparatively early stage and it is too early to comment on the degree of potential shown.

Senecio spp. (Ragworts)

Much work is being done in Europe on behalf of the USDA. Ragworts have rapidly colonized large areas of grassland in N. America after their introduction from Europe. Sedlar *et al.* (1983) list 19 potential biocontrol fungi amongst the species isolated from *Senecio* spp. As with docks, research on this weed is at a comparatively early stage and field data are not yet available.

Modified Mycoherbicides

During the research into potential mycoherbicides it has become clear that many potential agents are unable to achieve economic control when used alone or in an unmodified form. Consequently, several exciting new approaches have developed.

It has long been known that some pesticides, especially herbicides, can increase disease incidence and/or virulence in crops. Accordingly, attention has been given to inducing this effect with potential mycoherbicides applied to weeds. Schreepens (CABO, Wageningen, personal communication) has demonstrated that *Echinochloa crus-galli* (barnyard grass) is killed by a combination of the weak pathogen *Curvularia lunata* and a very low dose of atrazine, neither being effective on its own. Much of the research in this area is not yet published except in provisional, informal reports. Thus, Quimby at the USDA-ARS laboratory, in Stoneville, Mississippi, USA has found that glyphosate, at a dose which is sub-injurious to soybeans was highly beneficial to the action of *Alternaria cassiae* in the control of sickle-pod in growth chamber experiments. Similarly, Dr L. Sedlar and her colleagues, at ETH, Zurich, have shown a beneficial interaction between separate applications of Asulox and the rust *Uromyces rumicis* in controlling *Rumex crispus* (curled dock). Recent research at Oxford University (Drs Hall and Plummer) is examining interactions between herbicides and pathogens as means of increasing biological control efficacy. Interest here is centred on control of *Avena fatua* (wild oat) with the leaf stripe fungus *Pyrenophora avenae*. A similar project will begin at the author's institute in the near future using EEC funding. Work on curl tip of bracken has shown the beneficial effects of mixing the inoculum with low doses of certain contact herbicides (M. Burge, Univ. Strathclyde, personal communication). This approach suggests much exciting potential for increasing mycoherbicide efficacy and extending the range of weeds which can be attacked.

Many pesticides have detrimental effects on mycoherbicides. Fungicides applications to a crop may, in particular, limit the times at which mycoherbicides can be used. TeBeest & Templeton (1985) report that, not only can Collego be tank mixed with the herbicides acifluorfen and bentazon without loss of activity, but benomyl-tolerant strains have been produced by mutation. This development minimizes problems associated with timings of sequential applications of chemical and biological agents. Such mutations will undoubtedly be sought more actively in future. Protoplast fusion techniques and recombinant DNA technology are powerful tools which offer the potential for great improvements in mycoherbicides. Recent experiences in the USA and Australia suggest there may be difficulties in getting permission to release genetically engineered strains into the environment. Hopefully, further careful research will overcome the objections and the development of environmentally safe, economically effective microbial herbicides will continue unabated.

Conclusions

Biological control of weeds with plant pathogens, particularly those used as 'mycoherbicides' is an established practice with a promising future, especially in relation to arable crops. Many of the serious weeds of grassland especially perennial species, may prove to be less amenable to control with mycoherbicides. However, these weeds in permanent grassland may be amenable to control by the classical strategy, particularly if mixtures of biological agents are used. Recent developments of combinations of fungal pathogens with low doses of herbicide may also offer practical advantages in this context. As yet, however, too little attention has been paid to biological control of weeds of grassland in Europe and much research remains to be done. Perhaps this will be stimulated by the successes being achieved against weeds of arable crops.

References

CHARUDATLAN, R.; WALKER, H.L. (1982) *Biological Control of Weeds with plant Pathogens*, New York: John Wiley and Sons.

CULLEN, J.M. (1974) Seasonal and regional variation in the success of organisms imported to combat skeleton week *chondrilla juncea* L. in Australia. *Proceedings III International Symposium on Biological Control of Weeds, Montpelier. 1973*. 111–117.

CULLEN, J.M. (1978) Evaluating the success of the programme for the biological control of *Chondrilla juncea*. *Proceedings IV International Symposium on Biological Control of Weeds, Gainesville 1976*, 117–122.

GOEDEN, R.D.; ANDRES, L.A.; FREEMAN, T.E.; HARRIS, P.; PIENKOWSKI, R.L.; WALKER, C.R. (1974) Present status of projects on the biological control of weeds with insects and plant pathogens in the United States and Canada. *Weed Science* **22**, 490–495.

LINDOW, S.E. (1983) Impact of *Ascochyta pteridis* on bracken fern. In: *Annual Research Report, Regionae Research Project S-136 (Jan–Dec 1983)*. (Obtainable from Dr C.G. van Dyke, N.C. State University, Raleigh, NC 27650, USA).

SCHROEDER, D. (1982) Biological control of weeds. In: *Recent Advances in Weed Research* (Ed. W.W. Fletcher) pp. 41–78. Farnham Royal: Commonwealth Agricultural Bureaux.

SEDLAR, L.; VONMOOS, R.; DEFAGO, G.; KERN, H. (1983) *Fungi occurring on selected weeds. A compilation from literature data*. Zurich: Institut für Phytomedizin, ETH-Centrum.

TEBEEST, D.O.; TEMPLETON, G.E. (1985) Mycoherbicides: Progress in the biological control of weeds. *Plant Disease* **69** (1), 6–10.

TEMPLETON, G.E.; SMITH, JR, R.J.; KLOMPARENS, W. (1980) Commercialization of fungi and bacteria for biological control. *Biocontrol News and Information* **1**, 291–294.

WATSON, A.K. (1981) Biological control of weeds. In: *Proceedings, Ecology of Agriculture and Biological Control Symposium*, Toronto: American Association for the Advancement of Science Meetings.

Discussion on Session 3 (Session Organiser – J. Johnson)

Question: Do the mineral contents quoted vary according to soil type?

Barber: The figures in my paper were 'normal'; soil, location and season can affect both nutritive value and mineral content.

Forbes: Grass mineral contents differ less on copper deficient soils than on copper abundant soils. High copper contents are needed on a copper-deficient site and herbs have a place there – the range is wide although higher coppers are seen in herbs than in grass.

Question: What changes have taken place in grass and weed levels in the last 10 years on the re-surveyed farms in the south west?

Hopkins: There has been an increase in perennial ryegrass content and a decline in indigenous grasses and broad-leaved weeds, notably buttercups, presumably as a result of increased nitrogen use, increased stocking rate and the change from hay to silage. Nitrogen use has almost doubled in the last 10 years.

Question: The 40% production loss in the seeding year of the ADAS/GRI trial seems high – is it higher than normally found in practice?

Dibb: Yes; on-farm use of techniques such as pre-harvest desiccation could reduce the loss further.

Budd: Establishment by under-sowing under spring barley still has a place in rotational systems, and is good for clover. On grass farms arable silage could be undersown.

Haggar: Ryegrass performs best at N levels above 300 kg ha^{-1}, but at lower levels than this, where there is a desire to maintain white clover, the rhizomatous and stoloniferous grasses tend to crowd it out: although reseeding is best for white clover there is a need to establish and maintain it in long-term swards.

Dibb: Timothy/meadow fescue mixtures allow clover to develop, but these swards do not respond well to high levels of N.

Question: Do herbicides used for thistle control affect clover?

Oswald: Only the bentazone/MCPB mixture would not harm clover; the more effective herbicides do damage clover.

Question: Are thistles associated with extensive and lax systems such as haymaking?

Oswald: It is difficult to confirm this and the subject needs more study.

Question: Will use of fungicide/herbicide mixtures encourage resistance?

Greaves: This is difficult to predict – none has appeared up to now with 14 years use of Collego, but the possibility could not be ruled out.

Question: Do temperature and humidity affect the effiacy of biological control systems?

Greaves: Yes, work in south-west USA has shown this, but new developments including gels and capsules could well remove some of the constraints.

Question: In the dock-treatment trials, is the reduction in grass yield at low dock levels due to the effects of the chemicals on the grass?

Courtney: I have no confirmation of this.

Comment: There is need for a nutritional rather than agronomic emphasis on the role of weeds.

Oswald: There is need to confirm or deny the nutritional role and work should be done at the nutritional research centre with adequate facilities.

Forbes: There is no need to consider ragwort on nutritional grounds as it constitutes a definite problem as a poisonous plant.

Courtney: My Department will be working with Dr Gordon of Hillsborough in feeding dock nuts to cattle to determine the effects of oxalic acid content.