PART 4

PEST AND DISEASE PROBLEMS OF ESTABLISHED GRASSLAND

Pest Damage to Established Grassland and the Feasibility of Control

R.O. CLEMENTS and
B.R. BENTLEY
The Animal and
Grassland Research
Institute, Hurley,
Maidenhead, Berks

ABSTRACT

Pest damage to temporary lowland grassland, permanent upland and permanent lowland grassland was assessed at several sites in England and Wales. Damage to Italian ryegrass leys was also assessed at some sites. Significant damage to upland permanent grass occurred less frequently than elsewhere. Italian ryegrass was particularly severely damaged and pests seemed a major cause of yield loss and lack of persistence in this species.

A number of pests were implicated in causing yield losses including soil-inhabiting Diptera, plant-sucking bugs, and larvae of frit fly (e.g. Oscinella frit*). The severe damage noted on Italian ryegrass seemed to be caused by frit fly larvae.*

A number of strategies inclusing use of pesticides, cultural and biological measures for controlling pests are discussed.

Introduction

The perennial nature of the grass crop ensures there is always some and usually an abundance of vegetation and root material present. Consequently large numbers of invertebrates, many of which are recognised pest species or are at least phytophagous, build-up. The biomass of pest species can be very large and for example the weight of leatherjackets (*Tipula*) alone can exceed that of grazing domestic livestock (Coulson & Butterfield 1978).

The invertebrate fauna of grassland is also very diverse – no doubt a reflection of the varied botanical composition as well as the long-term nature of the crop. In addition absence of the frequent gross soil disturbances associated with arable crop production allows species with long life cycles, e.g. wireworms (*Agriotes*) to become established.

A series of investigations or surveys were carried out by Grassland Research Institute, in collaboration with either Rothamsted Experimental Station or

Agricultural Development and Advisory Service, to quantify the level of pest damage caused by pests to established grassland in England and Wales. In each case a pesticide treatment was applied to small plots and the effect on herbage yield determined. Populations of some insect and other invertebrate species were usually assessed.

First Survey – lowland temporary grass 1971–72

Four simple small-plot trials were done in Yorkshire, Lancashire, Kent and Devon during 1971–72. Four pairs of plots each 3 × 7 m were laid out on existing perennial ryegrass (*Lolium perenne*) and ryegrass dominant swards (Henderson & Clements 1977). One plot in each pair was treated at the beginning of each year with the organochlorine soil insecticide aldrin at 11.2 kg h a.i./ha and also with the systemic organophosphorus insecticide phorate every six weeks during the period March–November. Yields were measured 4 times each year at the 2 northern sites and 5 times at the 2 southern sites, using an autoscythe technique. All plots received 251 kg N/ha/year. Populations of several foliage and soil inhabiting invertebrates were assessed.

Significant yield increases following insecticide application were obtained in one or more cuts at three of the four sites. The response at the Devon site was sufficiently consistent to give a significant increase in total annual dry matter in both years (Table 1).

Table 1: First survey. Annual yield of pesticide-treated and untreated temporary lowland grass at four sites, 1971–1972 (d.m., t ha^{-1})

	1971			1972		
Site	Untreated yield	Treated (diff. from untreated)	s.e. diff.	Untreated yield	Treated (diff. from untreated)	s.e. diff.
High Mowthorpe (Yorks)	10.41	+0.02	0.25	5.57	+0.29	0.27
Great House (Lancs)	9.15	+1.01*	0.33	6.18	−0.34	0.53
Wye (Kent)	9.62	+0.58	0.47	10.34	+0.97	0.72
Starcross (Devon)	6.86	+1.64*	0.45	7.00	+1.63*	0.32

* Significantly different from untreated ($P = 0.05$)

As data had been collected from only 4 sites a reliable calculation of correlation between grass yield enhancement and invertebrate numbers was not possible. But there was a suggestion that yield was decreased by high densities of plant-sucking bugs, soil inhabiting Diptera and stem-boring Diptera.

Second Survey – lowland temporary grass 1973–74

Similar small-plot experiments were carried out during 1973–74, on ten, widespread lowland temporary ryegrass sites (Henderson & Clements 1977). At each site 12 plots were laid-out on swards sown 5–48 months previously. All plots received 376 kg N/ha/year and 6 plots were treated with aldrin and phorate as before. Herbage yield was assessed using an autoscythe technique on four occasions each year. Populations of several foliage and soil inhibiting invertebrates were assessed.

In 1973, 9 of the 10 sites showed an increase in yield after treatment in one or more cuts and annual dry matter output was significantly improved at 5 sites. In 1974 all sites responded to pesticide treatment in at least one cut and annual production was increased significantly by between 9 and 32% at 8 of the 10 sites (Table 2).

Table 2: Second survey. Annual yield of pesticide-treated and untreated temporary lowland grass at 10 sites, 1973–1974 (d.m., t ha^{-1})

Site	1973 Untreated yield	1973 Treated (diff. from untreated)	1973 s.e. diff.	1974 Untreated yield	1974 Treated (diff. from untreated)	1974 s.e. diff.
Riseholm (Lincs)	13.25	+1.08*	0.33	9.07	+2.92*	0.28
Farndon (Cheshire)	12.63	+0.20	0.28	8.90	+1.48*	0.39
Sutton Bonington (Leics)	9.19	+0.15	0.48	7.98	+0.69	0.31
Walford (Salop)	12.90	+1.22*	0.47	8.34	+1.66*	0.20
Moulton (Northants)	10.90	+0.29	0.51	7.99	+1.53*	0.25
Rosemaund (Hereford)	12.12	+0.72*	0.17	8.99	+0.83*	0.28
Hartpury (Glos)	14.81	+1.69	0.76	12.43	+2.14*	0.52
Writtle (Essex)	8.76	−0.17	0.22	6.52	+1.21	0.72
Lacock (Wilts)	11.63	+1.38*	0.16	10.67	+2.17*	0.21
Cannington (Somerset)	11.65	+1.44*	0.28	10.95	+1.59*	0.48

* Significantly different from untreated at $P = 0.05$

Yield response was again linked to the reduction of high densities of plant sucking bugs (r = 0.60), aphids (r = 0.78) and stem-boring *Diptera* (r = 0.76)

Third Survey – upland permanent grass 1975–77

Small plot experiments were done at 13 widespread sites in upland England and Wales (Clements *et al.* 1982). One plot in each of 4 pairs was given a pesticide treatment (aldrin 8.9 kg a.i./ha) in March 1975 and monthly applications of phorate at 2.7 kg a.i./ha commenced at the same time. The molluscicide methiocarb was applied monthly at 1.4 kg a.i./ha until October 1976. All plots received 100 kg N fertilizer/ha/year. Herbage yield was assessed at 4-weekly intervals from May–October each year. During 1975 this was done by cutting 4 quadrats (30 × 30 cm) per plot to ground level, but gave very variable results. In 1976–77 an autoscythe technique was used instead. Populations of several soil invertebrates and frit fly larvae (e.g. *Oscinella frit*) were assessed.

No significant effects on total dry matter yield attributable to pesticide use were found in the first year. But sampling errors associated with the quadrat method used were very large. Significant increases in total annual dry matter yield were found in both the second and third year at the same 3 sites using the autoscythe method. Pesticide treatment depressed total annual yield at one site in 1976 and at a different site in 1977 (Table 3).

Table 3: Third survey. Annual yield of pesticide-treated and untreated upland permanent grass, at 13 sites 1976–1977 (d.m., t ha^{-1})

	1976		1977	
Site	Untreated	Treated (difference from untreated)	Untreated	Treated (difference from untreated)
Llysfasi (Clwyd)	5.7	−0.1	6.9	+0.3
Corwen (Clwyd)	3.6	+0.2	2.9	+0.6
Pwllpeiran High (Dyfed)	4.6	+0.1	5.3	−0.7
Pwllpeiran Low (Dyfed)	5.4	−0.3	6.4	−1.5*
Brecon (Powys)	5.0	0	5.4	−0.2
Clunton (Salop)	6.1	+0.7*	8.0	+1.1*
Redesdale (N'berland)	4.5	−0.5	6.1	−0.2
Penrith (Cumbria)	4.9	+1.1*	6.2	+1.5*
Selside (N. Yorks)	6.6	−0.1	5.6	+0.1
Oswaldtwhistle (Lancs)	4.1	+0.8*	6.7	+0.9*
Macclesfield (Cheshire)	3.8	+0.5	5.5	−0.4
Liscombe High (Somerset)	2.9	−0.5	2.9	+0.1
Liscombe Low (Somerset)	6.1	−0.1*	6.9	−0.7
s.e. diff.		0.32		0.38

* Significantly different from untreated at $P = 0.05$

The small and inconsistent yield responses to insect-controlling treatment contrasted with results of the first 2 surveys. Phytophagous insects were generally less numerous than previously recorded on lowland grassland and few of the acknowledged pests of grassland such as leatherjackets and chafer beetles (*Scarabaeidae*) were found. The comparative scarcity of stem-boring Diptera also seemed relevant. Whether this was due to adverse climatic conditions and poor survival or to the shortage of their preferred host, ryegrass, was not resolved. Insect damage appeared to be much less in upland pastures, possibly because insect pests are less numerous and/or a large proportion of the grasses present are more tolerant of insect damage.

Fourth Survey – lowland permanent grass 1983–84

Small plot experiments were carried out at 8 permanent pasture sites in England and Wales during 1983–84 (Clements *et al.* 1985). All swards were unimproved, at least 10 years old and had a diverse botanical composition. Plots were arranged in 4 replicate blocks and received a range of treatments including (a) an initial once-only drench of gamma-HCH 3.3 k a.i./ha, and chlorpyrifos 1.5 kg a.i./ha plus methiocarb 0.7 kg a.i./ha every four weeks during the growing season, or (b) no treatment, control. Populations of several soil inhabiting invertebrates and frit fly larvae were assessed.

In 1983 the mean response to insecticide treatment in total annual herbage yield was 8% (or 0.7 t/ha) compared with 15% (or 1.6 t/ha) in 1984. In 1984 significant increases in total annual yield to one or more treatments occurred at 7 of the 8 sites indicating that damage by pests was widespread (Table 4).

Table 4: Fourth survey. Annual yield of pesticide-treated and untreated lowland permanent grass at 8 sites 1983–1984 (d.m., t ha^{-1})

	1983			1984		
Site	Untreated	Treated (diff. from untreated)	s.e. diff.	Untreated	Treated (diff. from untreated)	s.e. diff.
Barnard Castle (Durham)	10.3	+0.7	0.61	11.0	+1.9*	0.75
Winterburn (Yorks)	10.3	+0.8	0.53	12.2	+1.7*	0.39
Pant-y-Dwr (Powys)	9.4	+1.3	0.51	11.6	+1.0	0.82
Ponterwyd (Dyfed)	11.0	−0.1	0.40	11.2	+1.5*	0.54
Highclere (Hants)	7.1	+1.8	0.64	10.3	+1.5*	0.60
Gt. Alne (Warwick)	7.2	+0.4	0.42	10.6	+1.6	0.71
Exminster (Devon)	6.8	+0.6	0.54	8.3	+2.1*	0.52
N. Wyke (Devon)	10.9	0	0.70	11.5	+1.3	0.72

* Significantly different from untreated at P 0.05

Preliminary scanning of the data shows that leatherjackets and crambids (*Crambidae*) occurred commonly and may have been the cause of the yield losses.

Italian Ryegrass

In an early experiment the herbage yield and the longevity of Italian ryegrass was greatly increased by the application of pesticides (Henderson & Clements 1979). In further work survival of 3 cultivars of Italian ryegrass tested was much greater when treated with either of the insecticides chlorpyrifos or phorate (Table 5) (Clements & Henderson 1983). There was a link between reductions in frit larval numbers and yield response. The major pest involved in other related work was also frit fly (Clements 1983, and C.T. Guile, unpublished).

Table 5: Italian ryegrass. Mean number of plants remaining/m^2 of each of 3 cultivars with and without phorate and chlorpyrifos

Cultivar	Untreated	Phorate	Chlorpyrifos
RvP	16.5	21.5	23.0
S22	12.3	17.0	16.0
Delecta	10.3	18.8	22.3
s.e. diff		2.53	

Scotland and Northern Ireland

Work done in S.W. Scotland showed that leatherjackets could markedly reduce the herbage yield of grassland. The proportion of grassland that was at risk fluctuated greatly from year to year, for example from nil to 27% during the period 1966–79 (Newbold 1981).

In Northern Ireland, Mowat (1974) found that elimination of frit fly larvae increased grass yields during the September–May period usually by less than 10%, but in one instance by 60%. Blackshaw (1984) found that even low populations of leatherjackets may do detectable damage and that damage by higher populations may be more widespread than previously thought.

Discussion and Conclusions

In upland grassland severe outbreaks of certain pests, e.g. chafers (*Phyllopertha*) are known to occur sporadically, but normally little can be done to forecast or prevent this damage and such pastures are usually left to their fate. Insidious pest damage did not seem to be a problem in upland grassland. Of the 13 sites studied there were significant (positive) responses to pesticide treatment at only 3 sites, which averaged 17% or 1.02 t/ha/year.

In contrast, in lowland areas, both permanent, indigenous swards and temporary grass were often significantly affected by pests. In Surveys, One, Two and Four, losses of up to 2.92 t/ha/year were noted, and averaged 1.1 t/ha/year across the 22 sites studied. Soil dwelling *Diptera* (e.g. leatherjackets), plant-sucking bugs and frit fly larvae were all implicated in the losses.

In Italian ryegrass yield reductions were great and often amounted to a total loss. Frit fly larvae seemed the most important pest.

Pesticides are a useful, tactical solution to certain problems but other methods need to be developed because there are many situations where the use of agro-chemicals would be inappropriate. An integrated control strategy is required. Some elements of this approach to overcome losses caused by for example frit fly are now known. To illustrate this point differences between varieties of Italian ryegrass in their resistance to frit fly larvae are known to occur (Clements & Henderson 1983) and these differences may be linked with the distribution of silica bodies in plant tissue (Moore 1984). Much more is now known about the epidemiology of frit fly attack, that of their parasitoids (Moore 1983), the effects of N fertiliser (Moore & Clements 1984a) and sward defoliation (Moore & Clements 1984b). It should be possible to combine these elements, perhaps with the tactical use of pesticides, in a strategy to reduce losses.

It may be feasible to develop an integrated control strategy for leatherjackets, using simple techniques such as heavy rolling, and defoliating swards at critical times. However the use of approved environmentally safe pesticides seems a simpler, if more costly, approach. A difficulty, however, is guaging when it is necessary to exert control. But a rapid on-farm technique for estimating leatherjacket populations is being tested by AGRI and another based on the use of 'St. Ives Fluid' can also be used to assess leatherjacket populations. These may prove to be valuable tools in deciding which fields are at risk and worth treating. Also, as a corollary, it would obviate the use of prophyllactic treatment.

A recent and exciting development based on work in New Zealand, is the possible use of an endophytic fungus, which could have widespread application for control of a range of grassland pests without the need to use pesticides.

Acknowledgements

The Animal and Grassland Research Institute is funded through the Agricultural and Food Research Council and the above work formed part of that done for a Commission by the Ministry of Agriculture, Food and Fisheries.

References

BLACKSHAW, R.P. (1984) The impact of low numbers of leatherjackets on grass yield. *Grass & Forage Science* 39, 339–343.

CLEMENTS, R.O.; HENDERSON, I.F.; BENTLEY, B.R. (1982) The effects of pesticide application on upland permanent pasture. *Grass & Forage Science* **37**, 123–128.

CLEMENTS, R.O.; HENDERSON, I.F. (1983). Improvement of yield and persistence of Italian ryegrass through pest control. *Proceedings XIV International Grassland Congress, Lexington, Kentucky 1981*. (Eds J.A. Smith and V.W. Hays).

CLEMENTS, R.O.; GILBEY, J.; BENTLEY, B.R.; FRENCH, N.; GREGG, I.A. (1985) Effect of pesticide combinations on the herbage yield of permanent pasture in England and Wales. *Tests of Agrochemicals & Cultivars No. 6 (Annals of Applied Biology* **105**, *Supplement)*

COULSON, J.C.; BUTTERFIELD, J. (1978) Animal communities of upland Britain. *Centre for Agricultural Research, Reading University. Bulletin No. 2. The future of upland Britain* pp. 417–436.

HENDERSON, I.F.; CLEMENTS, R.O. (1977) Grass growth in different parts of England in relation to invertebrate numbers and pesticide treatment. *Journal of the British Grassland Society* **32**, 89–98.

HENDERSON, I.F.; CLEMENTS, R.O. (1979) Differential susceptibility to pest damage in agricultural grasses. *Journal of Agricultural Science, (Cambridge)* **93**, 465–472.

MOORE, D. (1983) Hymenopterous parasites of stem-boring Diptera in perennial ryegrass in Britain. *Bulletin of Entomological Research* **73**, 601–608.

MOORE, D. (1984) The role of silica in protecting Italian ryegrass from attack by dipterous stem-boring larvae. *Annals of Applied Biology* **104.**

MOORE, D.; CLEMENTS, R.O.; (1984a) Stem-boring Diptera in perennial ryegrass in relation to fertiliser. I. Nitrogen level and form. *Annals of Applied Biology* **105**, 1–6.

MOORE, D.; CLEMENTS, R.O. (1984b) Stem-borer larval infestation of ryegrass swards under rotationally grazed and cut conditions. *Journal of Applied Ecology* **21**, 581–590.

MOWAT, D.J. (1974) The effect of short-fly larvae (Diptera) on grass yield. *Journal of the British Grassland Society* **29**, 285–290.

NEWBOLD, J.W. (1981) The control of leatherjackets in grassland by winter pesticide applications. *Proceedings Crop Production in Northern Britain Conference, Dundee, March 1981*. 207–212.

Seasonal Occurrence and Single-treatment Control of Pest Damage in Established Ryegrass

D.J. MOWAT and
S. JESS
Agricultural Zoology
Research Division,
Department of
Agriculture for Northern
Ireland, Newforge Lane,
Belfast, Northern Ireland

ABSTRACT

In 2 experiments, each of which continued through 3 years, frit fly was controlled in plots of Italian or hybrid ryegrasses. Positive yield responses to treatment were almost entirely confined to the period from late July to the first harvest in the following year. Although statistically significant responses occurred at seven harvests the total annual response was never significant and was, on average, only 0.44 t d.m. ha^{-1}*. Present and previous results indicate that this is recoverable by a single pesticide application in mid-July.*

Chlorpyrifos application at that time also controlled leatherjackets when they subsequently appeared in September. As this treatment is known to control the vectors of ryegrass mosaic virus it is suggested that almost all yield losses attributable to arthropod pests are recoverable by one annual application of pesticide.

Introduction

Leatherjackets (larvae of *Tipula paludosa*) are widely regarded as the major pests of established grassland. Damage is most noticeable in spring but the effects may remain detectable until August (White & French 1968) and severe damage may necessitate re-sowing. As *T. paludosa* is univoltine it is controllable by one application of pesticide *per annum*, with treatment in September (when the larvae first appear) giving the greatest yield response (Blackshaw 1984). Control of shoot-fly larvae (Diptera; Chloropidae and Opomyzidae) has given positive yield responses from September to May, when overwintering larvae are present, but little response at other times of year (Mowat 1974). Clements *et al.* (1983) found a relationship between yield responses and shoot/fly larval activity throughout the year, with larval numbers increasing from May to the following winter. Control of unspecified pests by frequent pesticide application has given appreciable yield increases, particularly in experiments including Italian

(*Lolium multiflorum*) and hybrid ryegrasses (Henderson & Clements 1979), the frit fly (*Oscinella frit*) usually being implicated as a probable cause of damage. As the frit fly is the only common shoot-fly in Northern Ireland which is both multivoltine (and therefore not entirely controllable by autumn application of pesticide) and a pest of ryegrass, the impact of different generations on grass yield was investigated in experiments described in this paper. Indications that only the second and subsequent generations might be important prompted further experiments on the effect of treatment, directed against the second generation of frit fly, on subsequent leatherjacket populations.

Materials and Methods

In 2 experiments adult frit fly activity was monitored with yellow water traps, and permethrin (Ambush) was sprayed at 125 g in 500 l/ha on appropriate plots when a generation was developing (Figs 1 and 2). In the first, at Newforge, Belfast, *Lolium multiflorum* (cv. R.v.P.) was sown in August 1981. From 1982 to 1984 plots were cut as a generation was developing (C1), to render them more vulnerable to frit fly damage, or were left uncut until numbers were declining (C2). Plots received 200 or 400 kg N/ha (C1) or 160 or 320 kg N/ha (C2), and 60 kg P and 180 kg K/ha applied from March to September. Plots (10 × 1 m) were cut to 4 cm on dates indicated in Fig. 1. With insecticide-treated and untreated plots at each combination of cutting and fertiliser there were eight treatments, fully randomized in each of 5 blocks.

In the second experiment 5 × 1.5 m plots of *L. multiflorum* (cv. R.v.P.), *L. multiflorum* × *L. perenne* (cv. Sabalan) and *L. multiflorum westerwoldicum* (cv. Weldra) were sown on 8 April, 1982 at Crossnacreevy, Belfast. Fertiliser application from March to September totalled 325 kg N, 64 kg P and 240 kg K/ha in 1982 and 400 kg N, 85 kg P and 320 kg K/ha in 1983 and 1984. Insecticide was directed against all three generations of frit fly or combinations of any two, but dead-heart assessments showed that treatment directed against generations 1 and 3 also controlled generation 2 and the treatment against generations 1 and 2 also controlled most subsequent attack. Plots were cut to approximately 4 cm on dates indicated in Fig. 2. There were 3 fully randomized replicates of 15 treatments.

To investigate the effect of summer applications of insecticide on leatherjacket populations in the following winter, 4 sites in the Belfast area were selected. Chlorpyrifos (Dursban) was sprayed on plots (5 × 2 m) on 13 July, 3 or 24 August or 14 September 1983 (7 d later in each case at site 4). Applications were 0.60, 0.72, 0.96 or 1.44 kg in 340 l/ha on the first three dates. On the last date the two highest rates were omitted. Fifteen treatments were randomized in 3 blocks. From mid-November to early December four 10 cm diam. cores were taken from each plot for leatherjacket population assessment.

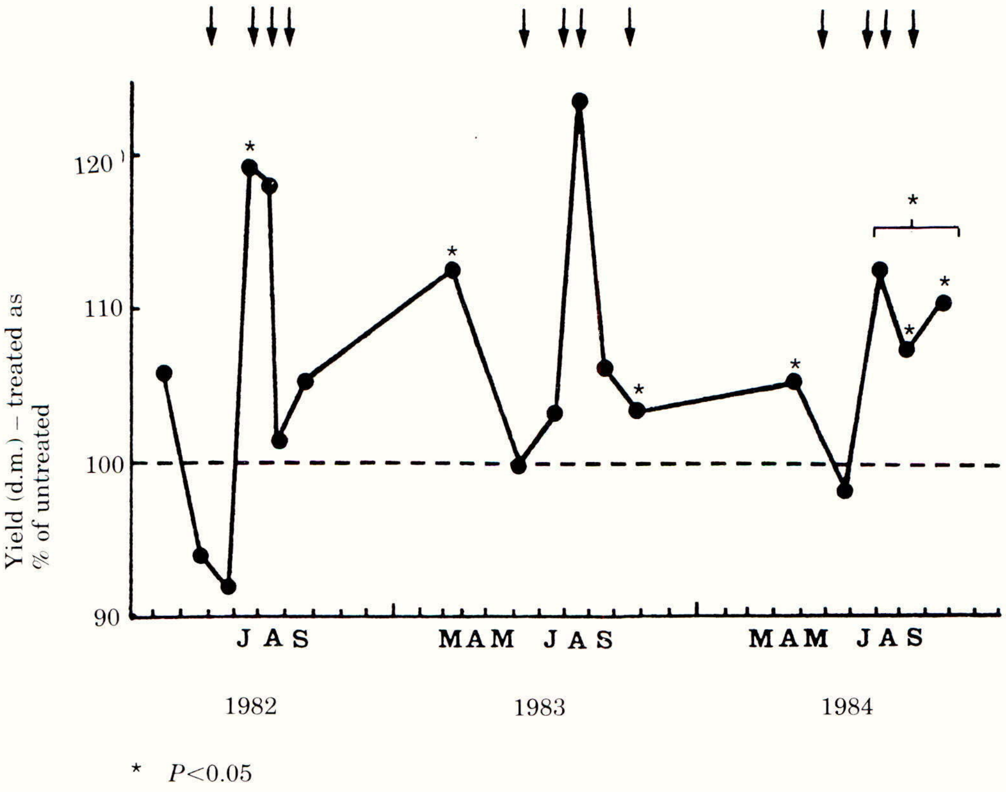
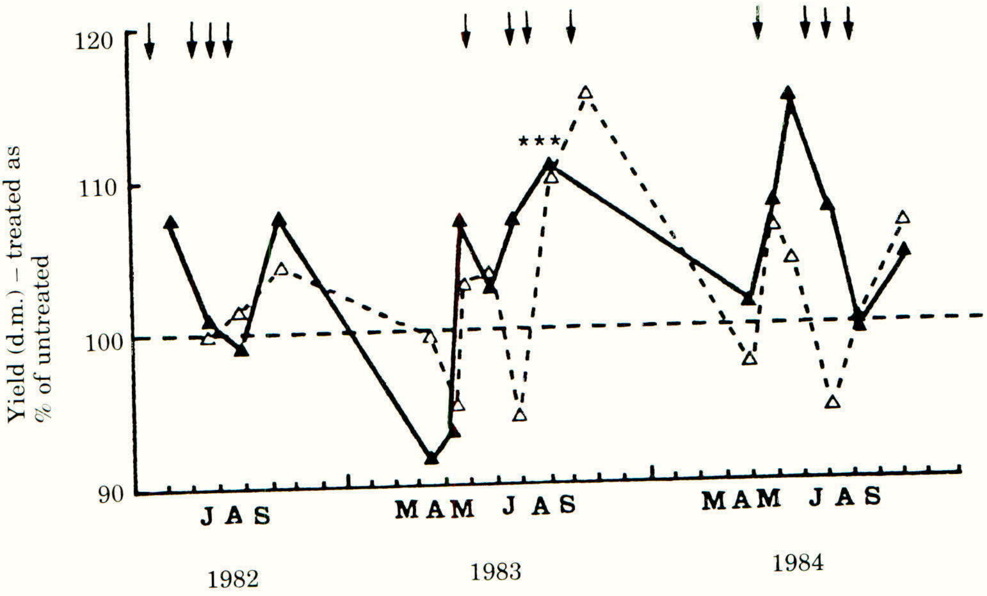


Figure 1: Seasonal response of *Lolium multiflorum* (cv. R.v.P.) (C1) to permethrin application (↓).



*** $P<0.001$

Figure 2: Response of ryegrass (mean of 3 cultivars) to control of all generations of frit fly(—) or of second and subsequent generations (---). In the latter case the first permethin application (↓) in each year was omitted.

Results

In the first experiment control of all generations of frit fly did not significantly increase the annual dry matter yield. The total response to insecticide differed negligibly between the different cutting and fertiliser programmes. The C1 cutting programme clarified the periodicity of response (Fig. 1) and the yield increase of 0.37 t d.m./ha associated with pesticide in C1 from August to the first harvest in the following year, during which period statistically significant increases ($P<0.05$) were recorded at five harvests, was almost identical to the overall annual response of 0.38 t d.m./ha, even though the period was incomplete in the third year.

In the second experiment the total annual response to control of all generations of frit fly averaged −0.13, 0.94 and 0.67 t d.m./ha for R.v.P., Sabalan and Weldra respectively and was significant ($P<0.05$) in the case of Weldra in 1982. The corresponding yield increases associated with the treatment which controlled only the second and subsequent generations were −0.17, 0.43 and 0.61 t d.m./ha. From 16 June 1982 (*i.e.* excluding the first harvest after sowing) to 3 May 1984 yields in plots which received no treatment, all treatments and treatments against generations 2 and 3 only were 27.53, 28.07 and 27.98 t d.m./ha respectively. Significant responses were recorded on 12 September 1983 for the cultivars collectively ($P<0.001$) and for Sabalan alone ($P<0.05$). The unusually prolonged spring response in 1984 was associated with a substantial leatherjacket population. The failure of yields to respond to treatment in late summer, 1984 (Fig. 2) was associated with an apparent failure of control measures, as assessed by dead-heart counts. It was thought that frequent cutting, in relation to slow growth in the dry summer, had produced unsuitable host grass for frit fly thus reducing the infestation (despite large numbers of adults) and giving the impression of poor control through the prolongation of symptoms of damage that had occurred previously. This was supported by the recovery of negligible numbers of larvae from turf samples in November.

In the leatherjacket control experiments all treatments differed ($P<0.001$) from untreated plots with respect to leatherjacket recovery, when analysed with site as one of the variable factors in a single experiment. Chlorpyrifos application at 0.60 and 0.72 kg/ha on 13 (or 20) July reduced numbers by 59 and 81% respectively (Table 1). Excluding site 2, at which the effect of the first application was impaired by the length of grass, the higher of these rates reduced leatherjacket numbers by 88%. Application on 3 (or 10) August reduced numbers by 86% at the lowest rate and by at least 92% at higher rates.

Table 1: Leatherjackets recovered/10 cm diam. sample from 16 November to 8 December following chlorpyrifos application. Square root transformed (and observed) means are presented.

Application rate, kg/ha	Application date			
	13–20 July	3–10 August	24–31 August	14–21 September
0.00	0.74 (0.81)			
0.60	0.43 (0.33)	0.19 (0.11)	0.06 (0.04)	0.10 (0.06)
0.72	0.27 (0.15)	0.10 (0.06)	0.09 (0.05)	0.08 (0.04)
0.96	0.29 (0.28)	0.08 (0.04)	0.00 (0.00)	–
1.44	0.20 (0.13)	0.00 (0.00)	0.08 (0.04)	–
s.e. (mean)	0.083			

Discussion

Although the observation of significant, positive responses to permethrin treatment at seven harvests demonstrated an effect of frit fly on ryegrass yield, the annual increase obtained by controlling all generations averaged only 0.44 t d.m./ha over the 2 experiments and did not indicate major pest status for the species. On only one occasion (14 July 1982 in the first experiment) was a significant increase associated with treatment directed against the first generation and in that case the effect seemed more likely to have been due to residual effectiveness against the early part of an unusually early second generation. Omitting that harvest, and another on 19 July 1983, from subsequent calculations (as such an early treatment has not been shown to control the other pests referred to here) the increase obtained in that experiment from control of the second and later generations from mid-July onwards was almost identical to the annual increase. This was due to a tendency to an opposite response in intergeneration periods. Even during the period of continuous larval presence from late July onwards the response was not cumulative, as also observed by Mowat (1974). In the second experiment the seasonality of response was similar, except as noted above. Deadheart counts showed that permethrin treatment against the second generation remained effective until early winter, and more persistent treatments, such as chlorpyrifos, are available (Mowat & Jess 1985).

In the leatherjacket control experiments all chlorpyrifos treatments except the lowest rate at the first application were considered to be satisfactory. Previous experiments (Mowat 1985) have shown that July application of insecticides, including chlorpyrifos, will control the vectors (Acarina; Eriophyidae) of ryegrass mosaic virus when they appear in autumn, and that the suppression of the population persists until the period of natural decline associated with dispersal in the following summer. Thus all major, common arthropod pests of established ryegrass are controllable by a single application of pesticide directed against the second generation of frit fly, preferably soon after a harvest to improve penetration to the ground for leatherjacket control, to increase the response to frit fly control and to reduce residues on grazed or conserved herbage.

Acknowledgements

We are grateful to Mr R. Hunter for his assistance, to the Agricultural Botany Research Division, D.A.N.I., for provision of a site and assistance in harvesting one of the experiments, and to the Agricultural Biometrics Division, D.A.N.I., for statistical analyses.

References

BLACKSHAW, R.P. (1984) The impact of low numbers of leatherjackets on grass yield. *Grass and Forage Science* **39**, 339–344.

CLEMENTS, R.O.; CHAPMAN, P.F.; HENDERSON, I.F. (1983) Seasonal distribution of stem-boring larvae including frit fly (Diptera: *Oscinella frit* L.) and pest damage in perennial ryegrass. *Grass and Forage Science* **38**, 283–286.

HENDERSON, I.F.; CLEMENTS, R.O. (1979) Differential susceptibility to pest damage in agricultural grasses. *Journal of Agricultural Science, Cambridge* **93**, 465–472.

MOWAT, D.J. (1974) The effect of shoot-fly larvae (Diptera) on grass yield. *Journal of the British Grassland Society* **29**, 285–290.

MOWAT, D.J. (1985) The control of *Abacarus hystrix* (Nalepa) on ryegrass by pesticides. *Record of Agricultural Research, Department of Agriculture for Northern Ireland* **33** (In press).

MOWAT, D.J.; JESS, S. (1985) A comparison of insecticide treatments for the control of frit fly, *Oscinella frit* (L.), in seedling ryegrass. *Grass and Forage Science* **40** (In press).

WHITE, J.H.; FRENCH, N. (1968) Leatherjacket damage to grassland. *Journal of the British Grassland Society* **23**, 326–329.

Nematode Problems of Grassland

R. COOK and P.A. YORK
Welsh Plant Breeding
Station, Plas Gogerddan,
Aberystwyth, Wales

ABSTRACT

This paper reviews WPBS practical experience with three grassland nematodes: clover cyst nematode Heterodera trifolii, *clover stem nematode,* Ditylenchus dipsaci *and the root knot nematode of grasses and cereals,* Meloidogyne naasi. *Information on incidence, population density and evidence for damage to grassland is summarised from surveys of small plots and on-farm trials. Problems in relating nematode numbers and results of experiments with nematicides to potential field losses are discussed. Progress in selecting for defined host reactions to give both resistant and susceptible genotypes is described. In the future, such selections will enable more precise damage assessments without gross disturbance of grassland/fauna dynamic. The potential of resistance can then be evaluated.*

Introduction

Many plant parasitic nematodes are associated with grassland hosts but there are few examples in Britain in which damage is unequivocably associated with any particular nematode. Grassland yield and productivity is the consequence of interactions between plants and environment: the nematode fauna is also complex, comprising not only plant parasites but other trophic groups, interacting with other soil flora and fauna. It is not surprising that direct observation fails to detect nematode induced damage. Treatments to influence plant parasitic nematode populations have other effects which made interpretation difficult. Conclusions from experiments with individual components of the grassland/nematode interaction are difficult to apply to field crops.

Some nematodes are closely host-adapted and specialised in their parasitism. Such specialisation may result in much denser populations compared with more general parasites. This paper outlines experiences with three specialised parasitic nematodes, two of white clover and one of ryegrasses, summarising our work on their incidence, population densities and status as grassland pests. Their host specialisation presents opportunities for the selection of host plant resistance: this may be developed for nematode control but is also of use for more precise damage assessment experiments.

Incidence

CLOVER NEMATODES

Two specialised clover nematodes have been studied: the cyst nematode, *Heterodera trifolii*, and the nematode, *Ditylenchus dipsaci*. *H. trifolii* juveniles hatch and invade roots, developing asexually to females feeding within roots. Eggs hatch on maturation so that several generations per year can be completed in moist soil with active clover growth. The females are preserved as cysts, which protect dormant eggs in cold or dry soils. At this stage it is possible to take soil samples, extract cysts and reliably determine soil infestations. *D. dipsaci* multiplies sexually within stem and leaf tissues, dispersing in soil moisture and reinfesting green tissue. Nematodes can survive drying in plant material but have no dormant or survival stage in moist soil. Soil population densities are often very low and multiplication within the host is rapid, so that reliable population estimates from soil samples cannot be made. Determination of presence of *D. dipsaci* depends upon identification of infested plants, or extraction of nematodes from herbage samples.

Incidence of these nematodes has been determined in established small plot trials, in samples from grazed on-farm trials and from trials on permanent grass. These observations are summarised in Fig. 1. *NIAB trial sites:* of 7 sites 3 were infested by *H. trifolii* with mean densities up to 40 eggs/g soil. Five of the sites were visited and one infestation of stem nematode identified. *GM23 sites:* 12 sites of this GRI/ADAS white clover experiment were examined: 4 were infested by both nematodes and one each by cyst and stem nematode alone. These NIAB and GM23 observations were on small plots where cutting managements favoured white clover content. On the GM23 trials decline of clover appeared to be associated with stem nematode. However, nematode prominence was clearly increased by clover contents, which were high relative to many farm contents. A further series of samples was therefore taken from *NIAB Grazed White Clover trials* sown between 1980 and 1983, situated on farms and subject to farm managements. Twelve sites were visited in spring 1984. Five were infested by *H. trifolii*, 4 in Wales and 1 in Yorkshire. Population densities ranged from 2 to 20 eggs/g soil. At 2 Welsh sites stem nematode infested plants were obvious in the field and *D. dipsaci* was detected in plant samples from 4 other sites. At no site were cultivar differences attributable to nematode damage. Soil samples were also examined from 8 trials sited on permanent grassland, throughout England and Wales (the GRI GF07 trials). *H. trifolii* was present in all sites, although in 2 only empty cysts were detected. The 6 viable populations ranged from 2 to 18 eggs/g soil.

These observations confirm the rather widespread incidence of both *H. trifolii* and *D. dipsaci* on white clover. A previous survey (Cook & York 1980) detected *H.*

trifolii in 75% of 67 Welsh grassland samples, incidence increasing with age of pasture. That similar proportions of established small plot trials and on-farm sites were infested with both nematodes suggests that their prominence may increase with increased clover content. Population densities of *H. trifolii* in excess of 100 eggs/g soil have been recorded in some trial plots. Such densities were not maintained in subsequent seasons. The occurrence of fungal pathogens of cysts was noted at some NIAB sites and seems to be a widespread phenomenon (R.A. Plowright, pers. comm.).

GRASS NEMATODES

The root-knot nematode, *Meloidogyne naasi* invades roots of many gramineae. On hosts, root galls are produced in which females mature and lay eggs into gelatinous egg masses within the gall. Although males are often present, *M. naasi* is said to reproduce by meiotic parthenogenesis. There is a single generation/year from spring hatch and invasion. Females are not persistent but egg masses survive overwinter within galled roots. Determination of infestations can be made by hatching juveniles from soil. This gives a reliable initial population estimate if samples collected in autumn are chilled before extraction.

M. naasi is widely distributed especially in Wales and western England. In Wales some 75% of spring barley fields and 46% of grassland sites are infested. Short term leys are more commonly infested than older grassland (Cook & York 1980). Incidence of *M. naasi* has increased as a consequence of the decline in oats (a non-host) and its replacement by barley in arable/ley rotations. In our recent samples from NIAB grazed trials the 3 south Wales sites and one in Devon were infested. None of the GF07 sites, all on permanent grass, were infested.

Populations of up to 200 juveniles/g soil under grassland in winter are commonly found. Populations on barley (except winter barley which seems a less suitable host) may exceed this density. The dynamics of *M. naasi* in grassland are currently under investigation; in some cases populations are maintained at high densities whereas low, stable populations, in one case persistencing for at least 20 years, are known.

Damage

H. TRIFOLII

Damage assessment with *H. trifolii* in controlled inoculations and a field experiment with nematicides on infested soil has shown clover losses at establishment and subsequently (Cook *et al.* 1983; Plowright & Cook 1984). Seedlings were significantly smaller after 8 weeks in soil infested with 20 eggs/g soil than in uninfested soil. Higher densities killed some seedlings. Four week old seedlings of cv. Olwen planted with or without S.23 perennial ryegrass yielded less in 3 cuts over 6 months in soil infested with 20 juveniles/g soil than in uninfested controls. Yield reductions were 92% in mixture and 80% in monoculture. In the infested mixture most clover had died by the end of the experiment. In a field trial control of up to 20 eggs/g soil of *H. trifolii* with topical post-harvest applications of aldicarb (5 kg a.i./ha) increased yield per established clover plant. In another trial clover growth over 2 years was good, mean yields being 7666 and 6540 kg/ha in years 1 and 2. *H. trifolii* densities increased to between 20 and 116 eggs/g depending on nematicide treatment. However year 3 yields were not correlated with *H. trifolii* density.

Population densities used in these experiments are similar to those found in fields and plots. These observations therefore suggest that cyst nematode may be a factor in clover decline or unpredictability. Patchy distribution of both nematode and clover and their dynamic interrelationship make it difficult to relate yields directly to nematode numbers.

D. DIPSACI

Damage by stem nematode is obvious when it occurs in previously dense clover swards. It is often seen in spring when damage may be ascribed to winter kill. However close examination shows the infested buds associated with dead stolons. Clover may re-establish in infested patches after *D. dispaci* numbers have declined or environmental conditions are less favourable for the nematode. Damage is often seen in 3–4 year old swards, although some first winter damage is commonly seen on WPBS plots. In one case, a trial sown at Pant-y-dŵr Hill Station, damage was first apparent in early winter of the sixth year, presumably the shorter growing season and lower temperatures in the hills giving slower rates of nematode multiplication. In a field trial on a well infested site yields of 4 cultivars were related to stem nematode infestation. Control of the nematode with aldicarb gave higher yield increases for two more susceptible cultivars, S.184 and Katrina than for more resistant cultivars Donna and Alice. These differences were especially marked at early cuts in the first harvest year (Evans & Cook 1983). However, the yield differences did not persist into the second year when all plots became clover dominant. It seems probable from the association of stem nematode with clover decline in some GM 23 trials (Cook *et al.* 1983), from improved establishment after nematicide treatment of infested soil, and from direct observation of *D. dipsaci* patches, that this nematode can cause a perturbation in clover population dynamics. The consequences may be reduced yield over short periods or long term loss of clover, depending upon the interaction with other factors.

M. NAASI

Damage is most likely to spring seeded or undersown ryegrass. Indeed such losses have been demonstrated using aldicarb at drilling (Cook & York 1980). Controlling 38 juveniles/g soil resulted in first year yield increases of 30 and 20% for cvs. Cropper and S.23. Better establishment of plants with more tillers occurs when *M. naasi* is controlled. Other observations associate patchy leys with very dense *M. naasi* populations. Population dynamics on grassland have not been much studied. Recent observations have recorded a presowing population of 45 juveniles/g soil increasing to 277 juveniles/g on spring sown ryegrass, compared with 87 on spring barley. A ryegrass/clover ley became dominated by clover as the *M. naasi* population increased to 150 juveniles/g in the second and third year. Such observations suggest that invasion damage to spring root growth may have longer term effects on grass productivity. Damage to established swards is difficult to relate to population densities since weaker plants support fewer nematodes.

Host Resistance

Resistant plants are ones in which nematode reproduction is prevented or reduced relative to susceptible controls. It is distinct from tolerance – the ability of plants to grow and yield well when infested. Resistant perennial plants outyield susceptibles since their resistance limits nematode increase.

H. TRIFOLII

No differences in mean susceptibility have been detected between white clover cultivars. However, selections have been made of genotypes which differ in the number of females developing. Clones from susceptible plants had a mean 116 females/plant from first generation invasion. Resistant clones with as few as 16 females/plant have been isolated. The proportion of white clover genotypes with such resistance is low: rather more red clovers were resistant. These selections must be tested with diverse *H. trifolii* populations to confirm the potential value of their resistance. Resistant and susceptible selections are being clonally propagated to establish swards for long term damage assessment.

D. DIPSACI

Varietal differences have been recorded on naturally infested spaced plants. Laboratory tests of seedlings or cuttings have not always been successful. Selection has been for plants which, whilst invaded (stunted as seedlings), fail to produce the hypertrophied susceptible response. Symptoms are assessed from 2 weeks after inoculation of buds or seedling growing points. Symptom development depends upon (a) invasion success (b) tissue susceptibility and (c) plant growth rate. Susceptible is better expressed in winter, or when plants grow slowly allowing nematodes to become established and reproduction to overcome tissue differentiation and escape. Non-hosts of the white clover race (e.g. lucerne, red clover) can be invaded and express 'susceptibility' at the seedling stage, but later older plants are nematode free. White clover cultivar S.184 has a high % of seedlings developing the susceptible reaction more quickly than others e.g. Donna. Resistance does not appear to be related intrinsically to leaf size and stolon numbers: however, larger leaved cultivars with fewer larger stolons may escape invasion more readily than smaller, more prostrate genotypes. In the presence of high densities of stem nematodes there may be selection for resistant seedlings in field sowings. However, avoidance of infection through stolon elongation may be a survival mechanism.

Currently, selections which have remained symptomless after 3 cycles of clonal propagation and inoculation are being compared with susceptible selections from three cvs. (S.184, Katrina and Donna) to evaluate their resistance to stem nematode spread and damage.

M. NAASI

Tests over a number of years at WPBS have shown clear differences in host status of grasses as measured by differences in the degree of galling and the number of egg producing females. Species differences are very marked: ryegrasses are very good hosts, fescues rather worse and timothy and cocksfoot much poorer. There are also cultivar differences within ryegrasses and these appear to be transmitted to ryegrass/fescue hybrids. Initial tests suggested that from within both good and poor host grass species it was possible to identify genotypes of extreme susceptibility or resistance. Subsequently, carefully controlled inoculation of seedling populations of 2 perennial and 5 Italian ryegrasses has permitted the selection of plants of defined host status. Between 3 and 20 resistant plants from 150 were selected on the basis of 5 or less galls/plant. Similar numbers of susceptibles with 70 or more galls have been selected. Microscopic evaluation showed these low and high gall lines to have few and many egg producing females respectively. This material will form the parents of polycrosses to provide seed stocks of *M. naasi* selected populations. Confirmatory tests on vegetatively propagated stocks are being made.

Conclusion

Selections of white clover and ryegrasses resistant and susceptible to three common and potentially damaging grassland nematodes provide a useful way forward in assessing nematode damage. They will allow precise experimentation with limited disturbance of the grassland dynamic. It should be possible to control nematode populations in such a way as to quantify their pest status. Such an approach has to be justified by reference to initial assessments of nematode significance.

Acknowledgements

We are grateful for the help and cooperation of NIAB Trials Officers and GRI staff in providing access to, or samples from, their trials.

References

COOK, R.; PLOWRIGHT, R.A.; RUSHTON, W.H.; BOWLING, P.J. (1983) Effect of nematodes on white clover establishment and persistence. *Report of the Welsh Plant Breeding Station for 1982*, pp. 67–69.

COOK, R.; YORK, P.A. (1980) Nematodes and herbage improvement. *Report of the Welsh Plant Breeding Station for 1979*, pp. 177–207.

EVANS, D.R.; COOK, R. (1983) Effects of aldicarb on stem nematode infestation and yields of white clover cultivars. *Report of the Welsh Plant Breeding Station for 1982*, pp. 48–50.

PLOWRIGHT, R.A.; COOK, R. (1984) Effects of clover cyst nematode on the establishment and yield of clover. *Report of the Welsh Plant Breeding Station for 1983*, pp. 97–98.

Figure 1: Incidence of clover cyst nematode (*Heterodera trifolii*) and stem nematode (*Ditylenchus dipsaci*) at trial sites, 1981–1984

Assessment of Disease in Grassland

M.R. THOMAS
Disease Assessment
Branch, MAFF,
Harpenden Laboratory,
Harpenden, Herts

ABSTRACT

Diseases have been shown to affect both yield and quality in the grass crop. Little information exists, however, relating losses to known levels of disease. Recent evidence suggests that significant losses may be occurring at much lower levels of disease than would be expected from experience with the cereal crop. The methods used to estimate crop losses with regard to the grass crop are outlined. In order to quantify such low levels of disease a method of assessment is descibed which should standardise disease recording and allow realistic relationships to be applied to disease appraisal studies.

Introduction

One principal objective to disease assessment is to establish a relationship between disease levels as observed in the field and the resultant losses than may be occurring in the crop. The consequences of such a study lie in the establishment of economic damage thresholds and the ability to estimate national losses caused by diseases. Such estimates allow an appraisal, on economic grounds, of policies for long term disease control through management, resistance breeding or chemical control. These political considerations are generally beyond the scope of this paper but it is noted that the current round of cut backs in the funding of agricultural research are likely to continue into the foreseeable future and it is not sufficient to state vaguely that diseases are likely to cause a loss. Any losses must be clearly quantified and related to an agent against which appropriate action may be taken, particularly if further funding is to be justified.

Unlike many crops on which disease-level/yield-loss studies have been undertaken, the grass crop offers a complex system where a direct relationship between assessable damage and fresh or dry matter yield is only one step in a chain of economically important losses that may be occurring. Grass on its own is rarely sold other than through the rental of grazing rights and is a difficult commodity on which to attach a value. Consequently, its value is generally thought of in terms of livestock production and losses must be assessed with regard to the end product, the grazing animal.

Grass diseases cause losses in the form of reduced growth and yield which will indirectly affect the animal by providing less grass per unit area, with obvious economic consequences. However, other effects of disease such as reductions in nutritive value, lowering of palatability and changes of sward type more commonly affect the animal by causing changes in acceptance and feeding habits, and may result in more serious losses in the long term.

Many diseases on a diverse range of fodder crops have been shown to reduce nutritive value by lowering digestibility, usually expressed as the percentage digestible organic matter or D value (Davies *et al.* 1970; Gross *et al.* 1975; Isawa 1983), water-soluble carbohydrate (Carr & Catherall 1964; Lancashire & Latch 1966; Isawa 1983) or protein (Lancashire & Latch 1966; Mainer & Leath 1978; Isawa 1983).

Both crown rust (*Puccinia coronata*) and scald (*Rhynchosporium orthosporum*) have been shown to affect palatability, and badly infected plants are commonly rejected by sheep and cattle (Cruickshank 1957; Latch 1966).

Indirectly, yields may fall because of undesirable changes in botanical composition, as preferred species give way under pathogen pressure to agriculturally inferior but more resistant and aggressive species (Michail & Carr 1966; Carr 1979).

Disease assessment must clearly take into account all these factors and, therefore, in addition to yield studies, changes in quality, percentage ground cover of preferred or sown species and livestock preference may also require consideration.

Crop Loss Estimation

Several approaches have been used to establish the relationship between disease levels and loss in a range of crops.

Single Plant Methods

This method involves the use of large numbers of single plants or tillers which are tagged for leaf diseases or sampled for root diseases and, in the case of cereals, are threshed individually when ripe. Because of the heterogeneity within even single varieties of ryegrass species, this method is wholely unsuitable for yield loss work though the method has proved useful in investigations of the effect of varying but low levels of foliar disease on quality (Lam 1985).

Field Plot Methods

These methods rely on the establishment of conventional field plot experiments and may employ three techniques for contriving a range of disease levels, including a disease/free treatment, for comparisons of yield and quality loss.

PLOT INOCULATION

Artificial inoculation methods have been successfully used in cereals (King *et al.* 1983) but are somewhat labour intensive and prone to failure if the environmental conditions subsequent to inoculation are unsuitable for disease development. Little has been done along these lines with grasses in the field though production losses for ryegrass infected with *Drechslera* species have been investigated in the laboratory (Cook 1975). The following methods are thought to be more suitable.

FUNGICIDES

Perhaps the most widely used technique for the modification of disease levels is through the controlled application of fungicides. Many of the established relationships between disease levels and likely losses have been derived using this method (Lancashire & Latch 1966; Davies *et al.* 1970; O'Rourke 1972, 1982; Lam & Lewis 1983).

CULTIVARS

The use of cultivars that vary in susceptibility to disease but whose heading and yielding characteristics under disease-free conditions are similar offers an ideal opportunity to investigate the effects of a disease without the complications of fungicide side-effects.

At present, the most suitable method for quantifying disease impact on agriculturally important grasses would seem to be through the combined use of fungicide applications and varietal variability. The use of small plots established specifically for such yield-loss work using comprehensive plot management and mechanised harvesting is likely to be the most profitable way of establishing a relationship. This method is currently employed in a series of regional trials run jointly between the ADAS and NIAB.

Current Methodology

Yield and Quality Assessment

To date, all ADAS trials have used the NIAB standard plot size of 5 × 1.3 m. Harvesting has been carried out using an Haldrup harvester where possible, with a cutting frequency based on the UK National List conservation regime (NIAB 1985). Fresh weight yield is determined by harvesting the whole plot and dry matter production calculated from a sub-sample of approximately 400 g, dried at 105°C for 8 h. This dried and milled sample is then used to determine digestibility, water-soluble carbohydrate and protein content using ADAS methods 33, 14 and 55 respectively from Reference Book 427 (MAFF 1979).

Disease Assessment

The Manual of Plant Growth Stages and Disease Assessment Keys prepared by ADAS (MAFF 1976) offers three keys for the assessment of ryegrass diseases. Keys 5.2.1 and 5.3.1 allow the assessment of leaf area damage from lesions of brown blight (*Drechslera siccans*) and pustules of crown rust respectively. Key 5.1.1 is a leaf area guide allowing the area covered by lesions to be assessed for leaves of different sizes and is in the form of a nomogram. Lam (1983) has criticised this latter key as it does not allow for the differences in shape between Italian and perennial ryegrass leaves and takes no account of the tapering of leaf tips. She has produced an improved version for each species and it is recommended that these area guides are used whenever single leaf assessment is considered.

One difficulty with all the keys, however, is the absence of any instructions on sampling. The pitfalls of small sample sizes when single tillers of a cereal crop are considered have been pointed out by King (1980). In order to decrease the standard error of a mean of n tillers by a factor F it is necessary to increase the sample size to approximately F^2n tillers. To achieve a reproducible assessment of the level of disease in a cereal crop somewhere in the region of 100–200 tillers would have to be assessed. The problem is exacerbated in grass trials because of the increased variability between plants resulting from the wider genotypic diversity inherent in outbreeding systems. One of the principal characteristics of diseases in grass lands is that they often occur at very low levels, usually below 5% leaf area damaged (Lam & Lewis 1983; Thomas 1983). Recent evidence (Lam 1985; Thomas unpublished) has shown that even at these low levels a significant reduction in quality may occur. Clearly an alternative method of assessment needs to be adopted where large numbers of plants are assessed collectively by eye at several points across the plot.

The method currently used by ADAS involves assessing each plot at four sampling points selected at random across the plot. In dense and flowering crops the foliage should be parted to expose the lower leaves. At each point an area of approximately 25 cm diam. is studied and for each disease a record is made of two factors:

Firstly the percentage of incidence is estimated. Dead leaves are excluded but the green areas of senescing leaves are included. Thus, an incidence of one infected leaf in three is 33%, one leaf in five is 20% etc. Similarly for high levels of disease incidence one, disease-free leaf in 20 would be 95% incidence etc.

Secondly the average percentage infection on infected leaves is estimated. By ignoring leaves not infected by the pathogen being assessed, a normal distribution of disease may be assumed, irrespective of the level of disease. At this point recourse to ADAS Keys 5.1.1–5.3.1 may be helpful in familiarising the assessor's eye withthe level of disease encountered.

The level of a given disease at each sampling point expressed as % leaf area damage (LAD) is computed as:

$$\% \text{ LAD} = \frac{(\% \text{ incidence} \times \% \text{ infection on infected leaves})}{100}$$

The level of a given disease for the plot as % LAD is taken as the mean of the four sampling points. This method has the advantage over other assessment methods of allowing reasonably accurate assessments of very low levels of disease. For example, it is not difficult to assess an incidence level of 5% for a pathogen that has an average severity on infected leaves of only 3%. The overall %LAD for the plot is then 0.015%, a figure that would be very difficult to derive from tiller assessments involving less than 100 tillers and unlikely to be achieved by a whole plot method.

Maintaining Disease-free Plots

The maintenance of disease-free grass plots using fungicides has proved something of a problem in comparison to other crops because of the continued defoliation resulting from harvesting. Though this can have the advantage of removing sources of inoculum, it also removes fungicide-treated foliage and encourages the growth of fresh, untreated material. An optimal spraying regime has been adopted by ADAS where 6–7 sprays are applied annually. These are timed to fall 10–14 d after harvest to protect regrowth, in November or December to protect over-wintering plants and in February/March and optionally 6 weeks later to protect spring growth up to the first harvest. However, intensive spray programs such as these have not protected crops completely from *Drechslera* diseases; even with broad spectrum systemic fungicides such as propiconazole. More intensive programs have resulted in phytotoxicity which has reduced yields (Thomas unpublished) and unless more efficient fungicides become available a certain amount of disease must be tolerated.

Further problems arise with weed control. The failure of plants to establish as a result of disease problems, and subsequent ingress of weeds is an important aspect of disease assessment but little thought has been given to the impact of fungicides on weed growth. Many weeds themselves suffer considerably the ravages of disease attack and respond well through increased growth and competitive ability to the therapeutic effects of fungicide application. This must be borne in mind before a series of trials is established, and weed control, or compensation for the absence of weed control, must be included in the overall design.

Discussion

Work to date suggests that diseases are a problem in the grass crop and may be alleviated through three main strategies: (a) management practices aimed at minimising damage through earlier harvesting and planned fertiliser applications (b) development of cultivars with improved resistance to the most important diseases or (c) the introduction of chemical control. As has been pointed out by James (1974), economic control of disease is not the aim of experiments in disease-loss appraisal and several applications of fungicide within one season are consequently justified. This must not be taken, however, as a recommendation for adopting fungicide use on grasslands. At present there is a strong environmental lobby which would oppose the widespread introduction of pesticides on a crop that occupies some 70% of the total agricultural area of the UK.

The natural genotypic heterogeneity of the crop, even within a single phenotypically uniform variety, should ensure that any selected resistance is of an horizontal nature. It would, therefore, be less likely to be eroded than the major gene resistance that has in the past been incorporated into cereals and potatoes.

Sound management to avoid, where ever possible, the build-up of disease to levels likely to cause a loss, is an obvious prerequisite of any intensive farming system, and fodder production is no less important in this respect. However, in an area where a particular pathogen has frequently caused losses in the past, we will not know if the sowing of a more resistant variety will in reality solve future problems without at least some effort being invested in disease assessment studies on these situations. Now that some idea has been gained of the losses that can occur and the diseases that cause them, I would suggest that future research should move from small plot/fungicide trials to extension advice and the monitoring of its effects in the growing crop on the farm scale.

References

CARR, A.J.H. (1979) Causes of sward change – diseases. In *Changes in sward composition and productivity,* (Eds A.H. Charles and R.J. Haggar) pp. 161–166, *Occasional Symposium No. 10, British Grassland Society,* pp. 253.

CARR, A.J.H.; CATHERALL, P.L. (1964) The assessment of disease in herbage crops. *Report of the Welsh Plant Breeding Station 1963.*

COOK, F.G. (1975) Production loss estimation in *Drechslera* infection of ryegrass. *Annals of Applied Biology* **81**, 251–256.

CRUIKSHANK, I.A.M. (1957) Crown rust of ryegrass. *New Zealand Journal of Science and Technology Series A* **38**, 539–543.

DAVIES, H.; WILLIAMS, A.E.; MORGAN, W.A. (1970) The effect of mildew and leaf blotch on both yield and quality of *Lolium multiflorum. Plant Pathology* **19**, 135–137.

GROSS, D.F.; MANKIN, C.J.; ROSS, J.G. (1975) Effect of disease on in vitro digestibility of smooth bromegrass. *Crop Science.* **15**, 273–275.

ISAWA, K. (1983) Deterioration in the chemical composition and nutritive value of forage crops by foliar diseases. III. Chemical composition and nutritive value of forage crops infected with Helminthosporium diseases. *Bulletin of the National Grassland Research Institute, Japan* **24**, 41–56.

KING, J.E. (1980) Cereal survey methodology in England and Wales. *Proceedings of E.C. Stakman Commemorative Symposium. Minneapolis 1980. Assessment of losses which constrain production and crop improvement in agriculture and forestry. University of Minnesota Agricultural Experiment Station. Miscellaneous Publication 7.*

KING, J.E.; JENKINS, J.E.E.; MORGAN, W.A. (1983) The estimation of yield losses in wheat from severity of infection by *Septoria* species. *Plant Pathology* **32**, 239–249.

LAM, A. (1983) Leaf area guides for assessing fungal leaf diseases of ryegrasses (*Lolium* spp.). *Plant Pathology* **32**, 213–215.

LAM, A. (1985) The impact of fungal diseases on in vitro digestibility and chemical composition of Italian ryegrass and tall fescue foliage. *Plant Pathology* (In press).

LAM, A.; LEWIS, G.C. (1983) Chemical control of foliar diseases of perennial ryegrass (*Lolium perenne* L.) and their effects on yield and quality of the crop. *Crop Protection* **2**, 75–83.

LANCASHIRE, J.A.; LATCH, G.C.M. (1966) Some effects of crown rust (*Puccinia coronata* Corda) on the growth of two ryegrass varieties in New Zealand. *New Zealand Journal of Agricultural Research* **9**, 628–640.

LATCH, G.C.M. (1966) Fungus diseases of ryegrasses in New Zealand I. Foliage diseases. *New Zealand Journal of Agricultural Research* **9**, 394–409.

MAFF (1976] Manual of Plant Growth Stages and Disease Assessment Keys. *Pinner: Ministry of Agriculture, Fisheries and Food Publications.*

MAFF (1979) *The Analysis of Agricultural Materials. RB427.* London: Her Majesty's Stationary Office.

MAINER, A.; LEATH, K.T. (1978) Foliar diseases alter carbohydrate and protein levels in leaves of alfalfa and orchardgrass. *Phytopathology* **86**, 1252–1255.

MICHAIL, S.H.; CARR, A.J.H. (1966) Italian ryegrass, a new host for *Ligniera junci. Transactions of the British Mycological Society* **49**, 411–418.

NIAB (1985) *Technical Leaflet No. 2: Grasses and Legumes for Conservation 1985.* Cambridge: National Institute of Agricultural Botany.

O'ROURKE, C.J. (1972) *Research Report Plant Sciences Division An Foras Taluntais, Dublin 1971*, 24–25.

O'ROURKE, C.J. (1982) Losses caused by disease in Irish Grassland. *Pesticide Science* **13**, 318–322.

THOMAS, M.R. (1983) Disease Assessment in *Lolium perenne* with particular reference to *Drechslera* species. PhD Thesis, University of Wales.

The Influence of Viruses on Grassland

S.J.I. HOLMES
West of Scotland
Agricultural College,
Auchincruive, Ayr,
Scotland

ABSTRACT

Ryegrass mosaic virus (RMV) and barley yellow dwarf virus (BYDV) are perhaps the most important of the 22 or so viruses which have been identified in agricultural grasses. Both are widespread in ryegrass in the UK. RMV rapidly invades newly sown leys, and can cause dry matter yield losses of up to 26%. Digestibility and water soluble carbohydrate are also reduced, and RMV can exacerbate winterkill. Although BYDV is largley symptomless in ryegrass, it can significantly reduce yields, and cause important changes to plant morphology and the pattern of seasonal productivity. Furthermore, BYDV-infected ryegrass serves as an important source of the virus and its aphid vectors for the infection of autumn-sown cereals. The control of virus diseases in agricultural grasses depends on the breeding of resistant cultivars. Some delay in virus spread in short term leys can be achieved by manipulating the management, but control of vectors with pesticides is largely uneconomic.

Introduction

There is accumulating evidence that diseases of grassland caused by viruses may be important factors limiting grass production. Viruses are ideally adapted to survival and spread in grass crops for, unlike fungi, they are systemic in the plants and can survive, and may even be spread by, the frequent cutting and grazing to which crops are subjected. Many viruses do not induce dramatic changes in the appearance of the crop, and it was not until detailed analyses were made of yield and quality that their potential was realised. The more important grass viruses are listed in Table 1. Whilst some of these (e.g. cocksfoot mottle) may be locally damaging, there can be no doubt that those viruses which infect ryegrass are of greatest importance nationally. Ryegrass mosaic virus (RMV) and barley yellow dwarf virus (BYDV) occur in ryegrass throughout the UK, and it is these which are dealt with in detail in this paper.

Ryegrass Mosaic Virus

The extensive infection of ryegrass by RMV has been demonstrated in surveys carried out in England (Heard *et al.* 1974), Northern Ireland (Cooper and McDowell 1978) and western Scotland (Holmes 1977).

RMV is spread by the eriophyid mite *Abacarus hystrix,* and mechanically in sap when leaves of infected plants are rubbed or crushed against those of healthy plants, as may occur during cutting and grazing. Although sap transmission occurs readily under experimental conditions, it may be less important than spread by mites in farm crops (Gibson & Plumb 1976). RMV is principally a disease of ryegrass although it can infect a range of graminaceous hosts including *Avenae sativa, A. fatua, Agrostis* spp, *Bromus* spp and *Dactylis glomerata.* Infection of newly sown leys is often rapid, and RMV may be found within months, or even weeks of sowing. The extent of infection within a crop tends to reach its peak after about 5 years, and then may decline as the susceptible members of the heterogeneous plant population die out to be replaced by more resistant plants. Plants of perennial, Italian and hybrid ryegrass infected with RMV develop a pale green or yellow flecking or streaking of the leaves. A more severe chocolate-brown necrotic streaking or flecking is caused by some isolates of the virus, and this can result in leaf or tiller death.

Effect of RMV on Grass Productivity

YIELD

The effect of RMV on ryegrass yield is influenced by a number of factors including, time of year, prevailing weather conditions, nutritional status (particularly nitrogen), ryegrass species and cultivar and virus strain. The biggest losses are likely to occur at the first cut in crops grown under a high nitrogen regime. For any one cultivar, the more severe the symptom development then the greater is the loss in yield, although different cultivars with the same severity of symptoms may not suffer a similar yield loss (Holmes, unpublished data). As a general rule, perennial ryegrass tends to be more tolerant to infection than Italian, and tetraploid Italian cultivars more tolerant than diploid (Doherty & Doodson 1980).

Yield reductions of up to 26% for perennial ryegrass (A'Brook & Heard, 1975) and 20% for Italian ryegrass (Jones *et al.* 1977) have been recorded. The importance on RMV in high input systems can be illustrated by the results of a trial on Italian ryegrass cv. S22 conducted at Auchincruive (Holmes 1980a). The season's dry matter yield of infected grass grown under a high nitrogen regime (378 kg ha^{-1} N) was reduced by the equivalent of 3.6 t/ha, and that of grass grown at a lower nitrogen level (189 kg ha^{-1} N) by 3.0 t/ha. Whilst the reductions at both nitrogen levels were about 15% compared to the comparable uninoculated controls, the yield of infected grass grown at the higher nitrogen level (20.4 t/ha) was less than that of healthy grass grown at the lower nitrogen level (21.0 t/ha). In other words, the virus had completely eliminated the benefits which should have been gained from the application of an extra 189 kg ha^{-1} N.

Table 1: Main virus diseases of agricultural grasses in Britain

Virus	Host(s)	Vector(s)
Sap transmissible		
Ryegrass mosaic	Ryegrass, fescue, cocksfoot, oat	Mites (*Abacarus hystrix*)
Cocksfoot mottle	Cocksfoot and cereals	Beetles (*Oulema* spp)
Cocksfoot streak	Cocksfoot and cereals	Aphids (e.g. *Myzus persicae*)
Cocksfoot mild mosaic	Cocksfoot, timothy, fescue and cereals	Beetles (*Oulema* spp) and aphids (e.g. *M. persicae*)
Non-sap transmissible		
Barley yellow dwarf	All agricultural grasses and cereals	Aphids (e.g. *Rhopalosiphum padi*)
Ryegrass chlorotic streak	Ryegrass and cereals	Aphids (*R. padi*)
European wheat striate mosaic	Ryegrass and cereals	Planthoppers (*Javesella* spp)
Oat sterile dwarf	Ryegrass and cereals	Planthoppers (*Javesella* spp)

Source: Catherall (1981)

Estimating the loss in yield in farm crops is difficult due to the complex management to which grass is subjected. However, in 1979 an attempt was made in 4 predominantly ryegrass swards (Holmes, 1980b). The assessments were made before the first cut at the end of May, and the results are summarised in Table 2. The dry matter yield loss of infected tillers varied considerably from field to field and presumably reflected differences in cultivar response to infection and nutritional status. As might be expected, where there was little infection the estimated yield loss was relatively small. In fields with a higher level of infection losses of up to 10% were predicted.

QUALITY

RMV has been found to have a significant effect on ryegrass quality (Holmes 1979). In 1976, a year in which RMV was particularly severe in the west of Scotland, sufficient infected material was collected from ten farm crops for chemical analyses to be conducted (Table 3). RMV infection was associated with a

Table 2: Estimated loss in dry matter yield in fields of perennial ryegrass infected with RMV – May 1979

Field	% d.m. yield loss of infected tillers	% Ryegrass content	% Tiller infection	Estimated % d.m. yield loss in crop
Donald's Thorn	12.9	85.0	18.6	2.0
Garden Holm	22.7	90.0	13.3	2.7
Mid Holm	13.7	95.0	65.4	8.5
North Holm	23.2	90.0	40.0	10.0

Source: Holmes (1980)

a significant reduction in the percentage organic matter, although the actual loss was small. There was, however, a most marked effect on the digestibility of the organic matter from grass which had the mottle + necrosis symptom, and this was significantly lower than that of the material with mottle only. Water soluble carbohydrate levels showed a similar pattern to digestibility. The D value of samples with mottle + necrosis was reduced on average by 5.4%, and even that of samples with leaf mottle was reduced by 1.8%.

Table 3: The effect of RMV on the quality of ryegrass

RMV symptoms	* % d.m.			
	Organic matter	Digestible organic matter (*in vitro*)	Water soluble carbohydrate	D† value
None	90.9	78.2	17.0	71.0
Leaf mottle only	90.1	76.8	14.5	69.2
Necrosis + leaf mottle	89.9	73.0	11.9	65.6
l.s.d. ($P = 0.05$)	0.46	1.2	2.1	1.2

* Mean of 10 fields

† D value $= \frac{\text{\% organic matter} \times \text{digestibility of organic matter}}{100}$

Source: Holmes (1979)

WINTERKILL

In 1975 A'Brook & Heard noted the possible involvement of RMV in the winterkill complex. This observation was reinforced by more recent data obtained at Auchincruive. During the winter of 1982 death of tillers was observed in field plots of 48 ryegrass cultivars sown in August 1981. The indications were that tiller losses were more extensive in those plots inoculated with RMV in the spring of 1982. An assessment of tiller numbers in June 1983 revealed this to be the case. Inoculated plots of perennial ryegrass (33 cultivars) had an average 16.4% fewer tillers than uninoculated plots. The loss in inoculated plots of Italian ryegrass (15 cultivars) was much higher, averaging 31.8%. Worst affected of the Italian ryegrass cultivars were Lema (73% reduction), Lipo (65%) and Delecta (62%). Whilst reductions in tiller numbers of perennial ryegrass varied between cultivars, none exceeded 40%. The involvement of RMV in winterkill is further complicated by evidence of a synergistic interaction between it and the common soilborne fungus *Fusarium nivale*, which can result in damage in excess of that caused by either pathogen individually (McMillan & Holmes, unpublished data.)

Barley Yellow Dwarf Virus

Although perhaps better known as a damaging disease of cereals, BYDV is in fact far more widespread in grass. For example, Doodson (1967) conducted a survey of perennial ryegrass cv. S24 crops in England and Wales in 1966 and found that 104 of the 112 examined were infected. In south-west Scotland, BYDV occurred in 26 of 37 ryegrass swards sampled in 1976 (Holmes 1977).

BYDV is frequently symptomless in ryegrass, and only rarely has widespread symptom development been reported (e.g. Carr 1965). The best time to look for foliar discolouration is prior to the first cut when two types of symptom may occur. The first develops on tillers which are apparently growing vigorously. The leaves show a pale golden yellow, orange, red or deep red to purple discolouration, often extending from the leaf tip down the leaf blade. Italian ryegrass usually shows this symptom particularly well, although in both perennial and Italian ryegrass it could easily be attributed to environmental or nutritional causes. The second type of symptom involves severe stunting of the plant and a red discolouration of the leaves which are often rolled and spikey in appearance. Plants with either symptom occur sporadically in crops and may be difficult to detect.

BYDV is transmitted by several species of aphids, and ryegrass may be infected by one or more strains of the virus. These strains are usually referred to as PAV, MAV and RPV. The PAV strain is transmitted by *Rhopalosiphum padi* (the bird cherry aphid) and *Sitobian avenae* (the rose grain aphid), the MAV strain is transmitted specifically by *S. avenae* and the RPV strain specifically by *R. padi* (Rochow 1969). The PAV and RPV strains are virtually always symptomless in ryegrass, although the former is responsible for severe stunting of occasional plants. The MAV strain has been fairly consistently associated with the type of foliar discolouration frequently attributed to non-pathogenic causes (Table 4; Holmes 1985).

Table 4: Detection of BYDV in ryegrass in relation to foliar discolouration

Year	Foliar symptoms	No. of samples	% Detection of BYDV strain			Total % infected
			PAV	MAV	PAV + MAV	
1981	Absent	47	13	13	15	40
	Present	52	4	62	19	85
1982	Absent	120	30	17	14	61
	Present	81	2	60	35	98

Source: Holmes (1985)

Newly sown swards may rapidly become infected with BYDV. At Auchincruive, for example, plots of perennial ryegrass cv. Reveille sown in May 1983 were extensively infected with the PAV strain by September of the same year. In a small but detailed survey of perennial ryegrass crops in 1983 infection was detected in all 13 fields examined (Holmes, 1985). The extent of infection in any one field varied between one and 12 of the 15 samples from each field tested. Although there was not a clear relationship between sward age and infection level (Fig. 1), on average, swards over 5 years of age had a higher level of infection (49.8%) than younger swards (26.6%). What is apparent is that once infected, perennial ryegrass remains an important source of virus for many years.

Effect of BYDV on Productivity

The effect of BYDV on ryegrass yield is difficult to determine because of the symptomless infection. However, Catherall (1966) reported a 20% yield loss in simulated swards of perennial ryegrass where few plants showed symptoms, and Latch (1980) noted a similar loss (22.4%) in simulated swards over a period of 18 months. Any direct effect which BYDV has on grass production is compounded by important changes which the virus causes to plant morphology. Infected plants may be reduced in height but have an increased number of tillers which limits compensatory growth from surrounding healthy plants. There may also be an increase in the ratio of vegetative to fertile tillers which may be of particular importance in crops grown for hay. The seasonal pattern of production of infected plants is altered, and they often yield less than healthy plants in the autumn, but more at the beginning of the following season. This advantage is quickly lost as fertile tillers are produced in healthy grass (Catherall 1966).

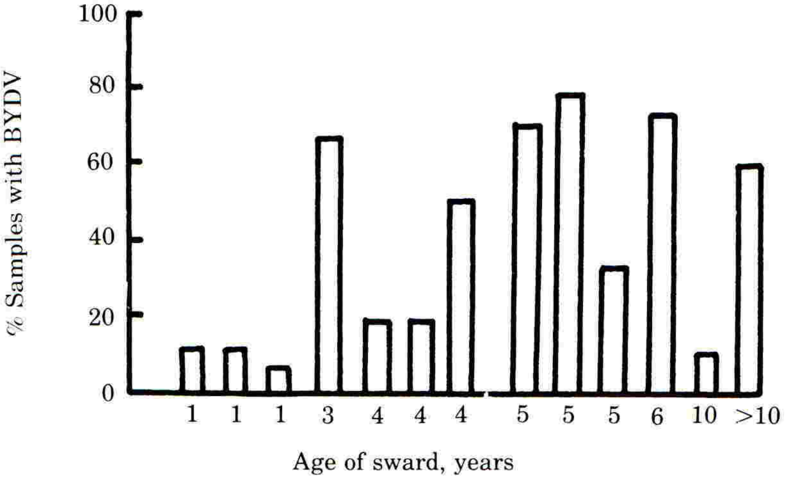


Figure 1: Incidence of BYDV in perennial ryegrass swards (15 samples/field tested in May 1983)

Whilst the effect of BYDV on ryegrass productivity has yet to be fully determined, there is no doubt of the importance of the role which infected ryegrass plays as a source of BYDV for the infection of autumn-sown cereals. The strains of BYDV which are symptomless in ryegrass are the same ones which can so severely damage winter barley and winter wheat. Furthermore, grass is the natural host for *R. padi* and *S. avenae*, the principal vectors of BYDV.

Discussion

The data presented in this paper were chosen to illustrate the important and varied effects which viruses can have on the major crop in the UK. It must be emphasised that these losses occur without any dramatic change in the appearance of the crop. Whilst the symptoms induced by RMV, BYDV and the other grass viruses may be fairly easily seen in small plots or spaced plants, they are much less apparent in the crop situation, and may easily pass unnoticed.

Viruses, and indeed other pathogens of grass, are likely to be of greatest importance in intensive management situations where cultural techniques approach the optimum, and nitrogen input is high. Disease then may become a limiting factor to further increasing output or reducing inputs. RMV, for example, may be responsible for the failure of increased nitrogen input to give the expected increase in yield and improvement in quality. The intensification of grass production, the growing of simpler mixtures or single species swards, the trend towards a narrower genetic base in cultivars, and the use of high nitrogen levels all leads to a situation which favours epidemic disease development.

There is at present no easy way to control grass viruses. Whilst it may be possible to delay the ingress of viruliferous vectors by the use of pesticides, this would require repeated applications of chemicals. With the exception perhaps of crops grown for seed, this is unlikely to be economic, it is undesirable on environmental grounds, and may pose problems with utilization of the grass. A useful delay in the build-up of RMV, and associated improvement in yield, can be achieved in short term leys by sowing the crop in the autumn, after the peak of mite activity, rather than in the spring (Catherall 1981). Grazing or cutting the grass in the autumn reduces mite numbers (Gibson 1976), and helps to reduce the chance of winterkill. Old turf lying on the soil surface when a ley is reseeded provides a source of virus and vectors. Thorough burial of turves and/or pre-ploughing desiccation of the sward will eliminate this source of infection. Such treatment is virtually essential if autumn-sown cereals are to be drilled, and failure to do so has resulted in the complete destruction of crops by BYDV.

The long term solution to virus diseases of grass undoubtedly lies in the breeding of resistant cultivars. That tolerance already exists in ryegrass is evidenced by the widespread occurrence of symptomless infection to BYDV, and the wide variability in response of plants to infection by RMV. Cocksfoot cultivars with excellent resistance to cocksfoot mottle, and the RMV-tolerant tetraploid Italian ryegrass cv. Sabalan have already been bred at the Welsh Plant Breeding Station. Other tetraploid Italian cultivars with tolerance to RMV include Wilo, Sabel and Augusta. The breeding of BYDV-resistant cultivars is likely to be difficult because the virus may have important effects on plant morphology without causing a big effect on yield. Direct measurement of yield as an indication of resistance is likely, therefore, to give a false impression of disease effect. Thus, the breeder is faced with the difficult task of selecting genotypes which not only suffer small yield losses when infected, but whose pattern of seasonal production is also not markedly modified.

References

A'BROOK, J.; HEARD, A.J. (1975) The effect of ryegrass mosaic virus on the yield of perennial ryegrass swards. *Annals of Applied Biology* **80**, 163–168.

CARR, A.J.H. (1965) Plant Pathology. *Report of the Welsh Plant Breeding Station for 1964*, 97–103.

CATHERALL, P.L. (1966) Effect of barley yellow dwarf virus on the growth and yield of single plants and simulated swards of perennial ryegrass. *Annals of Applied Biology* **57**, 155–162.

CATHERALL, P.L. (1981) Virus diseases of grasses. *Ministry of Agriculture, Fisheries and Food Advisory Leaflet 595 (Revised 1981).*

COOPER, P.; MCDOWELL, J.B. (1978) Ryegrass mosaic virus in Northern Ireland. *Record of Agricultural Research, Northern Ireland* **26**, 1–6.

DOHERTY, M.A.; DOODSON, J.K. (1980) The reaction of Italian ryegrass varieties to RMV. *Journal of the Institute of Agricultural Botany* **15**, 266–268.

DOODSON, J.K. (1967) A survey of BYDV in S24 perennial ryegrass in England and Wales 1966. *Plant Pathology* **16**, 42–45.

GIBSON, R.W. (1976) Effects of cutting height on the abundance of the eriophyid mite *Abacarus hystrix* (Nalepa) and the incidence of ryegrass mosaic virus in ryegrass. *Plant Pathology* **25**, 152–156.

GIBSON, R.W.; PLUMB, R.T. (1976) Transmission and effect on yield of ryegrass mosaic virus in a filtered air environment. *Annals of Applied Biology* **82**, 79–84.

HEARD, A.J.; A'BROOK, J.; ROBERTS, E.T.; COOK, R.J. (1974) The incidence of ryegrass mosaic virus in crops of ryegrass sown for seed in some southern counties of England. *Plant Pathology* **23**, 119–127.

HOLMES, S.J.I. (1977) Ryegrass mosaic virus and barley yellow dwarf virus in the west of Scotland. *Annals de Phytopathologie* **9**, 287–292.

HOLMES, S.J.I. (1979) Effect of ryegrass mosaic virus on the quality of perennial ryegrass. *Annals of Applied Biology* **91**, 75–79.

HOLMES, S.J.I. (1980a) Field studies on the effects of ryegrass mosaic virus on the yield of Italian ryegrass cv. S22. *Annals of Applied Biology* **96**, 209–217.

HOLMES, S.J.I. (1980b) Field studies on the effects of ryegrass mosaic virus on ryegrass yield. *Proceedings of the 3rd Conference on Virus Diseases of Gramineae in Europe* 103–108.

HOLMES, S.J.I. (1985) Barley yellow dwarf virus in ryegrass and its detection by ELISA. *Plant Pathology* (In press).

JONES, M.B.; HEARD, A.J.; WOLEDGE, J.; LEAF, E.L. (1977) The effect of ryegrass mosaic virus on carbon assimilation and growth of ryegrass. *Annals of Applied Biology* **87**, 393–405.

LATCH, G.C.M. (1980) Effects of barley yellow dwarf virus on simulated swards of Nui perennial ryegrass. *New Zealand Journal of Agricultural Research* **23**, 373–378.

ROCHOW, W.F. (1969) Biological properties of four isolates of barley yellow dwarf virus. *Phytopathology* **59**, 1580–1589.

Disease and the Influence of Herbage Variety – a NIAB Viewpoint

R.H. PRIESTLEY and
MAUREEN A.
DOHERTY
National Institute of
Agricultural Botany,
Cambridge

ABSTRACT

An anlysis of disease assessments made on plots of ryegrass varieties sown at seven sites in England and Wales between 1980 and 1984 is described. The diseases assessed were mildew, crown rust, Drechslera, Rhynchosporium *and ryegrass mosaic virus. Average disease levels differed widely between sites with higher levels of disease in the south than in the north. Disease levels were high in 1981 and low in 1983 and 1984. Substantial and significant differences were found between disease levels on 60 perennial, 18 Italian and 5 hybrid ryegrass varieties. Levels on the most popular varieties were compared with the most resistant and most susceptible varieties. Considerable scope was identified for reducing levels of disease by persuading farmers to grow the more resistant varieties currently available. Preliminary results from variety × fungicide trials at 8 sites in 1984 indicated that controlling foliar diseases in ryegrass varieties resulted in an average yield response of 3.5%, even in a low disease year.*

Introduction

Approximately 400,000 ha of grassland are resown each year in the UK. Grassland is usually resown with a mixture of grass varieties of different maturity date, often with white clover (*Trifolium repens*) as a companion. The most widely used grass species is perennial ryegrass (*Lolium perenne*) which accounts for approximately 65% of total grass seed sales. Italian ryegras (*L. multiflorum*) accounts for a further 15% of sales and hybrid ryegrass (*L.* × *hybridum*) for 9%.

The National Institute of Agricultural Botany (NIAB) is responsible for evaluating new varieties of ryegrass species. Promising new varieties are added to the UK National List and the best are recommended and included in NIAB Farmers Leaflet No 16 ‘Recommended varieties of grasses’. The main characters used by NIAB to evaluate ryegrass varieties are yield, persistence, quality (especially digestibility) and disease resistance.

Disease resistance is measured by assessing levels of natural infection in plots of varieties sown at seven NIAB Regional Trials Centres in England and Wales. This paper describes an analysis of disease assessments made between 1980 and 1984 inclusive to determine a) the regional distribution of the most important foliar diseases of ryegrass, b) the annual variation in levels of these diseases and c) the potential for controlling these diseases, by examining the disease resistance of 60 perennial, 21 Italian and 5 hybrid ryegrass varieties currently under trial at NIAB.

The NIAB Trials System

Trials are sown each year at 7 Regional Centres. Each variety is sown in at least 2 years. Perennial varieties are split into groups representing early, intermediate and late maturity and the groups are trialled separately. Each group is trialled under two management regimes; a 4 or 5 cut conservation management and an 8 or 9 cut simulated grazing management.

Italian and hybrid varieties are trialled together in a single group irrespective of maturity. Trials sown up to and including 1981 received both management regimes. Trials sown since 1982 have received only a 6 or 7 cut conservation management.

Disease Assessments

Plots were inspected from time to time by the local Regional Trials Officer. If appreciable disease was present, NIAB Headquarters at Cambridge was contacted and a pathologist sent to the Centre to make detailed disease assessments. Plots were not assessed routinely, so it is likely that there were occasions when disease was present but not recorded. Cereal disease assessment keys were used until 1984, when a new key developed from that devised by Thomas (1985) was introduced.

Diseases were recorded much more frequently on plots receiving the conservation management regime than on plots receiving the simulated grazing management regime. The diseases assessed most frequently on perennial varieties were mildew (*Erysiphe graminis*), crown rust (*Puccinia coronata*) and *Drechslera* spp. (*D. dictyoides of D. siccans*) and on Italian and hybrid varieties, mildew (*E. graminis*), *Rhynchosporium* spp. (*R. orthosporum* or *R. secalis*) and ryegrass mosaic virus (RMV).

There were clear differences in the time of the year when each disease was most frequently recorded. Mildew was seen most frequently in June and July, crown rust in September and October, *Drechslera* in January to March and August to September, *Rhynchosporium* in March to May, and RMV in June and July. RMV was assessed much less frequently than the other diseases (Table 1) and had to be excluded from some of the analyses. Each variety was assessed for the other diseases on an average of 11–22 occasions during 5 years.

Table 1: Average number of disease assessments per variety

Disease	Perennials			Italians and hybrids
	Early	Intermediate	Late	
Mildew	21	13	17	19
Crown Rust	22	15	19	–
Drechslera	20	11	14	–
Rhynchosporium	–	–	–	22
RMV	–	–	–	4

Table 2: Variation in % infection between Regional Trials Centres

Regional Trials Centre	Perennials			Italians and hybrids	
	Mildew, %	Crown Rust, %	Drechslera, %	Mildew, %	Rhynchosporium, %
Cockle Park, N'berland	–	–	–	0.8	–
Headley Hall, N. Yorkshire	1.5	–	–	1.6	–
Harper Adams, Shropshire	5.1	–	5.4	2.6	4.1
Trawsgoed, Dyfed	1.8	–	–	0.4	9.5
Cambridge, Cambridgeshire	6.1	2.5	4.5	7.1	–
Sparsholt, Hampshire	0.5	3.8	2.9	1.8	3.1
Seale Hayne, Devon	2.4	1.4	8.0	0.8	5.5
Mean (all centres)	2.5	1.1	3.0	2.2	3.2
	6.6%			5.4%	

–, Disease not recorded.

Variation in Disease Level Between Regional Trials Centres

The average % infection of each disease at the Regional Centres is shown (Table 2). The northern centres (Cockle Park and Headley Hall) were characterized by their general lack of recorded disease apart from low levels of mildew. The level of mildew was highest at Harper Adams and Cambridge. Crown rust was only recorded at 3 centres (Sparsholt, Cambridge and Seale Hayne) and, on average, did not reach very high levels. *Drechslera* infection was highest at Seale Hayne and *Rhynchosporium* was highest at Trawsgoed. Overall, the total average % infection for perennial varieties (6.6%) was slightly higher than that for Italian and hybrid varieties (5.4%).

Variation in Disease Level Between Years

The average % infection is shown for each year from 1980 to 1984 inclusive (Table 3). Disease levels were generally high in 1981 and low in 1983 and 1984.

Table 3: Variation in % infection between years

	Perennials			Italians and hybrids	
Year	Mildew, %	Crown rust, %	Drechslera, %	Mildew, %	Rhynchosporium, %
1980	1.9	0.5	3.8	4.0	3.4
1981	5.5	1.5	6.9	2.5	5.5
1982	1.6	2.1	2.1	1.2	3.8
1983	2.6	1.0	1.6	1.4	2.3
1984	1.0	0.5	0.6	1.9	0.8

Varietal Resistance to Disease

Average infetion levels for each variety were calculated using a 'fitting constants' technique. This adjusts the actual mean by adding or subtracting a value which depends upon the individual years and trials in which each variety is sown (Patterson 1978).

Varieties were analysed in the groups in which they were trialled, being a) early perennials, b) intermediate perennials, c) late perennials, and d) Italian and hybrid varieties. Least significant differences (l.s.d.) were determined to enable statistical comparisons to be made between varieties within each group.

The total number of varieties (86) is too large for the complete data to be presented here. Instead, the average infection levels for the most susceptible, most popular and most resistant varieties in each group are presented. The most susceptible and most resistant varieties were determined by locating the varieties within each group with the highest and lowest % infection respectively. The most popular variety was determined by inspecting seed production statistics (Anon. 1985) for the variety with the largest weight of certified seed.

The results of the analyses are given for perennial varieties in Table 4 and Italian and hybrid varieties in Table 5. The analyses show that there were substantial and significant differences in infection between the most susceptible and most resistant varieties to each disease. The most popular varieties were usually intermediate in disease level indicating that there is considerable potential for reducing levels of grass diseases in the field by persuading farmers to grow more resistant varieties. This potential is largest in Italian varieties, less so in perennial varieties and the least in hybrid varieties, where the most popular variety Augusta is close to the most resistant variety in average infection level.

In practice, reducing levels of disease in the field depends on the availability of varieties which combine high levels of resistance to a number of diseases. Varieties with less than average infection of all three diseases are given in Table 6.

Table 4: Average % infection on varieties of perennial ryegrass

Criterion	Mildew, %		Crown rust, %		Drechslera, %	
Amongst 18 early varieties						
most susceptible	Gremie	11.2	Callan	12.9	Gremie	10.1
most popular	Frances	5.8	Frances	4.8	Frances	7.0
most resistant	Liprior	2.2	Cropper	1.1	Reveille	2.7
l.s.d. ($P = 0.05$)		2.7		3.1		3.0
Amongst 18 intermediate varieties						
most susceptible	Barlatra	12.4	Amigo	6.3	Morgana	8.5
most popular	Talbot	6.1	Talbot	2.2	Talbot	7.2
most resistant	Merlinda	0.3	Hora	0.1	Fantoom	3.5
l.s.d. ($P = 0.05$)		5.5		2.0		6.2
Amongst 24 late varieties						
most susceptible	Tresor	17.9	Aber S23	9.5	Saver	10.9
most popular	Melle	5.3	Melle	4.4	Melle	7.0
most resistant	Alsinto	1.5	Perma	0.9	Belfort	3.9
l.s.d. ($P = 0.05$)		4.1		2.0		3.8

Table 5: Average % infection on varieties of Italian and hybrid ryegrass

Criterion	Mildew, %		Rhynchosporium, %		Ryegrass * mosaic virus, %	
Amongst 21 Italian varieties						
most susceptible	Omar	12.6	Exalta	12.3	Exalta	40.8
most popular	RvP	9.8	RvP	10.4	RvP	37.9
most resistant	Sabalan	1.6	Wilo	4.9	Wilo	5.9
Amongst 5 hybrid varieties						
most susceptible	Barcolte	10.5	Barcolte	10.3	Barcolte	27.1
most popular	Augusta	3.0	Augusta	4.5	Augusta	11.4
most resistant	Sabel	2.2	Sabel	3.6	Siriol	6.2
l.s.d. ($P = 0.05$)		2.4		3.5		23.4

* Disease index (0–100 scale)

Table 6: Ryegrass varieties with less than average infection of all 3* disease

Early perennials	Intermediate perennials	Late perennials	Italians	Hybrids
Barvestra	none	Perma	Bambi	Augusta
Moranta		Trani	Dalita	Butler
Peramo		Wendy	Roberta	Sabel
Reveille			Wilo	

* For perennials, the 3 diseases are mildew, crown rust and *Drechslera*; for Italians and hybrids, the diseases are mildew, *Rhynchosporium* and RMV.

Discussion

In an earlier review, Doodson (1974) concluded that the most important diseases of ryegrasses were crown rust, Ryegrass Mosaic Virus and, possibly, Barley Yellow Dwarf Virus (BYDV). It is difficult to draw any conclusions about the importance of RMV or BYDV from the data presented here. BYDV was only recorded once between 1980 and 1984 and RMV was recorded much less frequently than the other diseases. The main problem is that both viruses can be symptomless, so that visual assessment is not necessarily a good indicator of the presence or absence of the virus.

The data presented here do not indicate that crown rust is any more widespread or severe than mildew, *Rhynchosporium* or *Drechslera*. In fact, average levels of crown rust were lower than for the other three foliar diseases. A similar conclusion can be drawn from the results of an unpublished ADAS survey of diseases of ryegrass in England, Wales and Scotland in 1974. *Drechslera* spp. were the most frequently recorded (103 out of 170 fields examined) followed by mildew (63 fields), *Rhynchosporium* (44 fields) and crown rust (22 fields). Whilst it is probably true that crown rust has a greater potential to become epidemic and cause yield losses, this potential is not realised very frequently, hence average levels are not high. The data presented here suggest that mildew, crown rust, *Drechslera* and *Rhynchosporium* should be regarded as diseases of approximately equal importance.

It is clear from Table 2 that the seven NIAB Regional Trials Centres have widely different disease patterns. It is fortunate that there is at least one centre where each disease consistently occurs, as this enables new varieties to be exposed there to natural infection, so that an estimate of the resistance of each variety can be made. As crown rust and RMV occur less frequently at the centres than the other diseases, there is a requirement for inoculated tests to be done to make up for the lack of naturally occurring infection. A routine test in which plots of varieties are inoculated with crown rust has been set up at Cambridge and, clearly, there is a need to extend this work in the future to include plots inoculated with RMV.

The variation in disease levels between years (Table 3) is probably the result of differences in climate from year to year. Disease assessments made on Italian and hybrid varieties in 1983 and 1984 were made largely on plots receiving a 6 or 7 cut conservation management, whereas those made in 1980, 1981 or 1982 were on plots receiving a 4 or 5 cut conservation management. The 6 or 7 cut regime includes an extra cut in March/April during early spring growth and this coincides with the period when *Rhynchosporium* was most frequently recorded. Levels of *Rhynchosporium* were lower in 1983 and 1984 than the previous years and it is possible that this is partly due to the removal of infected material prior to assessment by the extra early cut.

One area that remains largely unresolved is the effect of foliar diseases on the yield and quality of grassland. Although there are a number of well documented cases where high levels of disease have reduced yield or quality (for references, see O'Rourke 1976; Williams 1984), it is by no means clear whether the levels of disease which occur in an average year actually have much effect. To try and resolve this uncertainty, NIAB and ADAS have started a joint series of variety ×

fungicide trials at 7 sites in England and Wales and one in Northern Ireland. At each site, the trial comprises 6 perennial varieties × 2 fungicide treatments × 3 replicates = 36 plots. The fungicide treatments are a) 5 compulsory + 2 optional applications of fungicide, and b) untreated. The trials were sown in 1983 and the yields obtained in the first harvest year are given in Table 7. The total yield response from fungicide treatment was 0.55 t/ha (3.5%) with the largest response of 0.30 t/ha (+7.0%) at cut 2. This suggests that grass diseases do reduce yield, even in a year when disease levels were generally low (Table 3). Hopefully, a clear picture will emerge when the trials have been completed and the second and third harvest year data are available.

The most economic way of reducing national levels of grass diseases is to persuade farmers to reseed with more resistant varieties. The list of varieties given in Table 6 represent the most resistant available at present. However, choice of variety is a complex process involving criteria other than disease resistance including yield, persistence and quality. Ideally, we need varieties which combine good performance in all these characters, but at present it is a matter of using sensibly what is already available. Ratings for the resistance of perennial varieties to crown rust and for Italian and hybrid varieties to mildew, *Rhynchosporium* and RMV are published annually in NIAB Farmers Leaflet No. 16 – 'Recommended varieties of grasses'. Ratings for the resistance of perennial varieties to mildew and *Drechslera* are published annually in Supplements to Farmers Leaflet No 16 (Varieties of Grasses), which is available on request from NIAB. Farmers reseeding grassland in areas with a high disease risk should take account of these ratings when choosing varieties of seeds mixtures. This is especially important in the south and west of England where disease generally occurs more frequently.

Table 7: Average yields from ADAS/NIAB variety × fungicide trials, 1984

	Yield, t/ha			
Cut	Untreated	Treated †	Response	response, %
1 (mid May)	6.96	7.10	+0.14*	+2.0%
2 (end June)	4.29	4.59	+0.30***	+7.0%
3 (early August)	1.68	1.80	+0.12***	+7.1%
4 + 5 (September/October)	2.62	2.61	−0.01 ns	–0.4%
Total	15.55	16.10	+0.55***	+3.5%

*, ** and *** denote significance at $P = 0.05$, 0.01 and 0.001 respectively
† 5 compulsory and 2 optional applications of Tilt (0.5 l/ha)

Acknowledgement

We thank I.R. Wright and B. Jones for technical assistance.

References

ANON. (1985) *Seed production in England & Wales, Herbage No 6, January 1985*. Cambridge: National Institute of Agricultural Botany.

DOODSON, J.K. (1974) Report of a working party on grass and herbage legume diseases held at the NIAB, 2 October 1973. *Journal of the National Institute of Agricultural Botany* **13**, 285–292.

O'ROURKE, C.J. (1976) *Diseases of grasses and forage legumes in Ireland*. An Foras Taluntais, Oak Park Research Centre, Carlow, Ireland.

PATTERSON, H.D. (1978) Routine least squares estimation of variety means in incomplete tables. *Journal of the National Institute of Agricultural Botany* **14**, 401–412.

THOMAS, M.R. (1985) Assessment of disease in grassland. Proceedings BCPC/BGS Symposium on *Weeds, Pests and Diseases of Grassland and Herbage Legumes*, Nottingham, April 1985, 188–194.

WILLIAMS, R.D. (1984). *Crop Protection Handbook – Grass and Clover Swards* pp. 105. Croydon: British Crop Protection Council.

Amelioration of Disease in Grassland Through Resistance Breeding

P.W. WILKINS
Welsh Plant Breeding
Station, Plas Gogerddan,
Aberystwyth, Wales

ABSTRACT

Disease levels are highly dependent on levels of host resistance. In Britain, most widely grown grass cultivars have adequate resistance to the common fungal and bacterial pathogens, but are prone to infection by one or two common viruses. Current and future breeding for yield and quality will tend to increase susceptibility to fungal diseases, unless special attention is given to maintaining present levels of disease resistance and genetic diversity. High levels of resistance to infection by ryegrass mosaic virus have been transferred successfully from selected perennial ryegrasses to Italian ryegrass, but effective resistance to the common strains of barley yellow dwarf virus has yet to be found in ryegrasses.

The Influence of Genetic Resistance on Disease Levels

With most field crops, the degree of host resistance has been of critical importance in determining disease levels. The available evidence strongly suggests that the same is true of temperate grasses, although in Britain genetic differences often are obscured by the widespread practice of sowing cultivar mixtures. Existing Italian ryegrass cultivars, although varying somewhat in tolerance, are more prone to infection by ryegrass mosaic virus (RMV) than are perennial ryegrasses (Salehuzzaman & Wilkins 1983; Wilkins & Hides 1976). Surveys and plot experiments have shown a considerably higher incidence of RMV in Italian ryegrass than in perennial ryegrass crops of similar age (Heard *et al.* 1974; Cooper & McDowell 1978; Plumb *et al.* 1976). In New Zealand, large differences between ryegrass cultivars in levels of damage by crown rust (*Puccinia coronata*) were found both in field surveys and yield loss trials (Lancashire & Latch 1966). In Louisianna, USA, an epidemic of ryegrass blast was due entirely to the widespread use of the cultivar Gulf (Carver *et al.* 1977). There have been several plot experiments in the British Isles in recent years using fungicides to assess the effect of disease levels on productivity and quality. When relying on natural infection the only trials that showed significant differences between sprayed and unsprayed plots employed unusually susceptible cultivars: Lior Italian ryegrass (Davies *et al.* 1977) and Irish Commercial perennial ryegrass (O'Rourke 1975).

Present Levels of Resistance

Until now grass breeding, combined with independent cultivar evaluation and recommendation, has tended to increase levels of resistance to fungal diseases. Charles (1973) found that cultivars of perennial ryegrass were, on average, more resistant to crown rust than were populations taken from intensively managed permanent pastures. Improvements in winter hardiness have tended to reduce damage due to snow mould fungi in areas where prolonged snow cover occurs (Arsvoll 1977). The low incidence of fungal diseases found on ryegrass in a recent survey (Lam 1983) suggests that levels of resistance to fungal diseases generally are adequate.

There also may have been some improvement in levels of resistance to viruses. Cv. Augusta shows less pronounced symptoms of RMV than does cv. RvP, and Cambria cocksfoot is more resistant to cocksfoot mottle virus than the older cv. S.37 (Catherall 1985). However, the Italian ryegrasses, early-flowering perennial ryegrasses and Italian/perennial hybrids remain susceptible to infection by RMV. Most perennial ryegrass cultivars, although reasonably tolerant, are prone to infection by barley yellow dwarf virus (Catherall & Wilkins 1977).

Current Breeding and Future Levels of Resistance

Unless particular attention is paid to disease resistance, plant breeding tends to increase susceptibility, especially to fungal and bacterial diseases. To appreciate the reasons for this it is necessary to consider plant breeding as a whole. Breeding consists essentially of combining genes to produce varieties which are superior in yield and quality. Resistances to various diseases are secondary characters, being of interest only when they affect yield or quality. Two factors conspire to reduce resistance to diseases.

Firstly, improving yield and quality often necessitates the use of exotic genetic material which is not adapted to the pathogens that occur locally. Ryegrass breeding at the Welsh Plant Breeding Station (WPBS) provides good examples of this. Italian ryegrasses introduced from the Po Valley region of Italy (typified by cv. Exalta) have very rapid regrowth after cutting and a high yield potential, as well as high digestibility of the flowering stems. However, they mostly are very susceptible to powdery mildew (*Erysiphe graminis*) and leaf rust (*Puccinia recondita*). Before the introduction of these Po Valley types, leaf rust was not generally acknowledged to be a pathogen of ryegrass (Wilkins 1973). Using a combination of field assessment and glasshouse inoculation techniques, a potential cultivar of this type was developed with good resistance to both leaf rust and mildew (Hides *et al*. 1980). This cultivar (Bb 1906, provisional name Tribune) will complete National List Trials this autumn, and still higher yielding disease resistant Po Valley types will be submitted for trials soon. In the perennial ryegrasses, hybrids between wild-type plants from northern Italy and bred material outyielded control cultivars by a wide margin and had good persistency (Wilkins & Lovatt (1983). However, the wild-type parents all are highly susceptible to scald (*Rhynchosporium* spp.), and this has added to the difficulty of fixing the best possible combination of genes by recurrent selection over generations. Each additional character that must be considered multiplies the difficulty of achieving the best combination. Perennial ryegrasses from the Swiss uplands also have proved to be very valuable as genetic resources for breeding but are very susceptible to crown rust (Humphreys *et al.* 1983). Currently at the WPBS we are aiming to produce cultivars which are as resistant to fungal diseases as the better recommended varieties. If we choose to ignore disease resistance there is little doubt that we would be able to make more rapid progress in improving mean plot yield; although this may be at the expense of reliability because of sporadic attack by fungi. The strategy that breeders employ in these situations depends very much on the emphasis given to disease resistance when it comes to decisions on official recommendation of their material.

Secondly, in most crops breeding has tended to increase genetic uniformity which encourages parasites to specialise and so become much more virulent (Day 1974). This is bound to happen eventually with grasses as well. As the gap in performance between wild types and cultivars steadily widens, breeders will tend to rely increasingly on a few elite cultivars as their source of material for further breeding. It is well established that resistance to rusts in cereals is controlled by a large number of race-specific genes with both major and minor effects on resistance. Effective control depends on having a large number and high level of diversity of these resistance genes, because it takes time for the pathogen population to re-organise its genes in order to multiply rapidly on different resistant plants (Parlevliet & Zadoks 1977). It is this genetic homeostasis which by and large prevents serious epidemics of fungal pathogens in natural populations. So far in cultivated ryegrasses, it seems that much of the natural diversity of resistance genes to crown rust has been retained and that several race-specific genes can be found in a single resistant cultivar (Wilkins 1978a, 1978b). Powdery mildew on ryegrass has not been investigated from this point of view but in barley resistance is controlled by at least 17 different race-specific genes (Wolfe 1972). It is difficult to be precise about the number of species of *Drechslera* that attack ryegrass because apparently distinct asexual forms have been shown to hybridise sexually (Paul & Parberry 1978). But at a conservative estimate there are 6 further species of pathogen that occur on perennial ryegrass in Britain and which belong to genera with proven ability to specialise on cereal varieties (Table 1). In addition, there are at least another 9 species which possibly would specialise if the crop became sufficiently uniform.

Clearly, it is impractical to combat the effects of increasing uniformity of the host by the production and tactical deployment of agronomically similar cultivars with different resistance genes. Perhaps it could be done with one or two species of pathogen, but not with all of them. Instead we should seek to preserve as far as possible the present high levels of genetic diversity while at the same time improving yield, quality and persistency. The surest means of preserving genetic diversity is to maintain several different breeding programmes. Even if they have identical objectives, different breeders will produce cultivars that are genetically distinct even if outwardly similar. Such cultivars can then be used in mixtures. Selecting for intermediate resistance rather than near immunity also is good practice since generally the former is controlled by more genes. The outbreeding nature of many forage grasses means that there is genetic variation within bred varieties. Breeders of such species should eschew the development of

Table 1: Fungal and bacterial pathogens of perennial ryegrass in Britain

Genus	Proven ability to specialise	No. of species
Erysiphe	+	1
Puccinia	+	2
Drechslera	+	2–6
Rhynchosporium	+	2
Claviceps		1
Gleotinia		1
Septoria		1
Spermospora		1
Asochyta		1–2
Fuscarium		2
Ophiobolus		1
Polymyxa/Ligneria		1–2
Xanthomonas	+	1
Total	8–12	17–23

inbred lines which has been suggested as a way of speeding up genetic recombination and cultivar production.

With the viruses on the other hand, the main problems lie with finding resistance which is really effective against all existing common strains and with identifying resistant genotypes among large numbers of susceptible ones. These problems have yet to be solved with barley yellow dwarf virus which has several strains transmitted by different aphid vectors and which often does not induce clear symptoms. However, new methods of detecting and assaying viruses are being developed constantly and it soon may be possible to breed for true resistance to this virus complex. RMV has been less of a problem because it is sap-transmissable and generally induces unambiguous symptoms in infested plants, especially if they are grown in a glasshouse. Gibson & Heard (1979) found clones of perennial ryegrass which were extremely resistant. On further investigation, this extreme resistance was found to be due to a combination of two distinct and independently inherited components: resistance to infection and resistance to virus multiplication and spread within the plant (Salehuzzaman & Wilkins 1984). The resistance to infection proved highly effective against all known strains of the virus, while resistance to multiplication and spread was strain-specific. Despite being polygenically inherited, this resistance to infection has been transferred by backcrossing to a predominantly Italian ryegrass (Bb 1906) background. Table 2 shows the mean resistance of 11 clones recovered after three cycles of backcrossing, polycrossing and recovery of resistant plants with Italian ryegrass-like morphology. They are similar in resistance to the original

Table 2: Number of plants out of 20 showing ryegrass mosaic virus symptoms 5 weeks after inoculation

	Inoculum concentration			
Genotype	1/8	1/69	1/512	Mean
Original resistant clones	2	3	1	2.0
Mean of 11 selected clones	4	1	2	2.3
Italian ryegrass parent	20	20	19	19.7

resistant perennial ryegrass parents and much more resistant than the recurrent Italian ryegrass parent. These eleven clones will form the basis of a synthetic variety this year and further backcrosses will be made to still higher yielding Po Valley types with good resistance to mildew and leaf rust.

References

ARSVOLL, K. (1977) Effects of hardening, plant age and development in *Phleum pratense* and *Festuca pratensis* on resistance to snow mould fungi. *Meldinger fra Norges Landbrukshogskole* **56**, p.14.

CARVER, R.G.; RUSH, M.C.; LINDBERG, G.D. (1977) An epiphytotic of ryegrass blast in Louisianna. *Plant Disease Reporter* **56**, 157–159.

CATHERALL, P.L. (1985) Resistance of grasses to two sobemoviruses, cocksfoot mottle and cynosurus mottle. *Grass and Forage Science*. (In press).

CATHERALL, P.L.; WILKINS, P.W. (1977) Barley yellow dwarf virus in relation to the breeding and assessment of herbage grasses for yield and uniformity. *Euphytica* **56**, 385–391.

CHARLES, A.H. (1973) A comparison of ryegrass populations from intensively managed permanent pastures and leys. *Journal of Agricultural Science, Cambridge* **81**, 99–106.

COOPER, P.; MCDOWELL, J.B. (1978) Ryegrass mosaic virus in Northern Ireland. *Record of Agricultural Research, Department of Agriculture, Northern Ireland* **26**, 1–6.

DAVIES, H.; WILLIAMS, A.E.; MORGAN, W.A. (1970) The effect of mildew and leaf blotch on both yield and quality of cv. Lior Italian ryegrass. *Plant Pathology* **19**, 135–138.

DAY, P.R. (1974) *Genetics of host-parasite interaction*. Oxford: W.H. Freeman and Co., pp. 238.

GIBSON, R.W.; HEARD, A.J. (1979) The resistance of two clones of perennial ryegrass and their progeny to ryegrass mosaic virus from different parts of Britain. *Annals of Applied Biology* **91**, 101–106.

HEARD, A.J.; A'BROOK, J.; ROBERTS, E.T.; COOK. R.J. (1974) The incidence of ryegrass mosaic virus in crops of ryegrass sown for seed in some southern counties of England. *Plant Pathology* 23, 119–127.

HIDES, D.H.; LOVATT, J.A.; WILKINS, P.W. (1980). Breeding for improved seasonal yield distribution and regrowth potential in Italian ryegrass. *Report of the Welsh Plant Breeding Station for 1979*, pp. 41–44.

HUMPHREYS, M.O.; JONES, J.L.; WILKINS, P.W. (1983) The potential for increasing crown rust resistance in Ba 9436. *Report of the Welsh Plant Breeding Station for 1982*, pp. 36–39.

LAM, A. (1983) A survey of ryegrass swards for the presence of fungal pathogens in relation to management. *Grass and Forage Science* **38**, 55–65.

LANCASHIRE, J.A.; LATCH, A.G.M. (1966) Some effects of crown rust (*Puccinia coronata*) on the growth of two ryegrass varieties in New Zealand. *New Zealand Journal of Agricultural Research* **9**, 628–640.

O'ROURKE, C.J. (1975) Common and newly recorded forage crop diseases in Ireland. *Annals of Applied Biology* **81**, 243–247.

PARLEVLIET, J.E.; ZADOKS, J.C. (1977) The integrated concept of disease resistance: a new view including horizontal and vertical resistance in plants. *Euphytica* **26**, 5–21.

Discussion on Session 4 (Session Organiser – A J H Carr)

Question: Does the presence of disease on grass reduce its persistence?

Thomas: Yes, by reduced tillering and by more weak plants that die.

Question: What future work is needed on disease assessment?

Thomas: At present small plots have been used to study single varieties. There is a need to monitor mixtures in field situations.

Question: Does the NIAB Recommended List of grasses place enough emphasis on disease?

Priestley: No, but the situation is under constant review as more comprehensive data becomes available. At present the Herbage Trials Advisory Committee takes account of disease ratings before putting new varieties on the List.

Question: Bearing in mind that most permanent pasture contains at least 75% grass species other than perennial ryegrass, what is the effect of pests and diseases on these other grasses?

Clements: Limited evidence suggests that cocksfoot is not attacked by frit fly.

Cook: Cocksfoot is resistant to root nematodes.

Carr: Timothy is particularly susceptible to rust and halo spot. There is no information on bents.

Mowat: Cocksfoot is resistant to leatherjackets; timothy and white clover are less resistant than perennial ryegrass.

Holmes: Leaf spots occur widely and limited infection can affect quality parameters such as water soluble carbohydrate (unlike cereals where such low infection would be tolerated.)

Carr: 10% lesion cover on the leaf can give 50% reduction in WSC.

Question: Most diseases are foliar: what about soil-borne diseases?

Priestley: These are much more difficult to assess in field trials.

Holmes: Fusiarium can affect perennial ryegrass; also eyespot can affect seed crops. Soil-borne disease problems are difficult to quantify.

Question: Use of Dursban in mid-July to control frit-fly also gave control of autumn leatherjacket attack – is this uncommon?

Mowat: The persistance of activity for 10–12 weeks is longer than the Manufacturer's recommendation. The effects reported were the mean of four rates of chlorpyrifos applications.

Question: Does July/August slurry application affect leatherjacket incidence?

Mowat: I have no information on this.