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SOIL-BORNE MOSAIC VIRUSES IN WINTER BARLEY: EFFECTS OF VARIETY AND MANAGEMENT ON BaYMV AND BaMMV EXPRESSION

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SOIL-BORNE MOSAIC VIRUSES IN WINTER BARLEY: EFFECTS OF VARIETY AND MANAGEMENT ON BaYMV and BaMMV EXPRESSION

by

M. J. ADAMS[1], R. OVERTHROW[2] AND M. F. F. CARVER[2]

1. IACR Rothamsted, Harpenden, Hertfordshire AL5 2JQ

2. Arable Research Centres, Manor Farm, Daglingworth, Cirencester,

Gloucestershire GL7 7AH

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ABSTRACT

In each of the three years of the project, field trials were conducted at two sites within 2.5 miles of each other in Gloucestershire, one heavily infested with barley yellow mosaic virus (BaYMV) and the other with barley mild mosaic virus (BaMMV). In each year, eight winter barley cultivars (Willow, Firefly or Epic, Target, Fighter, Sprite, Pipkin, Halcyon, Puffin) were sown at each site at malting N levels and the four feeding cultivars (Willow, Firefly or Epic, Target, Fighter) were additionally grown at feed N levels. There was a single sowing date at the BaYMV site, but at the BaMMV site four autumn sowing dates were planned. At the latest two dates, two spring cultivars (Alexis and Blenheim) were also sown and these were also sown at this site on two dates in the spring.

Disease incidence and yield data showed that the malting cultivars Pipkin, Halcyon and Puffin were much more susceptible to BaMMV than to BaYMV. Indeed, on BaYMV sites, their yields were sometimes comparable to those of the resistant cultivars. By contrast, the feeding cv. Fighter proved to be equally susceptible to both viruses. Although cv. Sprite is not immune to the viruses, it showed partial resistance to BaMMV and, like the other malting cultivars, was not very prone to BaYMV. Spring cultivars developed symptoms if sown in the autumn, but not in the spring.

At the BaMMV site, disease incidence on the susceptible cultivars decreased as sowing was delayed. Yields of resistant cultivars were usually greatest from the first sowing date, declining steadily as sowing was delayed. Amongst the fully susceptible cultivars (Fighter, Pipkin, Halcyon, Puffin) yields at the first sowing date (which developed the greatest levels of disease) were the lowest of any of the dates and were better at the later dates, although they never reached those of the resistant cultivars at the earliest sowing. Thus delayed sowing (e.g. from late September to late October) can produce greater yields of susceptible cultivars because the gain from decreased disease outweighs the negative effects on plant growth.

The results highlight the need for farmers to know which of the viruses is present on infested fields. Resistant cultivars should give the highest yields on infested land, but susceptible malting cultivars should perform well on sites infested only with BaYMV. If BaMMV is present, early sowing of malting cultivars should be avoided.

1. INTRODUCTION TO BARLEY MOSAIC VIRUSES

1.1. Symptoms, damage, distribution and spread

Barley yellow mosaic virus (BaYMV) and barley mild mosaic virus (BaMMV) are soil-borne viruses that infect autumn-sown barley crops in many countries worldwide. The disease is usually first noticed as irregular yellow patches in the crop during winter or early spring and may be confused with either nutrient problems arising from poor drainage or infection by barley yellow dwarf virus, which is transmitted by aphids. On inspection, infected plants have characteristic longitudinal pale streaks on their youngest leaves (Adams & Hill, 1992). Sometimes, leaves are rolled giving the plants a spiky appearance and brown, necrotic patches may be associated with the symptoms. Depending on cultivar and weather conditions, crops may appear to recover completely, or infected patches may remain stunted with weaker plants having significantly depressed yield (up to about 40% loss). This project continues and expands work reported in Project Report No. 65 (Adams, Grylls, Hill, Jones & Morris, 1992) but gives particular attention to the separate effects of the two viruses.

Barley mosaic viruses were first detected in the UK in 1980 but were almost certainly present, but unrecognised, for several years before that. Since then, the disease has been reported from all the areas of the UK where winter barley is grown intensively and is particularly severe in parts of Eastern England and in the Cotswolds (Hill & Walpole, 1989; Adams, 1991; Adams & Hill, 1992). In an HGCA-sponsored survey of 30,000 ha in the Cotswolds in 1988, 13% of the winter barley acreage was found to be affected to some extent by the virus (Adams, Grylls, Hill, Jones & Morris, 1992). The disease is also a serious problem in France, Belgium, Germany, Japan and China. Both viruses are transmitted to barley roots by a root-infecting fungus, *Polymyxa graminis* which has thick-walled resting spores that remain in soil for many years. The fungus is very common in arable soils, but probably does no direct damage unless it is also carrying virus. As far as is known, the viruses cannot be transmitted through seed or by insects and their spread is therefore dependent on movement of the fungus spores within infested soil.

BaYMV and BaMMV cause similar symptoms, may occur singly or together within plants, and can only be distinguished by serological tests (Adams, Swaby &

Jones, 1987; Huth & Adams, 1990; Adams, 1991). However, there seem to be important differences between cultivars in their response to the two viruses, which have implications for disease control (see below). It has also been suggested that BaYMV symptoms appear earlier in the winter, while those of BaMMV appear later and persist longer into the spring (Stanarius, Proeseler & Kühne, 1988).

1.2. Control

Several possible measures for controlling the disease have been examined in the UK and elsewhere. Fungicides applied to seed or soil to control the fungus vector do not appear to be effective or economic, at least with current products. Attempts to alleviate the effects of disease by varying the times and rates of nitrogen fertiliser application had no measurable effect (Adams, Grylls, Hill, Jones & Morris, 1992; Adams, Jones, O'Neill & Hill, 1993). In rotation experiments, a three-year break in either winter wheat (not a host of the virus and a relatively poor host for the fungus vector) or immune winter barley (not a host of the virus but a good host for the fungus vector) failed to decrease the level of soil infestation with virus and did not decrease disease levels when a susceptible barley crop was grown in the fourth year (Adams, Grylls, Hill, Jones & Morris, 1992; Jones, Adams, Morris & Grylls, 1992). There have been reports, mostly of an anecdotal nature, that virus incidence is more severe the earlier crops are sown in the autumn. However, the only experimental evidence is a brief report from Japan (Watanabe, Toshima, Ueda & Ogawa, 1989), where environmental conditions and cultivars are very different to those in Europe. Control of the disease therefore relies upon attempts to minimise the spread of contaminated soil (e.g. on farm machinery) and on resistant (immune) barley cultivars.

Laboratory and field trials have identified a number of UK cultivars which are resistant to both viruses and which yield better on infested sites than susceptible cultivars (e.g. Adams, Grylls, Hill, Jones & Morris, 1992). In the UK Recommended List for Cereals, the resistant cultivars included are Epic, Sunrise (Provisional Recommendation), Muscat (Provisional Recommendation) and Target (Becoming Outclassed). All of these cultivars (and all the earlier European resistant cultivars) possess the *ym4* resistance gene and this has proved universally effective against BaMMV. The disadvantages of using resistant cultivars have been that on uninfested land yields have often been less than those of the best susceptible cultivars and that (at least until very recently) no resistant cultivar suitable for malting has been available. In addition, since 1988, there have been a number of reports of BaYMV on *ym4* cultivars. This resistance-breaking isolate, sometimes called BaYMV-2, has only been detected in 17 fields in the UK, mostly in fairly small patches, but is much more widespread and damaging in France, Belgium and Germany. Plant breeders are therefore attempting to introduce other resistance genes from Far East germplasms into cultivars suitable for growing in Europe. Amongst the susceptible cultivars, there appear to be some differences in response to the viruses, but they have not been well characterised. Surveys of virus incidence on samples from different parts of the UK have suggested that malting cultivars are especially prone to BaMMV whereas feeding cultivars are more usually infected with BaYMV (e.g. Adams, 1991; 1993). In recent years, there has also been a suggestion that cv. Sprite displayed a degree of field resistance and this is supported by laboratory tests (Adams, 1994).

1.3. Objectives of present study

The principal purpose of this study was to examine the effects of sowing date on the performance of the recommended malting barley cultivars on land infested with BaMMV. Delayed sowing would normally be expected to depress yields, but it was thought that this might be offset, at least to some extent, if the crops suffered less from virus. Susceptible and resistant feeding cultivars were also included so that the effects of delayed sowing in the absence of virus could also be assessed.

A second objective was to get comparative disease and yield data for the same group of cultivars grown in the presence of BaYMV, especially because the survey data (mentioned above) had suggested that malting cultivars were rarely affected by BaYMV.

In selecting the cultivars used, the opportunity was taken to include cv. Sprite so that its field resistance to virus could be evaluated and also to examine the relative performance of spring barleys sown in the late autumn or the spring in the presence of BaMMV.

2. EXPERIMENTAL PROCEDURES

In each of the three years of the project, field trials were conducted at two sites within 2.5 miles of each other at Hatherop (BaMMV site) and Eastleach (BaYMV site), Gloucestershire. The soil at both sites was Sherborne series, containing limestone pieces over limestone. Both sites had grown continuous winter barley for at least 10 years and the viruses present had been monitored during previous experiments (Adams, Grylls, Hill, Jones & Morris, 1992).

2.1. Design of field experiments

The cultivars chosen and their characteristics are shown in Table 1. In each year, the eight winter cultivars were sown at each site at malting N levels and the four feeding cultivars were additionally grown at feed N levels. The spring cultivars were

Table 1. Cultivars used in the experiments

Cultivar	Type	Reaction to mosaic virus
Willow	Winter: Feed	Resistant
Firefly†		Resistant
Epic*		Resistant
Target		Resistant
Fighter		Susceptible
Sprite	Winter: Malting	Partially resistant?
Pipkin		Susceptible
Halcyon		Susceptible
Puffin		Susceptible
Blenheim	Spring: Malting	Susceptible?
Alexis		Susceptible?

† In 1992/3 only (then replaced with Epic)
* In 1993/4 and 1994/5 only

grown only at the BaMMV site.

In the experiments at the BaMMV site, it was planned to have four autumn and two spring sowing dates. Target sowing dates were 20 Sept, 5 Oct, 20 Oct, 20 Nov, 20 Feb and 20 March. Winter cultivars were sown on all autumn dates and the spring cultivars at the two later autumn dates as well as in the spring. In addition, the four feeding cultivars were also sown on the first spring date in 1992/3. Weather conditions prevented the fourth autumn sowing in 1992/3 and only one spring sowing was achieved in 1994/5. At the BaYMV site, there was a single, early autumn, sowing, using the eight winter cultivars. The full range of treatments is summarised in Table 2 and the amounts and timing of N fertiliser applied in each year and at each site is shown in Table 3. Actual sowing dates are shown in the relevant tables for each year.

Each experiment was conducted using a three-replicate randomised block design. At the BaMMV site, it was not possible to randomise the sowing dates, but the experiments were situated in slightly different positions each year and it is unlikely that there were large variations in the extent of virus infestation between the different dates. Plots of 16 x 1.25 m (BaMMV site) or 18 x 1.25 m (BaYMV site) were drilled with an Oyjord plot drill on the dates shown in the tables. Applications of herbicide, fungicide and insecticide were done by the host farmers according to local practice.

2.2. Field observations and measurements

Periodic visits were made to assess plant emergence. Visits were then made at least once a month from December to May to assess virus symptom development. This was done by estimating the approximate percentage of plants infected from inspection of several positions in each plot. In each year, samples of leaves with symptoms were collected from plots at both sites (usually 5 plants per plot, taken as indicated in the Results section, below) and used for laboratory testing to determine which virus was present. Occasionally, plants with roots were sampled in order to test the roots of symptomless plants for virus. Plots were harvested using a Claas Dominator combine harvester on dates shown in the Tables. Weights of grain per plot and grain moisture were recorded at harvest. Hectolitre weight and grain nitrogen analysis were subsequently done on samples from most treatments.

Table 2. Summary of cultivar and nitrogen treatments in the experiments

Cultivar type	N-regime	BaYMV site: 1 early autumn sowing	BaMMV site		
			1st and 2nd autumn sowings	3rd and 4th autumn sowings	Two spring sowings
Winter Feed (4cvs)	Malting	+	+	+	-
Winter Malting (4 cvs)	Malting	+	+	+	-
Spring (2 cvs)	Malting	-	-	+	+
Winter Feed (4cvs)	Feed	+	+	+	-*

* these cultivars were also sown at the first spring sowing date in 1992/3

Table 3. Amounts and timing of nitrogen fertiliser applied (kg/ha) at each site and each year

Application		1992/3		1993/4		1994/5	
		BaMMV	BaYMV	BaMMV	BaYMV	BaMMV	BaYMV
1st	Rate	55	75	50	58	60	50
	Date	mid Feb		10 March	6 April	14 March	2 March
2nd	Rate	66	50	66	67	60	76
	Date	early April		29 March	21 April	19 March	12 March
Top up*	Rate	75	75	75	75	50	50
	Date	Mar 17		29 April		21 April	
Totals		121/200	125/200	116/191	125/200	120/170	126/176

* applied to Feed N plots only

2.3. Laboratory procedures

Routine testing of leaf samples for BaYMV and/or BaMMV was done separately for each plant sampled using the enzyme linked immunosorbent assay (ELISA) as described by Adams (1991). This is a highly sensitive serological test in which crushed leaf extract is mixed with antiserum specific to each of the viruses. Occasionally, roots were tested for the presence of viral nucleic acid using the polymerase chain reaction as described by Schenk, Antoniw, Batista, Jacobi, Adams & Steinbiss (1995).

3. RESULTS

3.1. 1992/3 Experiments

Weather conditions delayed the first sowing until October 7/9 and at the BaMMV site, only three autumn sowings were achieved. All cultivars established well at both sites.

3.1.1. Disease assessments: Root samples were taken on 15 December from 24 plots at the BaMMV site and one at the BaYMV site, but no virus could be detected in any sample by ELISA. On 18 January, symptoms were just beginning to appear at both sites and by mid-February at the BaYMV site, disease levels were high on cv. Fighter but were insignificant on the malting cultivars (Table 4) and remained so throughout the season. Symptoms developed rather more slowly at the BaMMV site and reached their maximum in mid-April (Table 4) when cv. Fighter and the malting cultivars all had about 20% plants infected in plots sown at the earliest date. Although for most cultivars, the disease levels increased steadily from January to April, in cv. Sprite, almost no disease was seen until the April assessment. Disease levels were progressively less with the later sowings, but small numbers of plants of susceptible cultivars (including the spring cvs) were still infected when sown on Nov 6. The rather low levels of disease at this site were probably due in part to the delayed first sowing and to the fact that the trial appeared to have been sown at the edge of the most heavily infested area of the field. No virus symptoms were seen in the spring-sown plots at the BaMMV site or in any of the resistant cultivars. Leaf samples were taken from plots

Table 4. Disease levels (max % plants with mosaic symptoms) on cultivars sown on the different dates and with different N-regimes. 1992/3 trial

Cultivar	BaYMV		BaMMV					
	Oct 7		Oct 9		Oct 23		Nov 6	
	%	a*	%	a*	%	a*	%	a*
Malting N								
Willow	0	0	0	0	0	0	0	0
Firefly	0	0	0	0	0	0	0	0
Target	0	0	0	0	0	0	0	0
Fighter	77	63	22	24	10	15	5	12
Sprite	1	4	15	20	1	6	tr‡	2
Pipkin	1	6	7	13	1	5	tr‡	3
Halcyon	5	11	22	24	7	12	6	13
Puffin	2	7	15	20	6	11	2	7
Blenheim	-	-	-	-	-	-	4	11
Alexis	-	-	-	-	-	-	1	5
Feed N								
Willow	0	0	0	0	0	0	0	0
Firefly	0	0	0	0	0	0	0	0
Target	0	0	0	0	0	0	0	0
Fighter	48	43	20	23	12	18	3	9
SED†		7.9		3.2		4.4		2.9

* arcsin (angular) transformed values
† 10 df (14 df for Nov 6 sowing); cultivars without symptoms omitted from statistical analysis
‡ tr = trace (<1% plants infected)

with symptoms on 18 Jan and 15 Feb. A total of 105 individual plant samples were tested from the BaYMV site and 69 from the earliest sowing on the BaMMV site. ELISA results showed that all plants tested from the BaYMV site had only BaYMV and all those from the BaMMV site had only BaMMV. On 11 May, samples of roots from 15 separate plants were taken from spring-sown spring cultivar plots at BaMMV site but no virus could be detected in any of them by ELISA.

3.1.2. Yield and quality assessments: Yields are presented in Table 5. At the BaYMV site, cv. Fighter yielded significantly less than the resistant feed cultivars and amongst the malting cultivars, only cv. Puffin had a lower yield. Since Fighter would be expected to yield at least as well as the resistant cultivars in the absence of disease a yield depression of about 12% may attributed to virus infection. Firefly was poorer than the other resistant cultivars in these trials and it was decided to substitute cv. Epic in the following years. At the BaMMV site, resistant cultivars and cv. Sprite generally yielded best at the earliest sowing date, as would be expected. There was, however, some indication of a benefit from delayed sowing of the susceptible cultivars as Fighter, Pipkin, Halcyon and Puffin all yielded better from the Oct 23 than from the Oct 9 sowing. Spring cultivars yielded better from the first spring sowing (Feb 19) than when sown in November. The main effect of growing cultivars at feed rather than malting levels of nitrogen (which did not affect virus symptom expression) appeared to be a better tolerance of later sowing dates. Specific weights (Table 6) of the feed cultivars were not greatly affected by sowing dates or nitrogen levels. The malting cultivars showed a slight tendency to lower specific weights at the later sowing dates while the lowest grain nitrogen (Table 7) was at the first sowing date. Higher grain nitrogen at the BaYMV site reflects a slightly higher nitrogen input.

3.2. 1993/4 Experiments

At the BaMMV site, all sowing dates were achieved fairly close to target. However, soil conditions at the BaYMV site delayed the sowing until Oct 17.

Table 5. Yields (t/ha) of cultivars sown on the different dates and with different N-regimes. 1992/3 trial

Cultivar	BaYMV	BaMMV				
	Oct 7	Oct 9	Oct 23	Nov 6	Feb 19	Mar 15
Malting N						
Willow	5.82	5.76	5.79	5.09	4.26	-
Firefly	5.56	5.63	5.69	5.23	4.27	-
Target	5.96	5.23	4.96	5.11	4.26	-
Fighter	5.26	5.05	5.88	5.44	4.52	-
Sprite	5.64	5.64	5.10	5.29	-	-
Pipkin	5.73	4.73	5.04	4.52	-	-
Halcyon	5.71	5.19	5.26	5.10	-	-
Puffin	4.49	4.77	4.91	5.10	-	-
Blenheim	-	-	-	4.97	5.44	4.82
Alexis	-	-	-	4.36	5.33	4.58
LSD	0.49	0.56	0.68	0.62	0.68	1.41
Feed N						
Willow	5.68	6.05	5.73	5.76	-	-
Firefly	5.66	5.73	5.86	5.28	-	-
Target	5.91	5.95	5.35	5.60	-	-
Fighter	5.30	5.30	6.12	6.05	-	-
LSD	0.35	0.68	0.28	0.42		
Harvested	July 22	July 22	July 23	July 23	Aug 3	Aug 3

Table 6. Specific weights (kg/hl) of cultivars sown on the different dates and with different N-regimes. 1992/3 trial

Cultivar	BaYMV	BaMMV				
	Oct 7	Oct 9	Oct 23	Nov 6	Feb 19	Mar 15
Malting N						
Willow	69.5	69.1	68.4	69.0	69.2	-
Firefly	69.9	69.9	67.9	69.2	67.9	-
Target	68.9	69.0	65.3	67.2	67.5	-
Fighter	69.7	68.4	67.7	68.0	66.5	-
Sprite	70.5	70.8	68.0	69.5	-	-
Pipkin	71.0	69.7	66.7	70.0	-	-
Halcyon	70.9	70.5	68.4	69.7	-	-
Puffin	70.1	67.7	67.0	68.1	-	-
Blenheim	-	-	-	67.8	69.1	66.8
Alexis	-	-	-	69.6	67.1	65.4
Feed N						
Willow	70.4	69.0	66.7	70.1	-	-
Firefly	70.7	70.0	67.2	68.7	-	-
Target	68.7	66.8	66.0	66.5	-	-
Fighter	69.1	68.3	64.6	66.1	-	-

Table 7. Grain nitrogen (%) of malting cultivars sown on the different dates. 1992/3 trial

Cultivar	BaYMV	BaMMV				
	Oct 7	Oct 9	Oct 23	Nov 6	Feb 19	Mar 15
Sprite	2.00	1.66	1.79	1.61	-	-
Pipkin	1.83	1.56	1.69	1.84	-	-
Halcyon	1.87	1.62	1.80	1.59	-	-
Puffin	1.93	1.71	1.77	1.63	-	-
Blenheim	-	-	-	1.50	1.75	1.52
Alexis	-	-	-	1.63	1.68	1.54

3.2.1. Disease assessments: Symptoms appeared on the first sowing at the BaMMV site in early January and became severe on all the susceptible cultivars by mid-February. On cv. Sprite, symptoms developed more slowly than on the fully-susceptible cultivars, but ultimately reached similar levels (Fig. 1). On plots from the second sowing date, symptoms developed later and were only significant on cvs Fighter and Halcyon (Table 8; Fig. 1). Very few plants from the third sowing, and none from the fourth developed symptoms. Spring-sown plots were also disease-free. At the BaYMV site, symptoms began appearing on cv. Fighter in February and were moderately severe by mid-March. On the other cultivars, disease was slight, although 14% plants of cv. Halcyon were showing symptoms by mid-April. Resistant cultivars remained uninfected. Leaf samples with symptoms were taken from all susceptible cultivars from the first sowing date at the BaMMV site on 17 Jan and from the BaYMV site on 21 Feb. ELISA tests showed that of the 80 samples from the BaMMV site, all had BaMMV and one also had low levels of BaYMV. All 47 samples from the BaYMV site had BaYMV and four samples were jointly infected with BaMMV. Further samples of cv. Halcyon from the BaYMV site were taken on 11 April to examine the cause of the late-developing symptoms on this malting cultivar: all proved to be BaYMV. Root samples were taken from spring-sown spring cultivars at the BaMMV site on 9 May and tested by PCR but no virus was detected.

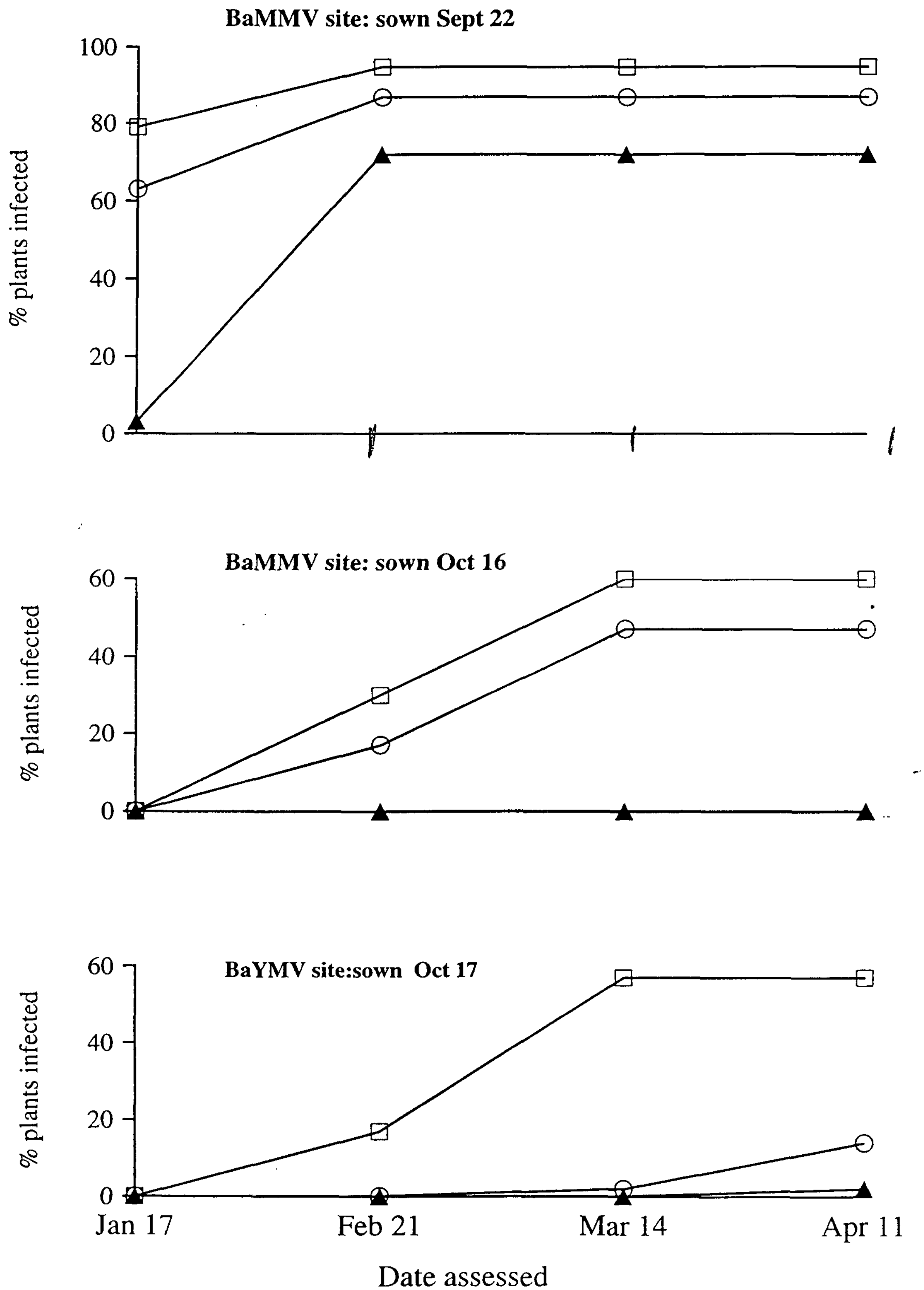

Fig. 1. Development of symptoms on cvs Fighter (○), Halcyon (□) and Sprite (▲) in plots sown on different dates. 1993/4 trial

Table 8. Disease levels (max % plants with mosaic symptoms) on cultivars sown on the different dates and with different N-regimes. 1993/4 trial

Cultivar	BaYMV		BaMMV					
	Oct 17		Sept 22		Oct 16		Nov 3	
	%	a*	%	a*	%	a*	%	a*
Malting N								
Willow	0	0	0	0	0	0	0	0
Epic	0	0	0	0	0	0	0	0
Target	0	0	0	0	0	0	0	0
Fighter	57	49	97	84	60	51	2	5
Sprite	2	6	82	65	tr‡	1	0	0
Pipkin	2	6	75	62	4	8	0	0
Halcyon	14	20	87	77	47	41	2	6
Puffin	2	7	97	84	2	8	tr‡	2
Blenheim	-	-	-	-	-	-	1	4
Alexis	-	-	-	-	-	-	tr‡	1
Feed N								
Willow	0	0	0	0	0	0	0	0
Epic	0	0	0	0	0	0	0	0
Target	0	0	0	0	0	0	0	0
Fighter	70	58	95	80	31	30	3	7
SED†		5.7				11.0		2.9

* arcsin (angular) transformed values
† 10 df; cultivars without symptoms omitted from statistical analysis
‡ tr = trace (<1% plants infected)

3.2.2. Yield and quality assessments: Yields are shown in Table 9. At the BaYMV site, yields were lowest from cvs Fighter and Halcyon, which were the only cultivars to develop significant amounts of disease. At the BaMMV site, yields of resistant cultivars were usually greatest from the first sowing date, declining steadily as sowing was delayed. Amongst the fully susceptible cultivars (Fighter, Pipkin, Halcyon, Puffin) yields at the first sowing date (which developed the greatest levels of disease) were the lowest of any of the dates and the highest yields were at the third (Nov 3) sowing, although they never reached those of the resistant cultivars at the earliest sowing. This effect is summarised in Fig. 2, which shows that delaying sowing can produce greater yields when the gain from decreased disease outweighs the negative effects on plant growth. The cv. Sprite, in which symptom expression is delayed, appears to have some disease tolerance and tended to have a constant yield across the sowing dates. Spring barley cultivars gave the best yields from the Nov 3 sowing. In almost all cases, yield was improved by the higher nitrogen levels of the feeding nitrogen regime. However there was no effect on cv. Fighter at the BaYMV site or on the first sowing date at the BaMMV site, confirming earlier experiments that showed that increased nitrogen cannot compensate for the effects of mosaic virus infection. Responses to the extra nitrogen were the smallest at the fourth sowing date, probably because of the lower yield potential. Specific weights were determined only for cultivars grown with malting nitrogen levels and, at the BaMMV site, only for the first sowing date. They were lowest for cv. Fighter (Table 10) and this may be an effect of virus infection. The feed cultivars usually produced higher grain nitrogen levels than the malting cultivars (Table 11). For most cultivars, grain nitrogen remained fairly constant over the first three sowing dates at the BaMMV site, but increased at the fourth date, associated with the general drop in yield. The spring cultivars gave the lowest grain nitrogen at this sowing date.

Table 9. Yields (t/ha) of cultivars sown on the different dates and with different N-regimes. 1993/4 trial

Cultivar	BaYMV	BaMMV					
	Oct 17	Sept 22	Oct 16	Nov 3	Nov 19	Mar 1	Mar 24
Malting N							
Willow	5.14	5.20	5.34	5.07	4.40	-	-
Epic	5.04	5.85	5.28	5.46	4.60	-	-
Target	5.22	5.80	5.65	5.17	4.47	-	-
Fighter	4.75	4.50	4.76	5.18	4.89	-	-
Sprite	5.20	5.37	5.10	5.35	4.94	-	-
Pipkin	5.02	4.02	4.44	5.16	4.76	-	-
Halcyon	4.86	4.51	4.85	5.09	4.64	-	-
Puffin	5.22	3.96	4.94	5.32	4.78	-	-
Blenheim	-	-	-	4.82	4.12	4.44	2.68
Alexis	-	-	-	5.23	4.96	5.55	3.00
LSD	0.57	0.73	0.60	0.34	0.58	1.62	1.62
Feed N							
Willow	5.59	5.90	5.49	5.18	4.45	-	-
Epic	5.00	6.27	6.22	5.30	4.72	-	-
Target	5.34	6.21	6.26	5.41	4.63	-	-
Fighter	4.87	4.27	5.28	5.57	5.06	-	-
LSD	0.83	0.78	0.84	0.34	0.68	-	-
Harvested	July 22	July 21	July 21	July 22	July 22	July 25	July 25

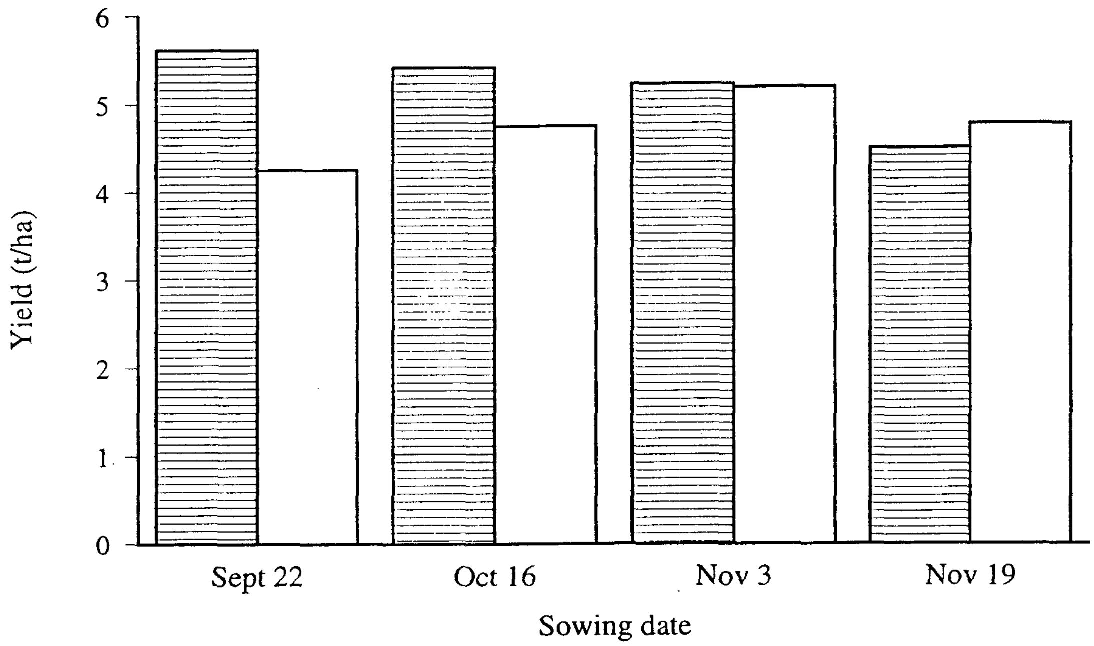

Fig. 2. Average yields of the resistant cultivars, Willow, Epic and Target (hatched columns) and the susceptible cultivars, Fighter, Halcyon, Pipkin and Puffin (open columns) sown on the different dates at the BaMMV site. 1993/4 trial.

Table 10. Specific weights (kg/hl) of cultivars sown on the different sites (malting N regime and first sowing date only at BaMMV site). 1993/4 trial

Cultivar	BaYMV	BaMMV
	Oct 17	Sept 22
Willow	70.9	71.4
Epic	70.3	71.7
Target	71.5	71.2
Fighter	67.5	65.7
Sprite	69.5	69.4
Pipkin	69.6	70.8
Halcyon	69.8	70.1
Puffin	69.6	70.2

Table 11. Grain nitrogen (%) of cultivars sown on the different dates (malting N regime only). 1993/4 trial

Cultivar	BaYMV	BaMMV			
	Oct 17	Sept 22	Oct 16	Nov 3	Nov 19
Willow	2.00	1.85	1.90	1.74	2.01
Epic	1.83	1.78	1.84	1.84	2.48
Target	1.87	1.74	1.78	1.72	2.00
Fighter	1.93	1.79	1.75	1.73	1.95
Sprite	1.98	1.71	1.73	1.73	1.94
Pipkin	1.99	1.64	1.68	1.73	1.89
Halcyon	2.02	1.68	1.64	1.76	1.91
Puffin	2.18	1.77	1.70	1.74	1.88
Blenheim	-	-	-	-	1.81
Alexis	-	-	-	-	1.78

3.3. 1994/5 Experiments

Autumn sowing dates were close to target at both sites. At the BaMMV site, only one spring sowing was possible (Mar 14) and grazing by hares prevented these plots from reaching harvest. The autumn was exceptionally mild, with soil temperatures above average until late November.

3.3.1. Disease assessments: Symptoms were seen on a few plants of cv. Fighter at both sites on 16 Jan. By 15 Feb, disease levels had rapidly increased. At the BaYMV site, cv. Fighter was the most severely infected (about 60% plants), with modest levels of disease in the susceptible malting cultivars (Table 12). At the BaMMV site, plants of susceptible cultivars from the first three sowing dates were very heavily, and almost uniformly, infected, although there was usually slightly less disease and slightly delayed symptom expression from the third sowing date. The spring cultivars sown on Oct 28 had more than 50% plants infected. No virus symptoms developed in plots from the fourth (29 Nov) sowing or on any of the plots of resistant cultivars at either site. On 13 March, leaf samples were taken from plots of cvs Fighter and Halcyon (BaYMV site) and from plots of cv. Fighter from the first three sowing dates at the BaMMV site. These were tested by ELISA to determine the virus(es) responsible. Of the 42 samples from the BaYMV site, all had BaYMV and 2 were dually infected with BaMMV, while of the 90 samples from the BaMMV site, all had BaMMV and 1 was dually infected.

3.3.2. Yield and quality assessments: Spring and summer 1995 were particularly dry and yields were very restricted on both sites (Table 13). This may have masked some of the effect of disease. However, at the BaMMV site, a similar effect to the previous year could be seen: yield decreased over the first three sowing dates in the resistant cultivars, but tended to increase amongst the susceptible ones (Fig. 3). As in the previous year, yield of the feeding cultivars was almost always improved by the higher nitrogen levels of the feeding nitrogen regime (especially on the first sowing date at the BaMMV site) except for the susceptible cv. Fighter. Specific weights (Table 14) tended to be lower where the disease was most severe and were not usually much affected by the nitrogen levels. Grain nitrogen levels were mostly rather high (Table 15) as a consequence of the low yields and there was no obvious effect of sowing date.

Table 12. Disease levels (max % plants with mosaic symptoms) on cultivars sown on the different dates and with different N-regimes. 1994/5 trial

Cultivar	BaYMV		BaMMV					
	Sept 22		Sept 23		Oct 13		Oct 28	
	%	a*	%	a*	%	a*	%	a*
Malting N								
Willow	0	0	0	0	0	0	0	0
Epic	0	0	0	0	0	0	0	0
Target	0	0	0	0	0	0	0	0
Fighter	60	51	100	90	100	90	88	71
Sprite	7	15	78	69	67	60	72	64
Pipkin	12	18	77	66	93	78	80	68
Halcyon	27	31	100	90	100	90	93	78
Puffin	20	26	100	90	100	90	83	75
Blenheim	-	-	-	-	-	-	57	49
Alexis	-	-	-	-	-	-	70	63
Feed N								
Willow	0	0	0	0	0	0	0	0
Epic	0	0	0	0	0	0	0	0
Target	0	0	0	0	0	0	0	0
Fighter	63	53	98	86	100	90	100	90
SED†		8.1		10.0		13.8		15.2

* arcsin (angular) transformed values
† 10 df (14 df for Oct 28 sowing); cultivars without symptoms omitted from statistical analysis

Table 13. Yields (t/ha) of cultivars sown on the different dates and with different N-regimes. 1994/5 trial

Cultivar	BaYMV	BaMMV			
	Sept 22	Sept 23	Oct 13	Oct 28	Nov 29
Malting N					
Willow	2.86	4.30	3.92	3.85	3.60
Epic	3.14	4.79	4.14	3.89	4.40
Target	3.22	4.43	3.80	3.97	4.43
Fighter	2.93	3.25	3.69	3.30	4.57
Sprite	3.68	4.42	3.43	3.70	4.25
Pipkin	3.55	2.37	2.73	2.97	3.25
Halcyon	3.52	2.95	3.65	3.17	3.80
Puffin	3.71	2.83	2.56	3.45	3.89
Blenheim	-	-	-	2.77	2.59
Alexis	-	-	-	2.08	*
LSD	0.53	0.71	0.63	0.64	0.53
Feed N					
Willow	3.63	5.55	3.87	4.00	3.95
Epic	3.61	5.57	4.51	4.52	4.49
Target	3.34	5.36	4.02	4.27	4.08
Fighter	3.13	3.41	3.69	3.37	4.75
LSD	0.53	0.71	0.63	0.64	0.53
Harvested	July 21	July 22	July 22	July 22	July 22

* Alexis failed to establish after Nov 29 sowing

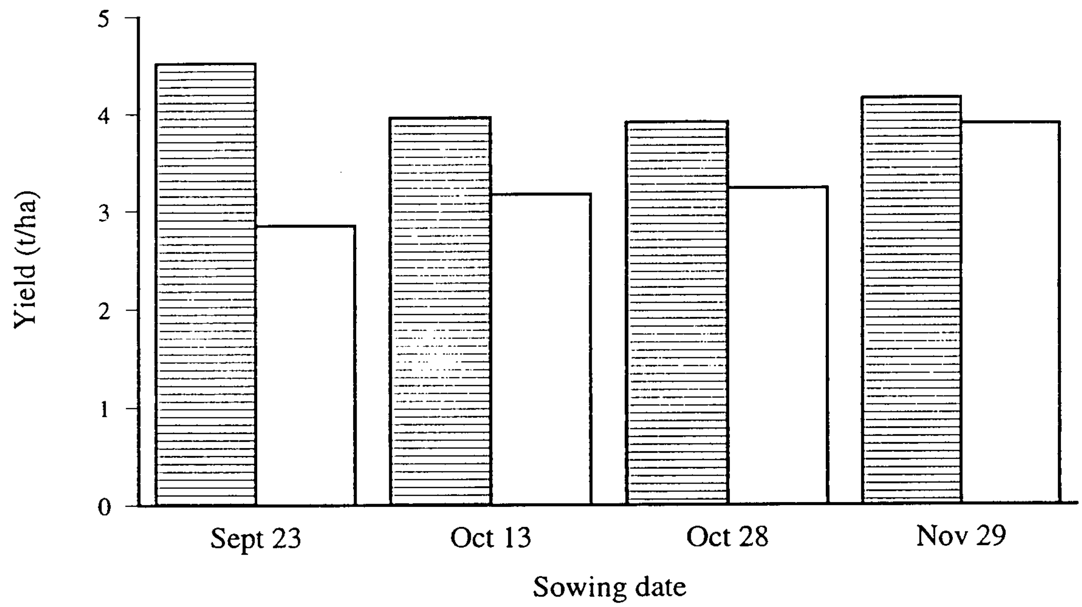

Fig. 3. Average yields of the resistant cultivars, Willow, Epic and Target (hatched columns) and the susceptible cultivars, Fighter, Halcyon, Pipkin and Puffin (open columns) sown on the different dates at the BaMMV site. 1994/5 trial.

Table 14. Specific weights (kg/hl) of cultivars sown on the different dates and with different N-regimes. 1994/5 trial

Cultivar	BaYMV	BaMMV			
	Sept 22	Sept 23	Oct 13	Oct 28	Nov 29
Malting N					
Willow	67.8	67.1	71.6	71.0	70.4
Epic	67.6	70.5	71.6	71.0	71.1
Target	69.8	69.5	67.6	70.9	70.2
Fighter	68.8	63.8	67.9	68.4	69.3
Sprite	69.5	70.2	68.0	73.0	74.8
Pipkin	70.3	69.7	73.6	72.1	70.4
Halcyon	69.7	66.8	68.4	70.7	70.0
Puffin	69.8	66.1	68.8	70.6	71.6
Blenheim	-	-	-	69.1	68.3
Alexis	-	-	-	68.7	-
Feed N					
Willow	70.7	69.6	71.3	71.5	69.5
Epic	69.8	70.6	71.0	72.1	71.1
Target	69.7	69.1	68.4	69.0	69.0
Fighter	67.0	65.6	65.5	69.0	65.8

Table 15. Grain nitrogen (%) of cultivars sown on the different dates (malting N-regime only). 1994/5 trial

Cultivar	BaYMV	BaMMV			
	Sept 22	Sept 23	Oct 13	Oct 28	Nov 29
Willow	1.93	2.04	1.99	*	*
Epic	1.88	1.99	1.94	2.01	2.02
Target	2.03	1.99	2.07	*	*
Fighter	2.02	2.20	1.95	1.90	2.03
Sprite	1.76	1.94	2.01	*	1.99
Pipkin	1.73	1.94	1.87	1.90	1.96
Halcyon	1.82	2.20	1.94	1.89	1.89
Puffin	1.80	2.14	2.02	*	2.06
Blenheim	-	-	-	*	*
Alexis	-	-	-	*	-

* data not obtained

4. DISCUSSION AND CONCLUSIONS

The two sites have proved to be consistently useful for these experiments, despite the fact that grain yields on these sites, with their thin, drought-prone soils, were generally rather low, especially in 1994/5. Detailed monitoring of infected plants demonstrated that the viruses were almost exclusively confined to their respective sites so that the different effects of the viruses could be compared on individual cultivars, providing that sowing dates were similar. Unfortunately the usefulness of data from the BaYMV site was limited by the delayed sowings in 1992/3 and especially 1993/4, and by the mild autumn and dry summer of 1994/5. There was no indication that symptoms of the two viruses developed at different times on susceptible cultivars sown on similar dates.

4.1. Relationship between sowing date, disease and yield

The experiments have given a conclusive demonstration, and for the first time under European conditions, that disease (at least if caused by BaMMV) is less if sowing is delayed. The decrease in disease resulting from later sowing was also reflected in the yield data, and it was clear that a susceptible cultivar sown on an infested site would yield better if sown in late October than in late September. It is, however, unlikely that these cultivars could ever be made to yield as well as the resistant ones sown early in the autumn.

The effects of delayed sowing on the disease are probably related to soil temperatures during the first few weeks of crop growth. The higher the temperature, the greater is likely to be the infection by the fungus vector, *Polymyxa graminis*, and multiplication of virus in the root cells. This in turn will lead to more symptoms in winter and spring when virus moves from the roots to the shoots. This also explains why the effect of delayed sowing on disease expression was less in 1994/5, when the autumn was exceptionally mild, than in the two previous seasons. An effect of autumn temperature on the response to delayed sowing was also noted in Japan (Watanabe, Toshima, Ueda & Ogawa, 1989).

4.2. Performance of cultivars and interaction with viruses

The experiments have given some useful indications of the relative susceptibilities of cultivars to the two viruses. Only in 1994/5 was it possible to compare disease levels on early-sown (3rd week of September) cultivars on the two sites, but it was then clear that the malting cultivars (Pipkin, Halcyon, Puffin) were much more susceptible to BaMMV than to BaYMV. Indeed, on BaYMV sites, their yields were sometimes comparable to those of the resistant cultivars. This confirms what has long been suspected from analysis of samples sent from commercial crops (Adams, 1991; 1993). By contrast, and rather unexpectedly, the feeding cv. Fighter proved to be equally susceptible to both viruses. Although cv. Sprite is not immune to the viruses, and sometimes a large proportion of plants became infected by BaMMV, symptom development was slower than on the fully susceptible malting cultivars and it appeared to have suffered much less yield penalty from the disease. It can therefore be regarded as partially resistant to BaMMV and, like the other malting cultivars, does not seem very prone to BaYMV. The spring cultivars tested proved susceptible to BaMMV if sown in the autumn, but it was not possible to detect virus in the roots of spring-sown plants. It is therefore not proven that spring cultivars sown in spring on an infested site would act as hosts for the virus even in the absence of leaf symptoms, but the possibility cannot be excluded.

4.3. Further work needed

There now appears to be a need, and an opportunity, to examine further the relative susceptibility of a wider range of feeding cultivars sown on sites with either BaMMV or BaYMV. To be comparable, these clearly need to be in geographical proximity and to be sown on similar dates (preferably before the end of September). It would also be valuable to determine if the effect of sowing date shown at the BaMMV site could also be demonstrated in the presence of BaYMV. It is also possible that increased seeding rates at the later sowings may further enhance the performance of susceptible cultivars sown relatively late on an infested site. Such experiments have now begun under a further grant to ARC and IACR-Rothamsted from the HGCA (project number 0022/01/95) for the period September 1995 to August 1998.

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