HGCA

PROJECT REPORT No. 203

INFLUENCE OF VARIETY, DRILLING DATE AND SEEDING RATE ON PERFORMANCE OF WINTER BARLEY VARIETIES GROWN IN THE PRESENCE OF BARLEY MOSAIC VIRUS

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by

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Contents

Part 1 - Summary

Introduction

Barley Mosaic Virus (BMV) is a soil-borne virus carried by soil fungi which is present in soils, to varying degrees, in most areas of the UK. Infection of barley crops by the virus can lead to severe yield penalties. Extensive research into the problem has indicated that agronomic measures or inputs have little or no effect on virus expression or associated yield losses. The main line of defence against the disease is through genetic resistance in mv resistant or tolerant varieties. Plant breeders continually select for BMV resistance in limited numbers of varieties, and the evaluation of such varieties for agronomic performance is just as important as it is for cereal cultivation generally. In this project a number of winter barley varieties, both mv-susceptible and mv-tolerant, were sown on land infected with BMV in order to evaluate the yield penalties associated with mosaic virus in susceptible varieties, and also the yield performance of tolerant varieties when grown on infected land. In addition, the project also looked at the aspect of sowing date and variety interaction, looking at four variety 'types' (malt or feed, mv - tolerant or susceptible). Also, the element of seed rate was investigated, as an agronomic measure which had not been considered previously. Increasing the seedrate may produce a yield response in a crop whose yield potential had been restricted by virus infection. It may also be beneficial in reducing the yield penalty associated with delayed sowing, which has previously had to be balanced against the benefits of reduced virus severity seen in late sown crops.

Methods

In each of three years, 1995, 96 and 97 a number of winter barley varieties were sown at two locations near Fairford in Gloucestershire in small plot randomised block trials. One site (Hatherop) is known to have soil uniformly infected with Barley Mild Mosaic Virus, the other site (Eastleach) being uniformly infected with Barley Yellow Mosaic Virus. The same fields had been monitored by IACR Rothamsted for several years beforehand confirming the identity and the extent of soil infection of the respective virus strains. The varieties sown consisted of those entered in HGCA Recommended List trials, for each respective year i.e. Recommended List varieties plus candidate varieties elevated to RLI trials. Each year approximately 25% of varieties drilled were mv-tolerant. Following establishment the plots were monitored for virus symptom development on several occasions. Assessments were made of virus infection by counting the percentage in each plot. Each trial was then taken to yield and the yield effects of virus infection related to symptom development in the spring.

All plots received routine management with general inputs, to best local farmer practice.

Target sowing date for both trials was September 20th each year. Each year a large sample of infected plants were collected and analysed at IACR Rothamsted by ELISA test to confirm the strain of the virus present at each site.

Trials were established in a continuous barley situation at both sites.

In addition to the variety trials, eight varieties of winter barley were sown at each of two seed rates. The varieties were chosen to represent virus-susceptible and virus tolerant types and also both feed and malt varieties. The varieties were:

Fighter (feed barley, mv - susceptible)
Pastoral (feed, susceptible)
Epic (feed, tolerant)
Tokyo (feed, tolerant)
Puffin (malt, susceptible)
Pipkin (malt, susceptible)
Gleam (malt, tolerant)
Falcon (malt, tolerant)

All eight varieties were sown at 350 and 450 seeds/m^2, and at three sowing dates in 1995 and 96. Extended wet weather in the autumn of 1997 prevented the planting of the third sowing date.

Results – Variety Trials

Virus infection assessments- 1996 figures given as example

The following tables give the highest recorded values for the percentage of plants infected with virus, from several assessment dates each year. Figures are given for both trial sites, and for each of the three years of the project.

Table 1 - 1996

% Plants Infected
(mean of 3 replicate plots)

Hatherop (BMMV)

Angora	100
Epic*	0
Falcon*	0
Fanfare	98
Fighter	98
Gaelic	98
Gleam*	10
Halcyon	100
Hanna	98
Intro	87
Linnet	92
Manitou	100
Melanie	100
Muscat*	0
Pastoral	93
Pipkin	100
Portrait	90
Prelude	100
Puffin	100
Regina	98
Rifle	98
Sprite	93
Sunrise*	0
Tokyo*	2

Eastleach (BYMV)

Angora	57
Epic*	0
Falcon*	0
Fanfare	90
Fighter	98
Gaelic	60
Gleam*	12
Halcyon	97
Hanna	98
Intro	97
Linnet	98
Manitou	98
Melanie	93
Muscat*	0
Pastoral	88
Pipkin	80
Portrait	45
Prelude	78
Puffin	63
Regina	90
Rifle	80
Sprite	78
Sunrise*	0
Tokyo*	0

* = mv tolerant

At Hatherop there was very little variation in infection levels: either most of the plants were infected in the case of the virus-susceptible varieties (minimum 87% with Intro) or virtually

virus free in the case of the virus-tolerant varieties, though both Tokyo and Gleam were showing symptoms in a low percentage of plants. At Eastleach a wider range of infection levels was recorded, with some mv-susceptible varieties showing low infection levels, e.g. Portrait (45%), Angora (57%). Again Gleam, an mv-tolerant variety, did show symptoms on some plants.

In 1997 and 98 trends in infection levels were very similar but the levels themselves were generally lower at both sites.

ELISA Sampling

Each year large numbers of plants were sampled and subjected to ELISA diagnostic testing to identify the strain of virus present at each site. Details of the sampling and results of the tests are as follows.

Table 2

	Hatherop			Eastleach		
	96	**97**	**98**	**96**	**97**	**98**
No of plants sampled	288	413	248	372	175	202
% infected with virus	98	85	98	96	63	69
% infected with BYMV	0	0	2*	94	61	68
% infected with BMMV	98	85	98*	2	2	1
* small percentage infected with both viruses						

Yields

The following tables give the yields in rank order, of the varieties in trial at each site, from the 1996 harvest year. Yield figures are expressed in tonnes/ha and also as a percentage of the site mean yield. Specific weights are also given.

Table 3 - 1996

Hatherop (BMMV)

Variety	t/ha	% Site Mean	Sp Wt kg/hl
UN20/51*	8.67	145	63.7
Tokyo*	8.59	144	65.5
Majestic*	8.55	144	60.3
Muscat*	8.23	138	66.1
Angela*	8.13	136	62.5
Gleam*	7.85	132	64.5
Theresa*	7.59	127	62.6
UN3254*	7.59	127	59.5
Sprite	7.42	126	67.2
Sunrise*	7.23	121	65.5
Falcon*	7.18	121	63.8
Regina	7.07	119	60.7
Hanna	6.95	117	65.5
Intro	6.48	109	63.9
Prelude	6.40	107	59.5
Epic*	5.91	99	68.9
Melanie	5.89	99	62.3
Angora	5.76	97	62.5
Pastoral	5.19	87	60.7
Linnet	4.90	82	60.7
Fanfare	4.66	78	64.2
Rifle	4.64	78	57.5
Fighter	4.24	71	65.0
Halcyon	4.08	69	64.0
Portrait	3.98	67	56.4
Spice	3.54	59	58.2
Manitou	3.46	58	65.5
Gaelic	3.39	57	64.6
Pipkin	3.17	53	64.1
Puffin	1.88	32	61.0
LSD 2.41 t/ha			
Site Mean Yield = 5.95 t/ha			
*mv-tolerant			

Eastleach (BYMV)

Variety	t/ha	% Site Mean	Sp Wt kg/hl
UN20/51*	7.67	126	63.7
UN3254*	7.36	121	60.0
Angela*	7.03	116	60.2
Falcon*	7.01	115	66.5
Muscat*	6.78	112	64.5
Majestic*	6.76	111	58.7
Fanfare	6.76	111	64.2
Tokyo*	6.67	110	62.7
Gleam*	6.51	107	68.1
Theresa*	6.46	106	62.4
Spice	6.46	106	66.0
Sprite	6.45	106	68.5
Epic*	6.31	104	66.8
Portrait	6.08	100	67.5
Pastoral	6.03	99	66.9
Intro	5.91	97	65.6
Prelude	5.90	97	67.4
Hanna	5.88	97	65.0
Rifle	5.87	97	66.2
Fighter	5.83	96	67.6
Angora	5.83	96	65.9
Sunrise*	5.74	94	67.0
Puffin	5.65	93	69.4
Pipkin	5.39	89	68.8
Manitou	5.38	88	59.6
Gaelic	5.33	88	70.7
Melanie	5.11	84	65.5
Halcyon	5.01	82	69.5
Linnet	4.94	81	66.1
Regina	4.29	71	61.7
LSD 0.73 t/ha			
Site Mean yield = 6.08 t/ha			
*mv-tolerant			

At both sites the yield clearly reflect the susceptibility of the variety to mosaic virus with the tolerant varieties giving highest yields. This trend is more clear at Hatherop than at Eastleach, reflecting the levels of infection seen at each site. However, the yields of susceptible varieties do not necessarily reflect their respective infection levels: at Eastleach, for example, Fanfare showed 90% plant infection but was the highest yielding susceptible variety, but Gaelic was 1.43 t/ha lower yielding but only 60% of plants were infected. At Hatherop there was little variation in infection levels,

Tables 4and 5 list the yields including three year mean yields, of the 16 varieties which were common to all three years of the project. Yields are expressed as a percentage of the mean yield (taken as 100%) of those 16 varieties in each case

Table 4

Hatherop (BMMV)

	96	97	98	3 year mean
Angela*	140	142	143	142
Tokyo*	146	117	113	125
Gleam*	135	108	128	124
Muscat*	141	111	123	123
Falcon*	124	103	125	117
Regina	121	94	108	115
Epic*	102	122	112	112
Intro	111	108	113	111
Angora	99	94	118	104
Pastoral	89	83	104	92
Rifle	80	81	108	90
Fanfare	80	110	66	85
Fighter	73	89	82	81
Halcyon	70	94	78	81
Pipkin	55	91	55	67
Puffin	32	55	109	65

Table 5
Eastleach (BYMV)

	96	97	98	3 year mean
Fanfare	112	106	127	115
Angela*	116	112	111	113
Tokyo*	110	97	109	105
Muscat*	112	107	89	103
Rifle	97	107	104	103
Gleam*	107	100	100	102
Falcon*	116	97	91	101
Fighter	96	108	100	101
Intro	98	105	101	101
Puffin	93	91	106	97
Epic*	104	108	76	96
Pastoral	100	93	96	96
Regina	71	100	115	95
Halcyon	83	94	102	93
Pipkin	89	83	97	90
Angora	96	91	75	87

At Hatherop the mv tolerant varieties have consistently yielded highest, the six row variety Angela and the two rows Tokyo and Gleam giving the best performances. The malt barleys, susceptible to the virus, such as Puffin, Pipkin Halcyon and Fanfare have given some of the lowest yields, however Regina has not shown the same poor yields as these other malt varieties, though its performance over the three years has been variable.

At Eastleach the range in yields is far less, but again the malt varieties (including Regina) have given some of the poorest yields. This is more likely due to their inherent yield potential than any differential response to the strain of virus, since infection levels at Eastleach have been relatively low. This is also highlighted by the fact that Fanfare, an mv-susceptible variety, has given the highest yield averaged over the three years. Its best performance relative to the other varieties was seen in 1998 when infection levels at Eastleach were at their lowest, though even in 1996 with higher virus levels Fanfare ranked equal third.

Where infection levels were significant the highest yielding varieties at both sites were Angela, Muscat (both six-row varieties) Gleam and Tokyo. With the less severe virus strain, (yellow), some malt varieties may yield well in years where mosaic virus incidence is lower, but as this cannot be predicted at the time of sowing, it is unlikely that such an option would be practical. However, where the areas of infection in a field are small, these varieties may represent a low risk option for growers wishing to retain mv susceptible varieties. With the more severe effects seen with the mild strain, it is more difficult to pinpoint specific varietal interactions with the virus and mv tolerant varieties have been the safest options irrespective of other varietal characteristics.

Results – Sowing date trials

Virus Infection Assessments

The following tables give the highest recorded levels of mv - infection, from the number of assessments carried out during the spring of 1996. Figures represent the percentage of plants infected with virus. As in the variety trials, virus levels were highest in this year and give the best indication of the effects of sowing date and seed rate.

Table 6 -1996

Sowing dates: September 20th, October 16th, November 6th

Hatherop (BMMV) Sowing Date

(BYMV) Date

	20/9	16/10	6/11
(a) 350 seeds/sqm			
Epic	0	0	0
Falcon	0	0	0
Fighter	98	100	78
Gleam	10	17	0
Pastoral	93	100	18
Pipkin	100	100	43
Puffin	100	100	23
Tokyo	2	0	0
(b) 450 seeds/sqm			
Epic	0	0	0
Falcon	0	0	0
Fighter	100	100	83
Gleam	7	17	0
Pastoral	100	100	17
Pipkin	90	100	28
Puffin	95	100	32
Tokyo	0	0	0

Eastleach Sowing

	20/9	16/10	6/11
(a) 350 seeds/sqm			
Epic	0	0	0
Falcon	0	0	0
Fighter	98	65	0
Gleam	12	5	0
Pastoral	88	33	0
Pipkin	80	5	0
Puffin	63	35	0
Tokyo	0	0	0
(b) 450 seeds/sqm			
Epic	0	0	0
Falcon	2	0	0
Fighter	78	83	0
Gleam	13	10	0
Pastoral	60	47	0
Pipkin	33	3	0
Puffin	50	40	0
Tokyo	1	0	0

Virus levels were generally higher at the mild-mosaic site (Hatherop), with some symptoms appearing on the tolerant varieties Gleam and Tokyo. Gleam also appeared to be infected at a

low level at the yellow mosaic site (Eastleach). At Hatherop delayed sowing to mid-October had little effect on virus levels, but when sowing was delayed until early November infection levels were reduced. At Eastleach a reduction in virus infection levels was achieved by delaying until October 16th, with no infection evident when delayed to November 6th. At Hatherop the higher seed rate appeared to have little effect on virus symptoms for any of the sowing dates, whilst at Eastleach there was some evidence of lower infection levels. However in subsequent years the effect of seed rate was less clear. In 1997 the higher seed rate seemed to increase virus levels in some varieties, whilst in 1998 there was no clear trend either way, at either site.
In terms of sowing date effects, the 1997 and 1998 data showed similar trends to that seen here. Delaying sowing until mid-October had little effect on virus levels, only the November sowings showing little or no infection. The exception was seen at Eastleach (BYMV) in1998 when virus levels generally were low at the earliest sowing and were almost absent at the second.

Yields

Again the yield figures from 1996 are given as an example, followed by a summary of the three years' data.

Table 7

Hatherop (BMMV)
Sowing Date

	20/9	16/10	6/11
(a) 350 seeds/sqm			
Epic	5.91	6.96	8.05
Falcon	7.18	7.36	7.18
Fighter	4.24	5.63	6.87
Gleam	7.85	7.61	7.33
Pastoral	5.19	6.28	6.73
Pipkin	3.17	6.61	5.43
Puffin	1.88	5.55	6.13
Tokyo	8.59	7.28	8.16
LSD (t/ha)	2.14	2.13	0.69
(b) 450 seeds/sqm			
Epic	8.43	8.56	7.70
Falcon	7.97	7.70	7.29
Fighter	5.65	5.29	7.23
Gleam	7.70	8.12	7.55
Pastoral	6.18	7.08	7.57
Pipkin	3.84	5.35	6.25
Puffin	4.27	3.71	6.62
Tokyo	8.00	8.42	7.84
LSD (t/ha)	2.41	2.13	0.69

Eastleach (BYMV)
Sowing Date

	20/9	16/10	6/11
(a) 350 seeds/sqm			
Epic	6.31	6.68	7.31
Falcon	7.01	6.30	7.43
Fighter	5.83	5.59	7.19
Gleam	6.51	6.61	7.32
Pastoral	6.03	6.28	6.95
Pipkin	5.39	5.83	6.40
Puffin	5.65	6.16	6.64
Tokyo	6.67	6.18	7.40
LSD (t/ha)	0.73	0.62	0.75
(b) 450 seeds/sqm			
Epic	6.85	6.34	7.34
Falcon	6.98	6.29	7.67
Fighter	6.13	5.87	7.11
Gleam	6.86	6.11	7.27
Pastoral	6.47	5.72	7.00
Pipkin	6.31	5.54	6.47
Puffin	6.62	5.86	6.54
Tokyo	7.36	6.08	7.24
LSD (t/ha)	1.07	0.62	0.75

Hatherop (BMMV): all mv-tolerant varieties except Epic significantly outyielded all mv-susceptible varieties. For the latter yield was improved by delayed sowing, the highest yields in most cases coming from the November 6th sowing. Yields for the tolerant varieties were stable across the first two sowings but did not significantly decline at the final sowing. Where yields were lowest, at DDI, increasing the seed rate improved yield in the susceptible

varieties, though not significantly. This effect was not seen in the tolerant varieties, or in any variety at the latest sowing date.

Eastleach (BYMV): yield differences were less at this site, though there was still a trend for the later drilling to produce higher yields in susceptible varieties. This was, however, also seen to some extent in the mv-tolerant varieties. Seed rate also had less effect on yield at this site.

As a means of summarising the three years results, the following table shows the yield effects of delayed sowing from the first to the last sowing date (delaying from the first to the second had little effect on yield in the majority of cases). Figures show the percentage change in yield (+or -) caused by delaying drilling until November, expressed as a mean of the four tolerant and susceptible varieties respectively, for each site and each seed rate. (Figures are not given for 1998, as a late drilling was not achieved).

Table 8

Variety Type	% Change in yield, Sept. vs November drilling			
	Hatherop (BMMV)		Eastleach (BYMV)	
	350 Seeds	450 Seeds	350 Seeds	450 Seeds
1996				
mv-tolerant	+4%	-6%	+11%	+5%
mv-susceptible	+74%	+39%	+19%	+6%
1997				
mv-tolerant	+4	-5	+1	+10
mv-susceptible	+47	+92	+1	+12

At Hatherop the delay in sowing from September to November considerably increased the yield of susceptible varieties in both 1996 and 1997. The influence of seed rate on this was different in the two years: in 1996 the yield increase from delayed sowing was greater for the lower seedrate (though the higher seedrate produced higher yields at the early sowing, thus reducing the difference between this and the late sowing for this seedrate). In 1997 the effect of delayed sowing was far more marked with the higher seedrate (though here the higher seedrate gave lower yields at the early sowing thereby increasing the difference in this case). With the resistant varieties the delayed sowing effect was much less, though in both years it was negative with the higher seed rate and positive with the lower. At the yellow-mosaic site (Eastleach) all varieties gave higher yields with delayed sowing whether tolerant or susceptible, and irrespective of seedrate or year. Again the two years varied in their effects, the advantage from delayed sowing being greater at the lower seedrate in 1996, and at the higher seedrate in 1997. This again appears to relate to the different effects of seedrate on yield with the early sowing. As at Hatherop, the high seedrate improved yield with the first sowing in 1996, reducing the difference between this and the later sowing. In 1997 the higher seedrate produced lower yields at sowing date 1.

Discussion

Over the three years of the project the yield penalties associated with mv infection have been more severe at the mild mosaic site (Hatherop) than at the yellow mosaic site (Eastleach). Unfortunately it is difficult to put this down to the relative severity of the two strains since the recorded levels of infection have also been lower at the Eastleach site. In 1996 virus infection levels were almost similar across the two sites and the variety yields ranked most of the mv tolerant varieties above the mv susceptible varieties at both sites. In 1997 and 98 infection levels were lower at Eastleach than at Hatherop and the variety rankings at Eastleach showed the tolerant varieties well scattered among the susceptible varieties.

However in 1996, again, with similar virus levels at both sites, the average yield penalty at Hatherop was 2.87 t/ha, and at Eastleach 1.06 t/ha. Whilst it was not possible to draw similar conclusions in the other years, due to insufficient virus levels it does support earlier observations that the mild strain can in fact be more severe, in terms of yield reductions, than the yellow strain.

In terms of the susceptibility of different variety types (feed or malt) to the two strains, the indications are also less clear. When infection pressure was particularly high (at Hatherop) susceptible feed varieties were affected (in yield terms) to the same extent as susceptible malt varieties (in 1996 and 97 Fighter and Manitou were as affected as the malt varieties). At Eastleach, the yellow strain of the virus would be expected to affect the feed varieties more than the malt varieties. In 1996 when the infection pressure was highest at this site, the highest yielding susceptible varieties were malting types (Fanfare, Spice, Sprite and Portrait) however in 1997 and 98 when infection pressure was lower, there was no such discrimination.

As was seen in the earlier HGCA funded project, delaying drilling has improved the yield of mv-susceptible varieties and this has related closely to the levels of virus seen at the different sowing dates. However due to the mild and extended autumns experienced during the course of the project, the delay in sowing necessary to reduce virus infection and improve yield was frequently as late as early November. Symptom levels were frequently similar for both the September and October drillings, and as a result these two sowings produced similar yields in susceptible varieties in most cases. However this effect was also seen in the mv-tolerant varieties, with yield reductions from late sowing only being seen with the November drilling and then only in some cases. At the yellow mosaic site where virus expression was consistently lower throughout the project delaying drilling until November produced yield benefits irrespective of variety type. However the benefits from delayed sowing were always more marked in the mv susceptible varieties than the mv tolerant varieties.

Delayed sowing has therefore helped susceptible varieties considerably, though this project did not produce a contrasting effect from the mv tolerant varieties, which did not suffer from late drilling in the way they would normally be expected to.

Overall the effects of increased seedrate were inconsistent. Higher plant densities would not be expected to influence levels of virus infection, and although some such effects were noted, they tended to be opposing effects from one year to the next (cf Eastleach 1996 and 1997). Increasing the seedrate might be expected to improve the yield of virus affected crops, where plant growth is restricted and so higher plant numbers may compensate for this. In 1996 this was indeed the case. At Hatherop in this year where the high virus levels produced very poor yields in some susceptible varieties, increasing seedrate from 350/m^2 to 450/m^2 increased the yield of all four susceptible varieties at the earliest sowing date. In 1997, however, the effect was reversed. Virus levels were slightly lower in this case, and for each susceptible variety

The influence of variety, drilling date and seeding rate on the performance of winter barley varieties grown in the presence of barley mosaic virus.

Full Report

Part 1: Yield performance of mv-tolerant and mv-susceptible varieties.

Introduction

Barley Mosaic Virus (BMV) is a soil-borne virus carried by soil fungi which is present in soils, to varying degrees, in most areas of the UK. Infection of barley crops by the virus can lead to severe yield penalties. Extensive research into the problem has indicated that agronomic measures or inputs have little or no effect on virus expression or associated yield losses. The main line of defence against the disease is through genetic resistance in mv resistant or tolerant varieties. Plant breeders continually select for BMV resistance in limited numbers of varieties, and the evaluation of such varieties for agronomic performance is just as important as it is for cereal cultivation generally. In this project a number of winter barley varieties, both mv-susceptible and mv-tolerant, were sown on land infected with BMV in order to evaluate the yield penalties associated with mosaic virus in susceptible varieties, and also the yield performance of tolerant varieties when grown on infected land.

Methods

In each of three years, 1995, 96 and 97 a number of winter barley varieties were sown at two locations near Fairford in Gloucestershire in small plot randomised block trials. One site (Hatherop) is known to have soil uniformly infected with Barley Mild Mosaic Virus, the other site (Eastleach) being uniformly infected with Barley Yellow Mosaic Virus. The same fields had been monitored by IACR Rothamsted for several years beforehand confirming the identity and the extent of soil infection of the respective virus strains. The varieties sown consisted of those entered in HGCA Recommended List trials, for each respective year i.e. Recommended List varieties plus candidate varieties elevated to RLI trials. Each year approximately 25% of varieties drilled were mv-tolerant. Following establishment the plots were monitored for virus symptom development on several occasions. Assessments were made of virus infection by counting the percentage in each plot. Each trial was then taken to yield and the yield effects of virus infection related to symptom development in the spring.

All plots received routine management with general inputs, to best local farmer practice.

Target sowing date for both trials was September 20th each year. Each year a large sample of infected plants were collected and analysed at IACR Rothamsted by ELISA test to confirm the strain of the virus present at each site.

Trials were established in a continuous barley situation at both sites.

Results

1. Virus infection assessments

The following tables give the highest recorded values for the percentage of plants infected with virus, from several assessment dates each year. Figures are given for both trial sites, and for each of the three years of the project

Table 9 - 1996

% Plants Infected
(mean of 3 replicate plots)

Hatherop (BMMV)

Angora	100
Epic*	0
Falcon*	0
Fanfare	98
Fighter	98
Gaelic	98
Gleam*	10
Halcyon	100
Hanna	98
Intro	87
Linnet	92
Manitou	100
Melanie	100
Muscat*	0
Pastoral	93
Pipkin	100
Portrait	90
Prelude	100
Puffin	100
Regina	98
Rifle	98
Sprite	93
Sunrise*	0
Tokyo*	2

Eastleach (BYMV)

Angora	57
Epic*	0
Falcon*	0
Fanfare	90
Fighter	98
Gaelic	60
Gleam*	12
Halcyon	97
Hanna	98
Intro	97
Linnet	98
Manitou	98
Melanie	93
Muscat*	0
Pastoral	88
Pipkin	80
Portrait	45
Prelude	78
Puffin	63
Regina	90
Rifle	80
Sprite	78
Sunrise*	0
Tokyo*	0

* = mv tolerant

At Hatherop there was very little variation in infection levels: either most of the plants were infected in the case of the virus-susceptible varieties (minimum 87% with Intro) or virtually virus free in the case of the virus-tolerant varieties, though both Tokyo and Gleam were showing symptoms in a low percentage of plants. At Eastleach a wider range of infection levels was recorded, with some mv-susceptible varieties showing low infection levels, e.g. Portrait (45%), Angora (57%). Again Gleam, an mv-tolerant variety, did show symptoms on some plants.

Table 10 - 1997

Hatherop (BMMV)

Angora	22
Epic*	0
Falcon*	0
Fanfare	27
Fighter	82
Gaelic	33
Gleam*	0
Halcyon	47
Hanna	5
Intro	10
Linnet	53
Manitou	90
Melanie	23
Muscat*	0
Pastoral	58
Pipkin	3
Regina	32
Rifle	55
Spice	67
Sunrise*	0
Tokyo*	0
Vertige	95

Eastleach (BYMV)

Angora	57
Epic*	0
Falcon*	0
Fanfare	90
Fighter	98
Gaelic	60
Gleam*	12
Halcyon	97
Hanna	98
Intro	97
Linnet	98
Manitou	98
Melanie	93
Muscat*	0
Pastoral	88
Pipkin	80
Regina	90
Rifle	80
Spice	10
Sunrise*	0
Tokyo*	0
Vertige	15

Infection levels were generally lower in 1997 at both sites. Although, at Hatherop, Manitou and Vertige showed high infection levels, most other susceptible varieties showed less extensive infection ranging from 82% in Fighter to 3% in Pipkin. At Eastleach infection levels were lower (as in 1996) with several susceptible varieties showing less than 10% of plants infected.

Table 11 - 1998

Hatherop (BMMV)	
Angela*	0
Angora	4
Baton*	0
Epic*	0
Falcon*	0
Fanfare	93
Fighter	93
Flute	22
Gleam*	0
Halcyon	83
Heligan	80
Intro	50
Jewel*	0
Muscat*	0
Pastoral	67
Pearl	32
Peridot	43
Pipkin	60
Puffin	87
Regina	60
Rifle	60
Tokyo*	0
Vertige	60

Eastleach (BYMV)	
Angela	0
Angora	5
Baton*	0
Epic*	0
Falcon*	0
Fanfare	0
Fighter	13
Flute	0
Gleam*	0
Halcyon	5
Heligan	5
Intro	15
Jewel*	0
Muscat*	0
Pastoral	2
Pearl	28
Peridot	7
Pipkin	13
Puffin	0
Regina	2
Rifle	25
Tokyo*	0
Vertige	60

Infection levels in 1998 were again low compared to the first year. At Hatherop all mv-tolerant varieties showed no symptoms, with infection levels on the susceptible varieties ranging from 4% (Angora) to 93% (Fanfare and Fighter). At Eastleach several susceptible varieties were symptom free and the highest infection level on susceptible varieties was 40% (Vertige).

Over the three years virus infection levels have varied considerably, most likely due to seasonal effects. However it is clear that infection pressure was consistently lower at the Yellow Mosaic Site (Eastleach) than at the Mild Mosaic Site (Hatherop). In the less severe years some susceptible varieties have shown little or no infection, whilst in more severe cases (e.g. Hatherop in 1996) even resistant varieties showed some infection, though the reasons for this are unclear. As the varieties drilled varied from year to year it is not possible to pinpoint which varieties have consistently shown worse symptoms, but at Hatherop, Fighter, Halcyon, Regina and Pastoral have consistently shown the highest levels of plant infection with the mild strain, whilst the yellow strain has been seen at highest levels in Rifle and Fighter, and in Hanna in 1996 and 1997.

ELISA Sampling

Each year large numbers of plants were sampled and subjected to ELISA diagnostic testing to identify the strain of virus present at each site. Details of the sampling and results of the tests are as follows.

Table 12

	Hatherop			Eastleach		
	96	**97**	**98**	**96**	**97**	**98**
No of plants sampled	288	413	248	372	175	202
% infected with virus	98	85	98	96	63	69
% infected with BYMV	0	0	2*	94	61	68
% infected with BMMV	98	85	98*	2	2	1
* small percentage infected with both viruses						

2. Yields and Specific Weights

The following tables give the yields in rank order, of the varieties in trial at each site. Yield figures are expressed in tonnes/ha and also as a percentage of the site mean yield. Specific weights are also given

Table 13

1996

Hatherop (BMMV)

Variety	t/ha	% Site Mean	Sp Wt kg/hl
UN20/51*	8.67	145	63.7
Tokyo*	8.59	144	65.5
Majestic*	8.55	144	60.3
Muscat*	8.23	138	66.1
Angela*	8.13	136	62.5
Gleam*	7.85	132	64.5
Theresa*	7.59	127	62.6
UN3254*	7.59	127	59.5
Sprite	7.42	126	67.2
Sunrise*	7.23	121	65.5
Falcon*	7.18	121	63.8
Regina	7.07	119	60.7
Hanna	6.95	117	65.5
Intro	6.48	109	63.9
Prelude	6.40	107	59.5
Epic*	5.91	99	68.9
Melanie	5.89	99	62.3
Angora	5.76	97	62.5
Pastoral	5.19	87	60.7
Linnet	4.90	82	60.7
Fanfare	4.66	78	64.2
Rifle	4.64	78	57.5
Fighter	4.24	71	65.0
Halcyon	4.08	69	64.0
Portrait	3.98	67	56.4
Spice	3.54	59	58.2
Manitou	3.46	58	65.5
Gaelic	3.39	57	64.6
Pipkin	3.17	53	64.1
Puffin	1.88	32	61.0
LSD 2.41 t/ha			
Site Mean Yield = 5.95 t/ha			
*mv-tolerant			

Eastleach (BYMV)

Variety	t/ha	% Site Mean	Sp Wt kg/hl
UN20/51*	7.67	126	63.7
UN3254*	7.36	121	60.0
Angela*	7.03	116	60.2
Falcon*	7.01	115	66.5
Muscat*	6.78	112	64.5
Majestic*	6.76	111	58.7
Fanfare	6.76	111	64.2
Tokyo*	6.67	110	62.7
Gleam*	6.51	107	68.1
Theresa*	6.46	106	62.4
Spice	6.46	106	66.0
Sprite	6.45	106	68.5
Epic*	6.31	104	66.8
Portrait	6.08	100	67.5
Pastoral	6.03	99	66.9
Intro	5.91	97	65.6
Prelude	5.90	97	67.4
Hanna	5.88	97	65.0
Rifle	5.87	97	66.2
Fighter	5.83	96	67.6
Angora	5.83	96	65.9
Sunrise*	5.74	94	67.0
Puffin	5.65	93	69.4
Pipkin	5.39	89	68.8
Manitou	5.38	88	59.6
Gaelic	5.33	88	70.7
Melanie	5.11	84	65.5
Halcyon	5.01	82	69.5
Linnet	4.94	81	66.1
Regina	4.29	71	61.7
LSD 0.73 t/ha			
Site Mean yield = 6.08 t/ha			
*mv-tolerant			

At both sites the yield clearly reflect the susceptibility of the variety to mosaic virus with the tolerant varieties giving highest yields. This trend is more clear at Hatherop than at Eastleach, reflecting the levels of infection seen at each site. However, the yields of susceptible varieties do not necessarily reflect their respective infection levels: at Eastleach, for example, Fanfare showed 90% plant infection but was the highest yielding susceptible variety, but Gaelic was

1.43 t/ha lower yielding but only 60% of plants were infected. At Hatherop there was little variation in infection levels, but yields within the susceptible varieties varied by 5.54 t/ha (cf. Sprite and Puffin). Clearly other factors are influencing the varieties yields other than mosaic virus infection.

The mean yields of susceptible and tolerant varieties were:

	Hatherop	**Eastleach**
Susceptible	4.90 t/ha	5.69
Tolerant	7.77	6.75

Table 14

1997

Hatherop (BMMV)

Variety	Yield (t/ha)	% Site Mean	Sp Wt kg/hl
Angela *	6.60	139	63.1
Theresa*	6.43	135	62.4
Mathias*	6.26	132	64.5
Epic*	5.69	120	65.0
Magnolia	5.66	119	67.2
Majestic*	5.59	118	62.0
Tokyo*	5.45	115	62.6
Elfe*	5.41	114	67.4
Muscat	5.17	109	67.4
Hanna	5.15	108	66.1
Fanfare	5.12	108	67.0
Gleam*	5.05	106	63.9
Intro	5.03	106	66.7
Sunrise*	4.86	102	64.6
Gaelic	4.83	102	66.6
Falcon*	4.80	101	61.2
Vertige	4.78	101	63.6
Regina	4.40	93	63.4
Sprite	4.39	92	66.8
Angora	4.37	92	63.1
Halcyon	4.37	92	65.5
Pipkin	4.22	89	63.3
Linnet	4.17	88	64.0
Fighter	4.13	87	64.8
Melanie	4.04	85	64.5
Pastoral	3.88	82	60.0
Rifle	3.78	80	60.0
Manitou	3.76	79	60.1
Spice	2.66	56	59.0
Puffin	2.56	54	60.8

Eastleach (BYMV)

Variety	Yield (t/ha)	% Site Mean	Sp Wt kg/hl
Elfe*	7.07	112	59.0
Theresa*	7.05	111	64.1
Angela*	7.02	111	59.6
Magnolia	6.91	109	64.5
Vertige	6.87	109	61.3
Hanna	6.78	107	65.4
Epic*	6.72	106	64.6
Fighter	6.72	106	64.6
Muscat*	6.68	106	63.7
Rifle	6.67	105	62.9
Mathias*	6.66	105	60.2
Fanfare	6.63	105	66.4
Majestic*	6.57	104	59.2
Intro	6.55	104	63.7
Sprite	6.53	103	65.8
Melanie	6.30	100	62.2
Gleam*	6.29	99	63.2
Spice	6.29	99	62.5
Regina	6.26	99	64.2
Gaelic	6.23	98	70.1
Tokyo	6.08	96	58.5
Falcon*	6.05	96	62.0
Halcyon	5.86	93	63.9
Pastoral	5.80	92	62.0
Angora	5.71	90	63.5
Sunrise*	5.70	90	60.3
Puffin	5.69	90	62.2
Linnet	5.47	86	62.3
Manitou	5.41	86	59.4
Pipkin	5.21	82	62.8

With the lower mosaic infection pressure at each site in this year, mosaic tolerant varieties were more scattered through the table. There was, however, a greater accumulation of tolerant varieties towards the top of the table at Hatherop than at Eastleach.

The mean yields of susceptible and tolerant varieties were:

	Hatherop	Eastleach
Susceptible	4.32 t/ha	6.19
Tolerant	5.61	6.58

Table 15

1998

Hatherop (BMMV)

Variety	Yield (t/ha)	% Site Mean	Sp Wt kg/hl
Angela *	8.34	123	58.6
Jewel*	7.96	118	63.7
BR2324b 616*	7.88	117	63.0
Peridot	7.88	117	64.3
Esterelle*	7.78	115	63.3
Pacific*	7.74	114	63.6
Laurel*	7.71	114	64.2
Amadea*	7.68	114	61.9
Baton*	7.59	112	62.4
Gleam*	7.48	111	64.3
2625-A16*	7.41	110	62.0
Pearl	7.37	109	65.5
Antonia*	7.37	109	65.1
Damas*	7.31	108	55.0
Falcon*	7.26	107	61.5
NSL94-6628b*	7.21	107	63.8
Rounder	7.21	107	62.5
Flute	7.05	104	61.1
BR2434b13 *	6.87	102	58.6
Angora	6.86	101	60.5
Muscat*	6.86	101	61.9
Vertige	6.72	99	62.0
Intro	6.61	98	62.1
Tokyo*	6.61	98	60.8
Epic*	6.55	97	60.4
Puffin	6.36	94	67.5
Regina	6.28	93	64.3
Rifle	6.27	93	62.2
Heligan	6.11	90	62.0
Pastoral	6.04	89	63.7
Symphony*	5.90	87	61.6
Fighter	4.76	70	58.3
Halcyon	4.57	68	58.7
Fanfare	3.84	57	61.8
Pipkin	3.21	47	65.7

LSD 0.78 t/ha
Site yield 5.30 t/ha

Eastleach (BYMV)

Variety	Yield (t/ha)	% Site Mean	Sp Wt kg/hl
Fanfare	6.62	125	59.1
Symphony	6.39	121	59.7
Antonia*	6.25	118	61.5
Laurel*	6.18	117	58.9
Flute	6.00	113	57.5
Regina	5.99	113	59.7
Peridot	5.92	112	58.0
Angela*	5.79	109	52.1
Tokyo*	5.67	107	55.6
NSL94-6628b*	5.66	107	61.0
Vertige	5.65	107	56.2
Rounder*	5.64	106	58.5
Pearl	5.63	106	62.1
Puffin	5.55	105	59.7
Amadea*	5.51	104	55.1
Jewel*	5.50	104	62.9
Rifle	5.43	102	60.4
Halcyon	5.33	101	61.3
Intro	5.24	99	60.7
Gleam*	5.23	99	57.9
Heligan	5.22	98	62.9
Fighter	5.19	98	58.4
Baton*	5.18	98	57.7
Pacific*	5.18	98	56.2
2625-A16*	5.17	98	56.4
Pipkin	5.07	96	58.0
Pastoral	5.02	95	58.1
BR2324b616*	4.95	93	56.1
Falcon*	4.73	89	56.4
Muscat*	4.64	88	55.7
Esterelle*	4.37	82	56.8
BR2434b13*	4.26	80	52.1
Epic*	3.99	75	54.2
Angora	3.89	73	52.6
Damas*	3.51	66	52.0

LSD 0.89 t/ha
Site yield 6.76 t/ha

Again the higher disease pressure at Hatherop has led to the mv-tolerant varieties dominating the top of the yield rankings, whereas at Eastleach, where infection levels were lowest in this year, there is no clear yield trend between variatal susceptibility and yield performance.

The mean yields of all susceptible and tolerant varieties were

	Hatherop	**Eastleach**
Susceptible	6.44 t/ha	5.45
Tolerant	7.34	5.46

Tables 4 and 5 list the yields including three-year mean yields, of the 16 varieties which were common to all three years of the project. Yields are expressed as a percentage of the mean yield (taken as 100%) of those 16 varieties in each case

Table 16

Hatherop (BMMV)

	96	**97**	**98**	**3 year mean**
Angela*	140	142	143	142
Tokyo*	146	117	113	125
Gleam*	135	108	128	124
Muscat*	141	111	123	123
Falcon*	124	103	125	117
Regina	121	94	108	115
Epic*	102	122	112	112
Intro	111	108	113	111
Angora	99	94	118	104
Pastoral	89	83	104	92
Rifle	80	81	108	90
Fanfare	80	110	66	85
Fighter	73	89	82	81
Halcyon	70	94	78	81
Pipkin	55	91	55	67
Puffin	32	55	109	65

Table 17
Eastleach (BYMV)

	96	97	98	3 year mean
Fanfare	112	106	127	115
Angela*	116	112	111	113
Tokyo*	110	97	109	105
Muscat*	112	107	89	103
Rifle	97	107	104	103
Gleam*	107	100	100	102
Falcon*	116	97	91	101
Fighter	96	108	100	101
Intro	98	105	101	101
Puffin	93	91	106	97
Epic*	104	108	76	96
Pastoral	100	93	96	96
Regina	71	100	115	95
Halcyon	83	94	102	93
Pipkin	89	83	97	90
Angora	96	91	75	87

At Hatherop the mv tolerant varieties have consistently yielded highest, the six row variety Angela and the two rows Tokyo and Gleam giving the best performances. The malt barleys, susceptible to the virus, such as Puffin, Pipkin Halcyon and Fanfare have given some of the lowest yields, however Regina has not shown the same poor yields as these other malt varieties, though its performance over the three years has been variable.

At Eastleach the range in yields is far less, but again the malt varieties (including Regina) have given some of the poorest yields. This is more likely due to their inherent yield potential than any differential response to the strain of virus, since infection levels at Eastleach have been relatively low. This is also highlighted by the fact that Fanfare, an mv-susceptible variety, has given the highest yield averaged over the tree years. Its best performance relative to the other varieties was seen in 1998 when infection levels at Eastleach were at their lowest, though even in 1996 with higher virus levels Fanfare ranked equal third.

Where infection levels were significant the highest yielding varieties at both sites were Angela, Muscat (both six-row varieties) Gleam and Tokyo. With the less severe virus strain, (yellow), some malt varieties may yield well in years where mosaic virus incidence is lower, but as this cannot be predicted at the time of sowing, it is unlikely that such an option would be practical. However, where the areas of infection in a field are small, these varieties may represent a low risk option for growers wishing to retain mv susceptible varieties. With the more severe effects seen with the mild strain, it is more difficult to pinpoint specific varietal interactions with the virus and mv tolerant varieties have been the safest options irrespective of other varietal characteristics

Discussion

Over the three years of the project the yield penalties associated with mv infection have been more severe at the mild mosaic site (Hatherop) than at the yellow mosaic site (Eastleach). Unfortunately it is difficult to put this down to the relative severity of the two strains since the recorded levels of infection have also been lower at the Eastleach site. In 1996 virus infection levels were almost similar across the two sites and the variety yields ranked most of the mv tolerant varieties above the mv susceptible varieties at both sites. In 1997 and 98 infection levels were lower at Eastleach than at Hatherop and the variety rankings at Eastleach showed the tolerant varieties well scattered among the susceptible varieties.

However in 1996, again, with similar virus levels at both sites, the average yield penalty at Hatherop was 2.87 t/ha, and at Eastleach 1.06 t/ha. Whilst it was not possible to draw similar conclusions in the other years, due to insufficient virus levels it does support earlier observations that the mild strain can in fact be more severe, in terms of yield reductions, than the yellow strain.

In terms of the susceptibility of different variety types (feed or malt) to the two strains, the indications are also less clear. When infection pressure as particularly high (at Hatherop) susceptible feed varieties were affected (in yield terms) to the same extent as susceptible malt varieties (in 1996 and 97 Fighter and Manitou were as affected as the malt varieties). At Eastleach, the yellow strain of the virus would be expected to affect the feed varieties more than the malt varieties. In 1996 when the infection pressure was highest at this site, the highest yielding susceptible varieties were malting types (Fanfare, Spice, Sprite and Portrait) however in 1997 and 98 when infection pressure was lower, there was no such discrimination.

This project has shown the severe yield penalties that can result from mosaic virus infection if conditions create sufficient infection pressure from the disease. Averaged across all mv-tolerant and mv susceptible varieties, the yield penalty associated with virus infection has been recorded as high as 37% when symptom levels were high (Hatherop 1996) but as low as zero when infection pressure was low, though still with symptoms expressed (Eastleach 1998). As it is not possible to predict the severity of virus symptoms on infected land at the time of sowing, this information stresses the value of genetic resistance as the main defence against this disease. It is essential that varieties tolerant or resistant to mosaic virus continue to be produced and evaluated if barley production in the UK is to be continued successfully.

Part 2: Drilling date and seed rate interaction

Methods

In each of three years (1995, 96 and 97) eight varieties of winter barley were sown at each of two seed rates. The varieties were chosen to represent virus-susceptible and virus tolerant types and also both feed and malt varieties. The varieties were:

Fighter (feed barley, mv - susceptible)
Pastoral (feed, susceptible)
Epic (feed, tolerant)
Tokyo (feed, tolerant)
Puffin (malt, susceptible)
Pipkin (malt, susceptible)
Gleam (malt, tolerant)
Falcon (malt, tolerant)

All eight varieties were sown at 350 and 450 seeds/m^2, and at three sowing dates in 1995 and 96. Extended wet weather in the autumn of 1997 prevented the planting of the third sowing date.

The trial was established at two locations in Gloucestershire; Hatherop and Eastleach. The former location was a field determined by previous tests conducted by IACR Rothamsted, to be uniformly infected with the mild strain of the virus (BMMV) whilst the latter was similarly known to be uniformly infected with the yellow strain (BYMV).

Following establishment the trials were monitored for mosaic virus symptoms and assessments made of the percentage of plants infected. Samples were also taken for ELISA testing to determine the strain of virus infecting the plants.

All plots were taken to yield and the effects of variety, sowing date and seed rate on yield were recorded.

Target sowing dates for three sowings were:-

September 20th
October 15th
November 10th

Trials were established in a continuous barley situation at both sites.

Results

1. Virus Infection Assessments

The following tables give the highest recorded levels of mv - infection, from the number of assessments carried out in spring of each year. Figures represent the percentage of plants infected with virus.

Table 18 - 1996

Sowing dates: September 20th, October 16th, November 6th

Hatherop (BMMV)
Sowing Date

	20/9	16/10	6/11
(a) 350 seeds/sqm			
Epic	0	0	0
Falcon	0	0	0
Fighter	98	100	78
Gleam	10	17	0
Pastoral	93	100	18
Pipkin	100	100	43
Puffin	100	100	23
Tokyo	2	0	0
(b) 450 seeds/sqm			
Epic	0	0	0
Falcon	0	0	0
Fighter	100	100	83
Gleam	7	17	0
Pastoral	100	100	17
Pipkin	90	100	28
Puffin	95	100	32
Tokyo	0	0	0

Eastleach (BYMV)
Sowing Date

	20/9	16/10	6/11
(a) 350 seeds/sqm			
Epic	0	0	0
Falcon	0	0	0
Fighter	98	65	0
Gleam	12	5	0
Pastoral	88	33	0
Pipkin	80	5	0
Puffin	63	35	0
Tokyo	0	0	0
(b) 450 seeds/sqm			
Epic	0	0	0
Falcon	2	0	0
Fighter	78	83	0
Gleam	13	10	0
Pastoral	60	47	0
Pipkin	33	3	0
Puffin	50	40	0
Tokyo	1	0	0

Virus levels were generally higher at the mild-mosaic site (Hatherop), with some symptoms appearing on the tolerant varieties Gleam and Tokyo. Gleam also appeared to be infected at a low level at the yellow mosaic site (Eastleach). At Hatherop delayed sowing to mid-October had little effect on virus levels, but when sowing was delayed until early November infection levels were reduced. At Eastleach a reduction in virus infection levels was achieved by delaying until October 16th, with no infection evident when delayed to November 6th. At Hatherop the higher seed rate appeared to have little effect on virus symptoms for any of the sowing dates, whilst at Eastleach there was some evidence of lower infection levels.

Table 19 - 1997

Sowing dates: September 20th, October 16th November 13th

Hatherop (BMMV)
Sowing Date

	20/9	16/10	13/11
(a) 350 seeds/sqm			
Epic	0	0	0
Falcon	0	0	0
Fighter	82	100	0
Gleam	0	0	0
Pastoral	58	100	0
Pipkin	3	87	0
Puffin	77	98	0
Tokyo	0	2	0
(b) 450 seeds/sqm			
Epic	0	0	0
Falcon	0	0	0
Fighter	98	100	0
Gleam	0	0	0
Pastoral	80	100	0
Pipkin	43	97	0
Puffin	93	98	0
Tokyo	0	0	0

Eastleach (BYMV)
Sowing Date

	20/9	16/10	13/11
(a) 350 seeds/sqm			
Epic	0	0	0
Falcon	0	0	0
Fighter	21	50	0
Gleam	0	0	0
Pastoral	33	42	0
Pipkin	30	10	0
Puffin	7	15	0
Tokyo	0	0	0
(b) 450 seeds/sqm			
Epic	0	0	0
Falcon	0	0	0
Fighter	73	40	0
Gleam	0	0	0
Pastoral	70	60	0
Pipkin	17	7	0
Puffin	7	15	0
Tokyo	0	0	0

At Hatherop in this year the tolerant varieties were clear of symptoms at all sowing dates and seed rates, with the exception of some Tokyo plants showing symptoms at the second sowing date. The susceptible varieties all showed good levels of symptoms which, contrary to previous experience, seemed to be higher at the second sowing date than at the first. Of the varieties, Pipkin seemed to be least infected at the earlier sowing, but at the second sowing levels of infection in susceptible varieties were uniformly high. At the Eastleach site all mv-tolerant varieties were clear of infection across all sowing dates. Levels of virus across the sowing dates in susceptible varieties were fairly constant although Fighter and Pastoral (feed varieties) showed higher levels at the earliest sowing when sown at 450 seeds/m^2. This effect of seed rate producing higher levels of virus infection was also evident at Hatherop in Pastoral and Puffin, an effect which contrasts with the 1996 results at Eastleach, where the higher seed rate showed lower levels of virus.

Table 20 - 1998:

Sowing dates: 23rd September and 20th October

Hatherop (BMMV)
Sowing Date

	23/9	20/10
(a) 350 seeds/sqm		
Epic	0	0
Falcon	0	0
Fighter	93	100
Gleam	0	20
Pastoral	67	57
Pipkin	60	62
Puffin	87	80
Tokyo	0	0
(b) 450 seeds/sqm		
Epic	0	0
Falcon	0	0
Fighter	73	100
Gleam	2	30
Pastoral	14	65
Pipkin	17	70
Puffin	63	72
Tokyo	0	0

Eastleach (BYMV)
Sowing Date

	23/9	20/10
(a) 350 seeds/sqm		
Epic	0	0
Falcon	0	0
Fighter	13	0
Gleam	0	0
Pastoral	2	0
Pipkin	13	0
Puffin	0	0
Tokyo	0	0
(b) 450 seeds/sqm		
Epic	0	0
Falcon	0	0
Fighter	10	0
Gleam	0	0
Pastoral	2	0
Pipkin	2	0
Puffin	0	0
Tokyo	0	0

At Hatherop virus levels were fairly high and in most cases constant across the two sowing dates, however at the higher seed rate levels are lower in the early sowing. The higher levels at the second sowing are also evident in Gleam, a tolerant variety which here was showing significant levels of infection at both seed rates when sown late. The Eastleach site produced very low levels of virus in the early sowing, with none in the later sowing. With only Fighter and Pipkin showing appreciable virus levels it is difficult to detect any effects of sowing date or seed rate.

2. Yields (t/ha)

Table 21 - 1996

Hatherop (BMMV)
Sowing Date

	20/9	16/10	6/11
(a) 350 seeds/sqm			
Epic	5.91	6.96	8.05
Falcon	7.18	7.36	7.18
Fighter	4.24	5.63	6.87
Gleam	7.85	7.61	7.33
Pastoral	5.19	6.28	6.73
Pipkin	3.17	6.61	5.43
Puffin	1.88	5.55	6.13
Tokyo	8.59	7.28	8.16
LSD (t/ha)	2.14	2.13	0.69
(b) 450 seeds/sqm			
Epic	8.43	8.56	7.70
Falcon	7.97	7.70	7.29
Fighter	5.65	5.29	7.23
Gleam	7.70	8.12	7.55
Pastoral	6.18	7.08	7.57
Pipkin	3.84	5.35	6.25
Puffin	4.27	3.71	6.62
Tokyo	8.00	8.42	7.84
LSD (t/ha)	2.41	2.13	0.69

Eastleach (BYMV)
Sowing Date

	20/9	16/10	6/11
(a) 350 seeds/sqm			
Epic	6.31	6.68	7.31
Falcon	7.01	6.30	7.43
Fighter	5.83	5.59	7.19
Gleam	6.51	6.61	7.32
Pastoral	6.03	6.28	6.95
Pipkin	5.39	5.83	6.40
Puffin	5.65	6.16	6.64
Tokyo	6.67	6.18	7.40
LSD (t/ha)	0.73	0.62	0.75
(b) 450 seeds/sqm			
Epic	6.85	6.34	7.34
Falcon	6.98	6.29	7.67
Fighter	6.13	5.87	7.11
Gleam	6.86	6.11	7.27
Pastoral	6.47	5.72	7.00
Pipkin	6.31	5.54	6.47
Puffin	6.62	5.86	6.54
Tokyo	7.36	6.08	7.24
LSD (t/ha)	1.07	0.62	0.75

Hatherop (BMMV): all mv-tolerant varieties except Epic significantly outyielded all mv-susceptible varieties. For the latter yield was improved by delayed sowing, the highest yields in most cases coming from the November 6th sowing. Yields for the tolerant varieties were stable across the first two sowings but did not significantly decline at the final sowing. Where yields were lowest, at DDI, increasing the seed rate improved yield in the susceptible varieties, though not significantly. This effect was not seen in the tolerant varieties, or in any variety at the latest sowing date.

Eastleach (BYMV): yield differences were less at this site, though there was still a trend for the later drilling to produce higher yields in susceptible varieties. This was, however, also seen to some extent in the mv-tolerant varieties. Seed rate also had less effect on yield at this site.

Table 22 - 1997

Hatherop (BMMV)
Sowing Date

	20/9	16/10	13/11
(a) 350 seeds/sqm			
Epic	5.69	6.47	5.17
Fighter	4.13	3.59	5.47
Falcon	4.80	4.98	5.51
Gleam	5.05	5.92	5.30
Pastoral	3.88	4.03	5.16
Pipkin	4.22	3.80	5.69
Puffin	2.56	2.28	5.55
Tokyo	5.45	5.99	5.86
LSD (t/ha)	0.83	0.98	0.79
(b) 450 seeds/sqm			
Epic	6.19	6.63	5.50
Fighter	3.30	3.21	5.82
Falcon	5.15	4.87	5.55
Gleam	5.92	5.84	5.62
Pastoral	3.80	4.09	5.06
Pipkin	2.55	2.60	5.57
Puffin	1.96	2.33	5.82
Tokyo	6.04	5.40	5.52
LSD (t/ha)	1.02	0.98	0.79

Eastleach (BYMV)
Sowing Date

	20/9	16/10	13/11
(a) 350 seeds/sqm			
Epic	6.72	4.93	6.82
Fighter	6.72	4.90	6.52
Falcon	6.05	4.88	5.79
Gleam	6.29	4.87	6.05
Pastoral	5.80	4.59	5.85
Pipkin	5.21	4.92	5.74
Puffin	5.69	4.78	5.46
Tokyo	6.08	4.58	6.81
LSD (t/ha)	0.74	0.62	0.76
(b) 450 seeds/sqm			
Epic	6.31	4.81	6.78
Fighter	5.75	5.13	6.74
Falcon	5.54	4.78	5.47
Gleam	5.94	4.54	6.31
Pastoral	5.03	4.59	5.52
Pipkin	4.80	4.96	5.58
Puffin	5.33	5.06	5.67
Tokyo	5.56	4.91	7.17
LSD (t/ha)	0.35	0.62	0.76

Hatherop: following the trends with virus levels, yields of susceptible varieties were similar for the first two sowing dates, but were considerably higher at the latest sowing. Yields of the tolerant varieties were consistent across the three sowings. Increasing the seed rate improved the yield of the tolerant varieties at the earliest sowing, but had little effect on the susceptible varieties. At later sowings, seed rate had less influence on yield for all varieties.

Eastleach: in most cases yields were lowest at the middle sowing, irrespective of variety. Seed rate had little effect on yield except at the earliest sowing where the higher seed rate significantly reduced the yield for every variety.

Table 23 - 1998

Hatherop (BMMV)
Sowing Date

	23/9	20/10
(a) 350 seeds/sqm		
Epic	6.55	7.34
Fighter	4.76	5.32
Falcon	7.26	7.39
Gleam	7.48	7.69
Pastoral	6.04	6.34
Pipkin	3.21	4.87
Puffin	6.36	5.90
Tokyo	6.61	7.63
LSD (t/ha)	0.89	0.74
(b) 450 seeds/sqm		
Epic	6.99	7.65
Fighter	6.24	5.33
Falcon	6.88	7.52
Gleam	7.53	7.56
Pastoral	7.40	6.53
Pipkin	6.96	4.65
Puffin	6.64	6.01
Tokyo	6.93	7.55
LSD (t/ha)	0.60	0.74

Eastleach (BYMV)
Sowing Date

	23/9	20/10
(a) 350 seeds/sqm		
Epic	3.99	6.02
Fighter	5.19	5.87
Falcon	4.73	6.21
Gleam	5.23	6.37
Pastoral	5.02	5.99
Pipkin	5.07	5.68
Puffin	5.55	5.94
Tokyo	5.67	6.58
LSD (t/ha)	0.78	0.84
(b) 450 seeds/sqm		
Epic	3.26	5.71
Fighter	4.76	6.14
Falcon	4.65	6.17
Gleam	4.37	6.23
Pastoral	4.95	6.22
Pipkin	4.03	5.53
Puffin	4.65	6.25
Tokyo	4.98	6.46
LSD (t/ha)	0.50	0.84

Hatherop: with the lower seed rate all varieties except Puffin gave higher yields with the second sowing. With the higher seed rate this sowing date effect was clearer in the mv-tolerant varieties. Generally, however, the influence of sowing date or seed rate was less than in previous years, though in this year a November sowing was not achieved.

Eastleach: virus symptoms were almost absent at this site in this year and consequently there are no clear effects of sowing date or seed rate on the susceptible varieties, though as at Hatherop most varieties tended to give higher yields at the second sowing for both seed rates.

As a means of summarising the three years results, the following table shows the yield effects of delayed sowing from the first to the last sowing date (delaying from the first to the second had little effect on yield in the majority of cases). Figures show the percentage change in yield (+or -) caused by delaying drilling until November, expressed as a mean of the four tolerant and susceptible varieties respectively, for each site and each seed rate. (Figures are not given for 1998, as a late drilling was not achieved).

Variety Type	% Change in yield, Sept. vs November drilling			
	Hatherop (BMMV)		Eastleach (BYMV)	
	350 Seeds	450 Seeds	350 Seeds	450 Seeds
1996				
mv-tolerant	+4%	-6%	+11%	+5%
mv-susceptible	+74%	+39%	+19%	+6%
1997				
mv-tolerant	+4	-5	+1	+10
mv-susceptible	+47	+92	+1	+12

At Hatherop the delay in sowing from September to November considerably increased the yield of susceptible varieties in both 1996 and 1997. The influence of seed rate on this was different in the two years: in 1996 the yield increase from delayed sowing was greater for the lower seedrate (though the higher seedrate produced higher yields at the early sowing, thus reducing the difference between this and the late sowing for this seedrate). In 1997 the effect of delayed sowing was far more marked with the higher seedrate (though here the higher seedrate gave lower yields at the early sowing thereby increasing the difference in this case). With the resistant varieties the delayed sowing effect was much less, though in both years it was negative with the higher seed rate and positive with the lower. At the yellow-mosaic site (Eastleach) all varieties gave higher yields with delayed sowing whether tolerant or susceptible, and irrespective of seedrate or year. Again the two years varied in their effects, the advantage from delayed sowing being greater at the lower seedrate in 1996, and at the higher seedrate in 1997. This again appears to relate to the different effects of seedrate on yield with the early sowing. As at Hatherop, the high seedrate improved yield with the first sowing in 1996, reducing the difference between this and the later sowing. In 1997 the higher seedrate produced lower yields at sowing date 1.

Discussion

As was seen in the earlier HGCA funded project, delaying drilling has improved the yield of mv-susceptible varieties and this has related closely to the levels of virus seen at the different sowing dates. However due to the mild and extended autumns experienced during the course of the project, the delay in sowing necessary to reduce virus infection and improve yield was frequently as late as early November. Symptom levels were frequently similar for both the September and October drillings, and as a result these two sowings produced similar yields in susceptible varieties in most cases. However this effect was also seen in the mv-tolerant varieties, with yield reductions from late sowing only being seen with the November drilling and then only in some cases. At the yellow mosaic site where virus expression was consistently lower throughout the project delaying drilling until November produced yield benefits irrespective of variety type. However the benefits from delayed sowing were always more marked in the mv susceptible varieties than the mv tolerant varieties.

Delayed sowing has therefore helped susceptible varieties considerably, though this project did not produce a contrasting effect from the mv tolerant varieties, which did not suffer from late drilling in the way they would normally be expected to.

Overall the effects of increased seedrate were inconsistent. Higher plant densities would not be expected to influence levels of virus infection, and although some such effects were noted, they tended to be opposing effects from one year to the next (cf Eastleach 1996 and 1997). Increasing the seedrate might be expected to improve the yield of virus affected crops, where plant growth is restricted and so higher plant numbers may compensate for this. In 1996 this was indeed the case. At Hatherop in this year where the high virus levels produced very poor yields in some susceptible varieties, increasing seedrate from 350/m^2 to 450/m^2 increased the yield of all four susceptible varieties at the earliest sowing date. In 1997, however, the effect was reversed. Virus levels were slightly lower in this case, and for each susceptible variety the yield was lower with the higher seedrate. This difference in seedrate response over the two years was also seen at Eastleach, where virus levels were lower, though still higher in 1996 than 1997. In 1998 at Hatherop, again with fairly high levels of infection, the yields of the susceptible varieties sown in September were raised on average by 33% as a result of increasing the seedrate. In contrast the effect in the October drilling, were virus levels were similar, as not seen, the yield effect of increased seedrate being +1%.

It is therefore difficult to draw conclusions on the seedrate effect. As previous research has shown, variety choice and sowing date were the only variables which offset the yield losses associated with mosaic virus. We have not been able to show consistently in this project that increased seedrate will also provide positive benefits in coping with this problem