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This is the joint final report of two related projects: No. 0076/3/87 (Management of winter barley in the presence of Barley Yellow Mosaic Virus (BaYMV) on the Cotswolds) and No. 0034/2/88 (Winter barley: varietal resistance to Barley Yellow Mosaic Virus and its effects on yield). Project 0076/3/87 commenced in February 1988 and lasted for 41 months. Project 0034/2/88 commenced in October 1988 and lasted for 30 months. Both projects were funded by the Home-Grown Cereals Authority, the grants being £57,584 for 0076/3/87 and £19,916 for 0034/2/88 respectively.

C O N T E N T S

ABSTRACT

In an aerial survey in 1988 of 30000 ha in the Cotswolds, 13% of the winter barley acreage was affected to some extent by virus. In a three-year experiment on three cultivars on the effect of nitrogen rate and timing on virus incidence and severity, there was an indication that nitrogen in November led to earlier symptom expression, but there was no evidence that nitrogen had any effect on virus concentration within plants. Nitrogen timing had a greater influence on yield of the resistant cultivar Torrent than on susceptible cultivars Igri and Plaisant. Cultivar resistance to virus was investigated. At one site, where the resistance-breaking strain of Barley Yellow Mosaic Virus was present, all cultivars were affected, but in most of the 'resistant' cultivars virus symptoms were less distinct and faded earlier than in the 'susceptible' cultivars. At the other three sites, where trials were harvested, a greater range of cultivars was affected at the two sites with Barley Yellow Mosaic Virus than at the site with Barley Mild Mosaic Virus only. The yield advantage of the resistant cultivars over the susceptible standard Igri was generally in the range 38 - 50%, but up to 72% at one site. There was also a four-year study of the survival of virus and vector in the soil. There was no evidence that a one, two or three year break with winter wheat or with a resistant winter barley cultivar had any effect on virus or vector survival.

OBJECTIVES

The objectives were:

1. To assess the importance of barley mosaic viruses on the Cotswolds by means of an aerial survey. (0076/3/87)

2. To investigate the effect of nitrogen rate and timing on BaYMV. (0076/3/87)

3. To evaluate cultivar resistance on four sites, one of which was affected by the resistance-breaking strain of BaYMV. (0076/3/87 and 0034/2/88)

4. To study long-term survival of the virus. (0076/3/87)

INTRODUCTION

Barley Yellow Mosaic Virus (BaYMV) and Barley Mild Mosaic Virus (BaMMV) are soil-borne viruses which affect autumn-sown barley. The vector is the soil-inhabiting fungus *Polymyxa graminis*. The two viruses cause identical symptoms, and can only be distinguished serologically (Adams, Swaby & Jones, 1987; Huth & Adams, 1990). The disease caused by the viruses was first recorded in the UK in 1980, and now affects winter barley in many areas of England, particularly in areas with a long history of intensive winter barley growing, including the Cotswolds.

Project 0076/3/87 developed from a series of trials on Eastleach Farms, Glos which had been carried out in collaboration between the Royal Agricultural College at Cirencester, ADAS, AFRC (Long Ashton Research Station) and ICI. Plots were drilled by ICI in the autumn of 1987 in a field uniformly affected by virus with the intention of studying the effect of nitrogen on virus development. This work was then incorporated into H-GCA Project 0076/3/87, coordinated initially by Mr E J Wibberley and later by Mr T I Morris. Other work by ADAS and IACR Rothamsted on barley mosaic viruses on the Cotswolds was also included in this Project from autumn 1988. ADAS work on the viruses at other sites, which had previously been funded by MAFF (Experiment CE34/001), was continued from autumn 1988 in Project 0034/2/88.

1988 AERIAL SURVEY TO ASSESS THE IMPORTANCE OF BARLEY MOSAIC VIRUSES ON THE COTSWOLDS

METHODS

A survey of part of the Cotswolds was made in 1988 in an attempt to determine the importance of barley mosaic viruses. The method adopted consisted of an aerial photographic survey to identify fields in which patterns within the crop indicated the possible presence of virus, followed by examination on the ground of fields where virus was suspected to be present. The aerial photographs were taken by the ADAS Aerial Photography Unit on 3 April, over an area of 25 x 12km, bounded by grid reference SU0002, SU2502, SU0014 and SU2514. Following examination of the photographs, approximately 150 fields were visited between 11 April and 22 April. Virus was identified visually, and confirmed as required by electron microscopy at the ADAS Virology Unit.The total area of the fields in which virus was found, together with the area of fields known to be infested but which did not have winter barley in 1988, was calculated from the photographs using a planimeter.

RESULTS AND DISCUSSION

Virus was found in 57 fields. In most cases only a few relatively small patches were affected, but in a few fields there were several large areas with virus, affecting up to 10% of the total area of the field. In addition to these 57, there were a further nine fields known to be affected but in which winter barley was not grown in 1988. The total area of these 66 fields was 780 ha. It has been estimated that 58% of the land in this area is under arable crops, and that winter barley comprises approximately 35% of the total area of arable crops. From these figures it can be calculated that the area of winter barley in the 30000 ha surveyed is 6960 ha, and that the 780 ha affected by virus represents 13% of the total area of winter barley. This figure will be an underestimate, for the following reasons:

1. Cultivars resistant to virus accounted nationally for approximately 3% of the total area of winter barley in 1988, and on the Cotswolds the proportion was higher (over 5%). Fields infested with virus sown with a resistant cultivar would not have been detected unless virus was already known to be present.

2. Infested fields in which a crop other than winter barley was grown in 1988 would not have been detected.

3. It is probable that some patches of virus which were not showing strong symptoms were not identified from the aerial photographs.

I: EFFECT OF NITROGEN TIMING AND RATE ON BARLEY MOSAIC VIRUSES

OBJECTIVE

To determine the effect of nitrogen rate and timing on the incidence of barley mosaic viruses, and the effect on yield.

INTRODUCTION

The cultivar Torrent was one of the first cultivars available with resistance to Barley Yellow Mosaic Virus, and was the first to be widely grown. However, it is a cultivar in which stem extension commences early in relation to other cultivars. Consequently, there was a possibility that Torrent may have different nitrogen requirements from other cultivars, particularly in relation to early dressings. In addition, it was thought that the effect of virus on susceptible varieties might be influenced by the timing and rate of nitrogen application. This experiment was therefore designed to examine the nitrogen requirement of Torrent and the effect of nitrogen regimes on two susceptible cultivars, Igri and Plaisant.

DURATION

Three years, starting autumn 1987.

MATERIALS AND METHODS

Site Details

SITE: Eastleach, Glos

SOIL SERIES: Sherborne

SOIL DESCRIPTION: 0 to 20 cm lightish brown silty clay loam with abundant small to large pieces of limestone over limestone.

SOIL ANALYSIS AT START OF EXPERIMENT:

	mg/l	index
Phosphorus	38	3
Potassium	307	3
Magnesium	45	1

pH 7.8

PREVIOUS CROPPING: Winter barley since early 1970s.

Treatments

Six nitrogen timing regimes were tested on three winter barley cultivars, giving a total of 18 treatments. The experimental design was a randomised block with three replicates. The three winter barley cultivars were Igri, Plaisant and Torrent and the nitrogen timing regimes are given in Table 1.

Table 1

Nitrogen timings and rates

N TIMING REGIME	NOVEMBER	FEBRUARY	kg/ha N MARCH	APRIL	TOTAL
1	NIL	NIL	NIL	160	160
2	NIL	NIL	40	120	160
3	NIL	40	NIL	120	160
4	40	NIL	NIL	120	160
5	NIL	40	40	80	160
6	40	40	40	80	200

The nitrogen was applied as ammonium nitrate.

Drilling dates, dates on which nitrogen and growth regulator were applied and harvest dates are given in Table 2.

Table 2

Drilling dates, dates of nitrogen and PGR treatments and harvest dates

	1987/88	1988/89	1989/90
Drilling date	20/9	15/9	19/9
November N	4/11	14/11	30/10
February N	18/2	14/2	16/2
March N	14/3	15/3	9/3
April N	11/4	7/4	2/4
Terpal PGR (Torrent only)	19/4	19/4	mid April (all cvs)
Harvest date	29/7	5/7	9/7

The seedrates were in the range 160 to 170 kg/ha. Fungicides, insecticides and herbicides were applied overall to the site by the host farmer when the field was treated. Growth stages on nitrogen application dates are given in Table 3.

Table 3

Growth stages on dates of nitrogen application

	Igri			Plaisant			Torrent		
	1987/8	1988/9	1989/90	1987/8	1988/9	1989/90	1987/8	1988/9	1989/90
Nov	23	23	24	23	23	24	24	24	24
Feb	23-24	21-23	24-26	23-24	21-23	24-26	31	30-31	30
Mar	24-29	21-23	24-30	23-29	21-23	24-30	31	30-31	31
Apr	30	23-30	31	30	23-30	31	32	31-32	33

Virus assessment

Visual assessments of virus presence were made at three to four week intervals from 19 December until early May. On three dates, samples (upper and lower leaves from each of four plants from each selected plot) were taken to enable quantitative assessment of virus concentrations within plants by the ELISA method. This is a serological test in which crushed leaf extract is mixed with antiserum specific to different strains of virus. In addition to identifying the strain of virus present, it also gives a quantitative indication of virus concentration within the leaves.

RESULTS

Tables of results of harvest data and ELISA determinations of virus content are as follows:

Table 4

1988 Grain yield - tonnes/ha at 15% moisture content

N treatment	1	2	3	4	5	6	Mean	LSD (5%)
N kg/ha								
November	Nil	Nil	Nil	40	Nil	40		
February	Nil	Nil	40	Nil	40	40		
Mid March	Nil	40	Nil	Nil	40	40		
Mid April	160	120	120	120	80	80		
Cultivar								
Igri	4.73	4.76	4.92	4.49	4.92	4.84	4.78	
Plaisant	5.78	5.65	5.55	5.30	5.71	5.84	5.64	0.23
Torrent	4.74	5.71	6.35	5.04	6.24	6.27	5.73	
Mean	5.08	5.37	5.61	4.94	5.63	5.65	5.38	
LSD (5%)			0.32					

% Coefficient of Variation 6.2

Table 5

1988 1000 grain weight - grams at 15% moisture content

N treatment	1	2	3	4	5	6	Mean	LSD (5%)
N kg/ha								
November	Nil	Nil	Nil	40	Nil	40		
February	Nil	Nil	40	Nil	40	40		
March	Nil	40	Nil	Nil	40	40		
April	160	120	120	120	80	80		
Cultivar								
Igri	44.8	45.3	43.7	41.5	41.9	41.9	43.2	
Plaisant	36.3	36.8	36.1	37.4	35.8	35.4	36.3	1.3
Torrent	34.6	37.3	36.2	34.4	37.1	35.4	35.8	
Mean	38.5	39.8	38.7	37.7	38.3	37.6	38.4	
LSD (5%)			1.8					

% Coefficient of Variation 4.9

Table 6

1988 Specific weight - kilograms/hectolitre

N treatment	1	2	3	4	5	6		
N kg/ha								
November	Nil	Nil	Nil	40	Nil	40		
February	Nil	Nil	40	Nil	40	40	Mean	LSD
March	Nil	40	Nil	Nil	40	40		(5%)
April	160	120	120	120	80	80		
Cultivar								
Igri	60.7	56.6	59.4	57.9	58.9	55.4	58.1	
Plaisant	57.7	57.1	58.0	61.0	56.0	55.5	57.5	1.7
Torrent	54.3	54.9	55.5	54.5	56.7	53.1	54.8	
Mean	57.6	56.2	57.6	57.8	57.2	54.7	56.8	
LSD (5%)			2.4					

% Coefficient of Variation 4.5

Table 7

1988 Ears/m^2

N treatment	1	2	3	4	5	6		
N kg/ha								
November	Nil	Nil	Nil	40	Nil	40		
February	Nil	Nil	40	Nil	40	40	Mean	LSD
March	Nil	40	Nil	Nil	40	40		(5%)
April	160	120	120	120	80	80		
Cultivar								
Igri	894	868	858	824	814	875	856	
Plaisant	579	566	609	556	649	671	605	66
Torrent	1066	979	977	973	892	1016	984	
Mean	846	804	815	785	785	854	815	
LSD (5%)			94					

% Coefficient of Variation 12.1

Table 8

1988 Nitrogen - % in grain dry matter

N treatment	1	2	3	4	5	6		
N kg/ha								
November	Nil	Nil	Nil	40	Nil	40		
February	Nil	Nil	40	Nil	40	40	Mean	LSD
March	Nil	40	Nil	Nil	40	40		(5%)
April	160	120	120	120	80	80		
Cultivar								
Igri	2.24	2.13	2.11	2.06	2.09	2.10	2.10	
Plaisant	1.99	1.78	1.95	1.74	1.80	1.84	1.85	0.05
Torrent	1.93	1.93	1.95	1.87	1.99	1.96	1.94	
Mean	2.06	1.95	2.01	1.89	1.96	1.97	1.97	
LSD (5%)			0.08					

% Coefficient of Variation 4.2

Virus development in 1988

Symptoms of virus were visible in all plots of Igri and Plaisant on 23 January, with virtually 100% plant infection. The chlorotic mottling and streaking symptoms remained obvious throughout February and March but began to fade during the second half of April, such that by early May virus was no longer visible in Plaisant although faint symptoms remained in Igri until the leaves senesced. Virus symptoms were not seen in Torrent.

Foliar disease in 1988

Foliar disease levels throughout the season were low, but there was some late development of net blotch, primarily on Plaisant and Igri, and of rhynchosporium, primarily on Igri. Although there was most disease and least green leaf area in plots which received February nitrogen than in others, and there was least disease in plots which did not receive nitrogen until April, the differences were small.

Harvest 1988

The highest yields were given by Torrent and the lowest by Igri. For Torrent, yields were significantly affected by nitrogen timing. Nitrogen regimes with 40 kg/ha in February (Treatments 3, 5 & 6) gave significantly higher yields than the other treatments. For Plaisant and Igri, there were no significant differences between treatments which included 160 kg/ha N in the spring, but the treatment with only 120 kg/ha N in the spring (Treatment 4) gave significantly lower yields than the other treatments.

Table 9

Plant populations in 1989

	Plants/m^2		
Cultivar	November	February -Nov N	+ Nov N
Igri	309	307	287
Plaisant	369	352	325
Torrent	368	333	311

Table 10

1989 Grain yield - tonnes/ha at 15% moisture content

N treatment	1	2	3	4	5	6		
N kg/ha								
November	Nil	Nil	Nil	40	Nil	40		
February	Nil	Nil	40	Nil	40	40	Mean	LSD (5%)
March	Nil	40	Nil	Nil	40	40		
April	160	120	120	120	80	80		
Cultivar								
Igri	6.08	6.09	5.82	6.22	6.53	6.16	6.15	
Plaisant	6.29	6.76	6.85	6.46	6.58	6.92	6.64	0.23
Torrent	7.14	7.79	7.49	7.49	7.93	7.58	7.57	
Mean	6.50	6.88	6.72	6.72	7.01	6.89	6.79	
LSD (5%)			0.32					

% Coefficient of Variation 4.9

Table 11

1989 1000 grain weight - grams at 15% moisture content

N treatment	1	2	3	4	5	6		
N kg/ha								
November	Nil	Nil	Nil	40	Nil	40		
February	Nil	Nil	40	Nil	40	40	Mean	LSD
March	Nil	40	Nil	Nil	40	40		(5%)
April	160	120	120	120	80	80		
Cultivar								
Igri	42.5	42.9	40.4	42.7	43.2	41.3	42.2	
Plaisant	33.9	33.3	34.9	34.4	34.0	34.3	34.1	1.09
Torrent	34.9	36.1	36.9	37.9	36.2	36.0	36.3	
Mean	37.1	37.4	37.4	38.3	37.8	37.2	37.5	
LSD (5%)			1.52					

% Coefficient of Variation 4.2

Table 12

1989 Specific weight - kilogrammes/hectolitre

N treatment	1	2	3	4	5	6		
N kg/ha								
November	Nil	Nil	Nil	40	Nil	40		
February	Nil	Nil	40	Nil	40	40	Mean	LSD
March	Nil	40	Nil	Nil	40	40		(5%)
April	160	120	120	120	80	80		
Cultivar								
Igri	63.9	62.5	64.3	63.7	63.7	63.9	63.7	
Plaisant	66.5	64.3	66.7	67.3	67.2	65.5	66.2	1.6
Torrent	65.6	68.3	69.1	67.7	68.9	68.3	68.0	
Mean	65.3	65.0	66.7	66.2	66.6	65.9	66.0	
LSD (5%)			2.2					

% Coefficient of Variation 3.4

Table 13

1989 Ear/m^2

N treatment	1	2	3	4	5	6		
N kg/ha								
November	Nil	Nil	Nil	40	Nil	40		
February	Nil	Nil	40	Nil	40	40	Mean	LSD
March	Nil	40	Nil	Nil	40	40		(5%)
April	160	120	120	120	80	80		
Cultivar								
Igri	755	763	740	777	753	746	755	
Plaisant	417	492	486	441	443	483	460	62
Torrent	961	903	899	899	899	922	914	
Mean	711	719	708	705	698	717	710	
LSD (5%)				88				

% Coefficient of Variation 12.9

Table 14

1989 Nitrogen - % in grain dry matter

N treatment	1	2	3	4	5	6		
N kg/ha								
November	Nil	Nil	Nil	40	Nil	40		
February	Nil	Nil	40	Nil	40	40	Mean	LSD
March	Nil	40	Nil	Nil	40	40		(5%)
April	160	120	120	120	80	80		
Cultivar								
Igri	2.30	2.18	2.19	2.14	2.20	2.18	2.20	
Plaisant	2.13	2.13	1.96	1.82	1.83	1.93	1.97	0.07
Torrent	2.09	1.95	1.96	1.92	1.94	2.07	1.99	
Mean	2.17	2.09	2.04	1.96	1.99	2.06	2.05	
LSD (5%)				0.09				

% Coefficient of Variation 4.6

Table 15

ELISA absorbence values, 3 January 1989

Cultivar	Leaf	November nitrogen –	November nitrogen +	Mean
Igri	Upper	0.938	0.918	0.928
	Lower	0.917	0.818	0.867
Plaisant	Upper	0.678	0.794	0.740
	Lower	1.421	1.276	1.348
LSD (95%)		0.5459		0.3861

Torrent (-N): Upper 0.142, lower 0.134
Healthy control: 0.138

Table 16

ELISA absorbence values, 6 March 1989

Cultivar	Leaf	Nitrogen timing				
		None	Nov	Feb.	Nov+Feb	Mean
Igri	Upper	0.665	0.666	0.666	0.633	0.658
	Lower	0.768	0.703	0.861	0.701	0.758
Plaisant	Upper	0.550	0.564	0.548	0.565	0.556
	Lower	0.750	0.921	0.678	0.512	0.716
LSD(95%)			0.2240			0.1120

Healthy control: 0.149

Table 17

ELISA absorbence values, 17 April 1989

Cultivar	Leaf	Nitrogen timing				
		None	Mar	Feb+Mar +Mar	Nov+Feb	Mean
Igri	Upper	0.647	0.586	0.620	0.678	0.633
	Lower	1.016	0.925	1.170	0.895	1.058
Plaisant	Upper	0.536	0.538	0.321	0.502	0.474
	Lower	1.168	1.333	0.782	1.088	1.093
LSD (95%)			0.2060			0.1260

Healthy control: 0.125

Plant populations in 1989

Higher populations were established of Plaisant and Torrent than of Igri. There were no clear effects of the autumn nitrogen treatment on plant numbers in February, but there was an indication that November nitrogen caused a slight decrease in the plant population.

Virus development in 1989

Virus symptoms were visible in Igri and Plaisant on 19 December and remained until April. All plots were uniformly infected. Virus symptoms were not seen in Torrent. All plants with symptoms contained BaYMV, and the results in Tables 15-17 are for this virus. A small number of plants also contained BaMMV, but this was not related to either the cultivar or to nitrogen use. Overall there were no effects of nitrogen timing on virus concentration and no differences between the susceptible cultivars Igri and Plaisant. Virus concentration was greater in the lower than in the upper leaves, especially in the last sample. While it is not possible directly to compare the values of tests done on different dates, the tendency for the virus to be confined to the lower leaves as the spring progressed is illustrated; this effect was clearer in Plaisant than in Igri.

Foliar disease development in 1989

Foliar disease levels were very low, and although there were small differences in brown rust levels on leaf 2 it is unlikely that foliar diseases had a significant effect on yield or on any component of yield.

Harvest 1989

As in 1988, Torrent gave the highest yields and Igri the lowest. The highest yield on Torrent was given by Treatment 5, with 40 kg/ha N in both February and March, and the treatment with nitrogen in March (No 2) gave a higher yield than the comparable treatment with nitrogen in February (No 3). For Plaisant, the highest yields were given by treatments with 160 kg/ha N in the spring, including 40 kg/ha N in either February or March or both (Nos 2, 3, & 6). For Igri, Treatment 5 gave the highest yield and Treatment 3 the lowest.

Table 18

Plant populations in 1990

Cultivar	Plants/m^2 November	February -Nov N	February + Nov N
Igri	290	271	272
Plaisant	408	348	374
Torrent	407	389	401

Table 19

Frost damage assessment, 21 May 1990

N treatment	1	2	3	4	5	6		
N kg/ha								
November	Nil	Nil	Nil	40	Nil	40		
February	Nil	Nil	40	Nil	40	40	Mean	LSD
March	Nil	40	Nil	Nil	40	40		(5%)
April	160	120	120	120	80	80		
Cultivar								
Igri	1.1	1.7	0.7	0.3	2.0	3.3	1.6	
Plaisant	5.3	5.7	10.0	7.3	7.3	4.7	6.7	1.57
Torrent	9.3	12.3	10.7	8.7	13.7	12.7	11.2	
Mean	5.4	6.6	7.1	5.4	7.7	6.9	6.5	
LSD (5%)	Not significant							

Table 20

1990 Grain yield - tonnes/ha at 15% moisture content

N treatment	1	2	3	4	5	6		
N kg/ha								
November	Nil	Nil	Nil	40	Nil	40		
February	Nil	Nil	40	Nil	40	40	Mean	LSD
March	Nil	40	Nil	Nil	40	40		(5%)
April	160	120	120	120	80	80		
Cultivar								
Igri	5.36	4.91	5.15	5.29	5.98	5.81	5.42	
Plaisant	4.94	4.56	4.36	5.06	4.79	4.55	4.70	0.35
Torrent	5.08	5.80	6.23	5.54	5.34	5.56	5.59	
Mean	5.13	5.09	5.25	5.29	5.37	5.31	5.24	
LSD (5%)			0.494					

% Coefficient of Variation 9.9

Table 21

1990 1000 grain weight - grams at 15% moisture content

N treatment	1	2	3	4	5	6		
N kg/ha								
November	Nil	Nil	Nil	40	Nil	40		
February	Nil	Nil	40	Nil	40	40	Mean	LSD
March	Nil	40	Nil	Nil	40	40		(5%)
April	160	120	120	120	80	80		
Cultivar								
Igri	34.7	33.1	34.7	33.0	34.5	33.5	33.9	
Plaisant	28.3	25.7	25.2	25.0	28.8	23.2	26.0	1.93
Torrent	29.6	31.9	28.6	31.6	31.5	31.4	30.8	
Mean	30.9	30.3	29.5	29.9	31.6	29.4	30.2	
LSD (5%)			2.73					

% Coefficient of Variation 9.4

Table 22

1990 Specific weight - kilograms/hectolitre

N treatment	1	2	3	4	5	6		
N kg/ha								
November	Nil	Nil	Nil	40	Nil	40		
February	Nil	Nil	40	Nil	40	40	Mean	LSD
March	Nil	40	Nil	Nil	40	40		(5%)
April	160	120	120	120	80	80		
Cultivar								
Igri	66.8	67.0	65.3	64.9	65.9	64.7	65.7	
Plaisant	64.8	64.5	64.3	63.9	66.3	65.0	64.8	1.14
Torrent	65.9	69.0	67.2	66.1	68.4	69.9	67.7	
Mean	65.8	66.8	65.6	64.9	66.9	66.4	66.1	
LSD (5%)			1.61					

% Coefficient of Variation 2.5

Table 23

1990 Ear/m^2

N treatment	1	2	3	4	5	6		
N kg/ha								
November	Nil	Nil	Nil	40	Nil	40		
February	Nil	Nil	40	Nil	40	40	Mean	LSD
March	Nil	40	Nil	Nil	40	40		(5%)
April	160	120	120	120	80	80		
Cultivar								
Igri	961	1020	947	1001	1015	1011	992	
Plaisant	563	617	575	524	617	717	611	58.8
Torrent	982	998	1071	1009	1032	1021	1019	
Mean	835	897	864	845	888	916	874	
LSD (5%)				91.1				

% Coefficient of Variation 9.6

Table 24

1990 Nitrogen - % in grain dry matter

N treatment	1	2	3	4	5	6		
<u>N kg/ha</u>								
November	Nil	Nil	Nil	40	Nil	40		
February	Nil	Nil	40	Nil	40	40	Mean	LSD
March	Nil	40	Nil	Nil	40	40		(5%)
April	160	120	120	120	80	80		
<u>Cultivar</u>								
Igri	2.37	2.23	2.20	2.34	2.27	2.23	2.27	
Plaisant	2.17	2.10	2.33	2.17	2.10	2.17	2.17	0.104
Torrent	2.23	2.03	2.13	2.17	2.20	2.20	2.16	
Mean	2.26	2.12	2.22	2.22	2.19	2.20	2.20	
LSD (5%)			0.148					

Table 25

Virus assessment, 9 January 1990

Cultivar	November nitrogen	Plants affected %	Plants affected angular transform
Igri	+	59.6	50.7
	-	39.9	38.7
Plaisant	+	76.5	63.6
	-	67.5	56.2
Torrent	+	0.0	0.0
	-	0.0	0.0
LSD (95%)			13.85

Table 26

ELISA absorbence values, 13 February 1990

Cultivar	November nitrogen -	November nitrogen +	Mean
Igri	0.911	1.107	1.009
Plaisant	1.154	1.111	1.133
Torrent	0.059	0.062	0.061
LSD (95%)	0.3652		

Table 27

ELISA absorbence values, 26 March 1990

Cultivar	Nitrogen timing None	Nov	Feb	Mar	Feb+Mar	Nov+Feb +Mar
Igri	0.474	0.409	0.331	0.517	0.478	0.504
Plaisant	0.452	0.310	0.472	0.468	0.391	0.440
LSD (95%)			0.2095			

Table 28

Mean grain yield 1988-90 tonnes/ha at 15% moisture content

N treatment	1	2	3	4	5	6	
N kg/ha							
November	Nil	Nil	Nil	40	Nil	40	
February	Nil	Nil	40	Nil	40	40	Mean
March	Nil	40	Nil	Nil	40	40	
April	160	120	120	120	80	80	
Cultivar							
Igri	5.39	5.25	5.30	5.33	5.81	5.60	5.45
Plaisant	5.67	5.66	5.59	5.61	5.69	5.77	5.67
Torrent	5.65	5.43	6.69	6.02	6.50	6.47	6.29

Plant populations in 1990

Higher populations were established of Plaisant and Torrent than of Igri. There were no clear effects of the autumn nitrogen treatment on plant numbers in February, but was an indication that November nitrogen caused a slight increase in the plant population.

Frost damage

Following a severe frost on 5 April 1990 (minimum temperature -8^{o}C recorded locally), there was extensive frost damage to some winter barley crops on the Cotswolds. The assessment of frost damage on all treatments in the trial on 21 May (Table 19) showed that, in contrast with the cultivar resistance trial at the nearby Hatherop site (Section III, below), there was relatively little frost damage in the nitrogen trial. There were, however, significant differences between the three cultivars, with most damage in Torrent and least in Igri. The difference in the extent of damage to Torrent at the two sites, which were only three miles apart, may be related to drilling date, which was eight days earlier at Eastleach than at Hatherop. The Eastleach crop was therefore at a more advanced stage of development at the time of the severe frost. There were no significant differences between nitrogen regimes in the extent of frost damage.

Virus development in 1990

Igri and Plaisant showed symptoms of virus by 9 January. The assessment on that date (Table 25) showed that symptoms appeared earlier on Plaisant than on Igri. Plants that received November nitrogen had more symptoms than those that did not. No symptoms were found in Torrent. By the end of January, virtually all plants of Plaisant and Igri were affected, and symptoms persisted until April. Virus symptoms were not seen in Torrent. The ELISA absorbence values (Tables 26 and 27) give a quantitative measure of virus concentration in plants. There were no significant differences between Igri and Plaisant, and no significant effects of nitrogen treatments on virus. Virus was not detected in Torrent, by ELISA or visually. Virtually all virus samples from this field were BaYMV, although BaMMV was detected in a few samples.

Foliar disease development in 1990

The main foliar disease was brown rust, which developed rapidly in late May and early June. Plaisant was most severely affected (approximately 10% leaf area affected on the top two leaves at GS77), with Torrent and Igri having lower levels (4% and 1% respectively). Levels of other diseases were very low.

Harvest 1990

Overall there was no significant difference in yield between Igri and Torrent. The cultivars responded differently to nitrogen timing. Splitting spring nitrogen reduced yield of Plaisant. The highest yields of Igri were given when some nitrogen was applied both in

February and March, whereas application of nitrogen in February or March alone did not increase yield. Application of nitrogen in February gave the highest yield of Torrent, but there was no additional benefit from applying nitrogen in March as well as in February.

DISCUSSION

In all three years for Igri the 40 kg/ha N February and March, 80 kg/ha N April treatment gave the highest or equal highest yields. For Plaisant the 40 kg/ha N November, February and March, 80 kg/ha April gave the highest yield in two out of the three years. For Torrent the 40 kg/ha N February and 120 kg/ha N in April gave the highest yield in two out of the three years. The average yields for the nitrogen timing regimes for each cultivar for the three seasons (Table 28) showed that on average for the three seasons there were for Igri, Plaisant and Torrent respectively yield differences of 0.56, 0.18 and 1.04 tonnes/ha between the 'best' and 'worst' nitrogen timing regimes. This shows that nitrogen timing influenced the yield of Torrent more than it influenced the yields of the other two cultivars. At its optimum nitrogen timing Torrent always out yielded Plaisant and Igri at their optimum nitrogen timings.

Yields in both 1988 and 1990 were relatively low. The probable explanations are that in 1988 there was some shedding of grain due to high winds just before harvest, and in 1990 the crop was severely affected by drought.

The only effect observed of nitrogen on virus in any of the three years was in 1990, when virus incidence in early January on Igri and Plaisant was higher in plots which received November nitrogen than in plots which did not. This may have been because the nitrogen accelerated plant development. There was no evidence that the nitrogen rate or timing had any influence on the concentrations of virus within the plants.

II: EVALUATION OF CULTIVAR REACTION TO A RESISTANCE-BREAKING STRAIN OF BaYMV

OBJECTIVE

To assess the reaction of winter barley cultivars to the strain of Barley Yellow Mosaic Virus which infects Torrent.

DURATION

Two years starting in autumn 1988.

MATERIALS AND METHODS

Site Details

SITE:	Eastleach, Glos
SOIL SERIES:	Sherborne
PREVIOUS CROPPING:	Continuous cereals, winter barley since 1986

Treatments

This experiment was in the area where the resistant cultivar Torrent was affected by BaYMV in 1988, and the design of the experiment was constrained by the size of this area (5 x 3m).

1988/89 trial

Twelve winter barley cultivars were sown on 3 October 1988 as single rows at 20cm spacing, and were unreplicated. A list is given in Table 29.

1989/90 trial

Nine winter barley cultivars were sown on 4 October 1989 as single rows at 20cm spacing, and were unreplicated. A list is given in Table 29.

In both years, husbandry was the same as for the field crop of winter barley. Plots were assessed for virus symptoms at three to four week intervals from mid December to early May. Plots were not harvested individually.

RESULTS

Table 29

Assessments of virus incidence, 1989 and 1990

Cultivar	% plants affected		
	1989	1990	
	22 February	27 February	21 March
Athene	30	-	-
Gaulois	70	<5	5
Igri	100	100	0
Maris Otter	100	100	100
Melusine	100	70	40
Mimosa	70	50	20
Nevada	-	100	100
Palomino	10	-	-
Sonate	100	-	-
Sonja	90	-	-
Target	90	40	50
Torrent	100	10	5
Waveney	70	<5	<5

- indicates cultivar not tested

1988/89

On 19 December virus symptoms were visible in the susceptible cultivars Igri and Maris Otter. By 13 January, symptoms were visible in all except Waveney, Palomino and Sonate, but only Torrent, Igri and Maris Otter had strongly developed symptoms. All cultivars were affected by 22 February, and results are given in Table 29. On 29 March and 12 April, virus symptoms were clearly visible only in Igri and Maris Otter, but faint symptoms were visible in all the other cultivars. By 3 May, virus symptoms were visible only in Igri and Maris Otter.

1989/90

Virus symptoms were not visible in any plot on 20 December. On 31 January, symptoms were evident in Igri and Nevada, and there were also faint symptoms in Torrent. All cultivars were affected on 27 February and 21 March, and results of assessments on these dates are given in Table 29. By 2 April, symptoms had disappeared in all cultivars except Igri, Nevada and Maris Otter, and symptoms were still visible in these cultivars on 1 May.

DISCUSSION

The resistance of Torrent to BaYMV is believed to be conferred by a single gene which is also present in all the other resistant cultivars in the trial. As a result, it is not surprising that all cultivars in the trial were affected by virus. However the 'resistant' cultivars were less affected than the susceptible cultivars in two respects:

1. Virus symptoms appeared earlier and persisted longer in the susceptible cultivars Igri, Nevada and Maris Otter than in the 'resistant' cultivars.

2. In the 'resistant' cultivars the symptoms were less strongly developed, and only a small percentage of plants were affected.

The results of the 1990 experiment were similar to those obtained in 1989, but the incidence of virus symptoms was lower in 1990 than in 1989 in most of the 'resistant' cultivars, and notably lower in Torrent. This may have been due to the particularly mild winter and warm spring of 1990, which was less conducive to symptom expression, and encouraged an early resumption of growth and disappearance of virus symptoms in the spring.

At present, this resistance-breaking strain of BaYMV has only been detected at ten sites in England. Until this new strain of the virus is found in larger areas within fields it will not be possible to estimate its effect on crop yield. It is, however, disturbing that all of the currently available resistant cultivars are susceptible to the new strain, so that if the new strain does become widely distributed it may impose a limitation on winter barley growing unless other sources of resistance can be incorporated into commercial cultivars.

III: EVALUATION OF CULTIVAR RESISTANCE

OBJECTIVE

To evaluate host plant resistance to barley mosaic viruses, and to determine the yield loss resulting from virus infection.

DURATION

Three years under H-GCA-funding, starting autumn 1988.

MATERIALS AND METHODS

Site Details

SITE:		Hatherop Glos	Stanton St John Oxon	Hail Weston Cambs
SOIL SERIES:		Sherborne	Fifield 2	Hanslope
PREVIOUS CROPPING:		Winter barley since 1986 or earlier at each site		
SOWING DATE:	1988	3 October	7 October	24 September
	1989	27 September	6 October	25 September
	1990	15 October	2 October	11 October

Treatments

Lists of the cultivars included in the trials each year are given in Tables 30 - 33 and 35 - 39. The same fertilisers and pesticides were applied by the host farmers to the trials as to the surrounding crops of winter barley. For the Hatherop trial, samples of Igri, Maris Otter and Sonja were taken on three dates in 1990 and ELISA tested to determine the frequencies of BaYMV and BaMMV. In 1990, severe frosts in early April caused extensive damage at Hatherop and some damage at Stanton St John. This was assessed at Hatherop on 21 May, on two half-metre lengths of row per plot. All trials were harvested; grain yields were corrected to 85% dry matter. Thousand-grain weight and specific weight were recorded for most trials.

RESULTS

Disease assessments, frost damage assessment (where appropriate) and harvest data is presented in Tables 30 - 39. BaYMV and BaMMV were both present at Hatherop, and the relative proportions of each in 1990 are given in Table 34. At Hail Weston BaMMV was the only virus detected, whereas at Stanton St John only BaYMV was detected.

Table 30

Hatherop, 1989: yield, relative yield and 1000-grain weight

Cultivar	% plants affected (mean)	Yield (t/ha)	Relative yield (Igri=100)	1000-grain weight (g)
Gaulois	0	8.14	129	39.27
Igri	100	6.31	100	38.92
Maris Otter	100	4.99	79	29.12
Melusine	0	7.58	120	46.40
Mimosa	0	8.71	138	46.31
Sonja	70	7.17	114	46.97
Target	0	7.68	122	45.48
Torrent	0	8.75	139	39.48
Waveney	0	7.91	126	39.48
cv (%)		5.0		4.2
LSD (5%)		0.55		0.82

Virus symptoms were visible on 19 December in Igri and Maris Otter only. By 13 January 100% plants of Igri and Maris Otter were affected, as were 70% plants of Sonja. There were no symptoms in other cultivars. In the three affected cultivars, virus symptoms remained visible until mid-May. Compared with Igri, Maris Otter gave significantly lower yields and all others gave significantly higher yields. The yields of Mimosa and Torrent were significantly higher than those of any other resistant cultivar.

Table 31

Hail Weston, 1989: % plants affected, yield, relative yield, 1000-grain weight and specific weight

Cultivar	% plants affected (mean)	Yield (t/ha)	Relative yield (Igri=100)	1000-grain weight (g)	Specific weight (kg/hl)
Gaulois	0	5.93	141	38.50	67.80
Igri	1	4.19	100	44.20	73.30
Maris Otter	23	3.13	74	34.70	71.60
Melusine	0	4.27	102	44.70	72.00
Mimosa	0	4.50	107	47.50	72.10
Sonate	0	3.76	90	49.20	70.10
Sonja	0	4.68	112	48.50	71.90
Target	0	4.97	119	45.60	70.70
Torrent	0	4.96	118	41.20	72.00
Waveney	0	5.39	129	42.60	73.30
cv (%)		8.00		3.60	2.10
LSD (5%)		0.61		2.61	2.49

Virus symptoms were first seen in Maris Otter on 14 December, but the incidence of virus remained low in this cultivar and very few symptoms were seen in any other cultivar. In spite of the low incidence of virus, four of the resistant varieties (Gaulois, Waveney, Target and Torrent) gave yields significantly higher than that of Igri.

Table 32

Stanton St John, 1989: yield, relative yield, 1000-grain weight and specific weight

Cultivar	% plants affected (mean)	Yield (t/ha)	Relative yield (Igri=100)	1000-grain weight (g)	specific weight (kg/hl)
Gaulois	1	4.66	129	36.01	53.80
Igri	50	3.61	100	42.05	59.90
Maris Otter	43	3.26	90	35.60	60.40
Melusine	8	4.14	115	45.10	62.90
Mimosa	10	4.39	122	44.30	60.20
Sonate	5	3.86	107	46.25	62.25
Sonja	59	4.06	112	44.10	62.00
Target	4	4.68	130	41.95	60.66
Torrent	2	5.01	139	41.25	59.80
Waveney	3	4.60	127	38.77	60.66
cv (%)		13.90		5.80	1.90
LSD (5%)		0.99		4.10	1.97

Virus was not uniformly distributed within the trial, and there were some areas unaffected by virus. In addition, the resistance-breaking strain of BaYMV was present in small areas within the trial, which accounts for the low percentages of infected plants of the resistant cultivars. The highest yield was given by Torrent, followed by Target, Gaulois and Waveney.

Table 33

Hatherop,1990: frost damage assessment, yield, relative yield, 1000-grain weight and specific weight

Cultivar	% main tillers killed	Yield (t/ha)	Relative yield (Igri=100)	1000-grain weight (g)	Specific weight (kg/hl)
Gaulois	10	5.51	138	37.37	69.73
Igri	4	3.99	100	37.15	70.43
Maris Otter	NA	2.70	68	31.69	72.28
Melusine	6	5.11	128	43.41	74.93
Mimosa	4	5.21	130	42.44	71.88
Sonja	10	4.21	106	45.97	74.00
Target	4	5.03	126	40.01	72.57
Torrent	66	3.74	94	36.66	71.10
Waveney	4	4.53	114	34.77	74.15
cv(%)	20.2	7.0		9.3	1.6
LSD (5%)	3.99	0.454		5.271	1.66

NA = Not assessed. Virus affected Maris Otter severely, and there were few main tillers at the time of the frost.

Table 34

Hatherop,1990: incidence of BaYMV and BaMMV

Cultivar	Number of plants: Total	Infected	BaYMV	BaMMV
		9 January 1990		
Maris Otter	40	34(85%)	0	34
Igri	38	33(87%)	4	30
Sonja	33	5(15%)	1	4
		13 February 1990		
Maris Otter	76	76(100%)	1	76
Igri	79	68(86%)	3	68
Sonja	65	18(28%)	0	18
		26 March 1990		
Maris Otter	83	67(81%)	2	67
Igri	89	76(85%)	3	76
Sonja	105	34(32%)	0	34

Virus symptoms were visible on 18 January in Igri, Sonja and Maris Otter, but symptoms were very indistinct. By 31 January virtually all plants were affected in all plots of Igri and Maris Otter, but a lower proportion of plants of Sonja. There were no symptoms in any other cultivars. In Igri and Maris Otter, symptoms remained visible until early May, but in Sonja they disappeared during April.

The severe frost (minimum temperature -8°C on 5 April) caused extensive damage to the plots of Torrent, the most advanced cultivar in terms of stage of development, with 66% of main tillers killed. Other cultivars were affected, to a much lesser extent, although there was significantly more damage to Gaulois and Sonja than to the other cultivars. The central shoot of each affected tiller was killed, and secondary tillers developed.

The 6-row cultivar Gaulois gave the highest yield. Among the 'resistant' 2-row cultivars, Mimosa, Melusine and Target gave higher yields than Waveney.

Table 35

Hail Weston, 1990: yield, relative yield, 1000-grain weight and specific weight

Cultivar	% plants affected (mean)	Yield (t/ha)	Relative yield (Igri=100)	1000-grain weight (g)	Specific weight (kg/hl)
Gaulois	0.0	7.70	97	45.40	65.70
Igri	0.9	7.93	100	43.60	70.70
Maris Otter	16.4	6.47	82	41.40	69.80
Melusine	0.0	8.38	106	50.90	72.80
Mimosa	0.0	8.83	111	50.10	69.50
Sonja	0.1	8.36	105	53.70	70.90
Target	0.0	8.17	103	46.50	70.90
Torrent	0.0	7.58	96	44.20	70.40
Waveney	0.0	8.36	105	45.60	71.40
cv (%)		17.6		10.50	2.40
LSD (5%)		1.15		4.02	1.35

As in 1989, the incidence of virus symptoms was low in Maris Otter and very few plants of other cultivars were affected. All cultivars except Torrent gave yields significantly higher than Maris Otter. Mimosa gave the highest yields, but this was significantly higher than Maris Otter and Torrent only.

Table 36

Stanton St John, 1990: yield, relative yield, 1000-grain weight and specific weight

Cultivar	% plants affected (mean)	Yield (t/ha)	Relative yield (Igri=100)	1000-grain weight (g)	Specific weight (kg/hl)
Gaulois	1	5.70	146	40.70	54.20
Igri	79	3.91	100	41.80	58.90
Maris Otter	51	4.08	104	39.00	59.80
Melusine	8	5.05	129	43.00	60.90
Mimosa	0	5.54	142	44.90	60.30
Puffin	54	4.36	111	45.10	62.70
Sonja	76	4.41	113	43.70	56.90
Target	5	5.51	141	44.30	58.80
Torrent	16	4.61	118	40.50	59.40
Waveney	0	4.27	109	35.30	55.70
cv (%)		11.10		9.40	6.70
LSD (5%)		0.74		5.50	5.60

Symptoms were obvious in Igri, Maris Otter, Puffin and Sonja throughout February and March. Among the 'resistant' cultivars more plants were affected in the plots of Torrent than of other cultivars. The yields of Gaulois, Mimosa and Target were significantly higher than those of any other cultivar. Two of the 'resistant' cultivars, Torrent and Waveney, gave yields which were not significantly greater than that of Igri.

Table 37

Hatherop, 1991: yield, relative yield, 1000-grain weight and specific weight

Cultivar	% plants affected (mean)	Yield (t/ha)	Relative yield (Igri=100%)	1000-grain weight (g)	Specific weight (kg/hl)
Bambi	39	6.58	146	45.55	70.02
Blanche	100	5.27	117	34.35	63.25
Bronze	78	6.39	142	47.60	69.92
Eagle	0	6.81	151	46.22	70.47
Firefly	0	7.13	158	43.82	69.17
Gaulois	0	7.72	172	33.72	61.80
Igri	100	4.50	100	34.60	64.30
Karisma	89	5.91	131	43.55	65.90
Maris Otter	100	3.55	87	29.10	62.57
Sonja	55	5.53	123	41.10	67.40
Target	0	7.03	156	44.22	67.97
Torrent	0	7.45	166	41.25	68.80
cv (%)		5.30		5.90	1.80
LSD (5%)		1.03		3.41	1.75

All plants of Igri and Maris Otter and also Blanche were visibly affected from early February until mid May. Bambi, Bronze, Karisma and Sonja showed a proportion of plants affected, and the symptoms faded earlier in these plots than in the fully susceptible varieties. There were no virus symptoms in the other cultivars. The highest yields were given by Gaulois and Torrent, followed by Firefly, Target and Eagle. The cultivars which were affected to some extent (Bambi, Bronze, Karisma and Sonja) gave significantly higher yields than Igri, and within this group Sonja gave the lowest yields, though not significantly lower than the others.

Table 38

Hail Weston, 1991: yield, relative yield, 1000-grain weight and specific weight

Cultivar	% plants affected (mean)	Yield (t/ha)	Relative yield (Igri=100%)	1000-grain weight (g)
Bambi	0	9.60	111	48.20
Blanche	100	8.86	102	41.30
Bronze	0	10.19	118	50.60
Eagle	0	9.29	107	44.40
Firefly	0	9.63	111	43.20
Gaulois	0	9.76	113	36.10
Igri	100	8.67	100	43.00
Karisma	0	9.82	113	48.00
Maris Otter	100	6.87	79	34.70
Sonja	0	8.54	99	47.20
Target	0	8.83	102	45.60
Torrent	0	9.56	110	42.10
cv (%)		7.20		3.10
LSD		1.19		2.44

Virus levels were much higher than in the previous two years at this site, with all plants of Blanche, Igri and Maris Otter affected. There were no virus symptoms in other cultivars. Compared with Igri, only Bronze gave a significantly higher yield whereas the yield of Maris Otter was significantly lower.

Table 39

Stanton St John, 1991: yield, relative yield, 1000-grain weight and specific weight

Cultivar	% plants affected (mean)	Yield (t/ha)	Relative yield (Igri=100%)	1000-grain weight (g)	Specific weight (kg/hl)
Bambi	62	7.87	130	36.46	55.65
Blanche	91	6.77	112	43.16	52.52
Bronze	59	8.15	134	43.21	56.45
Eagle	<1	8.38	138	41.32	51.77
Firefly	<1	9.09	150	44.62	58.45
Gaulois	2	8.36	138	36.70	51.65
Igri	95	6.07	100	43.47	51.92
Karisma	66	7.77	128	41.02	51.90
Maris Otter	86	6.05	100	42.86	55.42
Sonja	56	6.99	115	40.82	53.65
Target	<1	8.18	135	40.75	54.47
Torrent	1	7.53	124	40.12	54.30
cv (%)		6.20		11.20	3.90
LSD (5%)		0.73		7.18	3.28

The majority of plants of Igri and Maris Otter were infected, as were most plants of Blanche. Bambi, Bronze, Karisma and Sonja all had a proportion of plants affected. Very few plants of Eagle, Firefly, Gaulois, Target and Torrent were affected, all the affected plants being in the area within the trial where the resistance-breaking strain of the virus was known to be present. Igri and Maris Otter gave the lowest yields, and the yields of all other cultivars were significantly higher than those of Igri and Maris Otter. Among the other cultivars, Sonja and Blanche were lower-yielding than any of the others, and Firefly gave the highest yields. The yields of Bambi, Bronze and Karisma, all of which were affected by the virus, were similar to those of Target, Eagle, Gaulois and Torrent, which showed few symptoms.

DISCUSSION

These were the fourth, fifth and sixth years in which trials of this type had been completed, the first three years being funded by MAFF Chief Scientist's Group. In evaluating the cultivars, the differences in viruses present at the sites must be considered, with BaYMV at Stanton St John, BaMMV at Hail Weston and a mixture (predominantly BaMMV) at Hatherop. The most clear cut results were at Hail Weston, where in 1989 and 1990 only Maris Otter showed appreciable infection, although symptoms were also seen in Igri and a trace in Sonja. In 1991 virus levels were higher, possibly due to the colder winter of

1990-91, and all plants of Maris Otter, Igri and Blanche were affected. At Stanton St John and Hatherop a greater range of cultivars were affected, although Igri and Maris Otter (and in 1991 Blanche) generally had the highest incidence of virus symptoms. It is possible that BaYMV can infect cultivars such as Sonja, Karisma, Bronze and Bambi but that BaMMV either cannot infect them or only infects them to a limited extent. However, if this is the case, it is surprising that these cultivars were affected to the degree that they were at Hatherop, where BaMMV predominates. Further studies are required to elucidate this.

At Hatherop and Stanton St John, the yields of the highest-yielding cultivars were in the range 138-150% of the yield of the susceptible standard Igri, although at Hatherop in 1991 the yield differences were greater. At Hail Weston, the highest-yielding cultivars did not show such an advantage over Igri, particularly in 1990 and 1991. This may be because at this BaMMV site Igri was not affected as severely as it was at the other two sites, but it may also indicate that BaMMV has less effect than BaYMV on yield. There is circumstantial evidence that BaMMV symptoms develop later in the winter than do those of BaYMV, and this later development of BaMMV than BaYMV may account for the greater yield effects at the two sites with BaYMV. In this context it is interesting that the year in which virus had its greatest effect on yield at Hail Weston was the year in which virus symptoms appeared unusually early.

The low yield from Torrent in at Hatherop 1990 can be attributed to the extensive frost damage. Some frost damage was also observed in 1990 at Stanton St John, although this was not quantified, and this may explain why the yield of Torrent was substantially below those of Mimosa and Target. Frost damage was not recorded at Hail Weston, but Torrent also gave an unusually low yield at this site in 1990, so frost damage may also have occurred. This may also account for the poor performance of Gaulois at this site in 1990, although at other sites Gaulois was not generally affected by the late frost to the extent that Torrent was.

Differences between cultivars in thousand-grain weight and specific weight are primarily a reflection of the characteristics of the cultivars, and it is difficult to relate them to the viruses.

IV: LONG-TERM SURVIVAL OF THE VIRUS

OBJECTIVE

This was a four year study of the effect of growing a virus-resistant cultivar of winter barley (Torrent), and of growing winter wheat (Avalon) on the survival of virus in the soil.

DURATION

The trial started in autumn 1987 and was completed at harvest 1991. The first year of the trial was funded by MAFF Chief Scientist's Group. A similar trial funded by MAFF started in autumn 1987 at Hail Weston, Cambs, and finished in 1991.

MATERIALS AND METHODS

Site details

This experiment was in the same field as the variety trials at Hatherop detailed above. It was drilled on the same dates and received the same inputs.

Treatments

Treatments are listed in Table 40.

Table 40

Treatments in long-term virus survival trial

	Harvest year			
	1988	1989	1990	1991
1.	Igri/M Otter	Igri/M Otter	Igri/M Otter	Igri/M Otter
2.	Torrent	Igri/M Otter	Igri/M Otter	Igri/M Otter
3.	Torrent	Torrent	Igri/M Otter	Igri/M Otter
4.	Torrent	Torrent	Torrent	Igri/M Otter
5.	Avalon	Igri/M Otter	Igri/M Otter	Igri/M Otter
6.	Avalon	Avalon	Igri/M Otter	Igri/M Otter
7.	Avalon	Avalon	Avalon	Igri/M Otter

There were three replicates of each treatment, in a randomised block layout. Plots were 8m x 35m, except for the Igri/Maris Otter plots which had 4m x 35m of each cultivar. There was a 4m x 35m buffer of Torrent between plots in each block, and 10m buffer strips between blocks. The tramlines were in the 4m buffers of Torrent to minimise the possibility of soil movement between plots, and all cultivations were in the direction of drilling.

Assessment of survival of virus and vector in soil

1988/89

December 1988 sample. Samples of about 30 plants were dug on 8 December 1988 from plots representing each of the treatment combinations at that time (Treatments 1,2,3,5 and 6). The incidence of leaf symptoms was recorded and up to ten leaves per plot and two root samples per plot were tested by ELISA for the presence of BaMMV and BaYMV. Ten 2cm root pieces per plot were stained and examined for the presence of the fungal vector *Polymyxa graminis*.

Post-harvest soil samples. On 9 August 1989, a soil sample consisting of five cores (approximately 300cm^3) was taken from each of the plots sampled earlier and used in a bioassay to estimate the populations of *P.graminis* and amounts of BaMMV in the vector. After drying, crushing and sieving (2mm), a dilution series in sterile sand was prepared, diluting by a factor of five at each step to produce dilutions down to 1/15625. Samples of each step were distributed to ten cells of a divided seed tray and one seedling of barley (Maris Otter) was planted in each. After growing for seven weeks in conditions suitable for *P.graminis* development, the root systems of each plant were washed free of soil/sand. They were then examined for the presence of *P.graminis* and tested in ELISA for the presence of BaMMV. The results were analysed on a computer using the Genstat programme to fit a binomial model with a complementary log-log link function and estimating most probable numbers of both fungus and virus for each treatment.

1989/90

Plant samples were taken from each plot on 19 April 1990. Virtually all plants of Igri and Maris Otter were affected by virus, but amounts of *P. graminis* in the roots were too small to detect differences between treatments.

Soil samples were taken on 2 August 1990, and bioassays for virus and vector were carried out using the methods detailed above. The dilution series consisted of dilutions by a factor of three at each step from 1/20 to 1/4860. Later, the experiment was repeated using dilutions from 1/1620 to 1/43740.

Harvest

In 1990, plots of the five treatments with Igri/Maris Otter were harvested on 22 July. In 1991, all plots were harvested on 8 August.

RESULTS

The results of the December 1988 and 1989 post-harvest assesments for virus and vector are given in Tables 41 and 42 respectively. The 1990 post-harvest estimates of the vector are in Table 43; unfortunately there were problems with the tests for virus concentration in 1990, and no results were obtained. Harvest data for 1990 is in Table 44, and 1991 data in Table 45.

Table 41

Symptom expression and virus infection of roots, 8 December 1988.

Treatment	Cultivar	Leaf symptoms % plants	Root infection BaMMV, nos/6
1	Maris Otter	45.6	6
	Igri	0.0	1
2	Maris Otter	35.5	3
	Igri	4.2	0
3	Torrent	0.0	0
5	Maris Otter	49.9	4
	Igri	0.0	2
6	Avalon	0.0	0

Table 42

Estimates of most probable numbers (nos/ml soil) for fungus and virus in post-harvest soil samples taken in 1989.

Treatment	Cultivar	Most probable number (95% fiducial limits in brackets) fungus	virus
1	Maris Otter	1.83 (1.06-3.13)	8.68 (5.16-14.60)
	Igri	4.12 (2.41-7.05)	4.25 (2.51-7.18)
2	Maris Otter	6.03 (3.53-10.30)	0.63 (0.37-1.06)
	Igri	4.43 (2.60-7.57)	0.62 (0.36-1.04)
3	Torrent	6.78 (3.96-11.60)	3.86 (2.02-7.38)
5	Maris Otter	4.55 (2.66-7.78)	2.74 (1.61-4.63)
	Igri	1.75 (1.01-3.03)	1.42 (0.84-2.40)
6	Avalon	4.58 (2.66-7.86)	2.00 (1.03-3.88)

Table 43

Estimates of most probable numbers (nos/ml soil) for fungus in post-harvest soil samples taken in 1990

Treatment	Most probable number (95% fiducial limits in brackets)
1	37.2 (24.6-56.0)
2	39.0 (27.1-56.4)
3	47.8 (29.7-76.8)
4	47.2 (27.5-83.0)
5	56.6 (37.4-85.2)
6	47.9 (32.0-71.8)
7	27.8 (20.0-38.6)

Table 44

1990 yields from long term virus survival trial

Treatment	Yield (t/ha)		LSD
	Igri	Maris Otter	(5%)
1	5.09	3.35	
2	4.86	3.65	
3	4.92	3.44	0.248
5	4.78	3.45	
6	4.81	3.60	
LSD (5%)	1.116		

% coefficient of variation = 7.3

Table 45

1991 yields from long term virus survival trial

Treatment	Yield (t/ha) Igri	Maris Otter	LSD (5%)
1	3.80	3.54	
2	4.73	3.73	
3	5.36	4.31	
4	5.26	4.58	1.103
5	5.26	4.58	
6	5.19	4.25	
7	5.12	4.65	
LSD (5%)	0.248		

% coefficient of variation = 7.3

DISCUSSION

There was no clear evidence to suggest that any of the treatments had any effect on the incidence of virus. In the final year, there was an indication that where there had been two or three previous crops of Igri or Maris Otter the yields were reduced, compared with plots following only one year of these cultivars or following wheat, but the differences were not statistically significant. The analysis of post-harvest soil samples in 1989 showed that there were statistically significant differences among the most probable numbers estimates for both virus and vector, but these are difficult to interpret. For example, estimates of virus were highest in the plots with two years of susceptible barley (Treatment 1), but this did not apply to the vector. The virus population appeared to be higher after two years resistant barley (Treatment 3) than after one year (Treatment 2) so it appears that the differences may reflect natural variation in populations between field plots rather than differences resulting from the treatments. In 1990 the levels of *Polymyxa graminis* recorded were higher than in 1989, but because of difficulties in standardising the test conditions of temperature and watering comparisons between years, should be treated with caution.

GENERAL DISCUSSION AND CONCLUSIONS

Epidemiology

The virus is dispersed by movement of soil. Most of this occurs during agricultural operations, but some outbreaks of virus and some features of virus distribution cannot easily be explained in this way. The essential conditions for infection by the fungal vector are soil moisture and warmth. The resting spores of the vector (cystosori) germinate to produce swimming spores (zoospores) which need free water in the soil to be able to infect the roots. Early-sown crops generally show more virus than late-sown crops, presumably because conditions for infection are more favourable earlier in the autumn. Once in the roots, virus movement to the leaves is dependent upon low temperatures, and normally occurs after a period of frosty weather. The appearance of symptoms in the leaves is concurrent with the movement of virus from roots to leaves. When symptoms disappear in late spring, virus is no longer detectable in the leaves. BaMMV remains in the leaves at higher temperatures than does BaYMV, so symptoms tend to persist longer in plants affected by BaMMV than in those with BaYMV. In Experiment 1, there was no evidence that nitrogen rate or timing had any influence on virus incidence or severity.

Extent of the disease

Of the 30000 ha of winter barley surveyed in the Cotswolds in 1988, 13% of the fields were affected to some extent by virus. The proportion will inevitably have increased further since then due to continued cropping of affected fields with susceptible cultivars, and to movement of soil with the virus from field to field. Reports of the disease have now been received from most of the arable areas of England and Scotland (Hill & Walpole, 1989). In the period 1987-1990, over 70% of samples from the UK tested at IACR Rothamsted had BaYMV and 37% had BaMMV, with 11% containing both viruses (Adams, 1991). As yet, only BaMMV has been found in Scotland. BaMMV used to predominate in the east and north, with BaYMV more common in more western areas, but both viruses are now widely distributed. In some cases, both viruses can be found in one plant, and no antagonism or synergism has been detected.

Long-term survival of the viruses

The virus persists in its vector in the soil for a long period. The length of this period cannot be predicted accurately, but survival in soil stored in laboratories for over 20 years has been reported. In the long-term experiment in this project there was no evidence to suggest that levels of virus or vector in the soil can be reduced either by growing resistant winter barley cultivars or by growing winter wheat, at least in the short term. Because the vector persists in the soil for long periods, it has been suggested that there may be a highly specific stimulus for germination of the cystosori. If so, it may be possible to exploit this as a means of control (Adams, 1990).

Resistance-breaking strain of virus

Resistance-breaking strains of BaYMV were found at three sites in 1988, one in 1989, two more in 1990 and a further four in 1991. Resistance-breaking strains of BaMMV have not been found. The resistance-breaking strain of BaYMV is serologically indistinguishable from the normal strain of BaYMV, and the trials described in this report showed that it infects all resistant cultivars in the UK. It is thought that resistance in all these cultivars is conferred by the same resistance gene (Friedt et al. 1988). However, the degree of symptom expression is less than in most susceptible cultivars, so it is possible that the resulting yield loss is also less, although there is no data on this. It will not be possible to obtain reliable estimates of the effect on yield of the resistance-breaking strain until it is present in sufficiently large areas to lay down replicated trials which can be harvested.

Cultivar reaction to virus

Compared with the susceptible cultivar Igri, resistant cultivars gave yields up to 72% higher in the trials. Yield loss from a susceptible cultivar may be expected to be higher following a severe winter than after a mild winter. However, during the six-year period of the trials, including MAFF-funded trials (CE34/001) in 1986-1988, yield differences were generally similar from year to year although the winters were more severe in 1986, 1987 and 1991 than in the other three years. The cultivar Sonja is thought to exhibit partial resistance to BaMMV, which may account for its better performance than Igri at the three sites, and Bambi, Bronze and Karisma appear to be similar to Sonja in this respect. Sonja and these other cultivars are susceptible to BaYMV. There is evidence that several cultivars differ in susceptiblilty to the two viruses, and in particular that the malting cultivars Maris Otter, Pipkin and Halcyon are more susceptible to BaMMV than to BaYMV (Adams, 1991).

Future research

At present, the only method for identifying the resistance-breaking strain of BaYMV is by a host test, since it cannot be distinguished serologically. Improvements in detection methods are required. Recent Japanese work using a differential series of barley varieties has indicated that there are more strains of the virus than can be identified with the methods currently used in the UK. The value of this differential series in identifying virus strains in the UK needs to be investigated. Work on the biology and epidemiology of the fungal vector is also required, particularly on host-specialisation in the vector, genetic resistance to the vector and the possibility of stimulating germination of cystosori to reduce virus populations in fields.

Work on soil-borne viruses has become of greater importance following the discovery of rhizomania of sugar beet in the UK in 1987, since the vector of the rhizomania virus is Polymyxa betae, which is closely related to the vector of barley mosaic viruses. There are nine viruses known to be transmitted by Polymyxa graminis, of which only the two barley mosaic viruses and two oat viruses are known to occur in the UK. However, Wheat Yellow Mosaic Virus is present in France, and is serologically related to BaYMV, so that work on BaYMV may be of value in dealing with the wheat virus should it become established in the UK.

Agricultural implications of the disease

Of the 19 winter barley cultivars on the 1991 NIAB recommended list, only four (Gaulois, Melusine, Target and Torrent) are resistant to BaYMV and BaMMV. Two other resistant cultivars (Mimosa and Waveney) were removed from the list in 1990, so that seed will soon become unobtainable. At present, many farmers elect not to grow resistant cultivars, so that inevitably the area affected by virus will increase steadily, and the financial penalty from not growing resistant cultivars will increase. For those growing resistant cultivars, the appearance of the resistance-breaking strain is of great concern. Although of limited extent now, the threat is considerable, and the importance of breeding new cultivars with different sources of resistance cannot be over-emphasised. If breeders are unable to meet this challenge and if other methods of control cannot be developed, some farmers will have no option but to abandon winter barley growing.

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