HGCA

PROJECT REPORT No. 108

DEVELOPMENT AND EVALUATION OF IN-CROP MONITORING AS A METHOD OF IDENTIFYING BYDV HIGH RISK SITUATIONS

APRIL 1995

PRICE £6.00

PROJECT REPORT No. 108

DEVELOPMENT AND EVALUATION OF IN-CROP MONITORING AS A METHOD OF IDENTIFYING BYDV HIGH RISK SITUATIONS

by

S. J. HOLMES [1], G. N. FOSTER [1], A. MASTERMAN [2], A. BELL [3] AND L. WARD [3]

[1] Department of Plant Science, SAC Auchincruive, Ayr KA6 5HW

[2] Department of Environmental Sciences, SAC Auchincruive

[3] Department of Agriculture, Queen's University of Belfast, Newforge Lane, Belfast BT9 5PX

This is the final report of a three year project which commenced in August 1991. The work was funded by a grant of £137,685 from the Home-Grown Cereals Authority (HGCA Project No. 0034/1/91).

CONTENTS

DEVELOPMENT AND EVALUATION OF IN-CROP MONITORING AS A METHOD OF IDENTIFYING BYDV HIGH RISK SITUATIONS

HGCA Project No. 0034/1/91

S J HOLMES   A J MASTERMAN   G N FOSTER

Plant Science & Environmental Sciences Departments
SAC Auchincruive, Ayr, Scotland.

A BELL   L WARD

Department of Agriculture, Queen's University
Belfast, Northern Ireland.

Final Report 1 August 1991 - 31 July 1994

ABSTRACT

Annual, regional and between field differences in the numbers of aphids which infest cereals during the autumn provide opportunities for targeting insecticide treatments at the crops which have the highest risk of developing damaging Barley Yellow Dwarf Virus (BYDV) infection. In many autumns, only the small minority of crops which follow undesiccated ploughed-in grass leys have a high risk of developing damaging BYDV infection.

Using aphid and BYDV infection data collected from 20-45 crops annually in six growing seasons of winter barley in the west of Scotland and Northern Ireland, and aerial aphid density data of the Rothamsted Insect Survey, methods of identifying the autumns when the risk of damaging BYDV infection is likely to be high have been devised. These methods may be used to issue pre-drilling information on the risk of BYDV infection each autumn, and they can be used to organise more extensive and frequent aphid sampling of cereals in autumns which are predicted to be at high risk.

The aphid and BYDV data have also been used to identify field/farm characteristics which are associated with large aphid populations and subsequently higher levels of BYDV infection. These field/farm characteristics may be used to target insecticide applications at crops which have the highest numbers of aphids, ensuring that aphid populations are controlled in crops that require treatment while reducing the unnecessary use of insecticides in crops which have low numbers of aphids.

This new scheme, Strategic Monitoring, has the potential to reduce the annual cost of insurance spraying to control aphids during the autumn which has been estimated at £10 million. By reducing the uncertainty of when (which autumns?) and where (which regions and which fields?) damaging BYDV infection may develop, the need for insurance spraying of all crops is lessened. More years' aphid and BYDV data from winter barley crops are required to further test and refine Strategic Monitoring. To improve the ability of field/farm characteristics to identify high risk fields, a national database of field/farm characteristics and aphid/BYDV incidence needs to be constructed using data collected over a number of years. This study has greatly increased knowledge of BYDV in autumn-sown cereals but six years is not long enough to encounter sufficient variation in aphid/BYDV incidence to confidently forecast the disease risk on the regional and field scale required by advisers and cereal growers.

OBJECTIVES

To conduct a comparative study of existing methods of forecasting BYDV in autumn-sown cereals. Evaluate and develop new methods of forecasting BYDV, thus promoting the timely application of insecticides and reducing unnecessary pesticide usage.

INTRODUCTION

Barley Yellow Dwarf Virus (BYDV) has the potential to cause serious yield loss to autumn-sown cereals in the UK. However, the risk to crops varies annually and from place to place, and BYDV infection sufficient to cause serious yield loss is a fairly rare event. The annual cost of insurance spraying to control the aphid vectors of the disease has been estimated at around £10 million (Harrington *et al.*, 1994), but the annual cost of necessary spraying each year, although impossible to calculate, is probably a small proportion of this figure. The uncertainty of where and when BYDV may cause serious yield loss has contributed to the practice of insurance spraying.

Infectivity indexing (Plumb, 1986) aims to reduce this uncertainty by providing risk assessments for individual regions and for crops of different sowing dates. In southern England, aphid density (aerial measurements by suction traps and crop counts) is not significantly correlated with damage in contrast to the infectivity index, or an adjusted infectivity index which excludes gynoparae and males (Plumb, 1986; Kendall & Chinn, 1990). In this and other areas, a measure of aphid infectivity (i.e. the proportion of winged aphids which transmit BYDV) is essential to assessing the risk of BYDV infection. In northern England, the predominance of gynoparae and males in the autumn migration resulted in high infectivity indices when few bird cherry aphids were recorded in crops (McGrath & Bale, 1989). An adjusted index which excluded males was no better, but a modified index that was based on an estimate of the number of virginoparae in the migration gave much lower and more realistic indices. In Scotland and west Wales, much higher values of aphid infectivity are obtained (A'Brook & Dewar, 1980; Foster *et al.*, 1993) than in southern England suggesting that aphid infectivity may not be a limiting factor to virus spread in these regions. Moreover, infectivity indexing has consistently failed to assess the risk of BYDV infection from migrant bird cherry aphids in Scotland (Foster *et al.*, 1993).

Advisory experience has shown that there are large regional variations in the risk of BYDV infection in south-west Scotland and Northern Ireland. Unfortunately, there is only one 12.2 m suction trap in south-west Scotland located at the Scottish Agricultural College-Auchincruive, Ayr, although there are other traps located on the east coast at East Craigs and Dundee. The Ayr suction trap only provides good aphid information for Ayrshire and it provides no information on the regional variations in aphid populations that exist in south-west Scotland. As a consequence, it is impossible to predict the regional variations of BYDV risk to autumn-sown cereals from the Ayr suction trap samples.

The large regional variations in the risk of BYDV infection is probably due in part to the land use and topographical variations of the different Scottish regions (Figure 1). The major part of southern Scotland is upland which is unsuitable for arable farming while most of the lower altitude land suitable for cereal growing is confined to the coastal areas. Moreover, the coastal agricultural areas of Dumfriesshire, Wigtownshire and Ayrshire each have differences in climate and different agricultural traditions (i.e. land use). Livestock farming predominates in these three regions although there are a few large cereal farms and mixed farms are common. In Stirlingshire (Figure 1), cereal growing is predominant, and farmland tends to be flatter and less topographically diverse than farmland of the coastal regions described above.

In October 1987, the HGCA and the Scottish Office Agriculture and Fisheries Department jointly funded a three year project to improve the forecast of BYDV high risk conditions in autumn-sown cereals of Scotland and Northern Ireland. This project was extended in 1991 for a further three year period with funding from the HGCA. Throughout the six year study, sampling for aphids and BYDV infection in commercial winter barley crops in different regions of south-west Scotland and Northern Ireland was a major part of the project. The purpose of this sampling was not only to provide an invaluable record of aphid/BYDV incidence in winter cereals, but also to clarify the regional differences in the risk of BYDV infection. In addition to sampling in winter barley crops, ryegrass pastures and grass weed species have also been sampled for both aphids and virus, and various aphid transmission studies have been done. This work has been summarised in a previous report to the HGCA which also outlines the new scheme, Strategic Monitoring (Holmes *et al.*, 1991). From 1991 to 1994, the emphasis has been on the collection of more aphid/BYDV data from cereal farms throughout the year to extend the aphid/BYDV record and to develop and refine the in-crop monitoring scheme (Strategic Monitoring) as a method of identifying high risk situations.

Another BYDV study in the south of England, also funded by the HGCA, has been running concurrently with this Scottish/Irish project. Although it is well known that widely different BYDV regimes exist in different parts of the UK, there are certainly aspects of the Scottish/Irish project which have relevance to the English study and *vice versa*. In recognition of this, the staff of the two projects met at Rothamsted on 5 November 1993 to discuss their results to date and to agree on the priorities for future BYDV research. The product of this meeting was a paper presented at the *Annals of Applied Biology* conference at Cambridge in March 1994 (Harrington *et al.*, 1994).

In the south of England, assessments of BYDV risk based on sampling aphids by suction trapping and infectivity testing of aphids normally provide a satisfactory early warning of initial infection on a regional basis (Harrington *et al.*, 1994). Once the autumn migration of aphids has ceased, models which simulate the spread of virus within crops may reveal how key weather factors in the late autumn and winter are affecting aphid populations and subsequently virus spread (Kendall, Brain & Chinn, 1992; Harrington *et al.*, 1994). In the more western areas of England and Wales, and in Northern Ireland and south-west Scotland, the greater acreage of ryegrass and the more variable land use increases both the potential risk of damaging bird cherry aphid-transmitted BYDV and the between field variability in the risk of infection. In these areas, a greater reliance on field sampling is necessary to protect crops from potentially serious infection, and to identify the regional and between field variations. Strategic Monitoring should be useful in many western areas of the UK in deciding when and where to control the aphid vectors of BYDV in autumn-sown cereals.

This report details the results of the current project (August 1991 to July 1994) and it summarises the aphid and BYDV data collected from winter barley crops in six consecutive growing seasons (1988/89-1993/94). It also presents the new in-crop monitoring scheme, Strategic Monitoring.

MATERIALS AND METHODS

1. Infectivity Indexing

Infectivity Indices were calculated at Auchincruive, Ayr in 1991 and 1992, and at Newforge Lane, Belfast, in 1991, 1992 and 1993 using the procedures outlined in Holmes *et al* (1991).

2. Serological testing

Serological tests on plants using the ELISA technique were conducted using the methods described by Holmes *et al* (1991).

3. Aphid monitoring in winter barley crops

1991/1992. Eighteen winter barley crops in three regions (Dumfriesshire, Wigtownshire and Stirlingshire; Figure 1) were sampled on six occasions from early October to early December 1991. A further six crops were monitored by College advisers. All these crops were sampled again in the spring.

1992/1993. Twenty-nine winter barley crops in five regions (Dumfriesshire, Wigtownshire, Ayrshire, Renfrewshire and Stirlingshire; Figure 1) were sampled on up to five occasions from early October to early December 1992. All these crops were sampled again in the spring.

1993/1994. Thirty-six winter cereal crops in four regions (Dumfriesshire, Wigtownshire, Ayrshire and Stirlingshire; Figure 1) were sampled on 2 to 7 occasions from early September to late October 1993. All these crops were sampled again in the spring.

At each visit, the numbers of aphid colonies (not individuals) and their species were determined by examining 10 x 1m lengths of drill across the crop. A colony is defined as a discrete group of aphids: it could consist of one adult and several nymphs, or be a single adult or a single nymph. An aphid colony represents an infestation point, and the numbers of colonies should be more correlated with the subsequent number of infected plant patches than the total numbers of aphids.

4. Survey of BYDV incidence and strains in winter barley crops

Spring 1992. In late April and early May, the 18 Scottish winter barley crops which were sampled for aphids in the autumn of 1991 were surveyed for BYDV. In Northern Ireland, eight winter barley crops were surveyed.

Spring 1993. In late April, the 29 Scottish winter barley crops which were sampled for aphids in the autumn of 1992 were surveyed for BYDV. In Northern Ireland, 12 winter barley crops were surveyed.

Spring 1994. In early May, the 36 Scottish winter cereal crops which were sampled for aphids in the autumn of 1993 were surveyed for BYDV. In Northern Ireland, 8 winter barley crops were surveyed.

The same methodology was used each spring: single yellow leaves were collected from ten plants showing characteristic symptoms of BYDV infection during a circuit of each field and tested for BYDV by ELISA. The extent of crop yellowing and the abundance of yellow plants were also noted.

5. Pre-harvest sampling

During early July 1993, three winter barley crops in six regions (Dumfriesshire, Wigtownshire, Ayrshire, Stirlingshire, Down and Antrim) were sampled for aphids and BYDV. Single yellow leaves were collected from ten or twenty barley plants during a circuit of each field. In addition, twenty well-established *Poa annua* plants were also collected from each field. These plant samples were tested for BYDV by ELISA. The extent of grass weed infestation (mainly *Poa annua*), the abundance of cereal aphids, ladybirds and aphid mummies (parasitoids) were also noted.

6. Post-harvest sampling

During late August/early September 1993, cereal stubbles in six regions (Dumfriesshire, Wigtownshire, Ayrshire, Stirlingshire, Down and Antrim) were sampled for aphids and BYDV. *P. annua* were collected and tested for BYDV by ELISA. Ten volunteer groups and ten *P. annua* plants were assessed for aphid infestation. The extent of grass weed infestation (mainly *P. annua*) was also noted.

7. *Sitobion* spp. on weed grasses in 1993

Earlier work by the authors indicated that weed grasses in the field margins of cereal fields might be sources of infective aphids, particularly for the grain aphid (*Sitobion avenae*). This hypothesis was tested during the autumn 1993.

In the spring 1993, the abundance of two grass weed species in the field margins of 29 winter cereal crops was scored. The two species selected were Cocksfoot (*Dactylis glomerata*), and Yorkshire fog (*Holcus lanatus*) which have been found to be colonised by the grain aphid in a previous study (Holmes *et al.*, 1991).

In early August 1993, the inflorescences of twenty Cocksfoot and twenty Yorkshire fog in 11 fields (three per region except Stirlingshire) were examined for aphid infestation. The condition of their inflorescences was scored because the previous study identified that few aphids were found on senesced inflorescences. Scores: 0 completely fresh; 1 partially fresh; 2 totally senesced. Most plants had several inflorescences, but scores 0 or 1 were awarded if only 1 inflorescence was completely or partially fresh.

In late August/early September 1993, the inflorescences of ten Cocksfoot and ten Yorkshire fog in three fields per region (in seven cases, these fields were the same as those sampled in early August) were examined for aphid infestation, and the condition of their inflorescences was scored.

8. Summary of autumn aphid monitoring of winter barley crops 1988-93

Aphid numbers in winter barley crops in several regions of south-west and central Scotland have been recorded each autumn from 1988 to 1993. Methodologies for each year have been described by Holmes *et al* (1991).

9. Summary of BYDV spring survey of winter barley crops 1989-94

A survey of BYDV in winter barley crops in several regions of south-west and central Scotland has been conducted in each spring from 1989 to 1994. In each field, an estimate of the percentage of the crop comprised of plants with yellowed leaves was made, and yellow leaf samples were collected, and tested for BYDV by ELISA. At the same time, crops were sampled for aphids.

10. Summary of pre-harvest sampling 1989-93 and post-harvest sampling 1990 to 1993

In each year from 1989 to 1993, winter barley crops in different regions of south-west and central Scotland were sampled for aphids and BYDV in late June or early July. In each year from 1990 to 1993, winter barley stubbles in different regions were also sampled for aphids and BYDV in late August or early September. The purpose of this sampling was to gather data on aphid infestations and BYDV infection present in winter cereals fields during the summer, to ascertain whether these data could provide information on aphid numbers and the risk of BYDV infection in winter cereals in the following autumn.

RESULTS

1. Infectivity Indexing

Autumn 1991

Fine weather in late August and September permitted many winter barley crops to be drilled on time during the middle of September, so that many crops emerged in the first week of October.

Auchincruive. Twenty-five per cent of the 184 *R. padi* tested for BYDV infectivity were infective (Table 1). The peak of the *R. padi* migration as measured by Tower trap catches occurred in early September before crops had emerged, so that in October, the weekly indices were generally low (except for week ending 13 October). Even so, a typical winter barley crop emerging the week ending 6 October accumulated a large index of 594 by early November (Table 2), suggesting a high risk of BYDV infection by migrating aphids.

Belfast. From 8 September to 3 November, the Tower trap caught 5644 aphids. Fifty-four per cent of these were caught in October, when infective aphids were caught in the commode trap each week. A typical winter barley crop emerging the week ending 7 October accumulated a high index of 735 (Table 3), suggesting a high risk of BYDV infection by migrating aphids.

Autumn 1992

Very unsettled weather in August and September delayed drilling of autumn-sown cereals. Although some crops were drilled during mid-September, the last week of September was the earliest time most farmers could manage. An appreciable number of crops were drilled as late as mid-October.

Auchincruive. Sixteen per cent of the 128 *R. padi* tested for BYDV infectivity were infective (Table 4). The peak of the *R. padi* migration as measured by Tower trap catches occurred in late September/early October. The earliest crops which had emerged by 4 October accumulated a very large index of 1192 (Table 5) while crops emerging after this date had quite low cumulative indices. Therefore, only the small number of crops emerging in the first week of October would be expected to be at high risk of BYDV infection by migrating aphids.

Belfast. Two per cent of the 49 *R. padi* tested for BYDV infectivity were infective (Table 6). Eighty per cent of the 4481 *R. padi* caught by the Tower trap migrated in the two week period ending 7 October (Table 7). No infective aphids were caught after this date, so that most winter barley crops (perhaps all) would be expected to be at low risk of BYDV infection by migrating aphids.

Autumn 1993

Fine weather in late August and September permitted winter barley crops to be drilled early, or on time, in mid-September. Many crops had emerged by the first week of October.

Belfast. Nineteen per cent of the 165 *R. padi* tested for BYDV infectivity were infective (Table 8). Seventy-eight per cent of the *R. padi* sampled by the Tower Trap were caught during September, although none of the aphids caught in September by the commode trap was infective. Therefore, an erroneous infectivity index matrix (Table 9) was obtained which suggested that crops emerging in early September were at less risk from BYDV infection than crops emerging in early October. However, a winter barley crop emerging in the last week of September accumulated an index of 637 suggesting a high risk of BYDV infection from migrating aphids.

2. Aphid monitoring in winter barley crops

Autumn 1991. Aphid numbers were low in all regions in the autumn 1991 (Table 10; Figure 2). The grain aphid was scarce relative to recent autumns. Bird cherry aphids were more numerous in Dumfriesshire and Wigtownshire than in Stirlingshire where no more than three 1-metre lengths of drill were aphid-infested on any sampling occasion. Numbers decreased dramatically after October, so that only one aphid was observed during sampling in November and December. Most bird cherry aphids observed were winged individuals that didn't reproduce in winter barley crops. As in previous autumns, it is likely that these aphids were the sexual morphs (gynoparae & males) which do not contribute to BYDV spread.

Winter and Spring 1992. No aphids were observed during crop inspections during February and March. Aphids were found in three crops during sampling in late April/early May.

Autumn 1992. Aphids were much more numerous in Dumfriesshire, Wigtownshire and Ayrshire than in Renfrewshire and Stirlingshire (Table 11; Figure 2). In the first two regions, both wingless bird cherry and grain aphids occurred whereas in Ayrshire, only grain aphids were common. The wingless bird cherry aphids did not reproduce, but developed into winged forms that left the crops. It is thought that they were the sexual forms (gynoparae & males) that do not contribute to BYDV spread. Aphid numbers decreased after October with only a few grain aphids being observed in November and December.

Winter 1993 and Spring 1993. No aphids were observed during sampling in February and March. Grain aphids were present in some crops by the end of May 1993.

Autumn 1993. The mean number of aphid colonies per field in each region in the autumn 1993 (Table 12; Figure 2) shows that bird cherry aphids were more common than grain aphids in all regions except Stirlingshire. Grain aphids were common in early September-sown crops of both Stirlingshire and Ayrshire, while they were rare in late September-sown crops of all regions (Table 13).

Bird cherry aphids in the autumn 1993 were more common than in the previous five autumns of this H-GCA funded study into BYDV (the data from 1988 to 1993 are summarised in section 7). Unlike the previous five autumns, many of the winged bird cherry aphids migrating into cereals in the autumn 1993 were the non-sexual forms i.e.

exules. The sexual forms (gynoparae & males) do not reproduce in cereals, so although they may introduce some virus, there are no offspring to spread the virus to produce the damaging patches of infected plants. In contrast, exules introduce virus and reproduce, and their offspring may spread the virus to produce damaging patches of infected plants within a few weeks.

Although infectivity indexing was not measured at Auchincruive in 1993, Belfast infectivity indexing correctly suggested a high risk autumn for crops emerging in late September/early October (Tables 8 & 9). However, at Auchincruive and Belfast in 1991 (Tables 1 to 3), an equally high index was obtained for crops with similar emergence dates and a much higher index was obtained at Auchincruive in 1992 (Tables 4 & 5). In both 1991 and 1992, few exule bird cherry aphids colonised winter cereals of either Scotland or Northern Ireland (Tables 10 & 11; Figure 2). The wingless bird cherry aphids in Wigtownshire in 1992 did not reproduce, so patches of BYDV infection did not develop. The infectivity index in Scotland and Northern Ireland is uncorrelated with infestation of winter cereals by exule bird cherry aphids.

There are several important features of the bird cherry aphid data collected during the autumn 1993:

1. Four Ayrshire winter barley crops (one was drilled 25/8/93, while the other three were drilled on 5/9/93) were heavily infested by bird cherry aphids when sampled on 13/9/93 (data for 2 crops presented in Table 14). In all four crops there were several bird cherry aphid colonies in most of the ten 1m lengths of barley drill examined. Most of these aphids were first instar nymphs suggesting that they had been deposited by their winged exule parents within the last two days. The number of bird cherry aphids sampled by the Auchincruive suction trap in the week 6-12 September 1993 was 1197, which is larger than average. Of this total, only 13 were male, suggesting that there were few sexual forms migrating during this week. This is supported by the aphid infestations recorded in Ayrshire winter barley on 13/9/93. These infestations also show how numerous and fecund exule bird cherry aphids can be in the west of Scotland, where autumn-sown cereals comprise a small proportion of the total acreage relative to ryegrass pastures.

2. In some of the crops which were infested by bird cherry aphids, infestations were concentrated in parts of the fields. Although the ten 1 m lengths of barley drill sampled during a circuit of each field was sufficient to detect these localised infestations in these cases (eg. third crop in Table 14), it could be desirable to

increase the number of sampling points to 15 or 20, and to decrease the length of barley drill examined at each point to 0.8 or 0.5 m

3. There was considerable variation between fields in the extent of colonisation by bird cherry and grain aphids the autumn 1993 (Table 13). With respect to the bird cherry aphid, the most infested fields were either sown in late August/early September or they followed an undesicated ploughed-in grass ley. With respect to the grain aphid, the most infested fields were clearly those sown in early September. However, there were several crops drilled in the latter half of September which had sufficient bird cherry aphid numbers to require an insecticide application: D9; D14; & A6. In these three cases, the infestations were confined to one side of the fields, and the boundaries of these sides were enclosed by mature woodland. Exule bird cherry aphids appeared to accumulate in greater numbers in fields enclosed by trees, and parts of fields enclosed by trees, than in less sheltered fields. In the spring of 1989 when serious BYDV infection developed, it was noted that the winter cereal crops with the most extensive infection were those enclosed by mature woodland (Masterman, 1991). The effect was dramatically illustrated on a few farms, where two crops with similar sowing dates, but different levels of shelter, had significantly different BYDV infection levels. For example, the less sheltered field on a Wigtownshire farm had 4% infection compared with 50% in the crop enclosed by trees. At the time, it was assumed that these sheltered fields had more infection, because aphid reproduction and survival during the winter 1988/89 was favoured in sheltered fields. Aphid data from the autumn 1993 suggests that sheltered fields are also infested by greater numbers of exules during the autumn than more exposed fields. Other factors favouring larger numbers of bird cherry aphids in the autumn 1993 were land use (fields on farms with a major livestock component, and therefore large acreages of ryegrass) and a farm history of BYDV problems in winter cereals.

Winter and Spring 1994. No aphids were observed during sampling in February 1994 or during early May 1994.

3. Survey of BYDV incidence and strains in winter barley crops

Spring 1992. In Dumfriesshire and Wigtownshire, RPV was more common than the other two BYDV strains (Table 15). This corresponds with the greater numbers of bird cherry aphids in these regions in the autumn of 1991 (Table 10). Little virus was found in Stirlingshire. Both the RPV and the MAV strains were quite common in the samples collected in Northern Ireland. The abundance of yellow plants and the extent of crop yellowing were generally low in both Scotland and Northern Ireland except for four fields in Wigtownshire. In these cases, BYDV is not thought to be the cause of crop yellowing. Patches of yellow plants characteristic of BYDV were observed in only one field (in Northern Ireland).

Spring 1993. The RPV strain was present in yellow leaf samples of Dumfriesshire, Wigtownshire and Northern Ireland (Table 16). The PAV strain was present in these three regions and Stirlingshire. Little virus was found in the yellow leaf samples of Ayrshire and Renfrewshire. The greater incidence of the RPV and PAV strains in Dumfriesshire and Wigtownshire than in the other three Scottish regions is consistent with the autumn 1992 aphid count data (Table 11) which showed greater numbers of bird cherry aphids in these two regions.

Although single plants with characteristic symptoms of BYDV were detectable in most crops, patches of BYDV infected plants were observed in only 2 of the 29 Scottish crops, but in Northern Ireland, the comparative figures were 5 of the 12 crops (Table 17). In Scotland, there were three crops with extensive crop yellowing not due to BYDV.

Spring 1994. All three BYDV strains were present in yellow leaf samples of all regions although the MAV strain was generally least common (Table 18). Overall in Scotland, the PAV strain was predominant, although in some individual crops, the RPV strain was more common. In Stirlingshire, the MAV strain was most common, and only one crop had appreciable levels of the RPV strain in its yellow leaf samples. In Northern Ireland, higher levels of BYDV infection were found, although no strain was predominant.

Characteristic BYDV symptoms were observed in 35 of the 37 Scottish crops surveyed, and patches of infected plants were noted in 17 crops (45%). Seven crops were estimated to have 1-2% infection and one crop which followed undesiccated ploughed-in grass was estimated to have at least 5% infection (Table 19). In Northern Ireland too, BYDV symptoms were noted with three of the eight crops surveyed having estimates of infection of 1-5% (Table 19).

4. Pre-harvest sampling

1993. The levels of BYDV infection in the yellow cereal leaf samples of three Scottish regions were low (Table 20). However, in Stirlingshire, 27% of samples were infected with the MAV strain. In Northern Ireland, MAV was present in 96% of the Down yellow leaf samples while RPV predominated in the Antrim samples.

The levels of BYDV infection in the Scottish *Poa annua* samples were also low (Table 21) in contrast to previous years. However, higher levels of BYDV infection were present in the Northern Ireland samples where the RPV strain predominated in both Down and Antrim.

No BYDV strain was generally predominant in either cereal leaves or *P. annua*. Grain aphids (*Sitobion avenae*) were generally common, especially on *P. annua* (Table 22) where a majority of sampled plants were infested in three of the four Scottish regions. In Northern Ireland, aphids were less common on *P. annua* than on the barley crop. Aphids were most numerous in Stirlingshire where the rose-grain aphid (*M. dirhodum*) was also common in one crop. Infestations by *P. annua* were less than in some previous years with only 25% of Scottish fields having extensive infestations. Aphid mummies (aphids killed by parasitoids) were present in 41% of Scottish fields. Ladybirds were observed in two Scottish crops, but none were observed in Stirlingshire where aphids were most common.

5. Post-harvest sampling

1993. BYDV was more common in the *P. annua* samples collected post-harvest (Table 23) than in those collected pre-harvest (Table 21). The MAV strain was generally most common post-harvest although the RPV and PAV strains were quite common too Both *R. padi* and *S. avenae* were common on both volunteer cereals and *P. annua* weeds within cereal stubble fields (Table 24). In the one other previous year (1990) when *R. padi* was common in cereal stubbles, the observed individuals were not reproducing. In 1993, *R. padi* was reproducing on both host plant types.

6. *Sitobion* spp. on weed grasses in 1993

Both Cocksfoot (*Dactylis glomerata*) and Yorkshire Fog (*Holcus lanatus*) were found to be quite common in the field margins of most crops although the latter species appeared to be absent from a few fields. Both these weeds were rarely seen within cereal crops although a few plants were present in the headlands of a minority of crops.

In 7 of the 11 fields sampled during early August, more than 50% of the Cocksfoot sampled were scored as having totally senesced inflorescences compared with eight of the nine fields during late August/early September. Two of the three fields where the inflorescences were mostly fresh during early August were in Stirlingshire.

In contrast, the majority of sampled Yorkshire Fog were scored as either wholly fresh or partially fresh in all fields during both early August and late August/early September.

A higher percentage of Yorkshire Fog were aphid infested than Cocksfoot (Table 25). More aphids were generally found on both these grass weeds in early August than in the later period. This was probably due to the less senesced condition of grass weed inflorescences during early August. In both periods, a much higher percentage of plants was infested in Stirlingshire (except for Cocksfoot in late August/early September) than in the other three regions.

Most of the aphids present on these grass weed inflorescences (Table 26) were the blackberry-grass aphid (*Sitobion fragariae*). In four fields in early August, and five fields in late August/early September, some grain aphids (*Sitobion avenae)* were present on either Cocksfoot or Yorkshire Fog inflorescences. The comparative figures for the bird cherry aphid (*Rhopalosiphum padi*) were one and three fields respectively.

Masterman (1991) found the grain aphid and the blackberry-grass aphid to be approximately equally common on the inflorescences of Cocksfoot and Yorkshire Fog in the summer of 1990. Loxdale & Brooks (1990) found the blackberry-grass aphid to be more prevalent on Cocksfoot than the grain aphid while Watt (1981) found the grain aphid to be more common. Two of the years in which Watt (1981) studied the grain aphid on wild grasses were years when this aphid was numerous on winter wheat (1976 & 1977). He observed the highest densities on Cocksfoot in the field margin of a winter wheat crop heavily infested by the grain aphid, and concluded that wild grasses normally support aphid populations lower than their maximum carrying capacity, and that the highest densities are found in years when large populations build up in agricultural crops. In 1993, grain aphids were common in cereals pre-harvest (Table 22), but few grain aphids were found on Cocksfoot or Yorkshire Fog in August.

During this work, it was noted that outbreak numbers (2/3 of tillers with > 5 aphids) of grain aphids, bird cherry aphids and rose grain aphids (*Metopolophium dirhodum*) were present in winter wheat crops of Stirlingshire during August, while aphids were much fewer in winter wheat crops of other regions. All tillers of some Stirlingshire crops had hundreds of aphids, particularly grain aphids. The growth stage of these crops was such that the need for an insecticide application was uncertain. Some crops were sprayed (G N Foster, personal communication) while some other crops which were unsprayed due to their mature growth stage, developed some shrivelled grain.

It was hypothesised that the large grain aphid infestations in Stirlingshire winter wheat crops during August would increase the risk of grain aphid-transmitted BYDV in Stirlingshire winter cereals during the autumn 1993. On 15 September 1993, the stubble field of one Stirlingshire winter wheat crop where aphids had been very numerous pre-harvest, was examined for aphids. No aphids were found on *P. annua* within this stubble. However, another Stirlingshire wheat crop, which had not yet been harvested, was also examined. No aphids were present in the crop, but grain and bird cherry aphids were present on *P. annua* weeds. Grain aphids were common on barley volunteers within two oil seed rape crops sampled on this date. Grain aphids were also observed in eight of the ten 1 m lengths of drill examined in an early sown oat crop sampled on the same day. Three oat crops sampled on 28 September 1993 had high levels of grain aphid infestation (nine or ten of the ten 1 m lengths of drill were infested), but few grain aphids were found on later sampling dates in these and other Stirlingshire crops.

Regional comparisons (Figure 2) show that the hypothesis was partly correct, although only crops drilled in the first half of September were infested by appreciable numbers of grain aphids and numbers decreased during the autumn. Inflorescences of Cocksfoot or Yorkshire Fog (Table 26) did not appear to play an important role in maintaining grain aphid numbers from one winter cereal growing season to the next. First, few grain aphids were found on these weeds, and second, by late September, most of the inflorescences were in a senesced state. *P. annua* and barley volunteers within cereal stubble fields (Table 24), and barley volunteers in oil seed rape crops appeared to be acting as a green bridge for the grain aphid in Stirlingshire during 1993.

7. Summary of autumn aphid monitoring of winter barley crops 1988-93

Differences in aphid numbers between regions and between fields within a region were characteristic of winter barley aphid infestations each year from 1988 to 1993 (Holmes *et al*, 1991; Tables 10 to 13). These large variations are characteristic of BYDV, and this uncertainty of where BYDV may be a problem partially explains why this disease is a major concern to cereal growers.

The aphid infestations in winter barley in four regions in the autumns of 1988 to 1993 are summarised in Table 27. Despite the large between field variations, Table 27 provides a good summary of aphid numbers in winter barley crops each year.

With respect to bird cherry aphids, Table 27 excludes data from crops which followed undesiccated ploughed-in grass leys. These crops are susceptible to serious BYDV infection produced by wingless aphids crawling from the ploughed-in grass onto the emerging cereal crop (Plumb, 1988). Therefore, the bird cherry aphid data of Table 27 are a measure of the infestations produced by migrant aphids. The much higher numbers of bird cherry aphids in Wigtownshire than in Ayrshire and Stirlingshire in the autumn 1988 was of great importance. Damaging BYDV infection developed in winter barley crops of all regions during the milder than average winter and spring 1989. While grain-aphid transmitted BYDV was generally common in winter cereals of south-west and central Scotland, bird cherry aphid-transmitted BYDV only occurred in Wigtownshire, causing serious yield loss in some crops. From 1989 to 1991, few bird cherry aphids were found except in Dumfriesshire in 1990. However, in this case, wingless bird cherry aphids were not sufficiently numerous to produce patches of infected plants. In 1992, bird cherry aphids were more numerous in Wigtownshire and Dumfriesshire than elsewhere, but these infestations were comprised of single wingless individuals which did not reproduce, so patches of infected plants did not develop. Bird cherry aphids were much more common in the autumn 1993 than in the previous five autumns. Again, there were large differences between fields but all regions had at least one heavily infested crop (Table 13).

Only in the autumns of 1988 and 1993 were wingless bird cherry aphids (data from crops following undesicated ploughed-in grass excluded) common in winter cereals although winged bird cherry aphids were common in most crops for a week or two during October of each year. Therefore, only in 1988 and 1993 did the October migration of the bird cherry aphid include appreciable numbers of exules in Scotland. From 1989 to 1992, the vast majority of the autumn migrants were the sexual forms (gynoparae & males), so that wingless bird cherry aphids were very rarely found during sampling of winter barley in these autumns.

For grain aphids too (Table 27), there were differences between years, although they were less dramatic. Grain aphids were least common in the autumn 1991. Generally, only crops emerging after mid-October escaped infestation by grain aphids, while only crops emerging in the first half of September had sufficient numbers to cause concern. In each year, peak grain aphid numbers occurred early in the autumn, and by November, few grain aphids were generally sampled.

8. Summary of BYDV spring survey of winter barley crops 1989-94

The incidence of the three BYDV strains in yellow leaf samples and the percentage of each crop comprised of yellow plants is shown for three regions in each spring from 1989 to 1994 (Table 28). Figure 3 shows the change in the incidence of the three BYDV strains with time for two contrasting regions.

The highest levels of BYDV infection of the yellow leaf samples collected in the spring occurred in 1989, the outbreak year. Only in Wigtownshire where the bird cherry aphid was common in the autumn 1988 (Table 27) were the RPV and PAV strains common in the spring 1989 (Table 28; Figure 3). In Dumfriesshire and Stirlingshire, MAV infection predominated. In 1990 and 1991, infection levels were mostly below 50% of samples, and the MAV strain was generally most common. The lowest levels of BYDV infection of the yellow leaf samples occurred in 1992 (Table 28; Figure 3), which corresponds with the low numbers of aphids sampled in the autumn 1991 (Table 27). The lowest numbers of grain aphids were sampled in the autumn 1991 and the MAV strain was rare in the leaf samples collected in the spring 1992 (Table 28). Infection levels of the yellow leaf samples generally increased in both 1993 and 1994, and the PAV strain was predominant (Table 28; Figure 3). This increase in infection levels in 1992 & 1993 corresponds with an increase in the numbers of bird cherry aphids and grain aphids in the autumns of 1992 & 1993 (Table 27; Figure 2). In the six year period, the RPV strain has been rare in Stirlingshire while it was frequently found in Wigtownshire and Dumfriesshire (Table 28; Figure 3).

Table 28 also summarises the estimates of the percentage of each crop comprised of yellow plants. Crop yellowing may be caused by factors other than BYDV, and this is clearly shown in the spring 1992 when several fields in both Wigtownshire and Dumfriesshire had extensive crop yellowing, although BYDV was least common in this spring. The highest levels of crop yellowing occurred in 1989, the outbreak year, when several fields in both Wigtownshire and Dumfriesshire had crop yellowing estimates greater than 10% due to BYDV. Indeed, estimates of 50% crop yellowing were made for two Wigtownshire and one Dumfriesshire crop while a further two Wigtownshire crops were estimated to have 75% crop yellowing. Patches of BYDV infected plants were noted in only a small number of crops in the springs of 1990 to 1993, and the extent of infection never exceeded 1 to 2%. However, in the spring 1994, patches of BYDV infected plants were observed in 45% of crops, and seven of the 37 Scottish crops surveyed had 1-2% infection. Twenty-six of these 37 crops received an insecticide application in the autumn 1993, therefore infection levels would have been greater had the aphid infestations not been controlled.

9. Summary of pre-harvest sampling 1989-93 and post-harvest sampling 1990 to 1993

The levels of BYDV infection in yellow leaf samples and *P. annua* samples collected from winter barley crops in the Julys of 1989 to 1993 (pre-harvest) are shown for three regions in Table 29. For both sample types, the highest levels of infection occurred in the outbreak year, 1989. Greater levels of BYDV infection were found in the *P. annua* samples than in the yellow leaf samples. In yellow leaf samples, infection levels below 10% of samples were normal while for *P. annua*, such low levels of infection were only common in 1993.

BYDV infection levels in *P. annua* samples collected from winter barley stubbles in late August/early September (post-harvest) 1991 to 1993 in three regions (Table 30) were higher than those of *P. annua* collected in July (Table 29). Appreciable levels of all three BYDV strains were generally found.

Aphid assessments made during July 1989-93 and late August/early September 1990 to 1993 (Tables 31 & 32; Figure 4) show that at pre-harvest, only the grain aphid is common in winter barley, while at post-harvest, both the bird cherry aphid and the grain aphid can be common on barley volunteers and *P. annua* weeds in most winter barley stubbles. However, in July 1991, the grain aphid was much less common pre-harvest (Table 31; Figure 4), and post-harvest, the bird cherry aphid was only common in two of the four years of study (Table 32; Figure 4).

During this study of BYDV in winter barley crops, it was observed that by July each year, most crops had extensive infestations of *P. annua* (Table 33). Extensive infestations were still present in late August/early September in most fields. Since *P. annua* is frequently infected with BYDV (Tables 29 & 30) and infested by cereal aphids (Tables 31 & 32), extensive *P. annua* infestations can be major sources of viruliferous aphids in the autumn.

During pre-harvest sampling, the incidence of parasitoids and ladybirds was noted in each crop. The incidence of parasitoids was measured by the observation of aphid mummies in aphid infestations. While aphid mummies were always present in winter barley crops infested by large numbers of aphids (more than 50% of tillers infested), ladybirds were more independent of aphid numbers. The highest numbers of ladybirds occurred in the outbreak year, 1989, when aphids had been very common in winter cereals from early spring onwards. In 1990 when cereal aphids were again very common in July (Table 31), ladybirds were not common in any of the sampled crops, and none were observed in 55%

of crops. From 1991 to 1993, ladybirds have been observed in a small proportion of crops during July or in cereal stubble fields during late August/early September.

DISCUSSION

In six growing seasons of winter barley in different regions of south-west and central Scotland and Northern Ireland, sampling for cereal aphids and virus has produced an invaluable record of BYDV in autumn-sown cereals. This record is sufficiently long to include years with widely different levels of BYDV infection in winter cereals. From 1988/89 to 1993/94, there has been one major outbreak of BYDV (1988/89), one year when appreciable levels of infection were present in a minority of crops (1993/94) and four years when the levels of BYDV infection in winter cereals were low.

Although many sampled crops each year were treated with an insecticide, sampling for aphids began prior to any insecticide treatments which were normally applied in late October after several sampling visits. Appreciable levels of BYDV infection in the spring only occurred in the sampled crops where higher numbers of aphids were recorded during the previous autumn. The observed levels of BYDV infection each spring 1989 to 1994 are not the product of varying levels of insecticide use but reflect variations in the main factors governing the incidence and extent of BYDV in autumn-sown cereals.

What are the main factors governing the incidence and extent of BYDV in autumn-sown cereals?

Weather. Variations in weather have major effects on the incidence and levels of BYDV in autumn-sown cereals.

First, winter temperature normally controls BYDV infection by killing the aphid vectors in cereals during the winter before serious levels of BYDV infection are attained. Higher than average winter temperatures may allow large numbers of aphids to overwinter in cereals (Oakley, 1989). The extensive BYDV infection in Scotland in 1989, and in southern England in both 1989 and 1990 owed to the failure of winter temperature to control the numbers of overwintering aphids in autumn-sown cereals (Table 34).

Second, weather in the January to August period influences to a large extent the size of the autumn migration of the bird cherry aphid (A'Brook, 1981; Masterman *et al.*, 1994), and also influences the number of exules migrating in October when cereals are emerging. Only in two of the six years of study were there appreciable numbers of exules migrating in

October (1988 and 1993). In 1988, this exule migration was confined to Wigtownshire (Table 27), and as a consequence, bird cherry aphid-transmitted BYDV was confined to Wigtownshire in the spring 1989 while grain aphid-transmitted BYDV occurred in all regions (Table 28). In 1993, appreciable numbers of exules migrated into several crops in each of Wigtownshire, Dumfriesshire and Ayrshire, but except for one early-sown crop, Stirlingshire was unaffected by exule bird cherry aphids (Table 13).

Summer temperature is probably the most important weather factor which controls the number of exules in the autumn migration. Both 1988 and 1993 had low temperatures in May-August and June-August relative to 1989 to 1992 (Table 35; Figure 5). The exule migration was more widespread in 1993, and this year had lower temperatures in these two periods than 1988 when exules migrated only in Wigtownshire.

It is apparent that regional variations are characteristic of exule numbers in the autumn migration of the bird cherry aphid. Understanding the spatial and temporal variations in the numbers of exules in the autumn migration is critical to improving the forecast of bird cherry aphid-transmitted BYDV in the UK (Tatchell *et al.*, 1988; Kendall & Chinn, 1990). Exules comprise a small proportion of the aerial population of the bird cherry aphid once the migration of gynoparae and males has commenced, usually in the first half of September (Tatchell *et al.*, 1988). This switch from exules to gynoparae and males is almost certainly associated with the dramatic decrease in the risk of BYDV infection during the autumn. Therefore, the data on male bird cherry aphid numbers recorded by the Rothamsted Insect Survey in the last 20 years provide an opportunity to learn more about the spatial and temporal variations in the numbers of exules in the autumn migration. Such work might lead to much improved forecasts of BYDV risk, including the prediction of safe sowing dates for autumn-sown cereals which could be issued to cereal growers in early September.

Previous workers have attempted to predict the size of the autumn migration of the bird cherry aphid (A'Brook, 1981; Wiktelius, 1987) and have identified correlations between aphid population growth in grassland during the summer and early autumn and the size of the autumn migration. Both authors demonstrated that large numbers of aphids build up in grass leys in late summer when rainfall is favourable for grass growth. In this situation, the autumn migration is normally large. Masterman *et al.* (1994) obtained similar results when modelling identified that May-August sunshine was a critical factor to the size of the autumn migration of the bird cherry aphid at Ayr. Low sunshine totals from May-August, which are characteristic of summers with above average rainfall, favour large migrations and *vice versa*.

The precise relationship between the total size of the autumn migration of the bird cherry aphid (gynoparae, exules and males) and the proportion comprised of exules has yet to be determined. However, observations made from 1988 to 1993 suggest that the risk of exules colonising Scottish cereals in October is greater in autumns which follow cool, wet, dull summers like 1988 and 1993 (Tables 34 & 35; Figure 5). In the south of England, it has been observed that there are greater numbers of exules in autumns which follow milder than average winters (Tatchell, 1992). However, in Scotland, Masterman *et al.* (1994) showed that winters with lower than average temperature favoured large migrations in the following autumn, although summer weather was more important. It is suspected that low temperatures in the preceding winter favour greater numbers of exules migrating in the following October in Scotland. More years' data on aphid numbers in cereals during the autumn are required to pinpoint the critical periods of weather which determine the number of exules which migrate in October.

Autumn weather was not overridingly important to aphid numbers recorded in the autumns of 1988 to 1993 although low temperatures in October or November in some years did adversely affect aphid numbers. The coldest October-November period was in 1993 when bird cherry aphids were most common (Tables 34 & 35). There were six consecutive nights with an air frost at Auchincruive in mid-October 1993 (2 nights with grass minima of -6°C) which caused considerable mortality amongst adult bird cherry aphids, but many first instar nymphs survived. Numbers of bird cherry aphids increased dramatically in late October 1993. A hard frost (grass minima below -5°C) in October has less severe effects on aphid populations than a hard frost in mid-winter, because in October, maximum temperatures will always rise well above 0°C during the day, while in mid-winter, temperatures will normally remain near or below 0°C all day. Therefore, even in very cold Octobers like 1992 & 1993, frosts only have the propensity to limit aphid numbers rather than to eliminate aphid populations. November temperatures are probably much more important in controlling aphid numbers, because night frosts are more common, and maximum temperatures following night frosts are lower. Mean temperatures at Auchincruive in November 1993 were 1.5°C below average, and it is probable that much higher levels of BYDV infection would have occurred in the spring 1994 if November temperatures had been above average. October-November temperatures were much higher from 1988 to 1991 (Table 35), and aphid numbers were generally lower than in 1992 to 1993 (Table 27). Therefore, aphid numbers in cereals during the autumn are not the product of autumn temperature. Bird cherry aphid numbers in cereals during the autumn are mainly determined by weather variations earlier in the year, particularly summer weather, as outlined above.

Grain aphid numbers in cereals during the autumn appear to be favoured by higher temperatures in the preceding January-June period. In the six autumns of aphid sampling, grain aphids have been common with few fields escaping infestation by this aphid species. Although no autumn had conspicuously larger numbers of grain aphids, autumn 1991 had conspicuously fewer grain aphid numbers (Table 27). In the six years of study, 1991 was the only year with lower than average mean winter temperature (Tables 34 & 35) and it had a much lower January to June mean temperature than the other five years (Table 35). In July 1991, grain aphids were difficult to find in winter barley (Table 31; Figure 4), while they were generally common in the other Julys. Although higher temperatures in the summer 1991 (Tables 34 & 35) allowed grain aphid numbers to build up in cereal stubble fields in late summer (Table 32), few grain aphids were observed in cereals during the autumn 1991 (Table 27). The growth of grain aphid populations in winter cereals in spring and early summer may determine the size of grain aphid populations during the autumn. Low temperatures from January until winter cereals ripen in June/July will result in slower aphid population growth and lower numbers of grain aphid alatae leaving the ripening cereals. This could mean fewer grain aphids entering cereals in the following autumn.

Field/Farm characteristics. Large between field variations in the numbers of aphids recorded in cereals during the autumn (for example, Table 13) were characteristic of the aphid data collected in the six years of study. Nevertheless, pooling of the field data into regions revealed that there were major regional differences in the aphid infestations. Analysis of these data (Masterman, 1991; Masterman *et al.*, 1993) has identified a number of field and farm characteristics which explain a major part of these between field and between region differences in aphid infestations.

Sowing date has long been known to be critical to the incidence and level of BYDV infection in autumn-sown cereals (Hill, 1988; Plumb, 1988). In this study, crops which were drilled in late August/early September generally had greater aphid numbers than later sown crops (for example, Table 13). This was particularly true for the grain aphid which only became a problem during the autumn in some early-sown crops. Later-sown crops seldom escaped infestation by the grain aphid, but numbers were usually low. In 1993, it was early-sown crops which had the greatest numbers of bird cherry aphids (Tables 13 & 14), but in other years, such early-sown crops were as equally uninfested by the bird cherry aphid as later-sown crops. In some years in Scotland (e.g 1989 and 1990), there are few exules migrating in the first half of September which means that early drilling of autumn-sown cereals in Scotland is not always associated with a high risk of bird cherry aphid transmitted BYDV.

Previous cropping was also confirmed as a critical factor (Hill, 1988; Plumb, 1988) influencing the risk of BYDV occurring in a specific field. Most crops which followed undesiccated ploughed-in grass were infested by large numbers of wingless bird cherry aphids using the "green bridge". Higher numbers of aphids were sometimes found in crops which followed oilseed rape. This is probably due to the fact that crops which follow oilseed rape may be early-sown. Aphid infestations in the few crops which followed set-aside were low. Crops following winter barley generally had larger aphid infestations than crops following spring barley or winter wheat. This higher risk may be due to factors such as land use and "green bridge" transfer of aphids.

The *land use* of each farm where sampling took place was either classified as "mainly cereal growing", or "mainly livestock". Analyses identified an association between grain aphid-transmitted BYDV and cereal farms, and bird cherry aphid-transmitted BYDV and livestock farms. Cereal farming, particularly continuous winter barley growing, is known to favour the incidence of the grain aphid (Hill, 1988). Pre- and post-harvest sampling has shown that the grain aphid is common in cereal crops, and winter barley stubble fields of Scotland during the summer (Tables 31 & 32). Other cereal stubbles were usually less aphid infested than those of winter barley, because they seldom contained volunteer cereals, and less time had elapsed since the crop had been harvested. After ploughing of a winter barley stubble, aphids may survive up to a few weeks on buried barley volunteers and *P. annua*, and infest an emerging cereal crop (i.e. "green bridge" transfer). Even if the previous crop was not winter barley, winter barley stubbles in neighbouring fields may be sources of winged infective grain aphids. Crops on cereal farms are more likely to have neighbouring winter barley stubbles than crops on livestock farms, and therefore, the risk of grain aphid-transmitted BYDV is greater. The association between livestock farming and bird cherry aphid-transmitted BYDV owes to the greater acreage of ryegrass on a mainly livestock farm relative to a mainly cereal farm. Ryegrass pastures are considered to be the principal habitat from which the bird cherry aphid migrates during the autumn (Plumb, 1988).

Shelter is another field characteristic that contributes to between field variations in aphid numbers during the autumn. Fields partially or totally enclosed by mature woodland may become infested by more winged aphids, and the sheltering effect of trees may favour increased reproduction and survival of aphids. Conversely, fields exposed to strong winds may be infested by fewer winged aphids, and the higher levels of wind chill and higher numbers of night frosts will slow the growth of aphid populations and increase the incidence of low temperature mortality.

These field characteristics not only explain between field variations in the numbers of aphids recorded each autumn, but also partially explain the regional variations. First, each region to some extent has a characteristic land use. For example, farms specialising in cereal growing are more common in Stirlingshire while in Wigtownshire, Dumfriesshire and Ayrshire, most farms are predominantly livestock with a small acreage of winter barley. Second, each region has characteristic topography. For example, in Wigtownshire, Dumfriesshire and Ayrshire, there are many farms situated on hillsides with sheltered fields enclosed by trees at low altitudes and exposed fields at higher altitudes. In Stirlingshire located in the central lowlands of Scotland, there is much less topographical variation, and fewer very sheltered fields.

Other regional variations may be explained by distance from the sea. It has long been known that bird cherry aphid-transmitted BYDV is most common in southern and western coastal areas of the UK (Plumb, 1988). One reason for this is that coastal regions have a milder winter climate which favours the survival and reproduction of aphids during the winter. Perhaps more importantly, October migrations of exule bird cherry aphids may be larger in southern and western coastal areas of Britain. In the six years of study, wingless bird cherry aphids (i.e. the offspring of exules) have been much more common in the coastal regions of Wigtownshire and Dumfriesshire than in the inland region of Stirlingshire (Figure 1; Table 27). Therefore, although winged bird cherry aphids (gynoparae & males) arrive in crops of all regions during the autumn, appreciable numbers of exules tend to be confined to the regions along the south and west coast of Scotland.

Weather also contributes to regional variations in aphid numbers. Fields in the same region obviously experience more similar weather than fields in different regions, and this will give rise to fields in the same region having similar aphid infestations.

The ability of field/farm characteristics to explain the incidence of pests/weeds/diseases in 50 winter barley crops and 50 oil seed rape crops is being investigated in three growing seasons in Scotland (McRoberts *et al.*, 1994). The results of this study will have great relevance to these preliminary results on field characteristics and BYDV incidence.

Bird cherry aphid- and grain aphid-transmitted BYDV

The BYDV outbreak in 1989 highlighted the difference in severity between bird cherry aphid- and grain aphid-transmitted BYDV. In Wigtownshire in the spring 1989, the RPV and PAV strains associated with bird cherry aphid infestations caused plant death and severe stunting of barley plants. In other regions, grain aphid-transmitted BYDV was widespread but the MAV strain associated with it caused at worst moderate stunting.

Although extensive infection with the MAV strain can seriously reduce the yield of cereal crops, every 1% of crop infection has a much greater yield reduction in the case of the RPV and PAV strains than the MAV strain. Moreover, extensive MAV infection is rare, because grain aphid populations seldom reach high densities in the autumn and winter. Early-September drilling resulted in larger numbers of grain aphids but there were only two crops in the six years of study which had sufficient grain aphid numbers to require an insecticide treatment during the autumn. It appears that high levels of grain aphid-transmitted BYDV are mainly associated with mild winters with a persistent lack of frost (e.g. in Scotland in 1988/89 and in southern England in 1988/89 and 1989/90). McGrath (1989) advocated a damage threshold for grain aphid-transmitted BYDV of 10% of tillers infected which relates to more than 10% of plants infested by the grain aphid. Even in the spring of 1989 in Scotland, after a winter with a mean temperature 3°C above average (Tables 34 & 35) a minority of crops were estimated to have MAV infection levels of 10% or more, although just 1% of MAV infection resulted in many patches with very obvious bright yellow discolouration which tended to alarm cereal growers.

This report recommends that advisers and cereal growers should view BYDV as two separate diseases: grain aphid-transmitted BYDV which may cause serious yield loss during a winter with a persistent lack of frost; and bird cherry aphid-transmitted BYDV which has the propensity to cause serious yield loss in October/November in a minority years, and widespread serious yield loss during a winter with a persistent lack of frost.

This report focuses on forecasting bird cherry aphid-transmitted BYDV because it poses a much greater threat to Scottish winter cereals.

Forecasting the risk of Barley Yellow Dwarf Virus in autumn-sown cereals

On the basis of the aphid and BYDV data collected over six seasons, a new scheme for deciding whether insecticides are required in autumn-sown cereals is proposed. The new scheme is called "Strategic Monitoring", and it is comprised of two main parts.

1. Forecasting the general risk of damaging BYDV infection developing in cereals during the autumn

BYDV and other aphid-transmitted virus diseases of arable crops cause serious yield loss when infection occurs at an early growth stage (Watson, 1943; Endo & Brown, 1963). In the case of the aphid-transmitted diseases of sugar beet and potatoes, the potential for damaging infection occurring in the first few weeks after crop emergence has led to the development of forecasting systems to identify the years when insecticide granules may be required at planting. For example, the scheme used in the sugar beet industry (Harrington *et al.*, 1989) provides a forecast in March of the possible need for insecticide granules during planting later in the spring.

Insecticidal granules are not available for use in autumn-sown cereals, and it is generally considered that insecticides applied in late October to mid-November effectively control aphid infestations before damaging spread of BYDV has occurred (Kendall & Smith, 1981; Hill, 1988). However, aphid data collected in the autumn 1993 show that very high levels of infestation by bird cherry aphids may occur within a few days of crop emergence in the west of Scotland (Table 14). The vast acreage of ryegrass pasture in the west of Scotland relative to the small acreage of winter barley would suggest that the potential for exule infestation of autumn-sown cereals is much greater than in the more arable areas of the UK. If possible, it is highly desirable to identify in advance the autumns when such large numbers of bird cherry aphids may infest autumn-sown cereals. Several methods of doing this are currently being tested.

(a) Models which predict the size of the bird cherry aphid autumn migration. One of the two factors used to calculate the infectivity index is the number of bird cherry aphids sampled by a 12.2 m suction trap during the autumn (Plumb, 1986). The numbers of exule bird cherry aphids which colonise a crop during the autumn is one of the principal determinants of the level of BYDV infection that might develop in the crop (Tatchell, Plumb & Carter, 1988). At present, it is assumed that there is a positive correlation between the numbers of exules and the total numbers of bird cherry aphids (exules, gynoparae & males) in the autumn migration.

The production of these models is described in Masterman *et al.* (1994). The models use weather data from the preceding September-August period to produce a prediction of the total number of bird cherry aphids (exules, gynoparae & males) sampled by the Ayr 12.2 m suction trap during September and October. The prediction can be prepared in the first few days of September, so that cereal growers can be given information in advance on the likelihood of damaging BYDV infection developing in autumn-cereals during October. These models have been tested each year from 1990 to 1993 (Table 36) and have given good predictions (either the correct score, or one score either side of the correct score) of the size of the bird cherry aphid migration in three of these four years. The highest predictions were in 1993 when large numbers of exule bird cherry aphids colonised some crops (Table 27). Predictions in 1990 and 1991 when very few exules colonised crops were low. In 1992, the observed number of bird cherry aphids at Ayr was high in contrast to all eight predictions. Although the model failed to predict the size of the migration, few exules migrated into crops in the autumn 1992 (Table 27). It can be argued that the models correctly predicted the risk of damaging BYDV infection developing in autumn-sown cereals in all four years.

(b) Use of the Lamb daily weather types and PSC indices to predict the size of the bird cherry aphid autumn migration. The Lamb daily weather types (LDWTs) and PSC indices are an alternative type of weather data which are essentially classifications of synoptic weather charts of the UK area. The LDWTs and the method of relating them to the autumn migration of the bird cherry aphid are described in Masterman *et al.* (1994). This method of predicting the size of the autumn migration has been tested each year from 1991 to 1993 (Table 37). The predictions relate to the bird cherry aphid autumn migration in the UK as a whole rather than western Scotland. In 1991, the prediction was poor as the migrations were below average at five of the six sites. In 1992, the predictions were better with above average migrations at four of the six sites. In 1993, the prediction was correct for two of the Scottish sites where migrations were large but poor for the three English sites where migrations were very small. Further years' data are required to test this method.

(c) The use of assessing aphid infestations in cereal stubble fields in late summer as a method of determining the likelihood of exule bird cherry aphids colonising autumn-sown cereals. Post-harvest sampling from 1990 to 1993 (Tables 24 & 32; Figure 4) has identified large annual variations in the abundance of bird cherry aphids on barley volunteers and *P. annua* weeds in cereal stubble fields during late August/early September. All sampled fields were infested by bird cherry aphids in 1990 and 1993 while a minority of fields were infested by this aphid species in 1991 and 1992. However, there were differences between the bird cherry infestations of 1990 and 1993. In the former year, most of the infestations were comprised of single individuals while in the latter, adult aphids were reproducing, so that most infestations were comprised of a number of aphids. In 1990, it is possible that many of the single aphids were either gynoparae or males which developed into winged forms and left the cereal stubbles without reproducing on the barley volunteers. In 1993, the fact that the aphids were reproducing shows that they were exules.

On the basis of these data from four years, it is suggested that the presence of wingless bird cherry aphids on barley volunteers and/or *P. annua* in cereal stubble fields during late August/early September might indicate that appreciable numbers of exules could be migrating in October. The absence of wingless bird cherry aphids or the presence of non-reproducing winged or wingless bird cherry aphids in cereal stubble fields might indicate that sexual forms (gynoparae and males) are already maturing or migrating, which suggests that exules are unlikely to be migrating in October.

If these three methods (a, b & c) can produce a reliable prediction of the general risk of bird cherry aphid-transmitted BYDV in autumn-sown cereals in a series of test years, then they could be used to prepare a forecast which could be issued to cereal growers and advisers in the first half of September each year.

2. Identifying the regions and fields where greater numbers of aphids colonise autumn-sown cereals

Features of the aphid sampling each autumn were regional and between-field differences in the numbers of aphids (Tables 13 & 27). Some of these differences have found to be associated with field/farm characteristics which have been described in the first half of this discussion. These field/farm characteristics may be used to identify the minority of fields which may be at risk of developing damaging BYDV infection even when the general risk is low. For example, many farms will have a low lying sheltered field which may favour aphid reproduction and survival. Fields enclosed by mature woodland are easy to identify, and such fields have a much higher risk of developing large aphid populations, and subsequently, damaging BYDV infection. Proximity to a river or large pond may reduce the incidence and severity of night frosts in the autumn and winter, again favouring aphid reproduction and survival. Land use also offers possibilities for identifying fields which are more prone to BYDV infection. An isolated winter cereal crop in an area of the farm where ryegrass pastures are predominant is likely to be at a higher risk from bird cherry aphid transmitted BYDV than a crop surrounded by other winter cereal crops. A good method of identifying the high risk fields is to recall which fields had the greatest levels of BYDV infection in previous outbreak years (e.g. spring 1989). Fields or farms where BYDV infection has been a problem in the past will have a high risk of developing damaging BYDV infection in the future. Using this "field/farm characteristics" method, cereal growers may reduce the uncertainty of where (i.e. which fields, and to some extent, which farms) damaging BYDV infection may be a problem each year.

Unfortunately, field/farm characteristics do not account for all between field and between regions variations in aphid numbers. Some crop sampling by specialists or advisers is necessary to identify the regional variations, hence the name, "Strategic monitoring". In years when the general risk is predicted to be low, crop sampling can be kept to a minimum e.g. one sampling visit to 6 crops in each of Wigtownshire and Dumfriesshire (where the risk of BYDV is generally highest) in late October would be sufficient to confirm a low risk autumn. It is important that crop sampling occurs, otherwise it will never be known if the forecast was correct. In years predicted to be at high risk, weekly sampling during October is necessary to identify the regions affected, and to ascertain whether aphid numbers are sufficiently high to justify insecticide applications. At present, it is uncertain how numerous exule bird cherry aphids can be in the west of Scotland where ryegrass is the predominant crop. It is possible that serious infection could develop prior to the end of October in a crop emerging in the first week of October. In a high risk autumn, cereal grower and adviser participation will help to ensure crop sampling is adequate, and that those crops requiring insecticide treatments are sprayed before damaging infection develops. The "field/farm characteristics" method can be used to select fields for sampling, and cereal growers and advisers can use this method to target insecticide applications at high risk fields.

Aphid Monitoring

Aphid monitoring was a major component of this research project. This experience has brought into question the use of the adjective "cryptic" to describe wingless bird cherry aphids. It is true that individual bird cherry aphids may feed at or close to ground level, and may feed in leaf axils, but equally, individual bird cherry aphids may feed on exposed areas of the plant. The use of "cryptic" is inappropriate for two reasons. First, barley plants are very small in October, so it is not difficult to see late instar or adult aphids (2 to 3 mm in length) which are feeding on them. Second, damaging BYDV infection is associated with large numbers of wingless bird cherry aphids which give small barley plants a blackened appearance evident from a distance of several metres. If winged exules colonise an autumn-sown cereal in appreciable numbers, their offspring, which are often deposited singly or in small groups on a number of separate plants, will give rise to large infestations on individual plants within 2 to 3 weeks. The purpose of aphid monitoring is to identify this phenomenon in the minority of autumns when appreciable numbers of exules are migrating in October.

The main difficulty of aphid monitoring is the bending down to be sufficiently close to barley plants which are only a few cm high in October. This more difficult aspect of the task may be lessened by using a kneeling pad for one or both knees.

Of course, the Ayr, Belfast, East Craigs and Dundee suction trap data provide good "after the event" information on the numbers of bird cherry aphids migrating during each week of the autumn which can be related to crops of different sowing dates, and the male data may show when the migration of exules has largely finished. However, the main problem is that the Ayr trap does not provide good information for Dumfriesshire and Wigtownshire where the risk of BYDV infection is generally greatest. Yet, these trap data do provide some information on the risk of bird cherry aphids, but only crop sampling can reliably identify whether exules have infested winter cereals. Few grain aphids are caught by 12.2 m suction traps in the autumn, so these traps cannot provide information on the risk of grain aphid-transmitted BYDV.

Identification of *wingless* **bird cherry aphids** is an important part of aphid monitoring:

Wingless forms are small and round, with a black, brown or olive green body, 1.5 to 3 mm long, with rusty red patches at the posterior end of the body, and short antennae.

Winged forms are small (2-3 mm long) with a green body although they appear black with the naked eye.

The other main BYDV vector is the **grain aphid.**

Wingless forms are large and oval, 3-4 mm long with long legs and long antennae, and may be green, brown or black.

Winged forms are large (4-5 mm long) with long legs, and have a green body.

Other aphid species were rarely encountered during six years of aphid monitoring.

The following aphid sampling method is recommended:

* using a 1 metre stick, examine 10 x 1 metre lengths of barley drill at widely spaced points across the field.

* examine plants closely for aphids. Avoid wet days.

* count the number of plants infested by aphids in each of the 10 x 1 metre lengths of drill.

* note the number of plants infested by bird cherry aphids and by grain aphids separately for each 1 metre length of drill on the aphid count record sheet (or in notebook). Do not bother to count more than five infested plants, just note > 5.

- **Action threshold** if one or more of the ten sampling points has > 5 plants infested by wingless bird cherry aphids, damaging patches of BYDV infected plants will probably develop. No-one has proposed an infestation damage threshold for the bird cherry aphid although the damage threshold of BYDV infection for this aphid species is 2-5 % infection (Kendall & Smith, 1981). The above action threshold is suggested as a guide for deciding whether insecticide treatments are required. If fewer than five plants in just one metre length of drill are infested by wingless bird cherry aphids, sample another 10 x 1m lengths of barley drill or sample again next week. Wingless bird cherry aphids reproduce quickly, they are present in the crop, an insecticide application will probably be required in due course unless frost kills the aphids. The low damage threshold of 2-5% infection means spraying is the safest strategy if wingless bird cherry aphids are reproducing in the crop and can be found in more than one area of the crop. In the six years of study, few crops had wingless bird cherry infestations above the action threshold.

In conclusion, infectivity indexing has consistently failed to correctly assess the risk of bird cherry aphid-transmitted BYDV in south-west and central Scotland. Field sampling in six seasons of winter barley growing has shown that the risk of BYDV infection was low in four autumns and in the two higher risk autumns, the high numbers of wingless bird cherry aphids were confined to the coastal regions of south-west Scotland. Moreover, there were large between field variations in the numbers of aphids which can be partially explained by field/farm characteristics. These annual and between field variations in the numbers of bird cherry aphids in autumn-sown cereals confirm that "insurance" spraying of the winter cereal acreage each autumn is unjustified. This report presents methods of identifying high risk autumns, and methods of identifying the fields and regions which have the highest risk of developing damaging BYDV infection. Insecticide applications should be targeted at high risk fields, and even in a high risk autumn, there are regions and fields which do not require treatment.

ACKNOWLEDGEMENTS

SAC receives financial support from the Scottish Office Agriculture and Fisheries Department.

The authors thank the staff of the Rothamsted Insect Survey, The Scottish Agricultural Science Agency, and the staff of other institutes who operate the traps, for their dedication which produced the *Rhopalosiphum padi* count data.

This report was written by Dr Andrew Masterman, Plant Sciences Department, SAC, Auchincruive.

REFERENCES

A'Brook, J. A. (1981). Some observations in west Wales on the relationships between numbers of alate aphids and weather. *Annals of Applied Biology*, **97**, 11-15.

A'Brook, J. A. & Dewar, A. M. (1980). Barley Yellow Dwarf Virus infectivity of alate aphid vectors in west Wales. *Annals of Applied Biology,* **96**, 51-58.

Endo, R. M. & Brown, C. M. (1963). Effects of BYDV on yield of oats as influenced by variety, virus strains and developmental stage of plants at inoculation. *Phytopathology*, **53**, 965-68.

Foster, G. N., Holmes, S. J. & Bone, S. F. (1993). Ten years' experience of infectivity indexing as a method of predicting the risk of Barley Yellow Dwarf Virus outbreaks in autumn-sown cereals in the west of Scotland. *Proceedings of Crop Protection in Northern Britain 1993*, 97-102.

Harrington, R., Dewar, A. M. & George, B. (1989). Forecasting the incidence of virus yellows in sugar beet in England. *Annals of Applied Biology*, **114**, 459-469.

Harrington, R., Mann, J., Plumb, R., Smith, A., Taylor, M., Foster, G., Holmes, S., Masterman, A., Tones, S., Knight, J., Oakley, J., Barker, I. & Walters, K. (1994). Monitoring and forecasting for BYDV control - the way forward? *Aspects of Applied Biology*, **37**, 197-206.

Hill, S. A. (1988). Cropping and virus incidence - An overview. *Aspects of Applied Biology*, **17**, 133-141.

Holmes, S. J., Foster, G. N., Mills, P., Bell, A., Dempster, L. & Masterman, A. J. (1991). Improving the forecast of BYDV high risk conditions in autumn-sown cereals. Project Report No. 56, Home-Grown Cereals Authority, London.

Kendall, D. A. & Smith, B. D. (1981). Yield benefit from autumn control of aphids and barley yellow dwarf virus on winter barley. *Proceedings 1981 British Crop Protection Conference - Pests & Diseases,* **1**, 217-221.

Kendall, D. A. & Chinn, N. E. (1990). A comparison of vector population indices for forecasting barley yellow dwarf virus in autumn-sown cereals. *Annals of Applied Biology,* **116**, 87-102.

Kendall, D. A., Brain, P. & Chinn, N. E. (1993). A simulation model of the epidemiology of barley yellow dwarf virus in winter sown cereals and its application to forecasting. *Journal of Applied Ecology*, **29**, 414-426.

Loxdale, H. D. & Brooks, C. P. (1990). Prevalence of *Sitobion fragariae* (Walker) over *S. avenae* (Fabricius) (Hemiptera: Aphididae) on wild cocksfoot grass (*Dactylis glomerata*) in south-east England. *Bulletin of Entomological Research*, **80**, 27-29.

Masterman, A. J. (1991). The epidemiology and forecasting of barley yellow dwarf virus in autumn-sown cereals. Unpublished Ph.D thesis, University of Glasgow.

Masterman, A. J., Foster, G. N. & Holmes, S. J. (1993). Barley Yellow Dwarf Virus in autumn-sown cereals - Testing a new approach to the analysis of crop infection data. *Proceedings Crop Protection in Northern Britain 1993*, 103-108.

Masterman, A. J., Foster, G. N., Holmes, S. J. & Harrington, R. (1994). The use of the Lamb daily weather types to investigate the autumn migration of *Rhopalosiphum padi* in relation to barley yellow dwarf virus in autumn-sown cereals. *Journal of Applied Ecology* (In Press).

McGrath, P. F. (1989). Vector relationships and disease epidemiology of barley yellow dwarf virus in northern England. Unpublished Ph.D thesis, University of Leeds.

McGrath, P. F. & Bale, J. S. (1989). Cereal aphids and the infectivity index for barley yellow dwarf virus (BYDV) in northern England. *Annals of Applied Biology*, **114**, 429-442.

McRoberts, N., Foster, G. N., Duffus, C. M., Evans, K. A., McKinlay, R. G., Davies, D. H. K. & Wale, S. J. (1994). COIRE: Crop Optimisation by Integrated Risk Evaluation. A new approach to crop protection in arable crops. *Aspects of Applied Biology,* **37**, 207-215.

Oakley, J. (1989). BYDV: What went wrong. *Farmers Weekly,* 25 August 1989, pp36-37.

Plumb, R. T. (1986). A rational approach to the control of barley yellow dwarf virus. *Journal of the Royal Agricultural Society of England*, **147**, 162-171.

Plumb, R. T. (1988). Opportunities for the integrated control of barley yellow dwarf viruses in the UK. *Aspects of Applied Biology,* **17**, 153-161.

Tatchell, G. M., Plumb, R. T. & Carter, N. (1988). Migration of the bird cherry aphid (*Rhopalosiphum padi*) and implications for the epidemiology of barley yellow dwarf virus. *Annals of Applied Biology*, **112**, 1-11.

Tatchell, G. M. (1992). Aphid life cycle strategies in a changing environment: the implications for barley yellow dwarf virus epidemiology. In: Diary of Meetings of the Society. *Antenna,* **16** (1): 35.

Watson, M. A. (1943). Sugar beet yellows: a preliminary account of experiments and observations of its effects in the field. *Annals of Applied Biology*, **29**, 358-365.

Watt, A. D. (1981). Wild grasses and the grain aphid (*Sitobion avenae*) pp 299-305. In *Pests, pathogens and vegetation.* Thresh, J. M. (Ed.) London, Pitman.

Wiktelius, S. (1987). The role of grasslands in the yearly life-cycle of *Rhopalosiphum padi* in Sweden. *Annals of Applied Biology,* **110**, 9-15.

Table 1. Aphid trapping and infectivity data used to calculate the Infectivity Index at Auchincruive in 1991.

	Rhopalosiphum padi				*Rhopalosiphum insertum*			
	Total Numbers				Total Numbers			
Week ending	Tower	Commode	Infective	Index	Tower	Commode	Infective	Index
1 September	433	4	1	108	371	1	0	0
8 September	1411	12	5	588	422	1	0	0
15 September	1447	29	14	699	96	2	0	0
22 September	119	11	2	22	38	0	0	0
29 September	446	19	4	94	1052	10	3	316
6 October	56	25	4	9	95	17	7	39
13 October	1738	16	5	543	3329	11	3	908
20 October	102	39	8	21	246	7	2	70
27 October	163	23	3	21	818	5	0	0
3 November	96	9	0	0	294	18	5	82
Total	6011	184	46	2105	6761	72	20	1415

Table 2. Infectivity Index - *Rhopalosiphum padi* only - Auchincruive 1991.

		CUMULATIVE WEEKLY INDEX									
		1.9	8.9	15.9	22.9	29.9	6.10	13.10	20.10	27.10	3.11
E	1.9	108	696	1395	1417	1511	1520	2063	2084	2105	2105
M	8.9		588	1287	1309	1403	1412	1955	1976	1997	1997
E	15.9			699	721	815	824	1367	1388	1409	1409
R	22.9				22	116	125	668	689	710	710
G	29.9					94	103	646	667	688	688
E	6.10						9	552	573	594	594
N	13.10							543	564	585	585
C	20.10								21	42	42
E	27.10									21	21
	3.11										0

Table 3. Infectivity Index - *Rhopalosiphum padi* only - Belfast 1991.

		CUMULATIVE WEEKLY INDEX									
		2.9	9.9	16.9	23.9	30.9	7.10	14.10	21.10	28.10	4.11
E	2.9	0	0	0	0	42	77	265	308	778	778
M	9.9		0	0	0	42	77	265	308	778	778
E	16.9			0	0	42	77	265	308	778	778
R	23.9				0	42	77	265	308	778	778
G	30.9					42	77	265	308	778	778
E	7.10						35	223	266	735	735
N	14.10							187	231	700	700
C	21.10								43	513	513
E	28.10									470	470
	4.11										0

Table 4. Aphid trapping and infectivity data used to calculate the Infectivity Index at Auchincruive in 1992.

	Rhopalosiphum padi				*Rhopalosiphum insertum*			
	Total Numbers				Total Numbers			
Week ending	Tower	Commode	Infective	Index	Tower	Commode	Infective	Index
17 August	23	1	0	0	10	1	0	0
24 August	5	0	-	-	5	0	-	-
30 August	5	0	-	-	7	0	-	-
6 September	25	0	-	-	3	0	-	-
13 September	6	0	-	-	4	0	-	-
20 September	2108	7	2	602	1345	10	0	0
27 September	1767	19	4	372	1032	26	1	40
4 October	4354	35	9	1120	1769	5	1	354
11 October	850	15	1	57	573	22	0	0
18 October	129	12	1	11	71	14	1	5
25 October	23	36	3	2	5	3	0	0
1 November	8	4	1	2	1	4	0	0
Total	9270	128	21	2166	4825	85	3	399

Table 5. Infectivity Index - *Rhopalosiphum padi* only - Auchincruive 1992.

		CUMULATIVE WEEKLY INDEX								
		6.9	13.9	20.9	27.9	4.10	11.10	18.10	25.10	1.11
E	6.9	0	0	602	977	2097	2154	2165	2167	2169
M	13.9		0	602	977	2097	2154	2165	2167	2169
E	20.9			602	977	2097	2154	2165	2167	2169
R	27.9				375	1495	1552	1563	1565	1567
G	4.10					1120	1177	1188	1190	1192
E	11.10						57	66	68	70
N	18.10							11	13	15
C	25.10								2	4
E	1.11									2

Table 6. Aphid trapping and infectivity data used to calculate the Infectivity Index at Belfast in 1992.

	Rhopalosiphum padi				*Rhopalosiphum insertum*			
	Total Numbers				Total Numbers			
Week ending	Tower	Commode	Infective	Index	Tower	Commode	Infective	Index
16 September	15	0	-	0	6	0	-	0
23 September	390	0	-	0	148	0	0	0
30 September	1839	36	0	0	1216	1	0	0
7 October	1716	5	1	232	371	0	-	0
14 October	459	5	0	0	153	0	-	0
21 October	40	0	-	0	26	0	-	0
28 October	22	3	0	0	2	0	-	0
4 November	0	0	-	0	0	0	-	0
Total	4481	49	1	232	1922	1	0	0

Table 7. Infectivity Index - *Rhopalosiphum padi* only - Belfast 1992.

		CUMULATIVE WEEKLY INDEX									
		2.9	9.9	16.9	23.9	30.9	7.10	14.10	21.10	28.10	4.11
E	2.9	0	0	0	0	0	232	232	232	232	232
M	9.9		0	0	0	0	232	232	232	232	232
E	16.9			0	0	0	232	232	232	232	232
R	23.9				0	0	232	232	232	232	232
G	30.9					0	232	232	232	232	232
E	7.10						232	232	232	232	232
N	14.10							0	0	0	0
C	21.10								0	0	0
E	28.10									0	0
	4.11										0

Table 8. Aphid trapping and infectivity data used to calculate the Infectivity Index at Belfast in 1993.

	Rhopalosiphum padi				*Rhopalosiphum insertum*			
	Total Numbers				Total Numbers			
Week Ending	Tower	Commode	Infective	Index	Tower	Commode	Infective	Index
9 September	354	5	0	0	122	0	0	0
16 September	1304	4	0	0	86	1	0	0
23 September	853	38	0	0	205	1	1	205
30 September	1851	25	4	296	1186	0	0	0
7 October	359	48	16	122	895	0	0	0
14 October	647	22	6	168	580	6	1	99
21 October	42	3	0	0	45	0	0	0
28 October	160	20	6	51	220	0	0	0
Total	5570	165	32	637	3339	8	2	304

Table 9. Infectivity Index - *Rhopalosiphum padi* only - Belfast 1993.

		CUMULATIVE WEEKLY INDEX								
		9.9	16.9	23.9	30.9	7.10	14.10	21.10	28.10	4.11
E	9.9	0	0	0	0	0	0	0	0	0
M	16.9		0	0	0	0	0	0	0	0
E	23.9			0	0	0	0	0	0	0
R	30.9				296	418	586	586	637	637
G	7.10					122	290	290	241	241
E	14.10						168	168	219	219
N	21.10							0	51	51
C	28.10								51	51
E	4.11									0

Table 10. The regional incidence of aphids in winter barley in the autumn 1991.

		Mean number of aphid colonies per 10 x 1m drill lengths/field[a]	
Region	No. of fields	Bird cherry aphids	Grain aphids
Dumfriesshire	6	5.5	1.3
Wigtownshire	6	2.5	1.8
Stirlingshire	6	1.3	1.5

[a] after six visits per field

Table 11. The regional incidence of aphids in winter barley in the autumn 1992.

		Mean number of aphid colonies per 10 x 1m drill lengths per field[a]	
Region	No. of fields	Bird cherry aphids	Grain aphids
Dumfriesshire[a]	9	4.3	5.4
Wigtownshire[a]	6	13.0	4.3
Ayrshire[a]	6	0.5	5.7
Renfrewshire[b]	3	0.3	1.0
Stirlingshire[b]	4	0.5	1.5

[a] 4 or 5 visits per field.

[b] 2 or 3 visits per field.

Table 12. The regional incidence of aphids in winter barley in the autumn 1993.

		Mean number of aphid colonies per 10 x 1m drill lengths per field[a]	
Region	No. of fields	Bird cherry aphids	Grain aphids
Dumfriesshire[b]	14	10.9	5.1
Wigtownshire	8	11.5	1.8
Ayrshire	6	115.5	16.3
Stirlingshire	7	5.6	12.9

[a] Two to four visits per field - visits after insecticide application excluded.

[b] One crop which followed undesicated ploughed-in grass ley excluded - heavily infested by bird cherry aphids.

Table 13. Total numbers of aphid colonies recorded in winter barley crops in three regions during autumn 1993.

			Total number of aphid colonies per 10 x 1m drill length/field[a]	
Field	Sowing date	Previous Crop	Bird cherry aphids	Grain aphids
Dumfriesshire				
D1*	5/9/93	WB	30	4
D2*	5/9/93	WB	8	8
D3*	5/9/93	WB	5	9
D4*	5/9/93	WB	6	6
D5*	7/9/93	WB	11	15
D6*	15/9/93	SB	13	1
D7*	7/9/93	WB	4	6
D8*	15/9/93	WB	6	4
D9*	17/9/93	SB	31	4
D10*	15/9/93	SB	14	4
D11	27/9/93	SO	2	1
D12*	26/9/93	Grass	110	1
D13	18/9/93	Set-aside	2	1
D14*	27/9/93	WB	19	4
D15*	27/9/93	WW	1	4
Ayrshire				
A1*	5/9/93	WB	108	25
A2*	5/9/93	WB	122	34
A3*	5/9/93	WB	74	13
A4*	25/8/93	Grass	338	20
A5	16/9/93	WB	3	1
A6*	16/9/93	WB	48	5
Stirlingshire				
S1* oats	1/9/93	WO	31	51
S2 oats	30/8/93	Set-aside	0	31
S3	13/9/93	SB	3	3
S4 oats	7/9/93	SB	2	3
S5 wheat	15/9/93	OSR	2	0
S6 wheat	1/9/93	OSR	0	0
S7 oats	5/9/93	WO	1	2

* Crop received insecticide application.

[a] Data from 2 to 4 visits prior to any insecticide application.

WB-winter barley SB-spring barley WO-winter oats SO-spring oats WW-winter wheat
OSR-oil seed rape

Table 14. Bird cherry infestation of Ayrshire winter barley crops during autumn 1993.

Variety: Pastoral *Sowing date*: 5/9/93 *Previous crop*: winter barley

Number of bird cherry aphids in each 1 m length of barley drill

Sampling date	1	2	3	4	5	6	7	8	9	10	Total
13/9/93 1 leaf	5	4	4	3	4	1	2	2	4	4	33
						Ambush C applied incorrectly					
21/9/93 2 leaf	1	9	1	3	1	1	2	5	5	1	29
27/9/93	1	4	1	4	>10	8	9	8	5	10	>60
						Ambush C applied					

Variety: Fighter *Sowing date*: 25/8/93 *Previous crop*: ryegrass ley (descicated)

Number of bird cherry colonies in each 1 m length of barley drill

Sampling date	1	2	3	4	5	6	7	8	9	10	Total
13/9/93 2 leaf	5	>10	>10	>10	5	3	8	4	1	>10	>66
21/9/93	>10	>10	>10	10	>10	>10	>10	10	5	3	>88
23/9/93	>10	>10	>10	>10	>10	>10	>10	>10	2	>10	>92
23/9/93	>10	>10	4	>10	>10	>10	>10	>10	>10	5	>89
						Ambush C applied					

Variety: Pastoral *Sowing date*: 16/9/93 *Previous crop*: winter barley

Number of bird cherry aphid colonies in each 1 m length of barley drill

Sampling date	1	2	3	4	5	6	7	8	9	10	Total
6/10/93 1 leaf	2	1	0	2	1	0	2	1	0	0	9
13/10/93	1	2	0	0	0	0	0	1	1	1	7
21/10/93	0	0	0	0	1	1	0	1	5	4	12
27/10/93	0	0	0	0	1	3	7	8	1	0	20
						Ambush C applied					

Table 15. BYDV spring survey 1992 - incidence and strains in cereal leaf samples.

			% of samples infected		
Region	No. of fields	No. of samples	RPV	PAV	MAV
Dumfriesshire	6	21	33	10	10
Wigtownshire	6	36	28	3	0
Stirlingshire	6	8	0	13	0
N. Ireland	8	8	25	13	38

Table 16. BYDV spring survey 1993 - incidence and strains in cereal leaf samples.

			% of samples infected		
Region	No. of fields	No. of samples	RPV	PAV	MAV
Dumfriesshire	9	56	3	30	12
Wigtownshire	6	76	9	38	32
Ayrshire	6	58	0	0	1
Renfrewshire	3	24	0	0	8
Stirlingshire	5	21	0	23	19
Armagh	4	63	41	19	41
Down	7	142	13	12	80
Antrim	1	28	50	0	10

Table 17. BYDV spring survey 1993 - extent of crop yellowing.

		Extent of crop yellowing		
Region	No. of fields	0-1%	1-5%	> 5%
Dumfriesshire	9	8	1	0
Wigtownshire	6	4	2	0
Ayrshire	6	4	2	0
Renfrewshire	3	3	0	0
Stirlingshire	5	5	0	0
Armagh	4	2	2	0
Down	7	5	2	0
Antrim	1	0	1	0

Table 18. BYDV spring survey 1994 - incidence and strains in cereal leaf samples.

			% of samples infected		
Region	No. of fields	No. of samples	RPV	PAV	MAV
Dumfriesshire	13	111	23	48	20
Wigtownshire	8	79	25	36	11
Ayrshire	4	40	27	42	5
Stirlingshire	9	94	8	19	28
Down	4	80	45	30	15
Antrim	4	41	48	48	51

Table 19. BYDV spring survey 1994 - extent of crop yellowing.

		Extent of crop yellowing		
Region	No. of fields	0-1%	1-5%	> 5%
Dumfriesshire	15	13	1	1
Wigtownshire	8	7	1	0
Ayrshire	5	0	5	0
Stirlingshire	9	9	0	0
Down	4	3	1	0
Antrim	4	2	2	0

Table 20. Pre-harvest sampling 1993 - incidence and strains in cereal leaf samples.

			% of samples infected		
Region	No. of fields	No. of samples	RPV	PAV	MAV
Dumfriesshire	3	44	2	0	4
Wigtownshire	3	47	0	2	0
Ayrshire	3	49	4	0	6
Stirlingshire	3	40	12	0	27
Down	5	99	2	1	96
Antrim	5	101	61	29	11

Table 21. Pre-harvest sampling 1993 - *Poa annua* samples.

Region	No. of fields	No. of samples	% of samples infected: RPV	PAV	MAV
Dumfriesshire	3	57	0	5	7
Wigtownshire	3	59	6	3	0
Ayrshire	3	36	8	13	2
Stirlingshire	3	58	0	1	1
Down	5	88	38	20	40
Antrim	5	77	58	18	23

Table 22. Pre-harvest sampling 1993 - Incidence and abundance of aphid species.

Region[a]	% of 1 m lengths of barley drill with aphids[b]	% of *Poa annua* plants with aphids[c]	No. of fields with aphid species: *M. dirhodum*	*R. padi*	*Sitobion spp.*
Dumfriesshire	3	36	0	0	3
Wigtownshire	23	71	0	2	3
Ayrshire	36	53	1	0	3
Stirlingshire	70	71	1	2	3
Down	14	8	0	3	1
Antrim	16	2	0	5	3

[a] Three fields sampled per region except in Down and Antrim where 5 fields were sampled
[b] Ten 1m lengths of barley drill sampled per field
[c] Twenty *Poa annua* plants sampled per field.

Table 23. Post-harvest sampling 1993 - *Poa annua* samples.

Region	No. of fields	No. of samples	% of samples infected		
			RPV	PAV	MAV
Dumfriesshire	3	44	6	9	20
Wigtownshire	2	43	9	25	4
Ayrshire	3	59	18	6	20
Stirlingshire	1	to test			1
Down	4	76	35	18	44
Antrim	5	87	22	12	64

Table 24. Post-harvest sampling 1993 - Incidence and abundance of aphid species.

Region	No. of fields	% with aphids[a]		No. of fields with aphid species		
		Cereal volunteers	*Poa annua*	*M. dirhodum*	*R. padi*	*Sitobion* spp.
Dumfriesshire	3	50	26	0	3	3
Wigtownshire	2	80	40	2	2	2
Ayrshire	3	85	26	2	3	3
Stirlingshire	1	-	100	1	1	1
Down	4	40	33	0	3	1
Antrim	5	25	22	0	5	3

[a] Ten groups of cereal volunteers and ten *Poa annua* plants sampled per field.

Table 25. Post-harvest sampling 1993 - Incidence and abundance of aphid species on two grass weed species in headlands.

		% with aphids[a]		No. of fields with aphid species		
Region	No. of fields	*Dactylis glomerata*	*Holcus lanatus*	*R. padi*	*S. avenae*	*S. fragariae*
Dumfriesshire	3	6	13	0	2	1
Ayrshire	3	13	10	0	1	2
Stirlingshire	3	6	50	2	2	3

[a] Ten plants of each species sampled in headland of each field.

Table 26. *Sitobion* spp. on Cocksfoot and Yorkshire Fog.

	% of aphid infested *Dactylis glomerata*		% of aphid infested *Holcus lanatus*	
Region[a]	Early August	Late August	Early August	Late August
Dumfriesshire	1	6	16	13
Wigtownshire	3	-	38	-
Ayrshire	5	13	30	10
Stirlingshire	60	6	82	50

[a] Three fields sampled per region.

Table 27. Summary of autumn aphid monitoring in winter barley 1988 to 1993.

Bird Cherry Aphids

Mean number of bird cherry aphid colonies per 10 x 1m drill length/field

Year	n	Wigtownshire	n	Dumfriesshire	n	Ayrshire	n	Stirlingshire
1988[a]	2	27	-	-	2	4	1	5
1989	3	4	7	1.3	3	3	3	4.7
1990	7	5.1	6	11.8	-	-	7	4.7
1991	6	5.5	6	5.5	-	-	6	1.3
1992	6	13.0	9	4.3	6	0.5	4	0.5
1993	8	11.5	14	10.9	6	115.5	7	5.6

[a] Mean numbers of aphids, not colonies.

n number of fields sampled

N.B. Fields which followed undesicated ploughed-in grass leys are excluded.

Grain Aphids

Mean number of grain aphid colonies per 10 x 1m drill length/field

Year	n	Wigtownshire	n	Dumfriesshire	n	Ayrshire	n	Stirlingshire
1988[a]	2	56	-	-	2	23.5	1	24
1989	3	4.3	7	2.6	3	4.6	3	0.3
1990	7	2.4	6	8.5	-	-	7	5.7
1991	6	1.8	6	1.3	-	-	6	1.5
1992	6	4.3	9	5.4	6	5.7	4	1.5
1993	8	1.8	14	5.1	6	16.3	7	12.9

[a] Mean numbers of aphids, not colonies.

Table 28. Summary of BYDV survey data in winter barley crops each spring 1989 to 1994.

Percentage of yellow leaves infected with BYDV

	Wigtownshire % of samples infected				Dumfriesshire % of samples infected				Stirlingshire % of samples infected			
Year	n	RPV	PAV	MAV	n	RPV	PAV	MAV	n	RPV	PAV	MAV
1989	5	73	58	77	10	4	6	52	7	0	0	88
1990	4	20	15	45	7	9	18	26	3	0	54	31
1991	9	3	16	30	6	8	24	24	9	2	22	42
1992	6	28	3	0	6	33	10	10	6	0	13	0
1993	6	9	38	32	9	3	30	12	5	0	23	19
1994	8	25	36	11	13	23	48	20	9	8	19	28

Percentage of crop comprised of yellowed plants

	Wigtownshire No. of crops in crop yellowing category				Dumfriesshire No. of crops in crop yellowing category				Stirlingshire No. of crops in crop yellowing category			
Year	n	0-1%	1-5%	>5%	n	0-1%	1-5%	>5%	n	0-1%	1-5%	>5%
1989	5	0	1	4	10	3	2	5	7	4	3	0
1990	4	4	0	0	7	7	0	0	3	2	1	0
1991	9	8	1	0	5	6	1	0	9	7	2	0
1992	6	1	1	4[a]	6	2	3	1	6	6	0	0
1993	6	4	2	0	9	8	1	0	5	5	0	0
1994	8	7	1	0	14	13	1	0	9	9	0	0

[a] Crop yellowing not due to BYDV.

Table 29. Summary of BYDV infection data collected during pre-harvest sampling 1989-93.

Yellow cereal leaves

		Wigtownshire % of samples infected				Dumfriesshire % of samples infected				Stirlingshire % of samples infected		
Year	n	RPV	PAV	MAV	n	RPV	PAV	MAV	n	RPV	PAV	MAV
1989	5	40	100	40	15	13	7	53	15	13	7	53
1990	20	0	0	5	27	18	3	40	20	5	0	0
1991	160	3	5	3	30	0	0	0	138	3	0	4
1992	60	0	0	3	54	11	0	13	1	0	0	0
1993	47	0	2	0	44	2	0	4	40	12	0	27

n number of samples

Poa annua samples

		Wigtownshire % of samples infected				Dumfriesshire % of samples infected				Stirlingshire % of samples infected		
Year	n	RPV	PAV	MAV	n	RPV	PAV	MAV	n	RPV	PAV	MAV
1989	29	72	82	31	25	48	56	100	30	3	16	63
1990	30	6	6	80	26	0	0	11	30	3	6	20
1991	160	12	11	12	30	7	13	17	30	7	23	23
1992	30	20	17	3	30	7	13	3	0	-	-	-
1993	59	6	3	0	57	0	5	7	58	0	1	1

n number of samples

Table 30. Summary of the BYDV infection of *Poa annua* collected during post-harvest sampling 1991-1993.

	Wigtownshire % of samples infected				Dumfriesshire % of samples infected				Down % of samples infected			
Year	n	RPV	PAV	MAV	n	RPV	PAV	MAV	n	RPV	PAV	MAV
1991	44	41	32	32	30	10	10	13	29	31	21	24
1992	61	36	18	34	79	15	24	33	40	35	10	40
1993	43	9	25	4	44	6	9	20	76	35	18	44

n number of samples

Table 31. Incidence of aphids in winter barley (either barley plants or *Poa annua* weeds) during late June/early July 1989 to 1993.

		Percentage of fields with aphid species		
Year	No. of fields	*Metopolophium dirhodum*	*Rhopalosiphum padi*	*Sitobion avenae*
1989	14	7	14	78
1990	9	33	11	100
1991	30	6	3	30
1992	15	0	26	80
1993	22	9	54	72

Table 32. Incidence of aphids in cereal stubbles (either barley volunteers or *Poa annua*) during late August/early September 1990 to 1993.

		Percentage of fields with aphid species		
Year	No. of fields	*Metopolophium dirhodum*	*Rhopalosiphum padi*	*Sitobion avenae*
1990	11	54	100	54
1991	21	19	33	66
1992	22	4	8	63
1993	18	27	94	72

Table 33. Extent of *Poa annua* infestation of winter barley crops during July 1989 to 1993.

		Percentage of fields in each weed infestation category		
Year	No. of fields	1	2	3
1989	14	28	50	22
1990	9	33	23	44
1991	30	3	20	77
1992	25	40	44	16
1993	12	16	50	34

Poa annua infestation categories:

0 No *P. annua* (didn't occur in practice).
1 Scattered plants in tramlines.
2 1-5% of tramlines infested.
3 extensive areas of *P. annua* infestation, extending beyond tramplines.

Table 34. Seasonal mean temperature anomalies at Auchincruive, 1987-1994.

	Seasonal mean temperature anomaly °C			
Year	Winter	Spring	Summer	Autumn
1988	+1.9	+0.5	+0.3	0.0
1989	+3.1	+0.2	+0.5	+0.1
1990	+0.9	+1.1	+0.6	-0.1
1991	-0.5	+0.7	+0.7	+0.1
1992	+1.5	+1.3	+0.4	-1.2
1993	+1.4	+0.3	-0.7	-1.8

Averages for 1951-80

Table 35. Mean temperatures at Auchincruive in selected periods of the six year study.

	Mean temperature °C					
Period[a]	1988	1989	1990	1991	1992	1993
September-August	9.0	9.6	9.4	8.9	9.5	8.6
January-August	9.4	9.9	10.1	9.2	10.0	9.3
January-June	7.9	8.2	8.5	6.9	8.7	8.0
May-August	13.2	13.4	13.5	13.4	13.7	12.2
June-August	14.0	14.2	14.3	14.4	14.1	13.0
December-February	4.9	7.0	4.8	3.4	5.4	5.3
October-November	8.0	8.3	8.3	8.1	6.5	5.8

[a] Year refers to last month of period, e.g. the temperature for the period September 1987 to August 1988 was 9.0°C.

Table 36. Testing of models which predict the number of bird cherry aphids sampled by the Ayr suction trap during September & October.

Year	Number of the 8 models which predict score[a] 1	2	3	4	Observed Score at Ayr
1990	8	0	0	0	1
1991	2	6	0	0	3
1992	0	8	0	0	4
1993	0	1	3	4	4
1994					

[a] Scores for number of bird cherry aphids sampled by the Ayr 12.2 m suction trap during September & October

1 - 1 - 99
2 - 100 - 999
3 - 1000 - 9999
4 - > 10000

Table 37. Testing of the Lamb daily weather types (LDWTs) and PSC indices as predictors of the size of the bird cherry aphid autumn migration.

		Observed numbers of bird cherry aphids sampled by 12.2 m suction traps					
Year	Prediction based on LDWTs/PSC indices	Elgin	Dundee	East Craigs	Starcross	Rothamsted	Broom's Barn
1991	Large	1926	3258	2205	1907	497	501
1992	Large	2038	1209	3792	6270	3466	5847
1993	Large	5740	2651	6667	262	176	680
Average 1971-90		3723	8171	3555	1333	744	1135

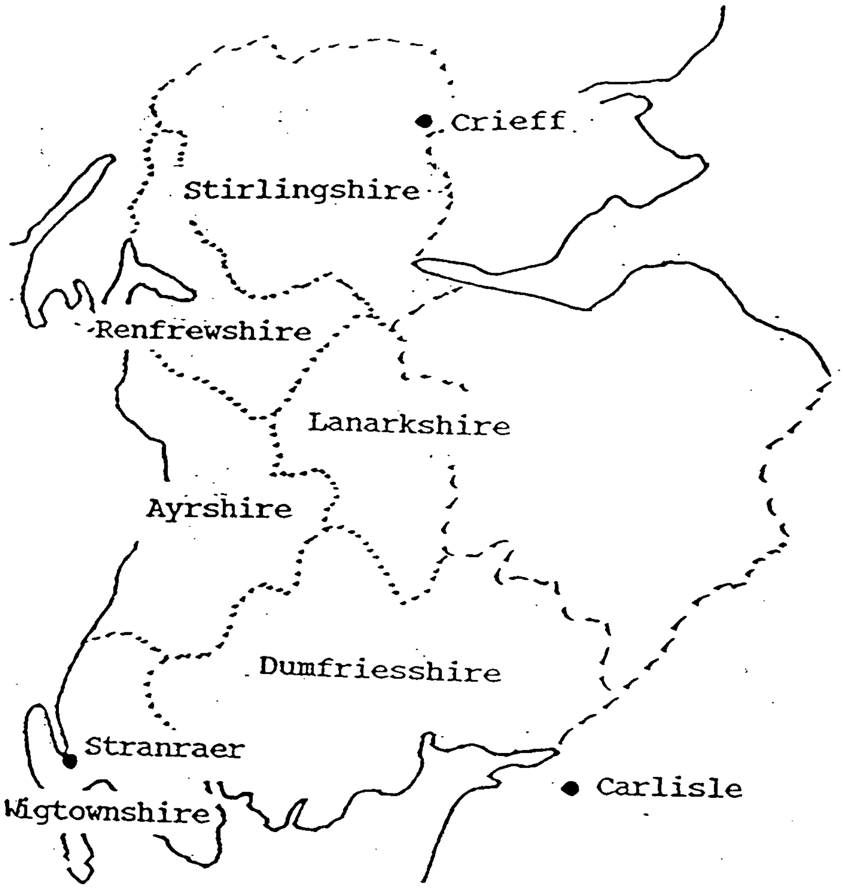
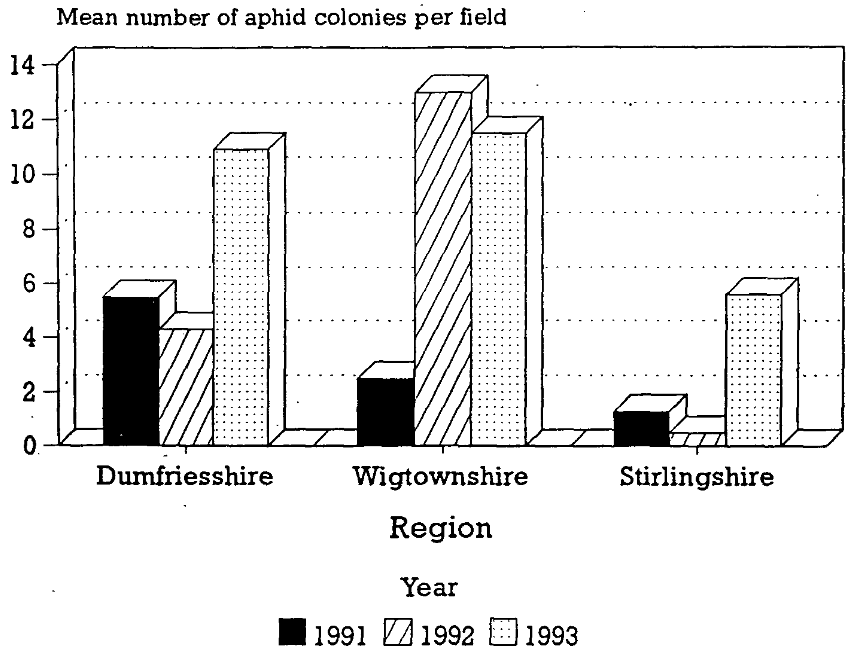


Fig. 1. Regions of south-west and central Scotland where commercial winter barley crops were sampled for aphids and Barley Yellow Dwarf Virus.

Bird cherry aphids



Grain aphids

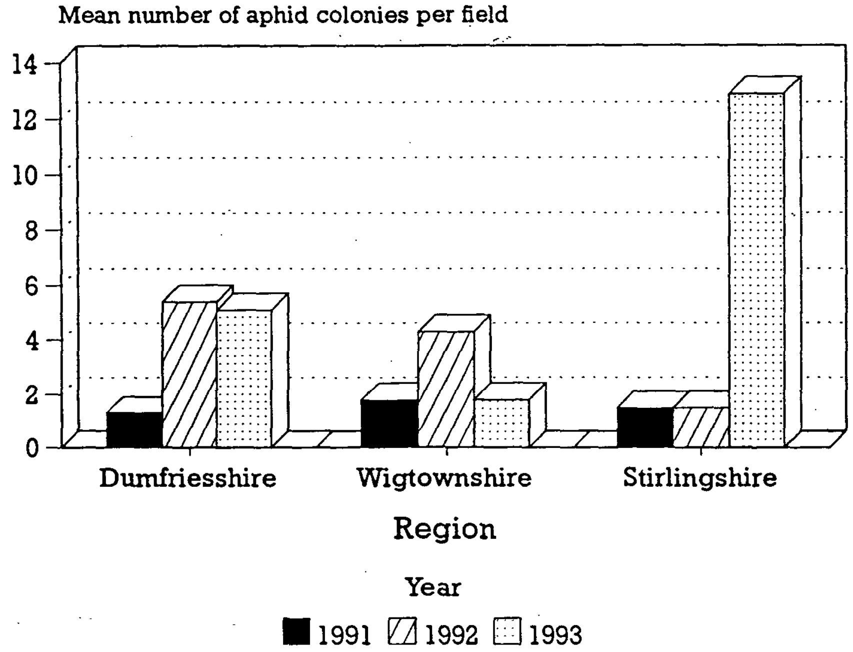


Fig. 2. Regional incidence of aphids in winter barley crops during the autumns of 1991 to 1993.

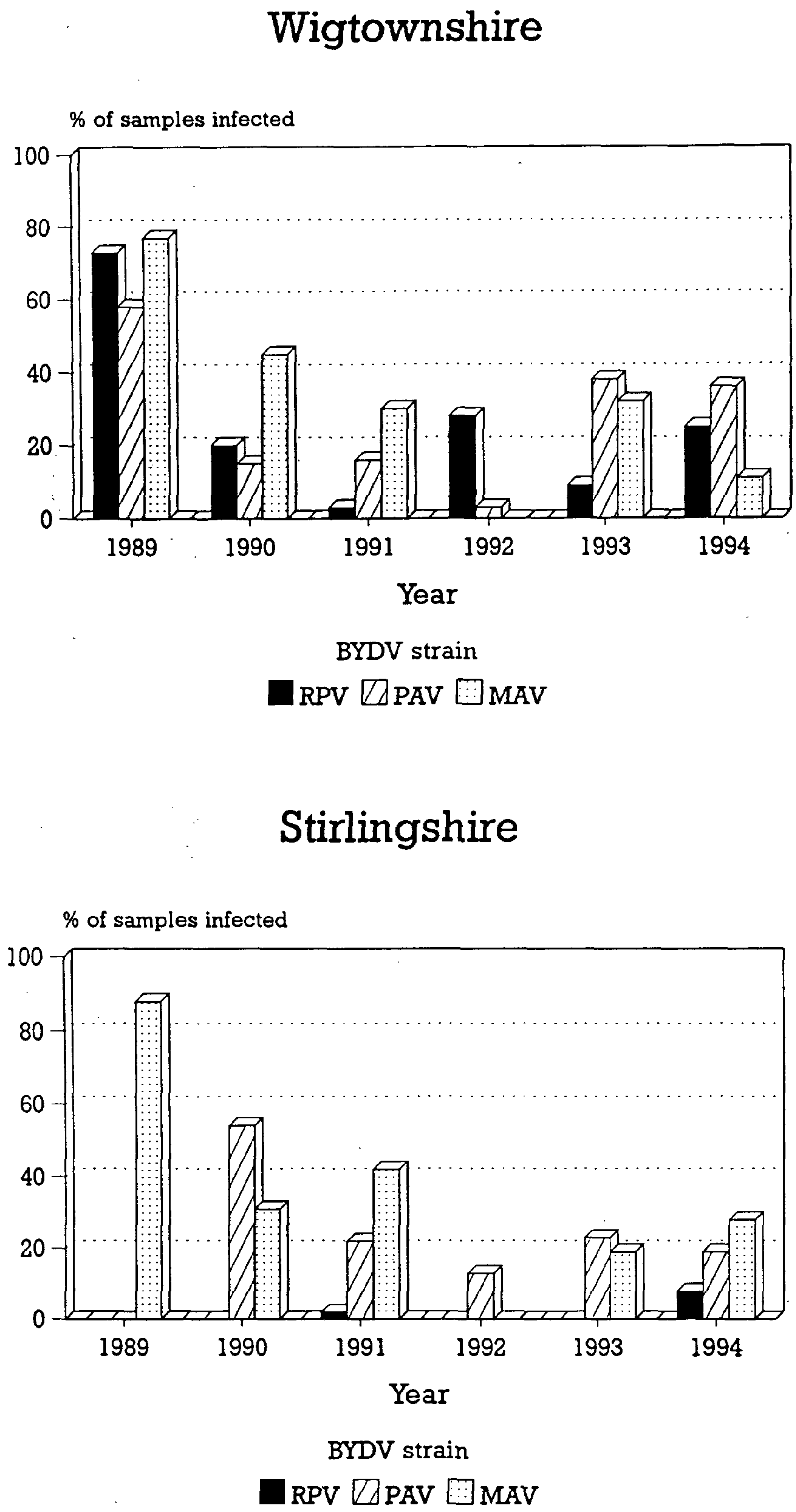


Fig. 3. Regional incidence of the three BYDV strains in yellow leaf samples collected from winter barley crops in the springs of 1989 to 1994.

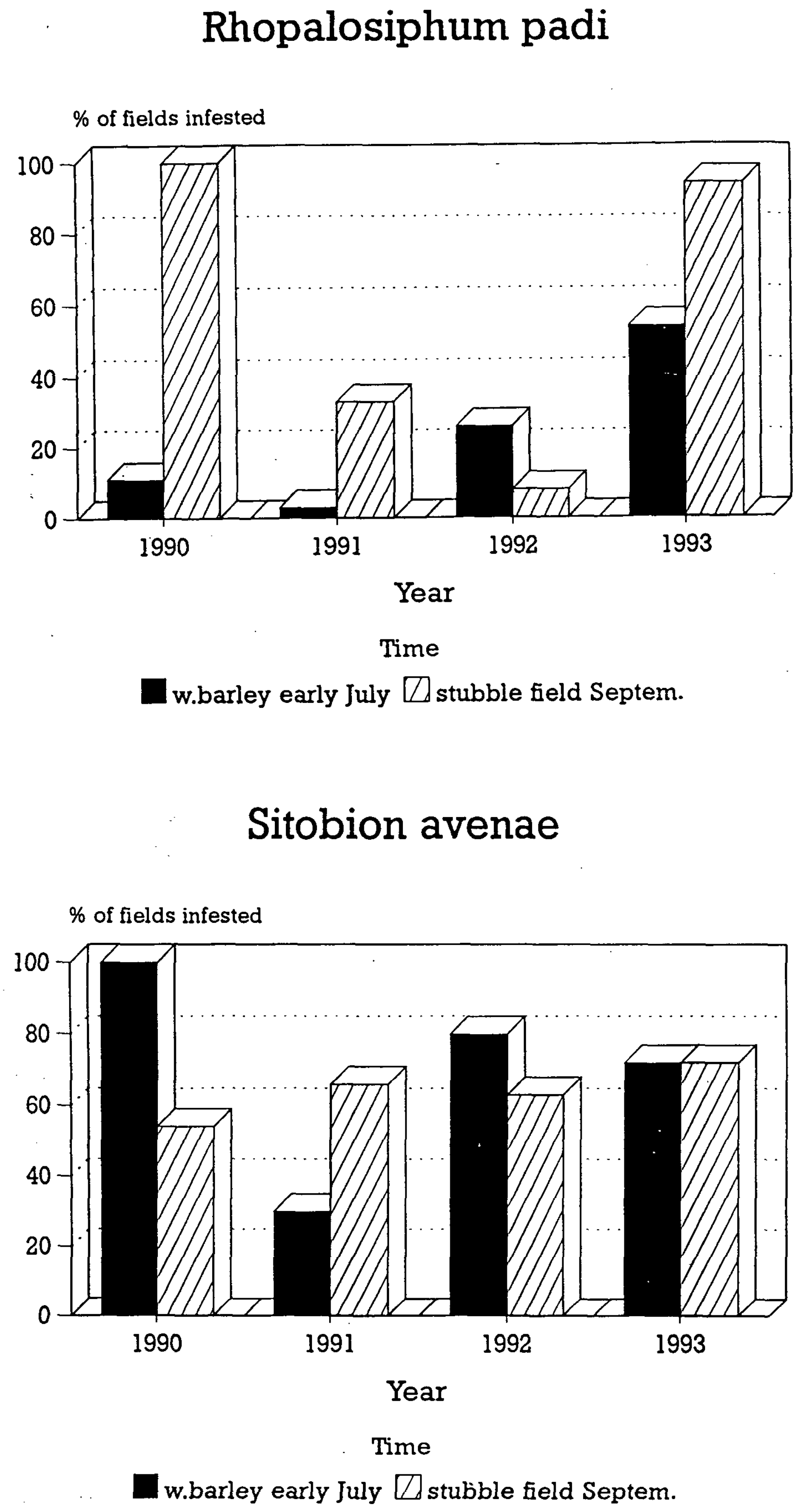


Fig. 4. Incidence of aphids on either winter barley plants or Poa annua weeds pre-harvest (late June/early July) and either barley volunteers or Poa annua weeds post-harvest in cereal stubbles (late August/early September) in 1990 to 1993.

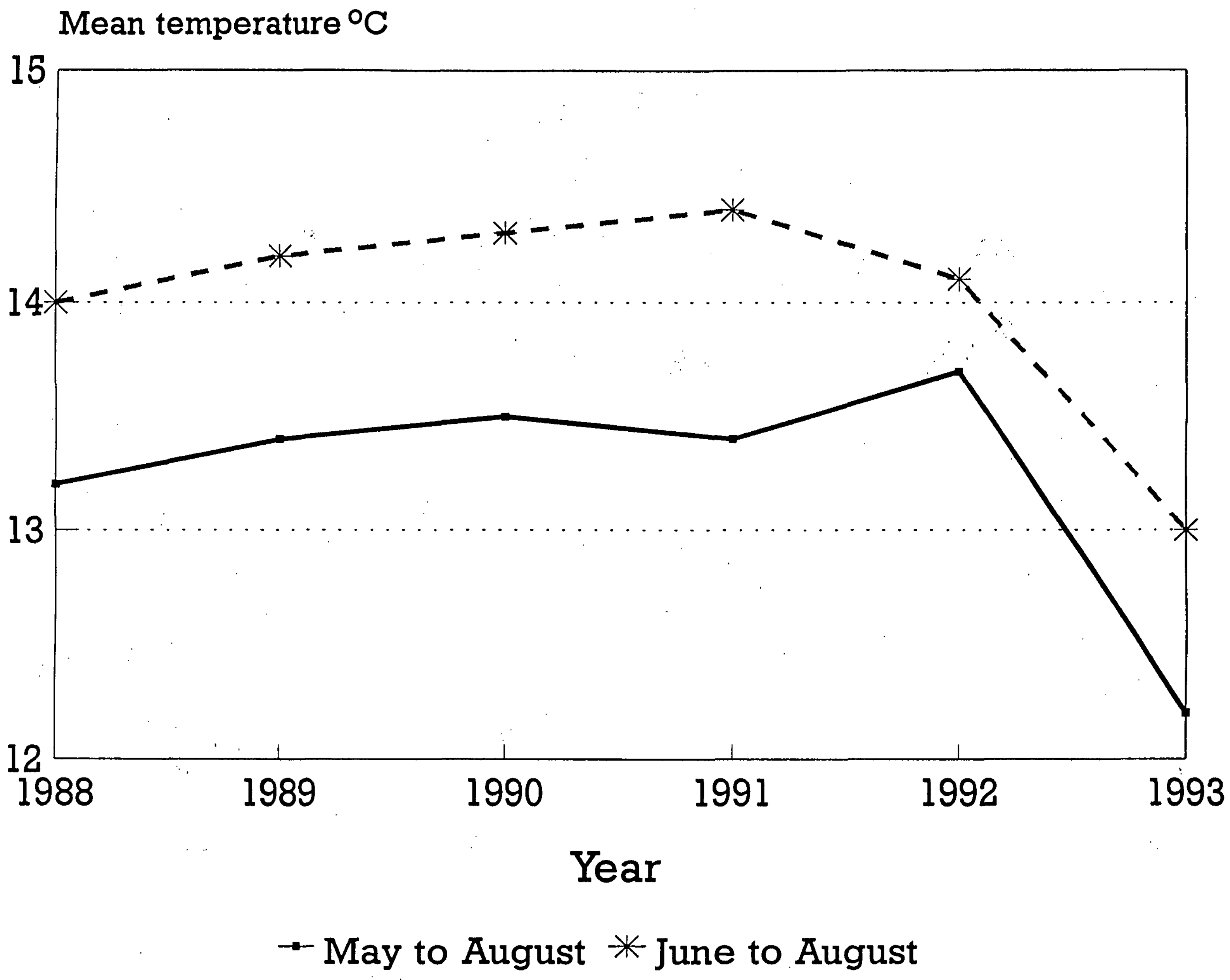


Fig. 5. Mean temperatures of the summers 1988 to 1993 at Auchincruive, Ayr.