Final Report

Aphids & Virus Transmission in Seed Crops

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1. SUMMARY

One of the major threats to the health of seed potato crops is the transmission of viruses by aphids. The viruses may be persistent (*e.g.,* Potato Leaf Roll Virus; PLRV) or non-persistent (*e.g.,* potyviruses such as PVY, PVA). The latter are transmitted immediately after aphids have fed on an infected plant. Non-colonising aphid species, such as cereal aphids, that do not use potato as a host but alight on potato plants and probe the leaves can transmit potyviruses. Previous studies have shown that PVY reduces yield in many cultivars.

The aim of the project was to fill the significant gaps in our understanding of the epidemiology of important potyviruses (PVY and PVA)[1].

The objectives were to:

1. Identify the most important potyvirus vector aphids using a combination of laboratory/glasshouse and field studies

2. Develop systems to allow aphid monitoring data to be effectively utilised to provide growers with the best quality information on which to base their virus management programmes

3. Identify sources of potyvirus inoculum and investigate their importance in the spread of virus to seed crops

4. Use any relevant, new information arising from the project to provide an improved understanding of the Estima-PVA interaction

5. Review available literature on the role of insecticides and mineral oils in preventing potyvirus spread and make recommendations for future research.

The methodologies used during the three-year project (which began in July 2009) included field and laboratory studies, surveys of plants in seed growing areas, as well as data mining exercises.

Plant material was collected from areas of high seed health and ware production as well as from field experiments. The samples included groundkeepers, ware crops, bait plants (tobacco), seed crops and weeds in and around potato crops. They were collected to provide information on the possible sources of virus inoculum in seed producing areas and to assess the importance of the different inoculum sources in the spread of the viruses. The numbers of groundkeepers were noted and sub samples were taken for virus testing. Potted tobacco bait plants were placed within some of the field experiments and were subsequently tested to determine if they had become infected with potyviruses whilst in the field (*i.e.,* to monitor virus transmission).

To help understand which aphids are important in spreading potyviruses Relative Efficiency Factors (REFs) were measured in the laboratory. The REF values reflect the transmission efficiency of a particular aphid species in relation to that of the peach-potato aphid, *Myzus persicae*, which is considered to be the most efficient vector of PVY. Having accurate and up to date REF values is important as they are used to calculate aphid vector pressure, which is reported via schemes such as the Potato Council's "Aphid Monitoring in Potato Crops" site. In addition, molecular techniques were used to investigate which field collected aphids were

[1] Two potyviruses were studied during this project: PVY and PVA. There are different types of PVY recognised. Throughout this report where PVY is referred to without a superscript, it refers generally to all the PVY types. An explanation of the PVY types and superscripts used is provided in Table 1 (Page 16).

actually carrying virus. The techniques were used with samples of aphids trapped at some of the trial sites in Scotland.

Three data mining exercises were carried out: A survey of the Scottish Seed Potato Certification Scheme (SPCS) data of sister stocks (which was used to investigate environmental potyvirus incidence in different areas); a literature review of the use of insecticides and mineral oils in controlling potyvirus spread (mostly PVY); and an assessment of the work required to incorporate other sources of aphid data into a potato virus risk assessment scheme.

The findings:
Objective 1
Virus Transmission: Aphid Relative Efficiency Factors (REFs)
The results confirm that *Myzus persicae* (peach-potato aphid) is generally more efficient at transmitting PVY and PVA than the other aphids tested. The REF values (for PVY transmission) for some aphid species have been revised or revision of the values is recommended. The changes are indicated in the shaded rows in the table and are explained below.

	Number of aphid clones tested	Current PVY REF value	Revised PVY REF value
Acyrthosiphon pisum	3	0.70	
Aphis fabae	3	0.01	
Brevicoryne brassicae	2	0.01	
Cavariella aegopodii	**2**	**0.00**	**0.50**
Drepanosiphum platanoides	1	0.00	
Hyperomyzus lactucae	1	0.16	
Macrosiphum euphorbiae	3	0.20	
Metopolophium dirhodum	3	0.30	
Microlophium carnosum	2	0.00	
Myzus persicae	3	1.00	
Rhopalosiphum padi	3	0.40	
Sitobion avenae	3	0.01	0.60

Values in grey shading, bold text:
On the basis of the results obtained during the project, the REF value for *C. aegopodii* (willow – carrot aphid) used in the calculation of the "cumulative vector pressure index" (and reported via the Potato Council- funded scheme) was updated for the 2012 season onwards. It has been allocated a value of 0.5 for PVY. A note in the weekly summary information was added to indicate that *C. aegopodii* transmits PVY and PVA and is present early in the season when the potato plants have not yet developed mature plant resistance to virus infection. A note was also included in the weekly summary stating that *A. fabae* (black bean aphid) is a good vector of PVA so growers of PVA susceptible potato varieties should take this into account or consult their agronomist.

Values in green shading:
In addition to the changes that were adopted in 2012, it is recommended that the REF value for another aphid species should be updated:

- *S. avenae* (grain aphid) from 0.01 to 0.6 for PVY. This species is also a good PVA vector.

In the case of *S. avenae* the revised REF value will be used in the calculation of aphid vector pressure from the 2013 season onwards. The revised value (0.5) adopted for *C. aegopodii* in 2012 will also be used in 2013 season onwards.

It is recommended that the *M. euphorbiae* (potato aphid) REF for PVY should remain at its present value because the difference between the REF currently used and the REF found during this study was not a large one and, since this species is a coloniser of potato plants, growers will be spraying even if it is found in low numbers.

It is also recommended that a further change is made to the aphid monitoring scheme reporting: *i.e.,* since *M. euphorbiae* and *S. avenae* have been shown to be good vectors of PVA a note should be included in the weekly summary stating that these species are good vectors of PVA so growers of PVA susceptible potato varieties should take this into account or consult their agronomist.

The project has shown, for the first time, that *A. fabae, Metopolophium dirhodum* (rose-grain aphid)*, S. avenae, Acyrthosiphon pisum* (pea aphid) and *C. aegopodii* are capable of transmitting PVA.

Virus Transmission: Epidemiology Field Trials

Field trials were designed to assess the timing of transmission and subsequent distribution of PVY and PVA in the experimental plots. At one site, the interactions between different PVY strains and isolates were studied. This involved plants infected with PVY (serotypes O/C and N; and EU-NTN and NA-NTN molecular groups (see Table 1 for an explanation of the terms and abbreviations used)). The results suggest that the PVY isolates are likely to be transmitted by the same aphid species. The proportion of plants that tested positive for PVY^{N} (in particular $PVY^{EU\text{-}NTN}$) post-harvest was higher in comparison to other strains ($PVY^{NA\text{-}NTN}$ and PVY^{O}). This apparent discrepancy between incidence at post-harvest and the weekly transmission rates for the PVY^{N} and PVY^{O} serotypes, suggests that PVY^{N} transmission and detection in tubers is more readily observed for PVY^{N} ($PVY^{EU\text{-}NTN}$) than for PVY^{O} in potato plants. This might explain the prevalence of PVY^{N} over the PVY^{O} serotypes in GB seed crops.

A logistic regression model, based on binomial response data, was used to relate virus transmission to aphid counts for individual aphid species (based on data from epidemiology trials sited in Edinburgh and Yorkshire). These results suggest that the relationship between the aphid data and PVY transmission in Edinburgh and York may differ. In Edinburgh there is a clear indication that *M. dirhodum* was the key species over the duration of the epidemiology trials (data is available for the period 2000-2011) and that the suction trap provided as good, if not better, relationship between aphid abundance and virus transmission, when compared to yellow water traps. In Yorkshire, over the duration of this project (2010-2011) a very different relationship was found, with the abundance of several species of aphids showing a stronger relationship with PVY transmission than does *M. dirhodum*. In addition, the aphid data from yellow water traps showed a stronger relationship than the data collected by the suction trap. This may in part be due to the suction trap at Askham Bryan being some 28 miles from the site of the epidemiology trials. However, the data collected at the two sites indicates that there may be differing relationships between yellow water trap catches and suction traps in different parts of GB.

Objective 2

Aphid Monitoring Data

Data from the two trapping systems (suction traps; yellow water traps) used to monitor aphids were analysed to understand how the datasets are related and whether the relationship could be used to improve the forecasting of the risk of virus transmission. The work focussed on data for *Myzus persicae* and *Metopolophium dirhodum.* The full report is provided in Appendix 2. Recommendations were made as to how the data from both trap

types could be displayed so that the field specific yellow water trap catches are provided in a more regional context (ie with data on regional patterns of aphid flight from suction traps). At the time of publication of this report, this has not been adopted. However, SASA provide email alerts with links to Scottish suction trap data which can be accessed at http://www.sasa.gov.uk/wildlife-environment/aphid-monitoring/virus-epidemiology The site also provides a link to the Potato Council-funded aphid monitoring (yellow water trap) information.

Objective 3

Incidence of Mosaic Symptoms and Sources of Potyvirus Inoculum

Potyviruses continue to be the most prevalent virus group in GB. Potyvirus incidence in seed potato crops in England and Wales is comparable to the incidence in Scotland. PVY^N represent more than 80% of PVY cases, confirming the prevalence of the tobacco necrotic strain PVY^N in GB. This is a trend that has been observed worldwide and is often associated with the occurrence of necrotising (PVY^{NTN}) variants. A higher proportion of $PVY^{O/C}$ to PVY^N serotype was found in England and Wales in comparison to Scotland. The causes of this discrepancy in the proportion of $PVY^{O/C}$ and PVY^N serotypes are not known. This might be due to regional differences in inoculum sources (seed or ware crops) and in the number of PVY^O susceptible varieties grown (such as Maris Peer, King Edward, Valor). Other potyviruses such as PVA and PVV are less prevalent than PVY^N and $PVY^{O/C}$ in England and Wales and Scotland. As PVA incidence was found to vary from year to year and is found to be associated with a limited numbers of crops, PVA relative incidence may reflect differences in inoculum sources (seed or ware crops) and in the amount of susceptible varieties to these viruses grown every year (such as Hermes, Estima, Desiree) in GB.

When considering conclusions based on analysis of classification scheme data it should be borne in mind that the primary purpose of the crop inspection procedures is not virus research and therefore not all the variables that might impact on virus epidemiology are recorded in the SPCS datasets. Nevertheless, the datasets can be used to provide information on potyvirus incidence in different geographical areas. Analysis of SPCS datasets indicates that variety has an important effect on the incidence of mosaic symptoms observed at classification inspections. The term 'varietal propensity' is used in this report to describe whether symptoms observed within a variety are above or below the average across the whole Scottish seed crop (i.e. Propensity = % of diseased crops of variety /% of diseased crops of all varieties). The table below summarises varietal propensity information collected over the period 2009-2011 using data on symptom expression at crop inspection and laboratory virus diagnoses on leaf samples submitted to SASA. Values greater than 1 indicate that virus/symptom is more likely to be found in that variety and values less than 1 indicate that it is less likely to be found in that variety.

Propensity values can be used to rank varieties in relation to any particular virus/symptom. However, they should not be used to make quantitative comparisons between viruses/symptoms. As the reliability of propensity data depends upon the inspection and sampling of an extensive number of crops, it is less reliable for varieties with relatively few crops which are only grown over a relatively small area *e.g.,* new varieties.

Varietal resistance scores, *e.g.,* those provided on the British Potato Variety database, relate to resistance to $PVY^{O/C}$ whereas propensity values relate to PVY^N (the dominant virus within the Scottish classification scheme). Therefore, there may not be a straightforward relationship between the two values.

Variety	Crops	Mosaics	PVY^N	$PVY^{O/C}$	PVA	PVV
MARIS PIPER	1390	1.7	1.7	1.1	0.1	0.0
HERMES	1274	0.6	0.1	0.5	2.0	0.0
DESIREE	775	2.0	1.2	0.5	5.9	0.0
MARIS PEER	536	2.0	2.2	2.8	0.0	0.0

ESTIMA	483	1.0	0.2	0.3	5.1	25.1
MARKIES	326	0.3	0.1	0.0	1.2	0.0
KING EDWARD	315	2.4	4.6	3.4	0.2	0.0
MARFONA	305	1.0	1.2	2.2	0.3	0.0
PENTLAND DELL	267	0.6	1.1	0.0	0.3	0.0
CABARET	266	1.1	1.4	1.5	4.6	0.0
SAXON	261	0.1	0.1	0.0	0.3	0.0
LADY ROSETTA	249	0.2	0.0	0.0	0.0	0.0
VALOR	236	3.5	2.4	4.6	0.0	0.0
SATURNA	227	0.5	0.6	0.6	0.0	0.0
CHARLOTTE	226	1.0	1.4	1.8	0.0	0.0
ATLANTIC	224	1.9	4.3	4.8	0.0	0.0
HARMONY	207	2.3	2.1	0.7	0.0	0.0
WINSTON	203	2.3	0.6	3.3	0.0	0.0
CARA	186	0.5	0.5	0.7	0.0	0.0
BURREN	173	0.3	0.4	0.0	0.0	0.0
ROOSTER	172	1.0	0.8	0.0	0.0	0.0
KERR'S PINK	171	0.9	0.6	0.8	1.3	0.0
RUSSET BURBANK	171	1.1	0.4	0.8	0.0	0.0
MARIS BARD	167	0.7	1.0	0.8	2.7	0.0
VALES SOVEREIGN	159	0.5	0.4	0.9	1.4	0.0
WILJA	131	1.5	2.0	1.0	0.0	0.0
KENNEBEC	128	0.2	0.0	0.0	0.6	0.0
MELODY	127	0.1	0.0	0.0	0.0	0.0

The presence of virus in the parental stock has a very significant effect on the incidence of mosaic symptoms observed at classification inspections. Over the period 2009-2011, whilst virus symptoms were observed in 16% of the crops grown, the virus incidence was 52% for stocks grown from infected parental material, and 13% for crops grown from parent stock in which no symptoms had been seen at the previous year's classification inspections. These data indicate a four-fold difference in the likelihood of mosaic being seen in a daughter crop depending upon whether virus had been observed in the parent crop. **Vertical transmission** is the term used to describe the situation where mosaic symptoms occur in the daughter stock when grown from an infected parental stock.

Horizontal transmission is the term used to describe the situation where mosaic symptoms occur in the daughter stock when grown from a clean parental stock. In this situation an external source of virus inoculum is assumed to be the origin of the potyvirus infection. (Groundkeepers within a seed crop would be considered a potential external source of virus inoculum). Analyses of SSPCS data (2009 - 2011) have shown that there is a clear increase in horizontal transmission associated with increasing field generation. However, generation *per se* is unlikely to have any direct effect on the likelihood of virus transmission, except for later generation crops tending to be larger and hence more likely to exhibit at least one plant showing virus symptoms at inspection. The location where later generation crops are grown is more likely to have an effect, with such crops grown in areas where more commercial stocks are grown. The presence of other potato crops within a geographical district has a highly significant effect on the likelihood of horizontal transmission, with the area of ware potato crops having a more significant effect than the area of seed crops. As mentioned above, not all the variables that might impact on virus epidemiology are recorded in the SPCS datasets and factors such as temperature, rainfall and the presence/extent of cereal crops in a geographical location may also impact on virus transmission.

Objective 4
Provide an Improved Understanding of the Estima-PVA Interaction
Assessments of virus incidence in Estima plants have provided information on the factors contributing to the more rapid degeneration of the health of Estima crops. Data from field

transmission trials revealed that a significantly higher percentage of Estima plants were infected with PVA in comparison to Desiree. Moreover, infected Estima plants were found to display a higher infection rate in tuber progeny in comparison to infected Desiree plants. As PVA is largely the most prevalent virus found in Estima crops in Scotland (see the above-mentioned high propensity value to PVA), the main cause for the rapid health degeneration of Estima crops is likely to be due to the combination of Estima high susceptibility level (horizontal transmission) and high PVA infection frequency in tuber progeny (vertical transmission).

Objective 5
Review of Role of Insecticides and Mineral Oils in Minimising Virus Transmission
The review has highlighted knowledge gaps relating to the use of mineral oils in GB. These are currently being addressed as part of a separate Potato Council-funded research project (R449) which began in Spring 2011.

Practical Recommendations

- In 2012, *C. aegopodii* was allocated a PVY index of 0.5 for the purposes of the aphid monitoring scheme for seed potato crops. This was accompanied by a note in the weekly summary stating that *C. aegopodii* transmits PVY and PVA and is present early in the season when the potato plants have not yet developed mature plant resistance to virus infection. A note was also included in the weekly summary stating that *A. fabae* is a good vector of PVA so growers of PVA susceptible potato varieties should take this into account or consult their agronomist. These changes should continue to be adopted in the 2013 season onwards.

The report authors recommend further changes to the aphid monitoring scheme reporting:

- The *S. avenae* REF for PVY should be increased from 0.01 to 0.6 since this species is now considered a much higher risk than it was prior to the glasshouse transmission efficiency tests.

- The *M. euphorbiae* REF for PVY should remain at its present value because the difference between the REF currently used and the REF found during this study was not a large one and, since this species is a coloniser of potato plants, growers will be spraying even if it is found in low numbers.

- Since *S. avenae* and *M. euphorbiae* have been shown to be good vectors of PVA a note should be included in the weekly summary stating that these species are good vectors of PVA so growers of PVA susceptible potato varieties should take this into account or consult their agronomist.

The other practical recommendations from the project are:

- Consider the risks of virus in seed when evaluating seed sources. Analyses of seed classification scheme data from Scotland indicate that crops with virus observed during the previous season are four times more likely to exhibit virus symptoms than those crops in which virus was not seen. Therefore, the acquisition of clean seed stocks is an important part of any virus management programme. This can be achieved by using certified seed or, if using farm-saved seed inputs, ensuring these are virus tested.

- Roguing will be more critical for stocks derived from seed in which virus symptoms were seen the previous season, *i.e*., eliminating as much of the virus inoculum inherent within the seed stock as soon as possible.

- Analyses of Scottish classification scheme data also indicate that other potato crops are a significant source of inoculum for virus to enter a seed stock. Therefore consideration of the virus risk presented by other potato crops on neighbouring farms is important.

- It is also important to be aware of crops in adjacent fields because of the implications for the presence of virus vectoring aphids. Cereal aphids appear to be efficient transmitters of virus and can migrate from cereal crops in significant numbers.

- The collection and testing of leaf samples from groundkeepers has highlighted the high prevalence of potyvirus infection in some groundkeepers. This information should be used to re-iterate the importance of the management of groundkeepers as a way to reduce external sources of potyvirus inoculum.

- Be aware of the virus susceptibility of varieties. Consideration of varietal propensity should be an important part of any virus management programme. Whether a variety has a propensity to PLRV or to PVY can be used to determine the appropriate means of protecting the crop through a control programme for the appropriate aphid species.

- Propensity should also be considered in any planting programme as there will be advantages in ensuring that varieties with a propensity to say, PVY are planted away from crops which are considered a likely source of inoculum for that virus.

- Fewer varieties are prone to PVA infection than to PVY. However, some varieties can mask virus symptoms in the growing crop. These infections can still lead to tuber symptoms, such as cracking.

- Sign up for aphid monitoring alerts. These are provided by the Potato Council, Fera and SASA and are available via e-mail, SMS text and through the Potato Council website.

Recommendations for future R&D

- The yellow water trap scheme should be extended across additional sectors including carrots, brassicas, OSR and winter wheat. This would produce a wider body of information about aphid populations at field level. The results could then be reported across sector and the additional information may assist in the production of more accurate predictive modelling of aphid populations. It would be necessary to undertake some research on aphid trap catches across sectors prior to implementing this approach to ascertain the effect of crop type on the assemblages of aphids caught.

- Investigate the virus transmission efficiency of *Brevicoryne brassicae* since this is known to transmit PVY. Its PVA vector status is unknown.

- Investigate the virus transmission efficiency of *Cavariella pastinaceae*. Its vector status for PVY and PVA is unknown and it is found in traps early in the season prior to potato plants having developed mature plant resistance.

- Carry out periodic surveys of the UK seed potato crop to look at changing virus populations and the varietal propensity for emerging varieties.

- Carry out a 'desk study' to examine the consequence of the adoption of the revised transmission efficiency factors (REF values). This could include a study on the PVA efficiency factors linked to the historic Estima post-harvest dataset held by SASA, or the impact of both the PVY and PVA REF values within the interpretation of historic epidemiology transmission data.

- Consider funding a study to investigate how growers/agronomists use the information from aphid monitoring and virus testing schemes to make decisions about their crops- to understand what are the barriers to using the available information and what would be the best way of conveying the information. This could be a cross-sector project.

- Development of an advanced model of PVY transmission for the Edinburgh location based on *M. dirhodum* suction trap catches and incorporating the effects of other species shown to have a significant effect on PVY transmission within the epidemiological field trials (*A fabae*, *S. avenae, M. certus* and *B. brassicae*). Test the effectiveness of the model using classification data from the Scottish Seed Potato Classification Scheme.

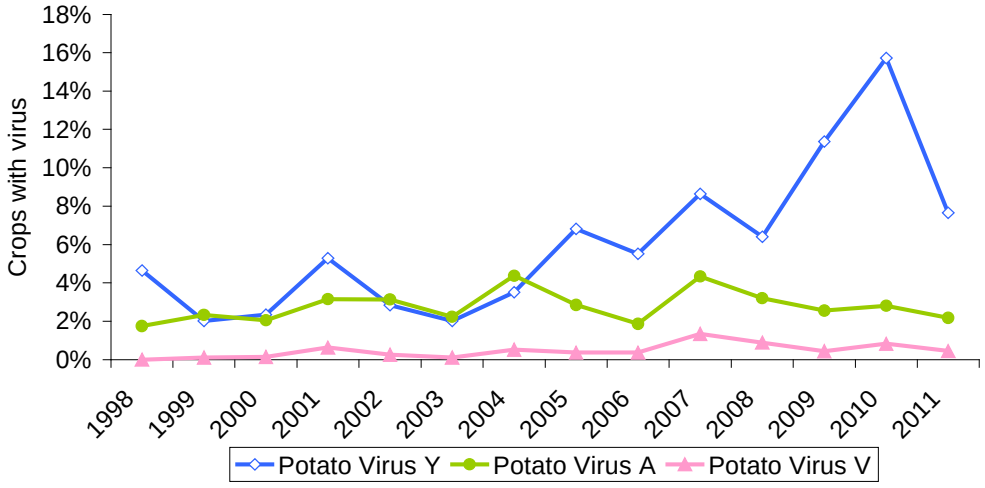
- Development of an alternative model for PVY transmission based on the Yorkshire model using yellow water trap catch data for *M. persicae,* incorporating the effects of other species (*A. fabae, H. lactucae, S. avenae* and *M. dirhodum).*

1. INTRODUCTION

The information in this section summarises the state of knowledge at the start of the project with respect to virus transmission in seed potato crops.

Background

By area, approximately 13.4% (16,293 hectares) of potatoes grown in GB in 2012 were seed potatoes. The majority of these were grown in Scotland, with nearly half of the rest in northern England. One of the major threats to the growers of these crops is the transmission of viruses by aphids. The viruses may be persistent (*e.g.,* Potato Leaf Roll Virus; PLRV) or non-persistent (*e.g.,* potyviruses such as PVY, PVA). The latter are transmitted immediately after aphids have fed on an infected plant. Non-colonising aphid species, that do not use potato as a host but alight on potato plants and probe the leaves, can transmit potyviruses. They tend to be more active in the crop than the colonising aphids (De Bokx and Piron, 1990) and can be far more numerous than colonising species. One school of thought suggests that there is a very quick loss of the ability to transmit a non-persistent virus and the risk of aphids arriving into the crop carrying infectious virus is relatively low. However, long-distance movement of potyviruses can only be explained if the virus remains intact on an aphid stylet for hours. By preventing infectious aphids from probing any surface, Berger *et al*. (1987) demonstrated that infectious potyvirus particles (maize dwarf mosaic virus) can be retained on an aphid stylet for 18 – 21 hours. Therefore, an alata (winged form) of any species which flies directly from an infected potato plant to a healthy potato plant could be considered a threat. In the case of potyviruses affecting potato crops, cereal aphids are non-colonising aphids able to transmit the viruses. However, as they are unable to colonise and reproduce on the crop, it is the alatae (winged forms) that are the vectors, leading to little chance of transmission by apterae (wingless forms). Potato Leafroll Virus (PLRV) has become less prevalent and is relatively well understood from an epidemiological perspective and was not considered in this project. Instead the work focussed on potyviruses. These cause mosaic symptoms and the estimated incidence of aphid transmitted viruses causing mosaic symptoms in Scottish seed potatoes (1998-2011) is provided below:



Potyvirus inoculum sources

Potyviruses decrease the yield of potato plants (Nolte *et al.*, 2004). The quality of seed is determined by the levels of virus present and this should be as low as possible. Sources of virus infection could be the seed crop itself (except for virus free pre-basic crops), plants (ground keepers) arising from tubers left over from previous seasons in and around the crop; from potato plants (volunteers) arising from true potato seed; ware crops; and a limited number of weed species. Work carried out at SCRI in 1996 suggested that groundkeepers were the most important field source of PVY (Jones *et al.,* 1996). The study comprised an analysis of PVY infection in ware fields of the cultivar Record. The study established that,

while input seed was essentially virus free, many crops became infected through local groundkeepers. In 1994, four crops started with no detectable PVY. Despite this, samples from the four crops at the end of the season contained 2, 36, 38 and 52% PVY, respectively. The fields were monitored the following year and the presence of infected groundkeepers was evident and the infection level reflected the levels found in the harvested crop the year before. The study also suggested that only one perennial weed (*Solanum nigrum*) could act as a virus source but this weed was not widespread.

Factors influencing potyvirus transmission
Genetic variation is an important factor influencing the transmission of potyviruses. In the plant, different potato cultivars differ in virus susceptibility and may be more or less vulnerable to virus transmission and acquisition at different times. Potato plants become resistant to virus infection as they mature and as infected plants approach senescence they will become less suitable as aphid hosts. The potyviruses themselves will accumulate mutations which could alter their properties. As described elsewhere in the report, different aphid species will transmit potyviruses with different efficiencies (ie they have different Relative Efficiency Factor values), but even within aphid species different clones can vary in their rates of transmission. An example of the extent of variation in PVY transmission within Greek *M. persicae* genotypes has been described by Kanavaki and Margaritopoulos (2006). They found that variation from the best (33.8%) to the worst transmitting genotype (17%) was a factor of 0.5. As a result the current study has included a range of clones for each aphid genotype.

Minimising potyvirus transmission
Control of potyviruses is difficult because acquisition and inoculation of potyviruses can both occur in seconds, well before many pesticides can take effect. In some other countries mineral oils are used to minimise potyvirus spread. The impact of mineral oil use on virus transmission is the subject of a separate Potato Council-funded study which began in 2011 and is not reported here.

2. MATERIALS AND METHODS

Objective 1: identify the most important potyvirus vector aphids using a combination of laboratory, glass house and field studies

2.1. Virus Transmission: Aphid Relative Efficiency Factors (REFs)

Previously Netherlands researchers had published results of a study to determine REFs for some of the 23 species of aphid reported to be capable of transmitting PVY in the Netherlands (Verbeek *et al*., 2010). Researchers from this GB study met with the Netherlands researchers and agreed the most appropriate methods for the GB virus transmission studies, so that results from the two studies would be comparable.

2.1.1. Virus Strains, Isolates

Two potyviruses were studied during this project: PVY and PVA. There are different strains of PVY recognised. Throughout this report where PVY is referred to without a superscript, it refers generally to all the PVY strains. An explanation of the superscripts used is provided in Table 1.

In virology, strains of virus are members of a virus species with differing but distinct characteristics. Traditionally these have been based on biological (host range or symptomology) or biochemical properties (antibody/coat protein specificity) (Hull, 2002). More recently with advances in genome sequencing, there have been moves to define strain differences at the molecular level. The amount of divergence at the genomic level to the type

strain of a species before a strain is considered a new species will be dependant upon the species/family of viruses and the location of the genetic differences in the viral genome.

A virus isolate is a sample of viable virus which has been 'isolated', *i.e.* taken from its original host plant and allowed to replicate in an alternate host. In some cases these will be 'true' isolates, where the virus sample has been passaged through a partially susceptible 'local lesion' host, with a single lesion being excised and the virus from that lesion being passaged on multiple occasions. The generation of 'single lesion isolates' was originally the only way of purifying virus populations. In some cases the isolates used in previous studies were not single lesion isolates, but had been host range characterised on potato as well as on the basis of genetic sequence to give known 'strain type' isolates.

The virus isolates used in this study were obtained from the SASA virus infected plots collection (‘DV’ potato plots), where a range of virus isolates are maintained in the field. These are field grown, secondarily infected tubers. Potato plants are grown from infected tubers and checked for viral infection using Enzyme-Linked Immunosorbent Assay (ELISA) prior to experimental work being carried out.

Table 1. Virus strains/isolates and the corresponding abbreviations used in this report and/or some published studies.

The abbreviations used for PVY isolates are often given additional codes to show that the isolate is a variant from the typical strain. Strains and strain variants are named according to serology, genomic organisation and their biological characteristics including reactions on potato cultivars, potato tubers and on tobacco plants (cv. Samsun or White Burley). Molecular analyses of some PVY^N isolates have shown them to be recombinants of PVY^O and PVY^N. This occurs as a result of exchange of blocks of genetic information between different viruses. The number of "recombinant junctions" varies in different isolates, with the isolates being given different strain names/codes.

Abbreviation used in this report	Definition	Serotype	Biological reaction on tobacco
Strain			
PVY^o ($PVY^{o/c}$)†	PVY Ordinary (PVY^O) or C (PVY^C) strain group. PVY^O is the strain commonly found affecting potato in the UK. PVY^C is rarely found affecting UK potatoes.	PVY^O	Mottle
PVY^N	PVY^N Tobacco veinal necrosis strain group	PVY^N	Veinal Necrosis
Strain Variants			
$PVY^{N\text{-}Wilga}$	PVY^N isolates originally detected in potato cultivar Wilga. This strain variant expresses the coat protein of PVY^O but induces a necrotic reatction on tobacco. (see Chrzanowska (1991)).	PVY^O	Veinal Necrosis
PVY^{NTN} $PVY^{NA\text{-}NTN}$ $PVY^{EU\text{-}NTN}$	PVY^N isolates able to cause Potato Tuber Necrotic Ringspot Disease (necrotic lesions on tubers do not always develop as a result of infection however, some cultivars are particularly prone to develop the symptoms when infected with these isolates). Includes North American ($PVY^{NA\text{-}NTN}$) and European ($PVY^{EU\text{-}NTN}$) isolates (see Singh *et al.*, 2008)	PVY^N	Veinal Necrosis

† Where antibody-based (serological) tests (*e.g.,* ELISA) are used to determine which viruses are present it is not possible to discriminate between PVY^O and PVY^C and the abbreviation $PVY^{o/c}$ is used. However, as there is little/no PVY^C to be found, certainly in potato in GB, for the purposes of this report the abbreviation PVY^O is used.

Like PVY, *Potato Virus A* (PVA) is a non-persistently transmitted potyvirus. There are 4 recognised strain groups of PVA which are classified on the basis of their biological and physical properties e.g. symptomatic reaction in potato and/or other hosts; thermal inactivation point and dilution end-point (AAB Descriptions of Plant Viruses: www.dpvweb.net). There is a lack of published data on the genomic characterisation of PVA strains. The strains used in this work were taken from a single Scottish field stock of cv. Desiree (SASA virus-infected plots collection) which had exhibited a range of symptoms, suggesting the presence of more than one strain of virus. These PVA isolates were labelled

'severe' and 'mild' on the basis of symptom differences generated through several passages through potato and alternate hosts. During this work it became apparent that only PVA ‘mild’ retained aphid transmissibility and so results are only presented for that PVA strain.

2.1.2. Aphid Populations and Culturing

Aphid populations (Table 2) were collected from the wild where possible and backed up with populations from cultures held at several of the project partners’ institutes. Single aphids were used to begin clonal cultures for use in the experiments.

Table 2. Clonal aphid cultures. Shaded rows indicate aphid clones that did not survive in culture long enough for testing to take place.

Aphid Species	Clone	Origin	Original Host	Culture Host
Acyrthosiphon pisum	clone 1	Rstd culture	Bean	Bean
	clone 2	Fera culture	Bean	Bean
	clone 3	N Yorks	Peas	Bean
Aphis fabae	clone 1	N Yorks	Nasturtium	Bean
	clone 2	England	not recorded	Bean
	clone 3	N Yorks	Bean	Bean
Brevicoryne brassicae	clone 1	N Yorks	B. Sprouts	Cabbage
	clone 2	N Yorks	Cabbage	Cabbage
Cavariella aegopodii	clone 1	N Yorks	Hogweed	Chervil/carrot
	clone 2	N Yorks	Hogweed	Chervil/carrot
	Clone 3	N Yorks	Hogweed	Chervil/carrot
Macrosiphum euphorbiae	me1	JHI culture	Potato	Aubergine
	me3	JHI culture	Potato	Aubergine
	me4	JHI culture	Potato	Aubergine
Metopolophium dirhodum	clone A	North Yorks	Winter wheat	Winter wheat
	clone B	North Yorks	Rose	Winter wheat
	clone C	North Yorks	Rose	Winter wheat
Myzus persicae	B	Rstd culture	OSR	OSR
	D	JHI culture	Potato	Aubergine
	E	JHI culture	Potato	Chinese cabbage
	MP2 (control)	Wageningen culture	Chinese cabbage	Chinese cabbage
Rhopalosiphum padi	1	Fera culture	Winter wheat	Winter wheat
	2	N Yorks	Winter wheat	Winter wheat
	3	Shropshire	Winter wheat	Winter wheat
Sitobion avenae	11	N.Yorks	Winter wheat	Winter wheat
	N	Northants	Winter wheat	Winter wheat
	E	Lincs	Winter wheat	Winter wheat
Drepanosiphum platanoides	A	N Yorks	Sycamore	Sycamore
	B	N Yorks	Sycamore	Sycamore
Hyperomyzus lactucae	A	N Yorks	Sowthistle	Sowthistle
	B	N Yorks	Sowthistle	Sowthistle
	C	N Yorks	Sowthistle	Sowthistle
	D	N Yorks	Sowthistle	Sowthistle
Microlophium carnosum	1	N Yorks	Nettle	Nettle
	2	N Yorks	Nettle	Nettle

2.1.3. Determination of aphid transmission efficiencies

Fifty aphids of the control *Myzus persicae* (MP2) and 50 aphids of the aphid species/clone being tested were collected for each of the five viruses. The aphids were starved for 2 hours. One leaf was collected from each virus infected potato plant. Two leaflets were taken from this leaf and the rest of the leaf was kept for virus testing. Fifty *M. persicae* were allowed to feed on one leaflet and 50 of the test species were fed on the other leaflet for 2.5 minutes. Each aphid was transferred onto an individual *Physalis floridana* or *Nicotiana hesperis* plant (cotyledon stage) depending on the virus and covered with a tube to prevent it from escaping. *Physalis floridana* was used for tests for transmission of PVY^{O}, PVY^{N} and PVY^{NTN} and *N. hesperis* was used for tests for transmission of PVA mild and strong strains. The tubes were removed after 24h and the aphids killed by spraying the plants with Bug Clear Ultra (0.05% acetamiprid), following the manufacturer's instructions. The plants were visually inspected for virus symptoms after seven days and again after 14 days. The plants were ELISA tested for the viruses at or closely after 21 days. The methods relating to the ELISA are described in section 2.7.This procedure was repeated for each clone (biotype) of each aphid species.

The REF of each aphid biotype was calculated according to Verbeek *et al.* (2010). That is: the number of infected plants inoculated by the biotype was divided by the number of infected plants inoculated by the internal control (MP2):

$$\text{REF (biotype)} = \frac{\text{Number of infected plants (biotype)}}{\text{Number of infected plants (MP2)}}$$

The REF for *M. persicae* as a species was calculated as the average of four *M. persicae* clones (MP2, B, D, E) for each of the PVY isolates used. This average was subsequently used as a correction factor to set the REF to 1.00 for the species *M. persicae* for each of the PVY isolates.

$$\text{REFcorr.(biotype)} = \frac{\text{REF(biotype)}}{\text{Correction factor}}$$

For the different PVY strains, the overall REF for each aphid species [REF (species, PVY strain)] was calculated from the average of the corrected REFs [REFcorr. (biotype)] determined for the available biotypes of a species and the different isolates per PVY strain.

The PVY strains studied were: PVY^{N}; PVY^{O}; PVY^{NTN}. Two PVA strains 'strong' and 'mild' were studied. Shortly after the tests began it was found that the PVA 'mild' strain was not aphid transmissible therefore no further tests were carried out using this strain and results for the PVA 'mild' strain are not presented in this report.

2.2. Epidemiology Field Trials

A field trial design proven to be an effective means of measuring the timing of non-persistent, aphid-borne virus transmission in the field was used in conjunction with yellow water trap and suction trap data to determine which aphid species were active during the time of PVY and PVA transmission.

As this project began in July 2009, it was not possible to establish trials in time for the 2009 growing season. Trials were established at three sites in both the 2010 and 2011 growing seasons. The sites were Fera (East Lutton, Yorkshire); SASA (Edinburgh); and Scottish Agronomy (Fife).

At Fera and SASA, two trials were planted adjacent to each other in both 2010 and 2011. The trials measured the timing of transmission of PVY or PVA. The PVY trials were planted

with Maris Piper and the PVA trials were planted with Estima. At Scottish Agronomy, two trials to measure the timing of transmission of PVA were planted adjacent to each other in both 2010 and 2011. The trials were planted with Estima or Desiree.

Each trial comprised 360 pre-basic (virus free) seed potatoes, planted at a commercial planting rate, extending 15 tubers each side of a single infector row (16 drills wide) (Figure 1). Within the plot, blank drills were left for the placement of potted tobacco (*Nicotiana debneyi*) bait plants. Each week throughout the growing season, 48 pots, double potted with 3-week old tobacco bait plants were placed out in blank drills. Pots were labelled to allow the exact placement of each pot and plant to be recorded for future reference. These bait plants were propagated in an insect free environment until they were three weeks old before being placed in the field and exposed to virus transmission pressure for one week. The plants were then removed to the glasshouse; fumigated to kill any aphids and therefore prevent further spread of virus; grown on for a further three weeks; and then tested by ELISA for the presence of common aphid transmitted viruses. At the end of each trial the position of infected potato plants in each plot was determined by post-harvest testing of 3 tubers from each plant in every plot.

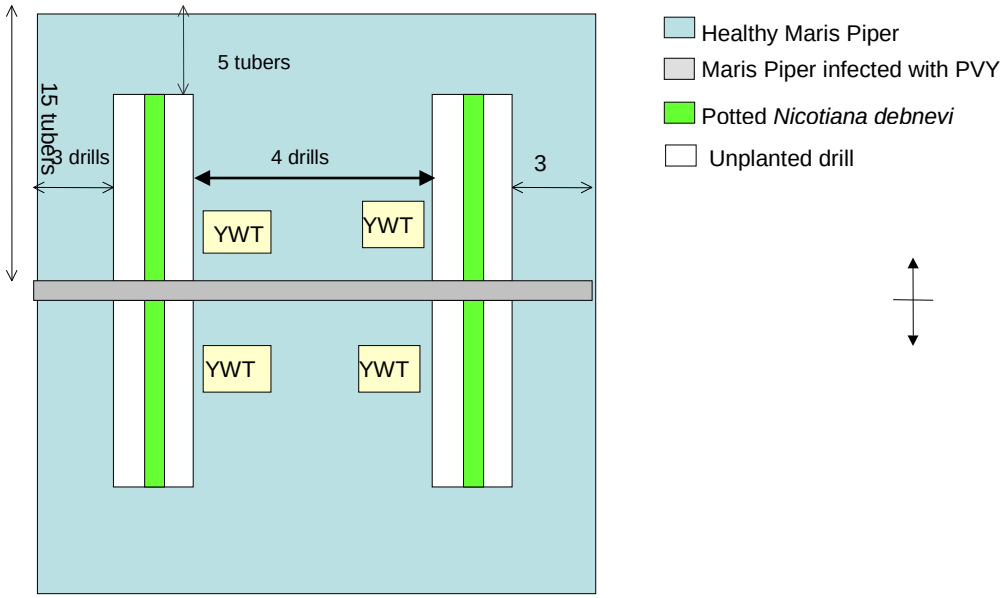
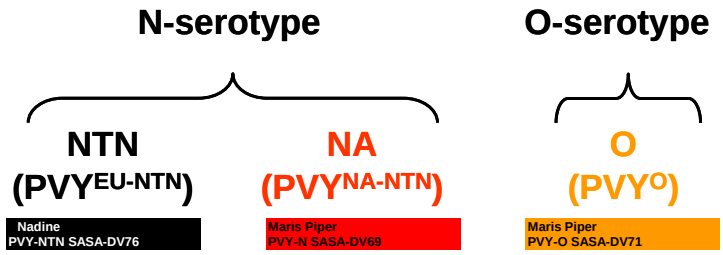


Figure 1. Layout of typical field epidemiology trial

At Fera, each plot measured 10 m x 16 drills, with an inoculum rate of 4.4% (i.e. 16 infector plants to 360 plot plants). This is slightly greater than the level permitted in the progeny of basic seed. In both years the surrounding field was planted with cv. King Edward. These potatoes were shown to also contain both PVY^{N} and PVY^{O} through ELISA testing of symptomatic plants.

At the Scottish Agronomy site, each plot measured 10 m x 16 drills, with an inoculum rate of 3.2%. The monitoring and other aspects of the experiment were as those described for the Fera site.

At SASA a modified plot layout was used to assess the transmission efficiencies of three different PVY isolates (PVY^{NA-NTN}; PVY^{EU-NTN}, and PVY^{O} serotype). This plot measured 10 m x 21 drills and a total of 450 pre-basic Maris Piper bait plants with an inoculum rate of 4.5% infection for PVY and 1.5% for each individual PVY^{EU-NTN}, PVY^{NA-NTN} and PVY^{O} isolate (Figure 2).



225	210	195	180	175	170	165	150	135	120	115	110	105	90	75	60	55	50	45	30	15
224	209	194	179	174	169	164	149	134	119	114	109	104	89	74	59	54	49	44	29	14
223	208	193	178	173	168	163	148	133	118	113	108	103	88	73	58	53	48	43	28	13
222	207	192	177	172	167	162	147	132	117	112	107	102	87	72	57	52	47	42	27	12
221	206	191	176	171	166	161	146	131	116	111	106	101	86	71	56	51	46	41	26	11
220	205	190	A12		G12	160	145	130	E10		K10	100	85	70	B12		H12	40	25	10
219	204	189		N		159	144	129		N		99	84	69		N		39	24	9
218	203	188		I		158	143	128		I		98	83	68		I		38	23	8
217	202	187	YWT	C		157	142	127	YWT	C		97	82	67		C	YWT	37	22	7
216	201	186		O		156	141	126		O		96	81	66		O		36	21	6
215	200	185		T		155	140	125		T		95	80	65		T		35	20	5
214	199	184		I		154	139	124		I		94	79	64		I		34	19	4
213	198	183		A		153	138	123		A		93	78	63		A		33	18	3
212	197	182		N		152	137	122		N		92	77	62		N		32	17	2
211	196	181	A1	A	G1	151	136	121	E1	A	K1	91	76	61	B1	A	H1	31	16	1
21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1
436	421	406	C1		I1	376	361	346	F1		L1	316	301	286	D1		J1	256	241	226
437	422	407		D		377	362	347		D		317	302	287		D		257	242	227
438	423	408		E		378	363	348		E		318	303	288		E		258	243	228
439	424	409		B		379	364	349		B		319	304	289		B		259	244	229
440	425	410	YWT	N		380	365	350	YWT	N		320	305	290		N	YWT	260	245	230
441	426	411		E		381	366	351		E		321	306	291		E		261	246	231
442	427	412		Y		382	367	352		Y		322	307	292		Y		262	247	232
443	428	413		I		383	368	353		I		323	308	293		I		263	248	233
444	429	414				384	369	354				324	309	294				264	249	234
445	430	415	C12		I12	385	370	355	F10		L10	325	310	295	D12		J12	265	250	235
446	431	416	401	396	391	386	371	356	341	336	331	326	311	296	281	276	271	266	251	236
447	432	417	402	397	392	387	372	357	342	337	332	327	312	297	282	277	272	267	252	237
448	433	418	403	398	393	388	373	358	343	338	333	328	313	298	283	278	273	268	253	238
449	434	419	404	399	394	389	374	359	344	339	334	329	314	299	284	279	274	269	254	239
450	435	420	405	400	395	390	375	360	345	340	335	330	315	300	285	280	275	270	255	240

Figure 2. Layout of PVY epidemiology trial at SASA (infectors of three different PVY isolates (PVY^{O}, PVY^{EU-NTN}, PVY^{NA-NTN}) are distributed along the central row as previously mentioned).

To replicate all trials as closely as possible, all sets of infectors were sourced through SASA. In all sites similar infectors PVY^{N}, PVY^{O} and PVA were used. These were: PVY^{O}; PVY^{NA-NTN} in the variety Maris Piper; PVY^{EU-NTN} in Nadine (used in the SASA trial); and PVA in the variety Desiree or Estima. Healthy, virus free, pre-basic Maris Piper, Estima and Desiree tubers were obtained through the same commercial source.

At each location, yellow water traps were set up (6 in the PVY plot, 4 in the PVA plot) and emptied weekly. In addition, one CSL aphid trap (http://www.potato.org.uk/online-toolbox/aphid-monitoring) was included in each of the SASA plots. The winged aphids within each trap were identified. Comparable data sets are available from the Gogarbank, Dundee and Askham Bryan suction traps.

The Fera trials were planted on 19 May (2010) and 26 April (2011), respectively to coordinate with local seed potato planting. Bait plants and yellow water traps were placed in the trial at around 50% emergence of the plots (9 June and 2 June, respectively). Similar emergence was observed across infectors and healthy potatoes in both plots (Desiree/PVA and Maris Piper/ PVY^{NA-NTN}).

The Scottish Agronomy trials were planted on 28 April (2010) and 2 May (2011), respectively. Bait plants and yellow water traps were placed in the trial on 27 May (2010) and 25 May (2011) and were maintained until burn-down. Similar emergence was observed across infectors and healthy potatoes in the plot (Desiree/PVA and Estima/PVA).

At SASA's site, the trials were planted on the 4 May (2010) and on 19 of May (2011), respectively. Crop emergence was observed two weeks later (18 May 2010; 31 May 2011) and the first set of tobacco bait plants were laid out in each trial. In both trials, similar

emergence was observed for the different infectors used *i.e.,* Desiree for PVA, Maris Piper for PVY^{O} and $PVY^{NA\text{-}NTN}$ and Nadine for $PVY^{EU\text{-}NTN}$.

Unless specified, diagnosis of viruses in leaves and tubers was undertaken by DAS-ELISA (section 2.7) as previously described (Fox *et al*., 2005). Tubers from each plant were tested in bulks of 3. Assessment of tuber infection rate in Estima and Desiree was effectuated by re-testing individually each of the 3 grown-on plants from all PVA positive bulk. Molecular genotyping of PVY $PVY^{NA\text{-}NTN}$ and $PVY^{EU\text{-}NTN}$ strains in tuber progeny was done as previously described (Davie *et al*., 2012)

Objective 2: develop systems to allow aphid monitoring data to be effectively utilised

2.3. Comparison of methods used to monitor vector aphid populations

Two trapping methods are used for aphid monitoring in Great Britain: suction traps (STs) and yellow water pan traps (YWTs). Potato Council currently funds a network of yellow water traps as part of its Aphid Monitoring in Potato Crops activity (http://www.potato.org.uk/online-toolbox/aphid-monitoring). The British Beet Research Organisation (BBRO) supports the analysis of yellow water trap catches on behalf of sugar beet growers. This involves monitoring of the aphid vectors of sugar beet yellowing viruses. A network of suction traps is co-ordinated by Rothamsted Research and SASA, in England and Scotland, respectively. Suction traps are emptied daily and provide a landscape-scale overview of flight activity of all aphid species. Yellow water traps are emptied weekly and provide a more local overview of aphid activity. Statistical investigations, using standard regression analyses, were conducted on a subset of the available data from suction traps from Broom's Barn, Askham Bryan and Dundee and yellow water traps within 100km of each of these traps to derive relationships between yellow water traps and suction traps for *M. persicae* and *Metopolophium dirhodum*. The aim was to understand if it is possible to optimise the use of the two sources of information and improve the efficiency of aphid monitoring/forecasting of the risk of virus transmission.

An independent assessment (carried out by Bill Hutchinson, University of Minnesota) of the current provision of aphid monitoring data was also completed as part of this objective. Recommendations on future delivery mechanisms were provided (See Appendix 2)

Objective 3: identify sources of potyvirus inoculum and investigate their importance in the spread of virus to seed crops

2.4. Survey of Symptomatic Plants

During the 2009, 2010 and 2011 growing seasons' inspections, a survey of viruses affecting seed potato crops was conducted by sampling plants affected by mosaic symptoms.

In England and Wales (2009, 2010), samples submitted to the Fera laboratory were tested by ELISA for PVY^{N}, $PVY^{O/C}$, PVA, PVV, PVM, PVS and PVX. Although PVX is not an aphid transmitted virus the mosaic symptoms induced by this pathogen can be similar to mosaics caused by other viruses.

In Scotland (2009, 2010, 2011), samples submitted to SASA were tested by ELISA for PVY^{N}, $PVY^{O/C}$, PVA, PVV, PVM, PVS, PVX, PLRV, TRV, PMTV, TBRV for a maximum of 6 samples per crop.

As the samples were screened using ELISA these data are based upon the serotypes of virus that were present. Data presented on PVY has been separated into PVY^{O} and PVY^{N} on this basis. Due to the nature of PVY recombination there will be strain variants included within these serotype groups. Most notably the PVY^{O} serotype will include both PVY^{O} types and $PVY^{N\text{-}Wilga}$ variants; PVY^{N} will include true PVY^{N} as well as several PVY^{NTN} variants. (Table 1) gives a fuller explanation of the PVY strains and strain variants commonly found within UK potato crops.

In each the year the approximate number of leaf samples submitted for testing were:
2009: 350 (England) and 1,500 (Scotland)
2010: 508 (England & Wales) and 1,726 (Scotland)
2011: 887 (Scotland)

The samples were submitted for testing to support the classification inspection and were usually accompanied with a specific testing request. However, when a non-persistent aphid transmitted virus was detected the sample was included within the survey.

Samples were taken from the following number of seed potato crops.
2009: 209 (England) and 664 (Scotland)
2010: 258 (England) and 684 (Scotland)
2011: 443 (Scotland)

The survey of symptomatic plants was designed to look at mosaic causing viruses. In focusing on gathering isolates from symptomatic plants, the survey was not representative of viruses causing latent or symptomless infection. Primary (current season) infections are also under represented. Several viruses have also been omitted from the survey. Infection with *Potato Leaf Roll Virus* can be accurately determined by observable symptoms, therefore, the incidence of this virus in the crop can be calculated from inspection returns.

2.5. Analysis of SSPCS data

Datasets collected by Scottish Government Rural Payments and Inspections Directorate (inspectors of seed potato crops) and maintained within SASA's Seed Potato Classification Scheme for the years 2008, 2009 and 2010 were analysed. The data include faults found during crop inspection of growing crops. Depending on the crop growth, crop inspections (first, second and where necessary third inspections) are usually carried out in July. The faults that are recorded include percentage of rogues; groundkeepers; mosaic symptoms; outcome of yearly virus leaf-testing surveys; and compulsory post-harvest testing of tuber samples. Additional data on the causative virus for mosaic symptoms is provided by SASA's Virology Laboratory where leaf samples submitted during inspection from the majority of crops exhibiting mosaic symptoms are tested by ELISA for the 11 potato-infecting viruses (see 2.4 above).

2.6. Survey of potential sources of virus inoculum and aphids potentially carrying potyviruses

During the three years of the project (2009, 2010, 2011) samples of ground keepers, ware crops and aphids were taken and tested for the presence of potyviruses. In addition, two more detailed case studies were carried out in 2009 and 2011, respectively. In 2009, a high health seed farm in the Aberdeenshire area was studied. Yellow water traps were used to monitor for the presence of aphid vectors and fields on the farm were surveyed for groundkeepers. In 2011, a farm in Angus was studied. This represented a high health seed

farm closer to ware producing areas, than the farm in Aberdeenshire, and it was used to study the factors that contribute to differences in the rate of horizontal transmission of potyviruses (*i.e.,* parental material is free of virus symptoms but they occur in the daughter crop- so infection is assumed to have occurred sometime during the parental crop growing season).

2.6.1. Groundkeepers

During the three years of the project groundkeepers were inspected or analysed in detail in almost 80 fields. The sampling included areas in the north as well as fields in Angus, Fife and Perthshire. The locations of the fields sampled are summarised in Table 3 below. The selection of sites was informed by the analyses of SSPCS sister stock data. This identified areas in which horizontal transmission rates were higher or lower than the overall average.

Location	Number of fields where groundkeepers were sampled		
	2009	2010	2011
Aberdeen	16	5	18
Angus	2	32	28
Fife	6	7	
Perthshire	2	5	
Roxburgh		1	

Table 3. Number and location of fields where samples of groundkeepers were collected.

2.6.2. Standardised protocol for virus sampling in potato groundkeepers

A standardised sampling procedure was developed for the collection of leaf material from potato groundkeepers. In each field a 100m distance in a transect or along a tramline in a cereal crop (1.8 m wide) was walked and the number of groundkeepers recorded. This was repeated four times in each field in different locations. Symptomatic or asymptomatic plants were chosen randomly and 3 to 4 leaves from top-middle-bottom of each plant collected. The 3 to 4 leaves from an individual plant were pooled into individual Bioreba bags for testing (counted as one sample). A total of 92 to 100 samples were collected per field. Initially samples of 100 were used but later 92 samples were used (as this corresponds to two ELISA plates (46 wells x 2)). Variety identification was conducted where possible using morphological characteristics. Samples were sent to SASA for ELISA tests.

2.6.3. Sampling other potential inoculum sources

In 2009, samples of ware crops, seed crops and weeds around potato crops were made from locations in Angus, Fife and Perthshire. In each field symptomatic or asymptomatic plants were chosen randomly and leaves were taken from three separate stems (top, middle and bottom) and placed into Bioreba bags for subsequent testing. The leaves from an individual plant were pooled into individual Bioreba bags for testing (counted as one sample). A total of 92 samples were collected per field.

In 2010, samples of potato ware crops (including crops from once grown seed) were taken. In each field symptomatic or asymptomatic plants were chosen randomly and 3 to 4 leaves from top-middle-bottom of each plant collected. The 3 to 4 leaves from an individual plant were pooled into individual Bioreba bags for testing (counted as one sample). A total of 92 samples were collected per field.
In 2011, samples of groundekeepers were taken. In each field where groundkeepers were recorded, symptomatic or asymptomatic plants were chosen randomly and 3 to 4 leaves

from top-middle-bottom of each plant collected. The 3 to 4 leaves from an individual plant were pooled into individual Bioreba bags for testing (counted as one sample). A total of 92 samples were collected per field.

2.6.4. 2009 Study of a high health seed farm in Aberdeenshire

A field of Maris Piper was selected for monitoring for aphid activity (GR NJ 669365). Four YWT's were established at emergence (mid June) in or adjacent to the field. On the south border of the field was a bank of coniferous trees and one trap was sited within this bank of trees. A second trap was placed at the field margin and two further traps 10 and 50m into the crop. All four traps were in a line. Samples from each trap were retrieved from each trap weekly and sent to Fera for aphid identification.

In mid-July almost all fields, two deep, surrounding the Maris Piper field were monitored for the presence of groundkeepers. This was achieved by walking crop tramlines around the edge of the field and at least two tramlines across each field. Where the field was in grass, a cursory walk was made in the field as these were all cut or grazed. A record was made of the constitution of field boundaries in case they would influence aphid movement. Only one field growing oilseed rape was not monitored as it proved impossible to walk through it.

Groundkeepers were sampled on the 5th August 2009. Three 200m x 1m sampling areas were marked out in each field. These sampling areas were distributed across the whole field in order to ensure a representative sample was obtained from each field. The total number of groundkeepers in each 200m x 1m sampling area was counted. If symptoms of virus infection were observed on the volunteer plants, one leaflet was sampled from four compound leaves on the affected stem. For healthy looking plants, one leaflet was sampled from four separate compound leaves on separate stems of the plant. The four leaflets were then placed into the back of a Bioreba homogenisation bag (Bioreba, AG, Switzerland). ELISA tests were carried out on the samples. A total of 100 groundkeepers were sampled from each field.

2.6.5. 2011 Study of a high health seed farm in Angus

In 2011, a pre basic farm in Angus was selected for study. The grower typically grows 25ha Pre Basic seed; 50 ha SE seed; and 25ha Hermes ware. The Pre Basic 2-4 pass rate in the period 2008-2010 had been low at 68%, 63% and 62%, respectively. The cause in the main was identified as Mild Mosaic. Fields in the vicinity of the 2011 seed crop, that were known to have been used to grow potatoes in previous years, were visited in June 2011 (and were assessed for the numbers of groundkeepers). Samples of groundkeepers (92 per field) were taken at random for virus testing. The SPUDS database was then utilised in combination with the laboratory results of virus testing to assess the location of the current seed crop in relation to the location of fields where groundkeepers had been found. This analysis was carried out for all of the available fields.

2.7. Double antibody sandwich enzyme-linked immunosorbent assay (DAS-ELISA)

Leaf samples were tested for potato viruses using the double antibody sandwich enzyme-linked immunosorbent assay (DAS-ELISA) method as previously described (Rajamaki *et al.,* 1998). Five ml of leaf extraction buffer (0.01M PBS (pH 7.4) containing 0.05% Tween-20, 2% Polyvinylpyrrolidone (PVP) MW 40,000 (Sigma)) was added to the bag and the leaflets were ground using a Homex 5 homogeniser (Bioreba AG, CH). A further 5ml of leaf extraction buffer was added to the bag after maceration.

Two hundred microlitres of the homogenised samples were added to the wells of microtitre plates that had been pre-coated with a PVA-specific monoclonal or PVY polyclonal antibody

at 1µg/ml. Each sample was analysed in duplicate. Leaf samples from positive and negative control material were also added to each plate. Following an overnight incubation at 4°C, plates were washed with 0.1M PBS containing 0.5% Tween-20. A PVA or PVY-specific alkaline phosphatase conjugate was added to each well at 250µl/ml and plates were incubated for a further 2 hours at 37°C. Plates were then washed three times with 0.1M PBS containing 0.5% Tween-20 prior to the addition of substrate. Wells were loaded with 200µl of p-nitrophenyl phosphate substrate (1mg/ml) and plates were incubated at room temperature in the dark for 1 hour to allow colour development.

Plates were read using a microplate reader (ThermoFisher, UK) at absorbance λ_{405nm}. Absorbance at λ_{620nm} was also measured as a reference to eliminate background absorbance. Samples were deemed to be positive when the mean OD values were greater than twice that of the negative controls.

2.8. Long term rotation experiment and collection of aphid samples for the analysis of the presence of potyviruses

At the JHI site, an experimental field has been divided into four and quadrants used to rotate three crops which include potato and an area of fallow which is sprayed with herbicide and follows the potato (see Table 4). This allows groundkeepers to build up in different crops, facilitating their study in different conditions.

Table 4. – History of rotation in JHI experimental field

Year	Quadrant NE	Quadrant SE	Quadrant SW	Quadrant NW
2011	Potato (Estima SE1)	Barley	Swede	Fallow
2010	Barley	Swede	Fallow (No herbicide)	Potato (Estima, M piper, Desiree, all PB)
2009	Swede	Fallow	Potato (Estima, PVA+)	Barley
2008	Fallow	Potato (Estima, PVA+)	Barley	Swede
2007	Potato (M. Piper, SE1)	Barley	Swede	Fallow
2006	Barley	Swede	Fallow	Potato (M. Piper, SE1)
2005	Potato (Desiree, SE1)	Fallow	Potato (Desiree, SE1)	Barley
2004	Grass/Clover	OSR	Barley	Potato (M. Piper SE1)
2003	OSR	Barley	Potato (M. Piper, SE1)	Grass/Clover
2002	Barley	Potato (M. Piper, SE1)	Grass/Clover	OSR
2001	Potato (M. Piper, SE1)	Grass/Clover	OSR	Barley

2.8.1. Analysis of plant samples

Reverse Transcriptase PCR (RT-PCR; modified from Singh 1998) was used for analysing virus in the potato plots and groundkeepers at JHI and all weed samples. This technique is more sensitive than ELISA and precautions were made to avoid cross contamination during sampling of leaves. This included sterilising scissors and forceps with bleach between samples. Leaf material was collected from top, middle and bottom leaves. Once leaf tissue had been collected, it was frozen until it could be extracted. The leaf extraction used a simple one step detergent extraction method based on the detergent TWEEN (Singh, 1999). Pooling of samples was carried out. For example, a batch of 100 plant samples would be extracted separately, but an aliquot was combined with others to make 10 groups of 10 for subsequent RT-PCR. After the initial test where for example, two groups were positive, these groups were then analysed as individual plants. Thus 100 plants are screened in 30 reactions. This increased the cost effectiveness of screening large numbers of plants for low levels of virus.

Two additional field experiments were carried out in 2010, one at the JHI site and a smaller variant at the Scottish Agronomy field site. These looked at the impact on virus transmission of mixing different potato varieties together in close proximity. The hypothesis was that growing the less PVA susceptible Maris Piper alongside the very PVA susceptible varieties Desiree and Estima could protect them from infection in a similar way to cereal barrier crops. The field at the Scottish Agronomy site had a very small plot size with the target area being plots of 5 x 5 (25 plants), surrounded by 56 barrier plants further embedded within PVA infectors.

The larger plots at JHI were replicates of 25 by 36 plants, four of Desiree and four of Estima. Between them were larger blocks of Maris Piper (50 x 36). These were set up so that plot ‘A’ received maximum exposure to virus from the PVA infected groundkeepers in the SW plot. From each test block (A to D) ten Desiree and ten Estima plants were analysed. The tests included PCR and post-harvest growing on followed by ELISA. An additional 50 plants from all rows adjacent to the PVA groundkeepers in plot A and the same from plot B were also tested. In total 130 plants were tested by growing on and ELISA and an additional 50 by PCR.

To follow the large scale 2010 experiments, further use was made of the JHI site in 2011 using two sizes of inoculum source within a virus free crop (established from clean stock, but also rogued). These infector plots were designed to produce a numerical relationship, with 49 (7 x 7) and 144 (12 x 12), infected tubers acting as sources of virus. It was hypothesised there would be a numerical relationship, with the area containing approximately three times as many infected tubers producing three times more new infections in the neighbouring clean stock

2.8.2. Collection and analysis of aphid samples

Prior to the start of the project work had been carried out a JHI, with EU funding, to develop techniques to test for the presence of viruses in aphid samples.

During this project, aphids were collected from the field (including the JHI rotations experiment) either alive from plants and Ashby traps, or from YWTs with the same solution as used by farmers but with the addition of the preservative EDTA (500mM). In later work YWT solutions were complemented by the addition of propylene glycol to the standard detergent solution.

Aphids were tested for the presence of PVA using RT-PCR. A similar approach to that described above (analysis of plant samples) was used but the preservation and extraction

used ‘Tripure’ reagent and procedures. It was only practical to analyse aphids in groups and not as individuals.

Objective 4: use any relevant information arising from the project to provide an improved understanding of the Estima-PVA interaction

Data from the vector efficiency factor studies, epidemiology trial and analysis of SPCS data have been considered and used to draw conclusions provided in section 3.2.3

Objective 5: review available literature on the role of insecticides and mineral oils in preventing potyvirus spread and make recommendations for future research

A review of publicly available information was produced and the report and associated recommendations are available from Potato Council. The recommendations are provided in the Results section of this report.

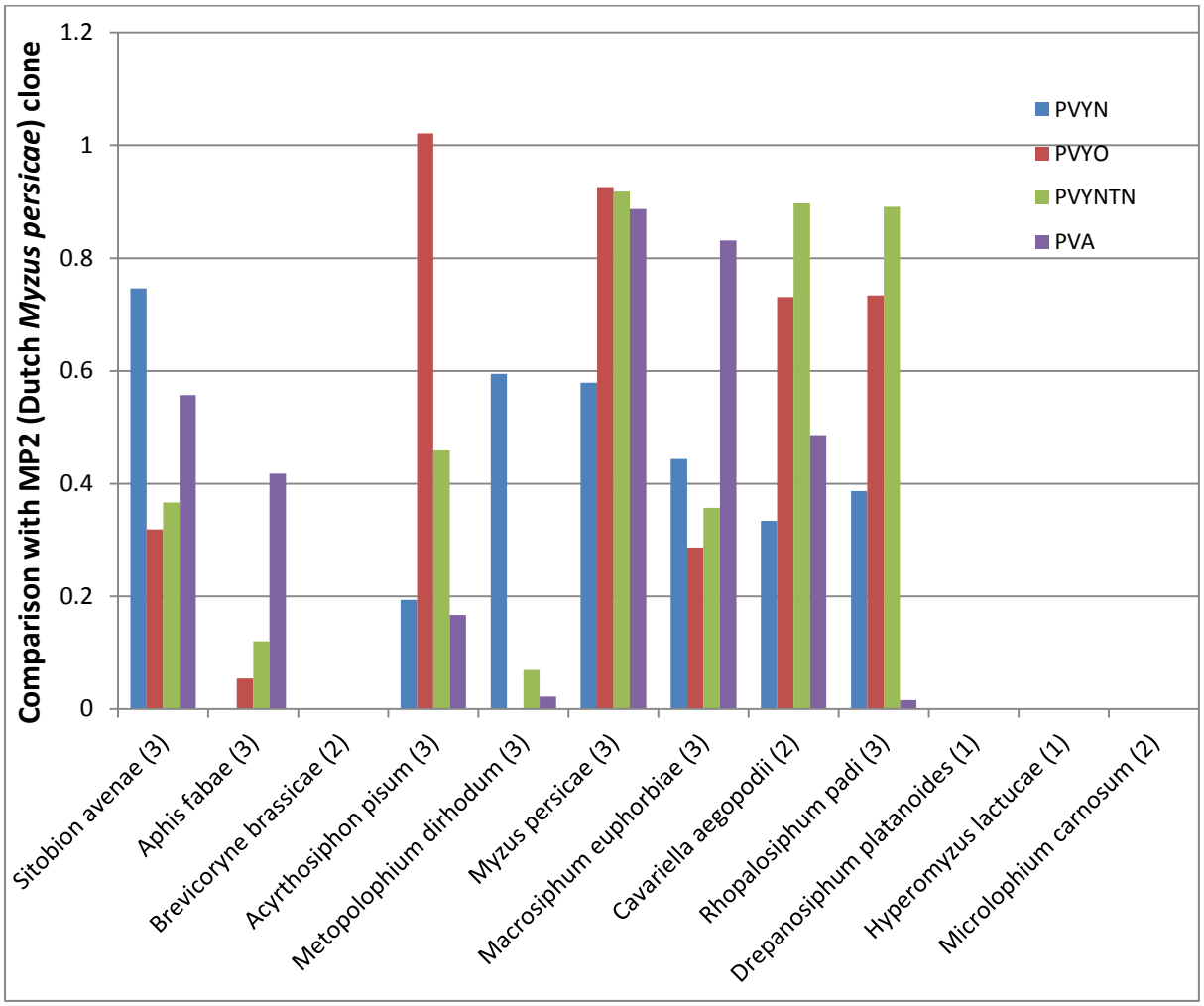
3. RESULTS

Objective 1: identify the most important potyvirus vector aphids using a combination of laboratory, glass house and field studies

3.1. Evaluation of Aphid Relative Efficiency Factors

All clones that were maintained for long enough have been tested. The numbers of infected plants compared with the internal controls (MP2 clone) for each virus or virus strain are shown in Figure 3a & b

3a.



3b.

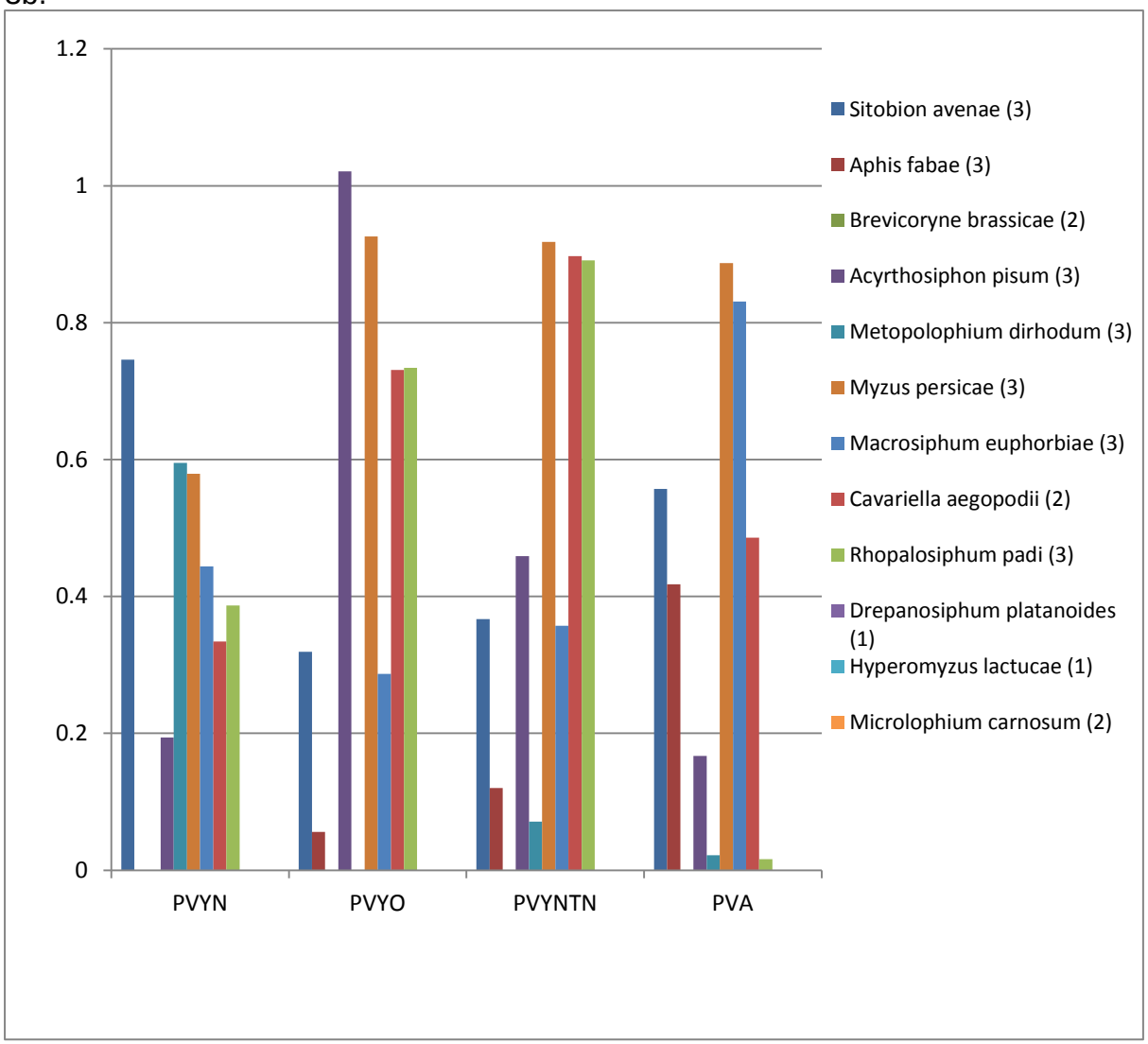
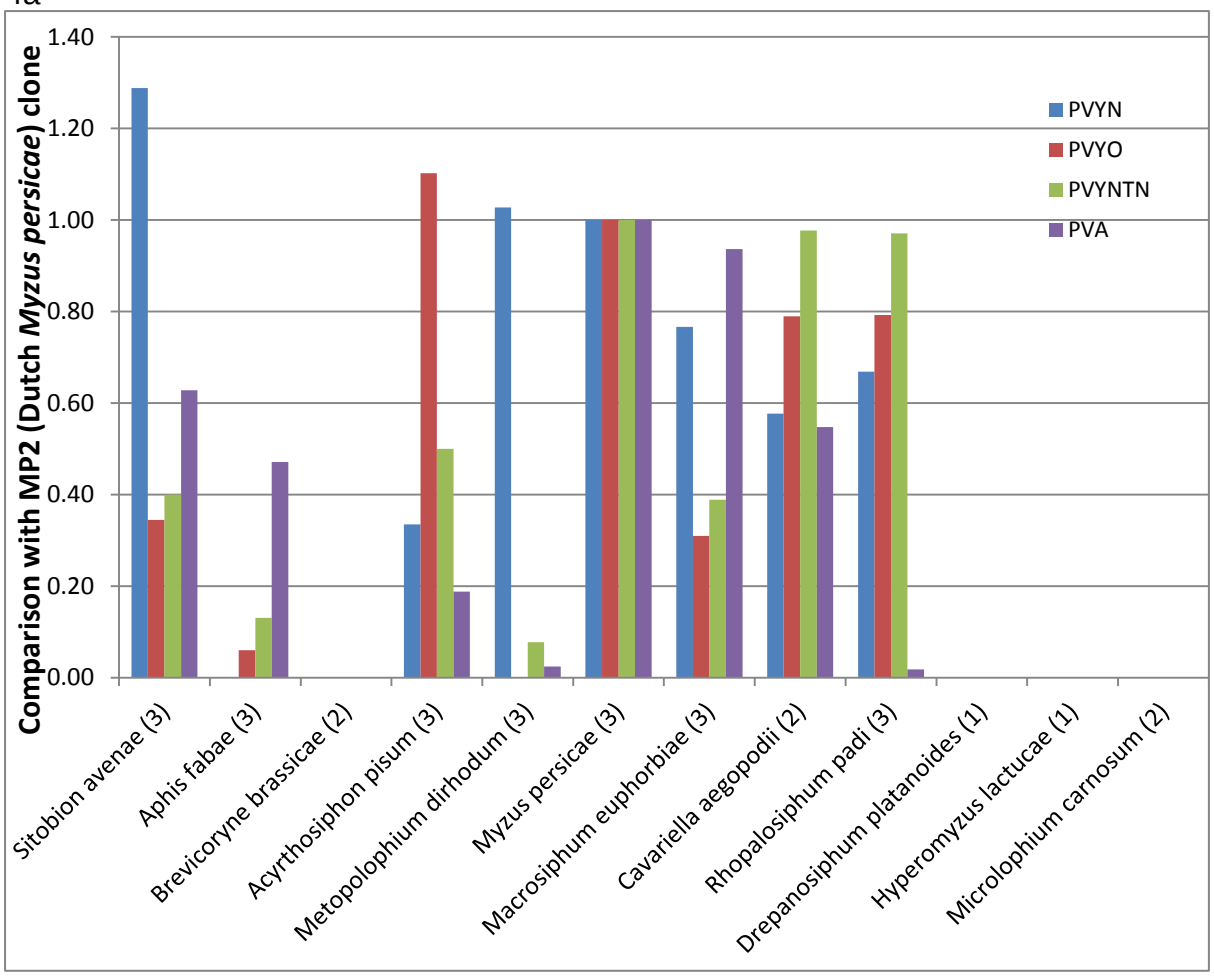


Figure 3. Proportion of plants with visual symptoms when compared to the plants with symptoms in the MP2 clone (internal positive controls). Numbers of clones tested in brackets. Data are grouped by (a) aphid species or (b) by virus strain
Within each virus or virus strain, for each species, the value for the comparison with MP2 is divided by the mean value for the *M. persicae* clones. This will give a value of 1 for *M. persicae* and a relative value for other species (Figure 4a & b).

4a



4b

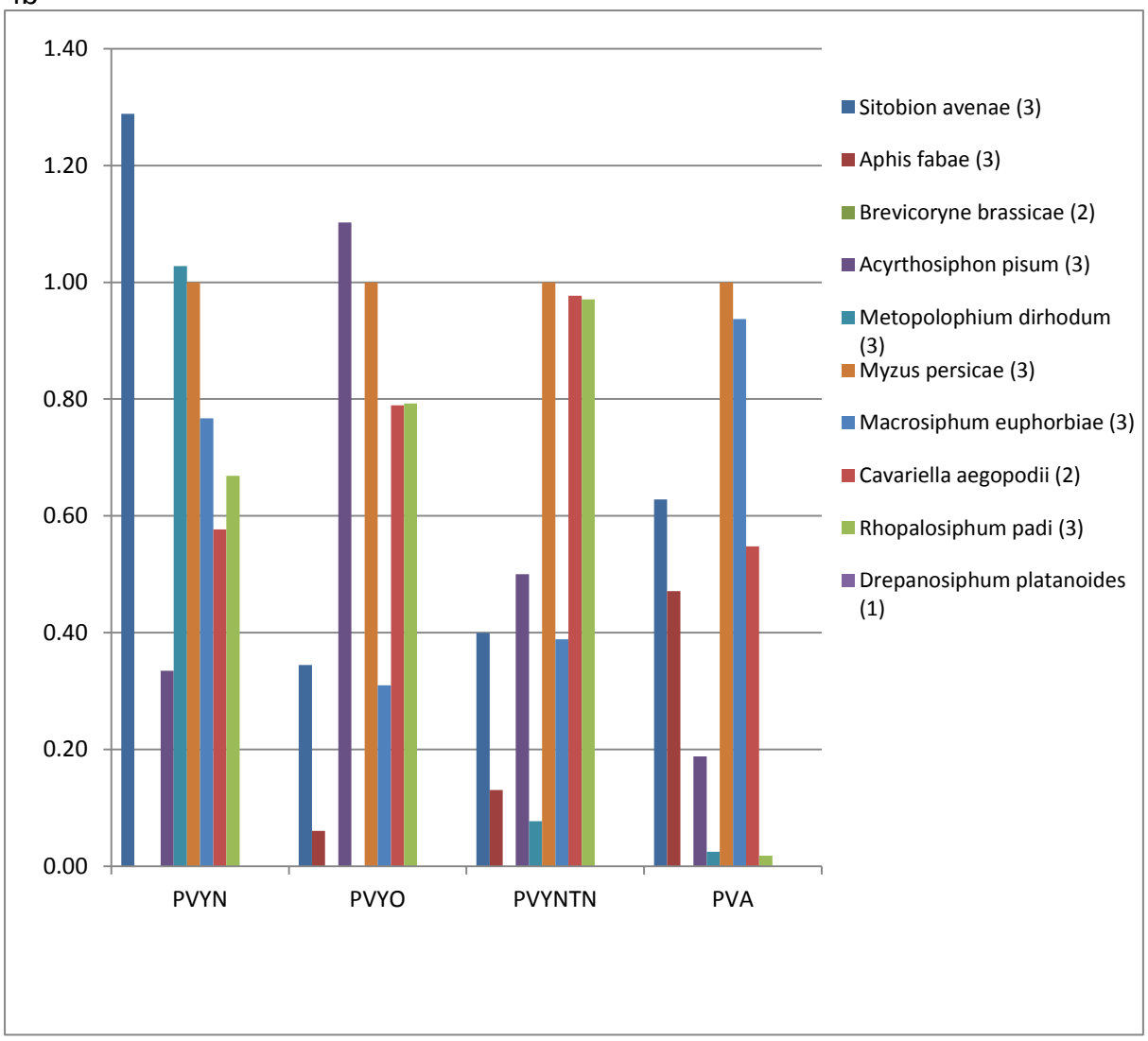


Figure 4. Proportion of plants with visual symptoms when compared to the plants with symptoms in the MP2 clone corrected such that the average value for *M. persicae* clones tested is 1. Numbers of clones tested in brackets. Data are grouped by (a) aphid species or (b) by virus strain

In order to provide a single PVY value, the mean for the three PVY strains is used (Table 5). Values for each aphid clone tested, corrected using its internal MP2 control, with each virus strain are given in Appendix 1.

Aphid species	Clones	Current PVY	PVY	PVA
Acyrthosiphon pisum	3	0.70	0.65	0.19
Aphis fabae	3	0.01	0.06	0.47
Brevicoryne brassicae	2	0.01	0.00	0.00
Cavariella aegopodii	2	0.00	0.78	0.55
Drepanosiphum platanoides	1	0.00	0.00	0.00
Hyperomyzus lactucae	1	0.16	0.00	0.00
Macrosiphum euphorbiae	3	0.20	0.49	0.94
Metopolophium dirhodum	3	0.30	0.37	0.02
Microlophium carnosum	2	0.00	0.00	0.00
Myzus persicae	3	1.00	1.00	1.00
Rhopalosiphum padi	3	0.40	0.81	0.02
Sitobion avenae	3	0.01	0.68	0.63

Table 5. Currently used PVY and experimentally derived PVY and PVA REF values for different aphid species. Highlighted rows are those where a change in the currently used PVY REF value should be considered.

Overall, the data confirm that *Myzus persicae* is generally more efficient at transmitting the viruses than the other aphid species tested. The data show that *Aphis fabae*, *Metopolophium dirhodum, Sitobion avenae*, *Acyrthosiphon pisum* and *Cavariella aegopodii* are capable of transmitting PVA.

3.2. Epidemiology Field Trials

3.2.1. Timing of transmission of PVY and PVA and aphid vector pressure.

FERA 2010

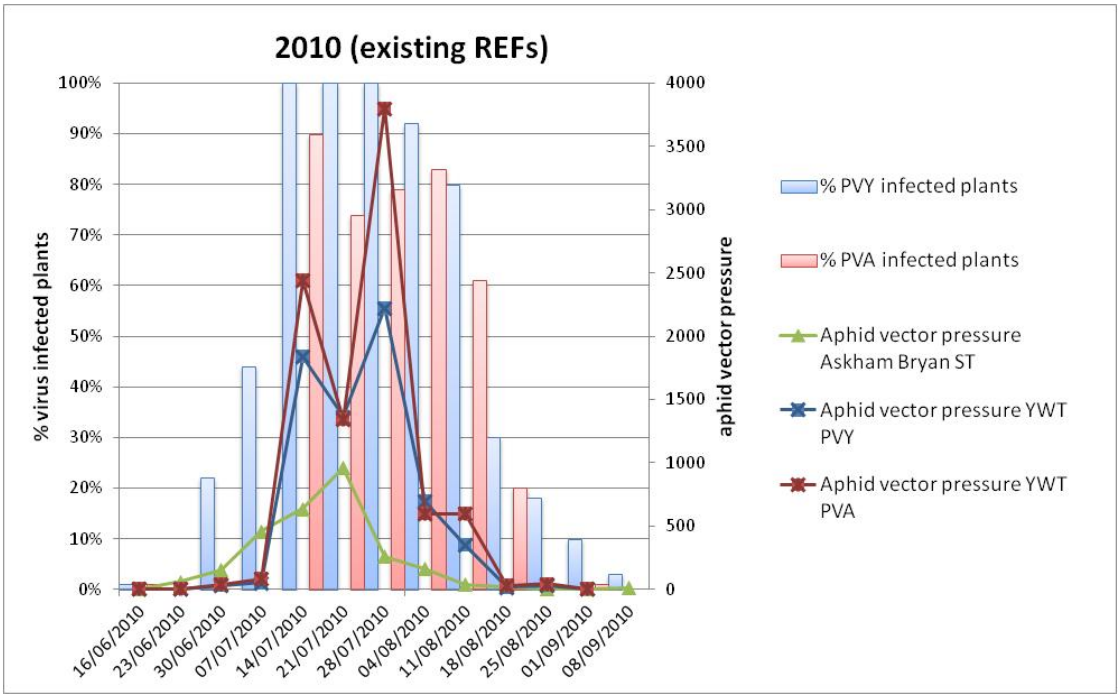
The trial site (East Lutton) on the Yorkshire Wolds is 28 miles away from, and about 70m higher than the Askham Bryan suction trap. Aphid vector pressure was measured by both this suction trap and yellow water traps in the trial plots.

Data for 2010 is presented in Figure 5. Very high levels of virus transmission (*e.g.,* 100% PVY transmission for the 3 weeks from the 14th July 2010) coincided with very high vector pressures in the field (note that the vector pressure values for the water traps are the mean per trap). The five weeks from the 14th July had vector pressure per water trap ranging from 125 (11th Aug) to 1317 (29th Jul) and had PVY infection above 80% and PVA infection above 60%.

The vector pressure during these high transmission weeks was driven by very high numbers of both *Myzus persicae* and *Metopolophium dirhodum* (Figure 6), at the same time as each other (with the exception of the final week when only significant numbers of *M. persicae* were present). *Rhopalosiphum padi* contributed to PVY and PVA transmission in mid-July and *Macrosiphum euphorbiae* contributed to PVA transmission at the end of July and beginning of August.

Using the new virus transmission factors from this study produced higher aphid vector pressure figures from YWT and ST data for PVY in mid-July but made little difference to the vector pressure figures for PVA.

a



b

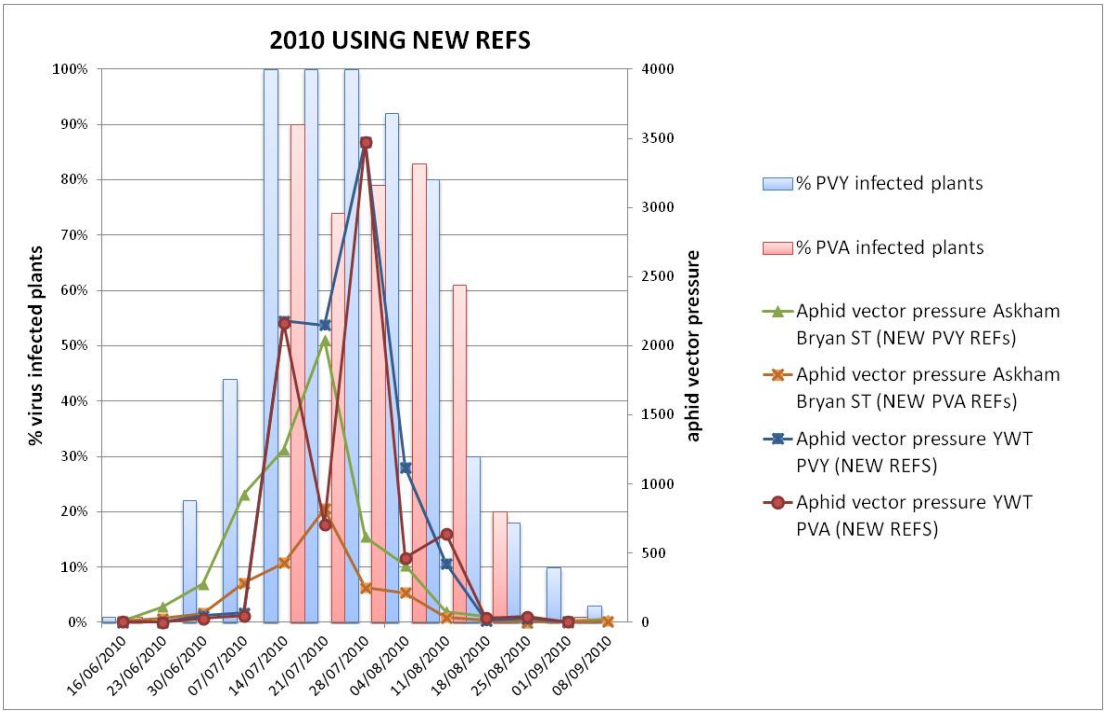
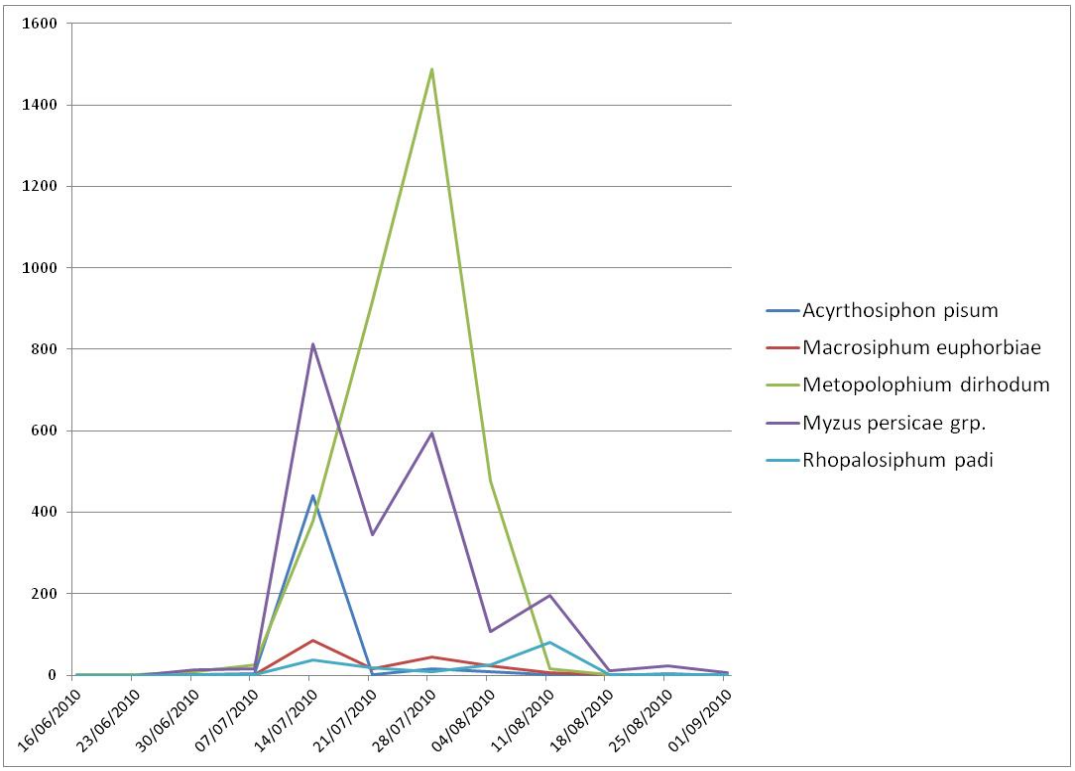


Figure 5a Aphid virus transmission in *Nicotiana debneyi* bait plants and weekly aphid vector pressure at the Yorkshire Wolds epidemiology trial 2010 (water traps are mean vector pressure values) calculated using existing REFs. **b** Aphid virus transmission in *Nicotiana debneyi* bait plants and weekly aphid vector pressure at the Yorkshire Wolds epidemiology trial 2010 (water traps are mean vector pressure values) using REFs from the lab studies.

a



b

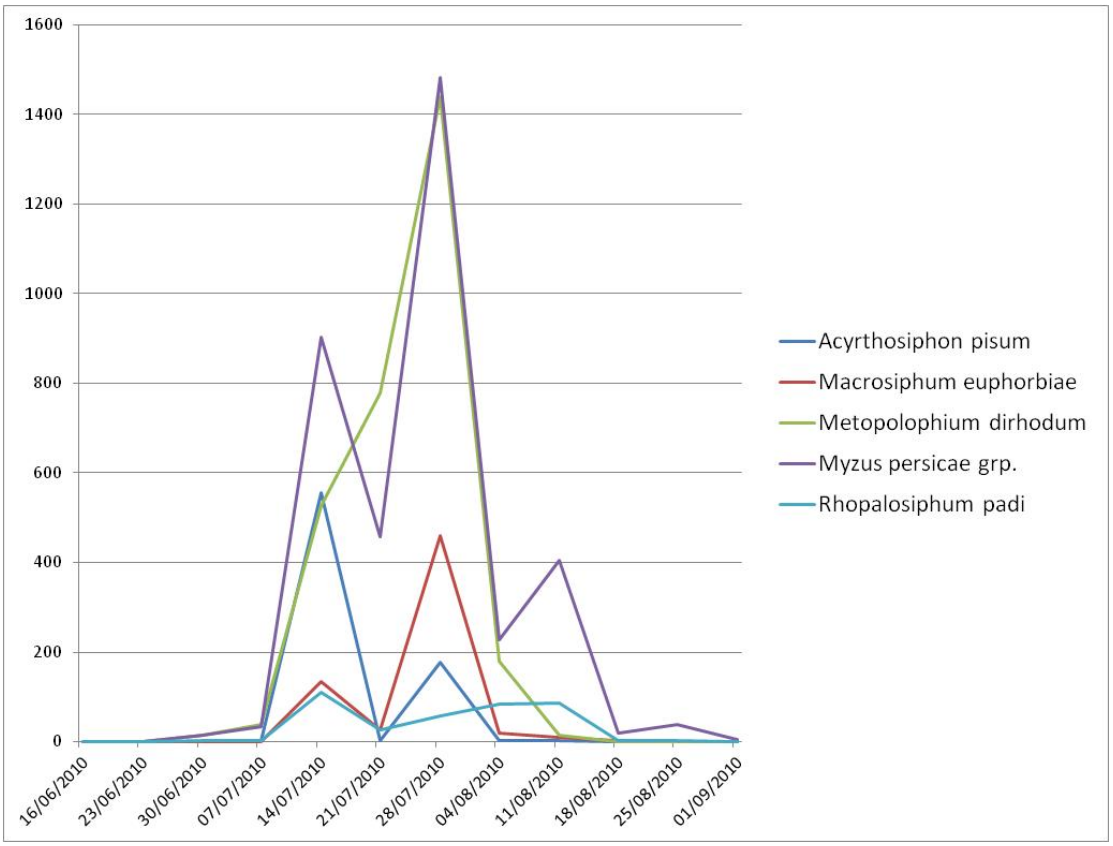
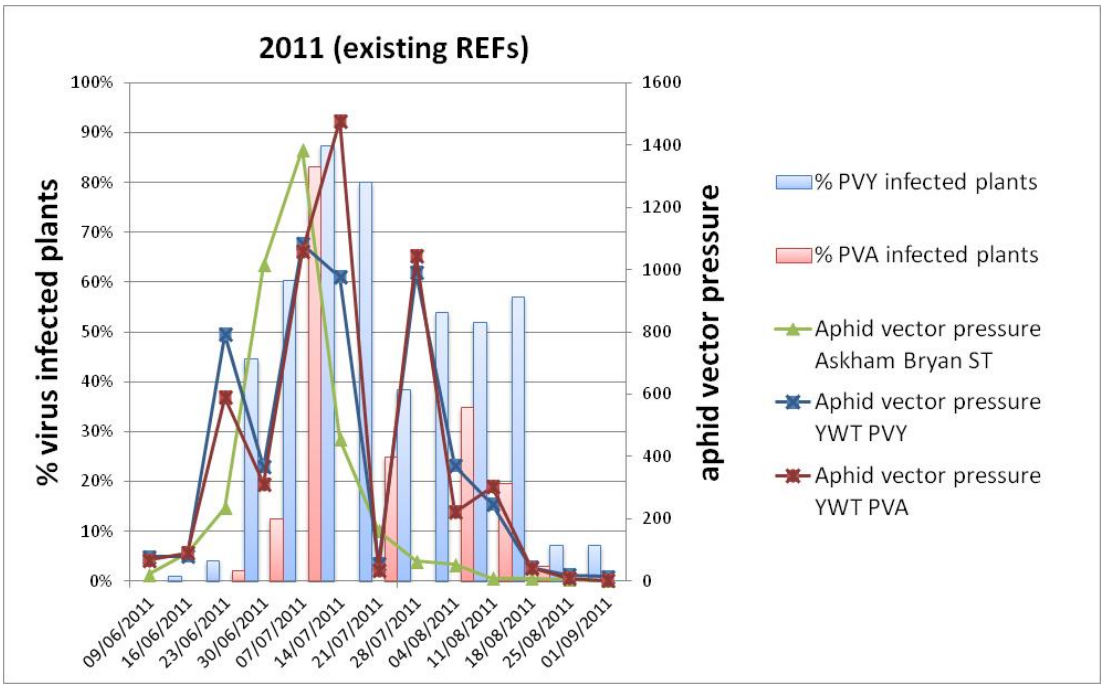


Figure 6a. Mean vector pressure per trap at the 2010 Yorkshire epidemiology trial (PVY plot) showing the contribution from the main aphid species. **b** Mean vector pressure per trap at the 2010 Yorkshire epidemiology trial (PVA plot) showing the contribution from the main aphid species.

Fera 2011

Data for 2011 is presented in Figure 7. Virus transmission was highest during the 3 weeks from 7th July (between 80 and 90% of plants infected). This again coincided with very high vector pressures in the field. The 5 weeks from the 21st July had vector pressure per water trap ranging from 56 (21st Jul) to 990 (4th Aug) and had PVY infection above 50% and PVA infection above 30%.

a



b

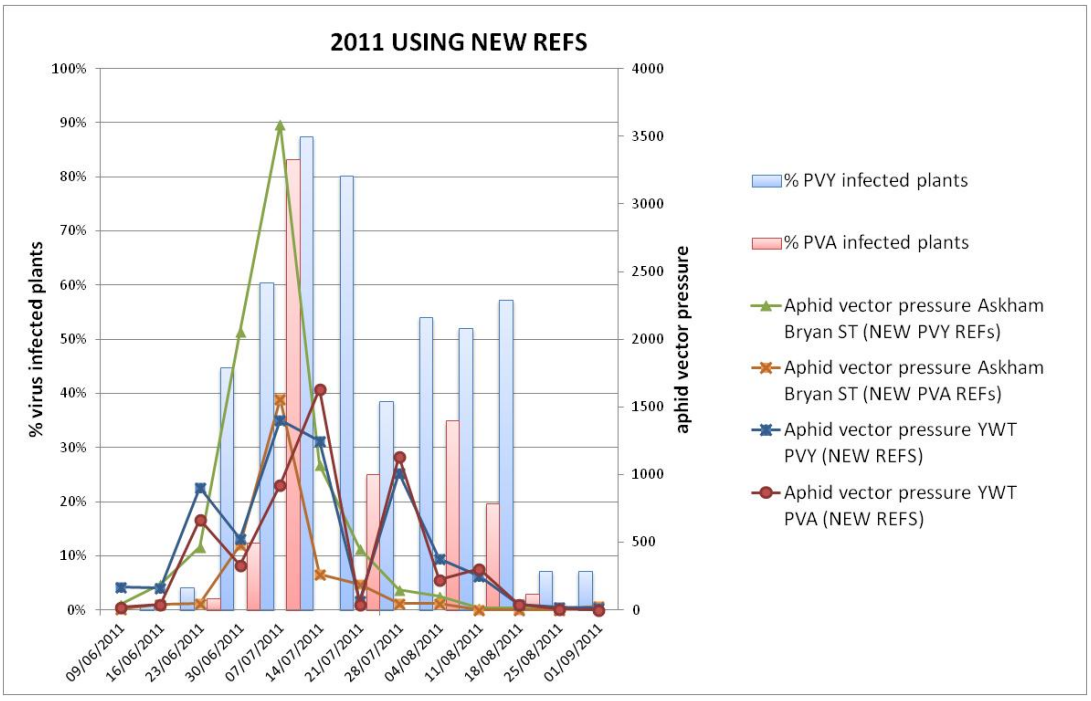


Figure 7. (a) Aphid virus transmission in *Nicotiana debneyi* bait plants and weekly aphid vector pressure at the Yorkshire Wolds epidemiology trial 2011 (water traps are mean vector pressure values) using existing REFs. **(b)** Aphid virus transmission in *Nicotiana debneyi* bait plants and weekly aphid vector pressure at the Yorkshire Wolds epidemiology trial 2011 (water traps are mean vector pressure values) using REFs from the lab studies.

The vector pressure during the high transmission weeks (3 weeks from 7th July) was driven by very high numbers of *Myzus persicae* (Figure 8a,b). *Metopolophium dirhodum* was again a factor as was *Rhopalosiphum padi*, particularly for PVA transmission.

Again, using the new virus transmission factors from this study produced higher aphid vector pressure figures from YWT and suction trap data for PVY in mid-July. The increase for suction trap vector pressure was particularly noticeable.

The YWTs picked up PVY and PVA transmission later in the season but the suction trap at Askham Bryan did not. The Askham Bryan suction trap picked up *M. persicae* up to and including 7th Aug 2011 and the YWTs also picked up *M. persicae* during every week until the end of the study. A similar pattern was observed during 2010: the last date on which the suction trap picked up *M. persicae* was 22nd August but they continued to be detected in YWTs up to the end of the season. This suggests that the YWTs are picking up lower altitude, local flights of *M. persicae* late in the season and that these are not detected by the high level suction trap.

a

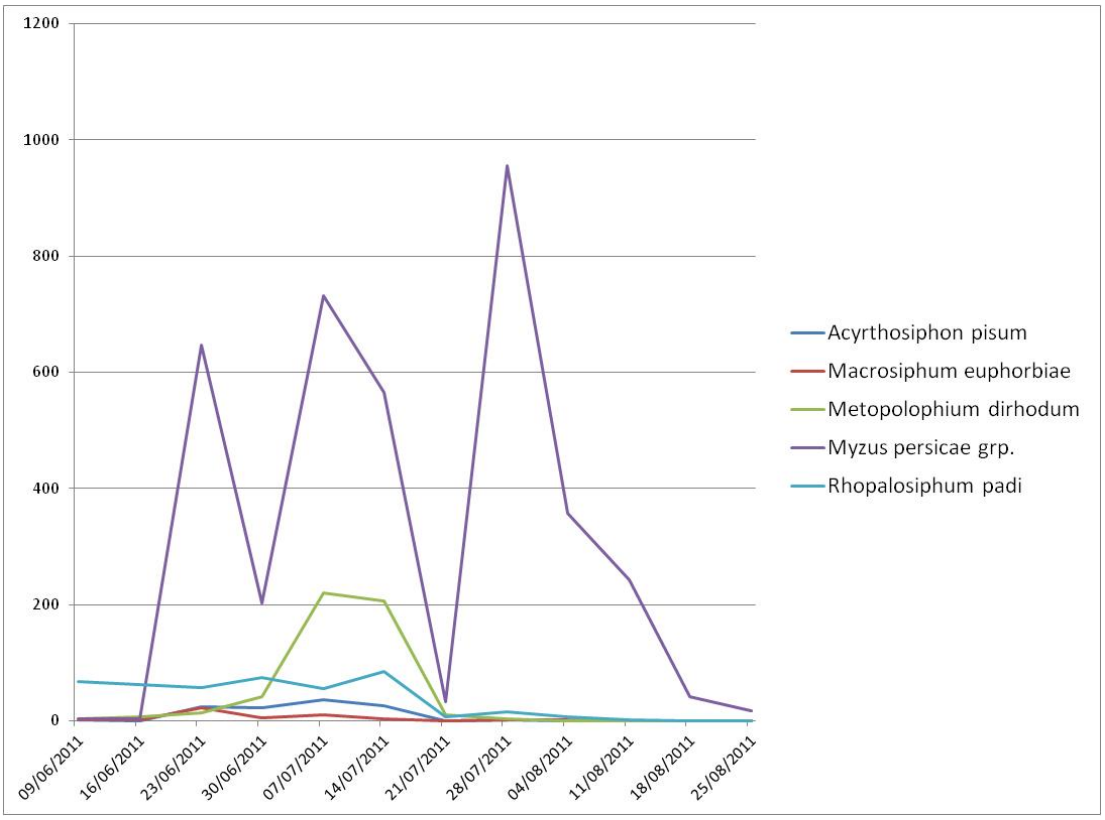


Figure 8a. Mean vector pressure per trap at the 2011 Yorkshire epidemiology trial (PVY plot) showing the contribution from the main aphid species.

b

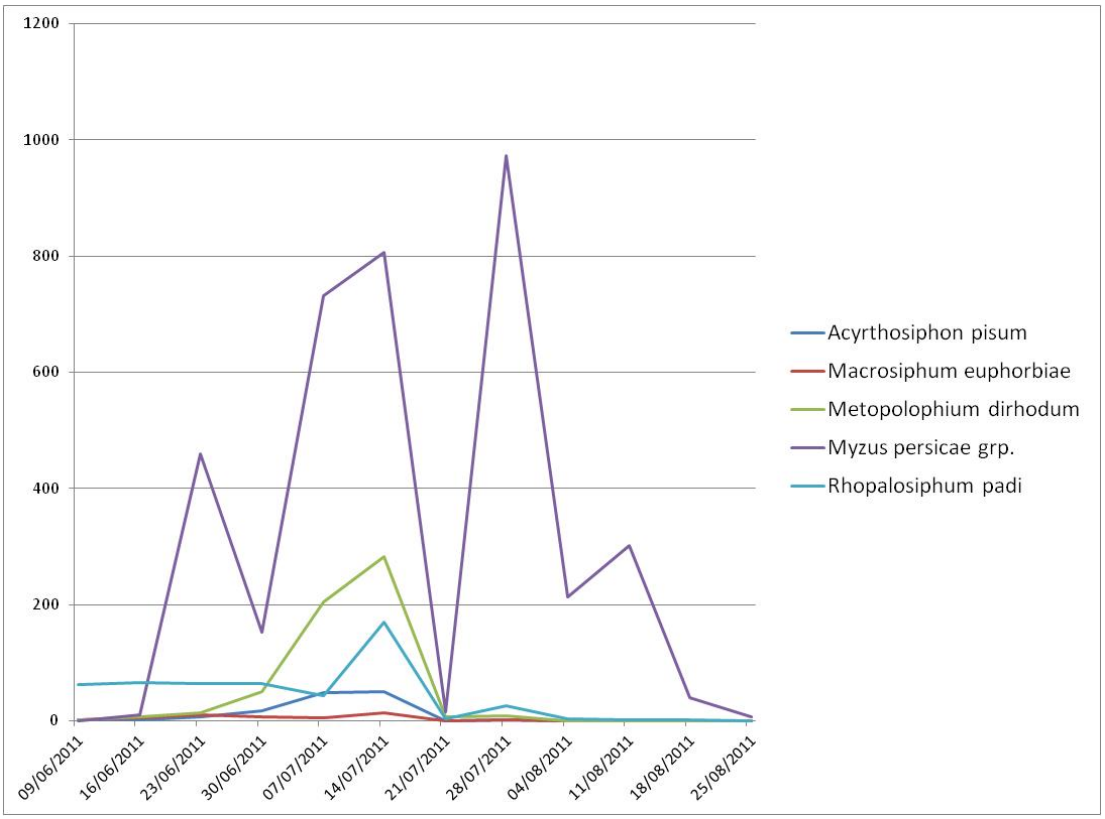


Figure 8b. Mean vector pressure per trap at the 2011 Yorkshire epidemiology trial (PVA plot) showing the contribution from the main aphid species.

SASA 2010

The weekly monitoring of virus transmission and corresponding aphid vector pressure at the SASA site in 2010 are presented in Figure 9. The aphid vector pressure was monitored by the Gogarbank suction trap and by yellow water traps (YWTs). The data were collated to provide totals over the weekly periods over which the tobacco plants were exposed to virus transmission. In 2010, the suction trap aphid vector pressure was low for the first three weeks, and began to increase steadily from week 3 (15/06) to reach a maximum by week 9 (27/07) (Figure 9). Highest PVY (both PVY^{O} and PVY^{N}) and PVA transmission was observed from week-5 (29/06) to week-10 (03/08).

Overall, PVY and PVA transmission did not strictly match aphid virus pressure from the suction trap or YWT: *i.e.,* (*i*) high aphid vector pressure vs decrease in virus transmission at week-8 (20/7); (*ii*) low aphid vector pressure vs increase in virus transmission at week-9 (27/7); (*iii*) significant PVY and PVA transmission at week 11 and 12 with low/no aphid catches in YWT. This reflects potential differences in efficiency of aphid trapping by both methods and as well local variation in the relative numbers of wingless or winged aphid species in neighbouring plots.

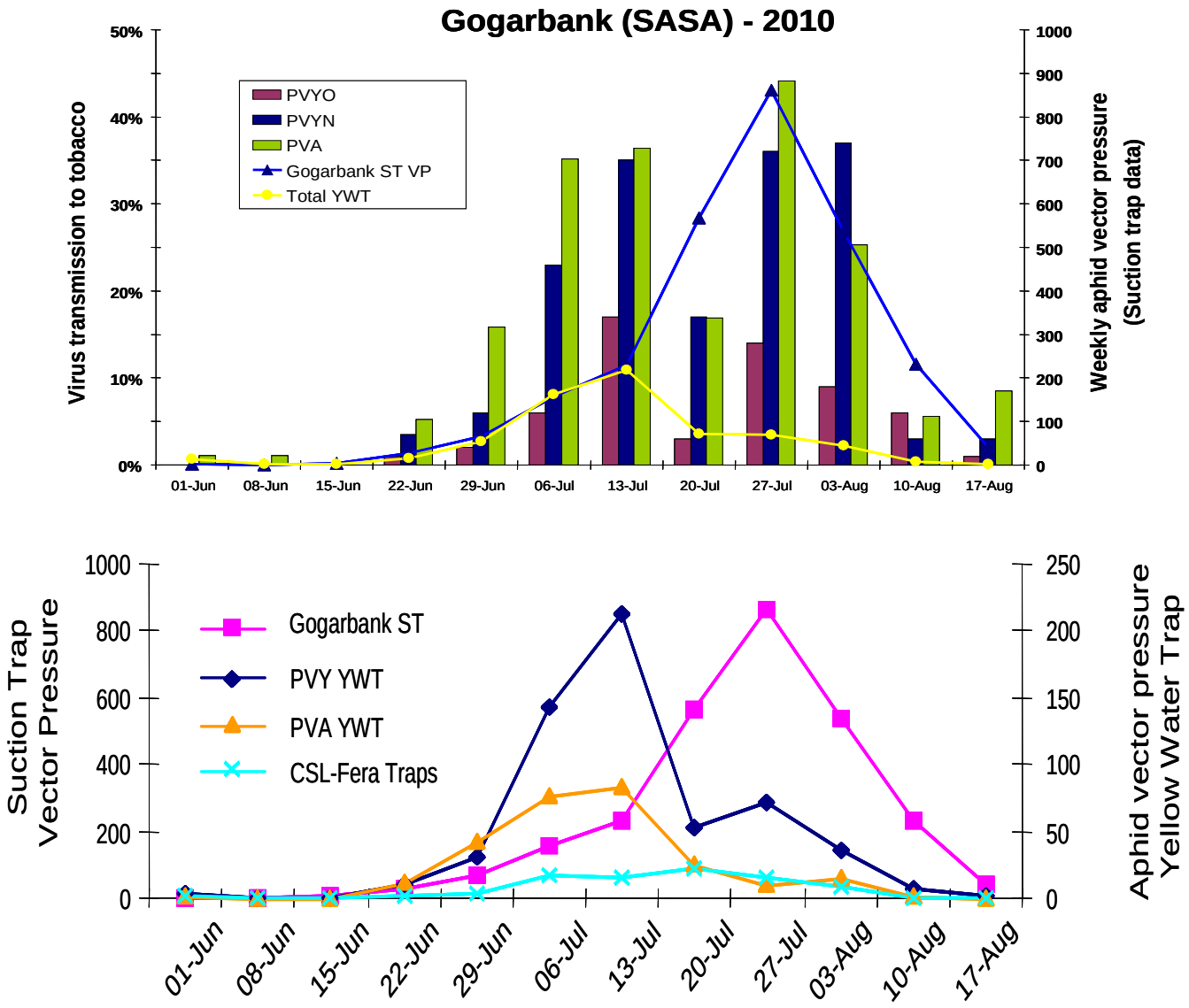


Figure 9. PVY and PVA transmission in *Nicotiana debneyi* bait plants (histograms upper panel) and weekly aphid vector pressure at SASA's site (Edinburgh, Gogarbank) in 2010. Weekly transmission rate (% of virus transmitted) of PVY^{N} (N serotype corresponding to $PVY^{EU\text{-}NTN}$ and $PVY^{NA\text{-}NTN}$) and PVY^{O} isolates are presented. Weekly aphid vector pressure from suction trap (Gogarbank-ST) and water traps (YWT and CSL-Fera trap) within PVY and PVA plots are presented (lower panel).

SASA 2011

The weekly monitoring of virus transmission and corresponding aphid vector pressure at the SASA site in 2011 is presented in Figure 10. In comparison to 2010, a higher weekly transmission was observed in 2011 reaching a maximum of ~80% for PVY^{N} isolates and PVA at week-5 (starting 6th of July 2011), maximum transmission was of 50% for PVA in 2010 (Figure 9). Aphid vector pressure measured from the suction trap appeared to be higher than for YWTs. However, similar aphid vector pressures were observed which mirrored the weekly trend in virus transmission with the only exception of week-6 (decrease in aphid virus pressure and increase in virus transmission).

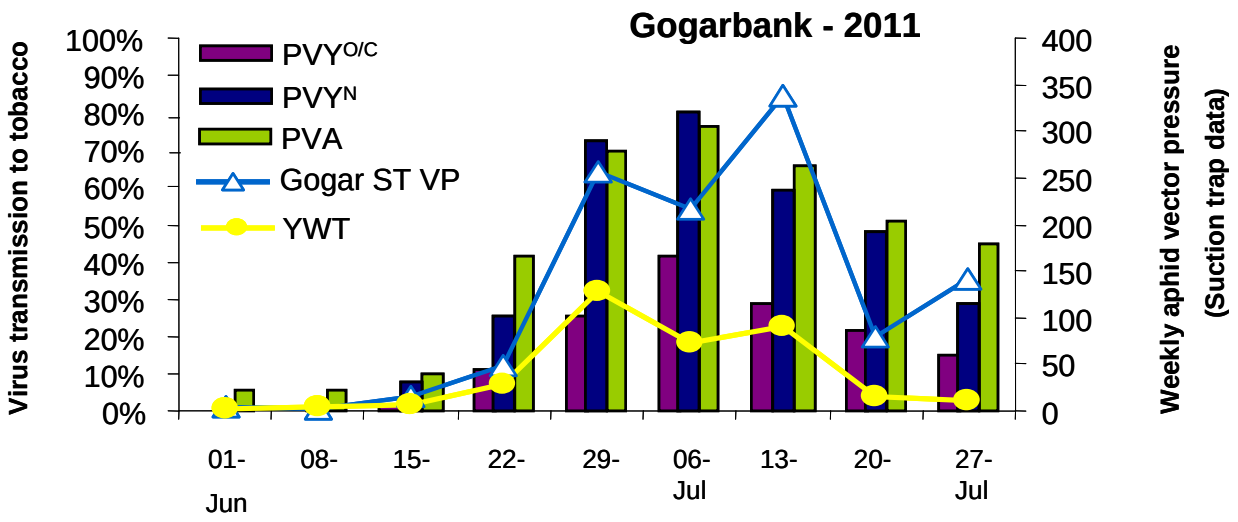


Figure 10. PVY and PVA transmission in *Nicotiana debneyi* bait plants (histograms) and weekly aphid vector pressure at SASA's site (Edinburgh, Gogarbank) in 2011. Weekly aphid vector pressure from suction trap (Gogarbank-ST) and water traps (YWT) from PVY and PVA plots are presented.

Scottish Agronomy 2010

The weekly monitoring of virus transmission and corresponding aphid vector pressure at the Scottish Agronomy site (Pittenweem, Fife) in 2010 is provided in Figure 11. At the Scottish Agronomy site, aphid monitoring began two days later than at SASA's trial in 2010. Timing of transmission of PVY and PVA isolates at both SASA and SA sites appeared to be comparable (Figure 10 and 11). A higher frequency of transmission for PVA was observed at the Scottish Agronomy site (maximum ~75% at week-9 - 29/07 Figure 11) than for SASA (Figure 10). These data show that the suction trap and YWT monitoring of aphid species known to vector potyviruses produced a good correlation between aphid activity and virus transmission at the site.

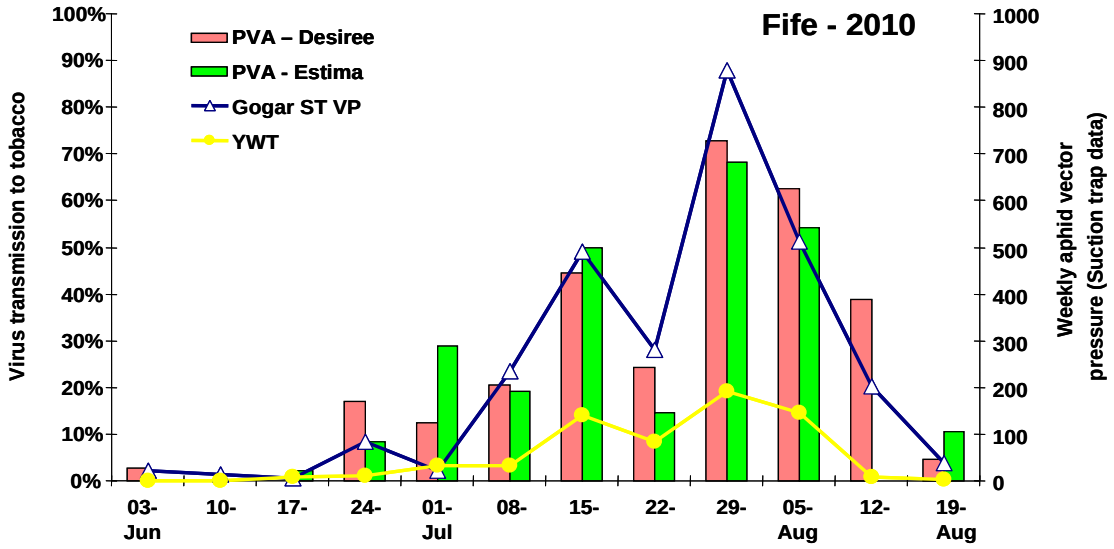


Figure 11. PVY and PVA transmission in *Nicotiana debneyi* bait plants (histograms) and weekly aphid vector pressure at SA's site (Pittenweem-Fife) in 2010. Weekly aphid vector pressure from suction trap (Gogarbank-ST blue line) and water traps (YWT yellow line) are presented.

In 2010, variation in aphid catches within plots (SASA) and between sites (SASA and Scottish Agronomy) resulted in different patterns of aphid virus pressure and virus transmission (PVY or PVA). There was a less obvious relationship between suction trap and YWT trap catches and virus transmission at the SASA site. This apparent discrepancy could be explained as follows: for logistical reasons, the traps and the plants within the SASA and Scottish Agronomy trials were changed on different days of the week. Therefore the weekly aphid catches differ by two days between the two sites. This was most noticeable in the aphid catches and calculated aphid vector pressure of the Gogarbank suction trap at week 8 for the two trials. The aphid catches were very high on two days (ie Tuesday 20th of July and Monday 2nd of August) and relatively low over the intervening period. For the SASA trial running Tuesday to Monday, these two dates fell into consecutive weeks. For the SA trial running from Thursday to Wednesday, these two dates fell into weeks separated by an intervening week of low aphid activity. At the SASA trial, there was a dip in virus transmission during the week beginning 20 July, that wasn't reflected by the suction trap aphid vector pressure. Given the very high aphid activity on that date relative to the rest of the week (Figure 12), the precise timing of the aphid activity in relation to the weekly changing of bait plants in the field may be responsible for the apparent discrepancy.

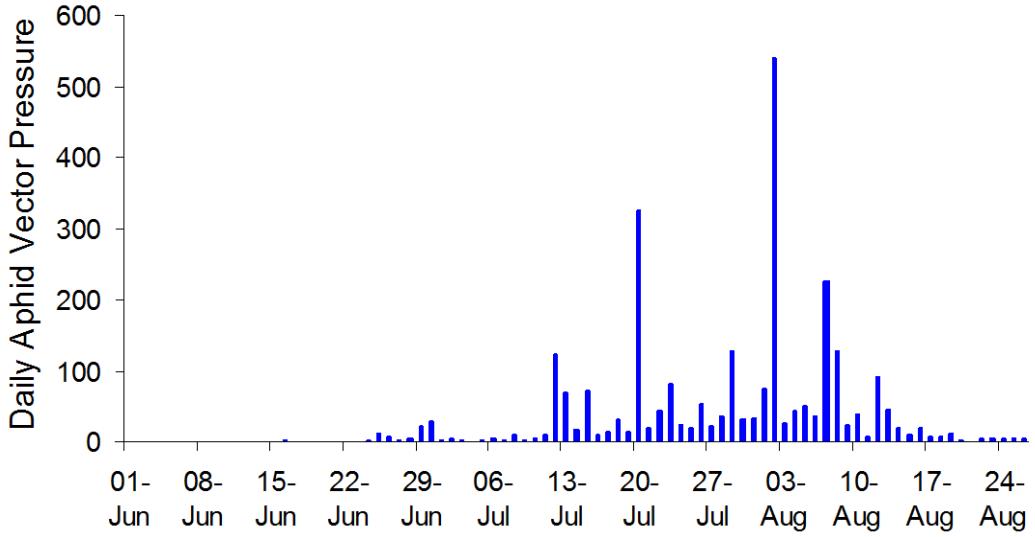


Figure 12. Daily aphid vector pressure from Gogarbank suction trap (2010). NB Only six days account for over 50% of the total vector pressure recorded over the 84 day period of the trial.

Scottish Agronomy 2011

The weekly monitoring of virus transmission and corresponding aphid vector pressure at the Scottish Agronomy site in 2011 is presented in Figure 13. In comparison to 2010, overall, a higher weekly transmission was observed in 2011 reaching a maximum of 95% and 80% for PVA at week-6 (starting 6th of July) in the Estima and Desiree plots, respectively. (The maximum transmission was 72% for PVA in Desiree plot in 2010 see Figure 11). Aphid vector pressure measured from suction trap data is higher than for YWT. However, similar trends in aphid vector pressure were observed and they mirrored the weekly trend in virus transmission with the only exception of week-6 (decrease in aphid vector pressure and increase in virus transmission).

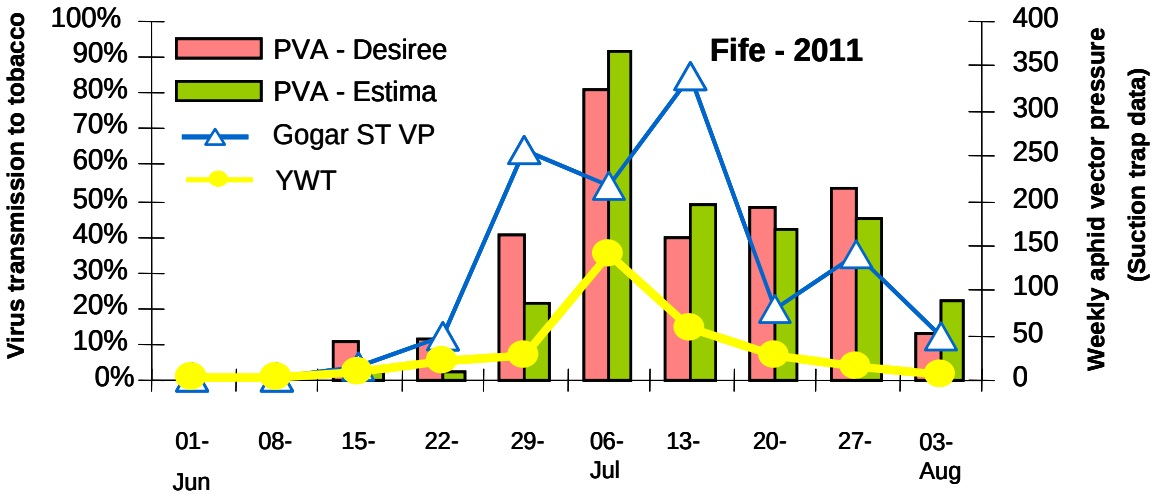


Figure 13. PVA transmission in *Nicotiana debneyi* bait plants (histograms) and weekly aphid vector pressure at SA's site (Pittenweem-Fife) in 2011. Weekly aphid vector pressure from suction trap (Gogarbank-ST) and water traps (YWT) within PVA plots are presented.

Relating PVY^{o} infection to aphid counts.

The aim of the analysis was to identify associations between PVY^{o} infections and aphid counts based on the SASA epidemiology trial (2000-2011) and to see if these hold at the Fera trial (2010-2011).

The analysis is based on the following data sets:

- PVY^{o} infection weekly data from the SASA epidemiology trial from 2000 to 2011*, expressed as the proportion of 96 *N debneyi* plants that were infected by PVY^{o} after a week's exposure.
- Related SASA suction trap and trial-site yellow water trap counts for species of aphids known to vector potyviruses.
- PVY^{o} infection weekly data from the Fera epidemiology trial from 2010 to 2011, expressed as the proportion of 96 *N debneyi* plants that were infected by PVY^{o} after a week's exposure.
- Related Askham Bryan suction trap and trial-site yellow water trap counts for species of aphids known to vector potyviruses.

*Access to data collected before the current project began was provided by SASA to allow a larger dataset to be analysed by BioSS staff.

The statistical methods used comprised a logistic regression model based on binomial response data. This was used to relate virus transmission to aphid counts for individual aphid species. A natural logarithm transformation was applied to the aphid counts (after adding 1) for their use as covariates. The differential effects of year were allowed for and BioSS staff also tested whether different slopes are required for each year. Overdispersion was estimated from the residual dispersion (a quasi-likelihood model). For testing, simpler models (with constant slopes in each year) were fitted based on the SASA trial data and then tested on the Fera trial data.

SASA Results: Table 6 shows the aphid species considered with their mean and maximum counts for the two types of trap at SASA and the PVY Relative Efficiency Factors used to calculate the Vector Pressure Index.

Table 6: Aphid species with summary statistics for SASA traps for the weeks covered by the SASA epidemiology trial 2000-2011.

		Suction Trap		Yellow Water Traps	
Species	REF	Mean	Max	Mean	Max
Acyrthosiphon pisum	0.70	7.3	107	1.3	19
Aphis fabae (group)	0.10	9.2	113	1.9	46
Aphis nasturtii	0.40	0.0	1		
Aulacorthum solani	0.20	0.7	12	0.2	6
Brachycaudus helichrysi	0.21	13.2	185	4.3	55
Brevicoryne brassicae	0.01	0.9	14		
Cavariella aegopodii	0.50	5.9	104	1.3	36
Cavariella pastinaceae	0.00	10.2	130	7.9	630
Hyalopterus pruni	0.00	5.1	53		
Hyperomyzus lactucae	0.16	2.2	32	1.9	44
Macrosiphum euphorbiae	0.20	6.0	120	3.9	49
Metopolophium dirhodum	0.30	109.4	1235	37.5	672
Myzus ascalonicus	0.20	0.3	7		
Myzus certus	0.00	0.2	3	0.1	1
Myzus ornatus	0.20	0.4	12		
Myzus persicae	1.00	1.8	14	1.6	17
Rhopalosiphoninus latysiphon	0.20	0.2	2		
Rhopalosiphum insertum	0.00	64.6	700	3.9	38
Rhopalosiphum padi	0.40	136.0	3099	3.5	42
Sitobion avenae	0.01	117.3	4221	7.3	127
Vector Pressure	-	103.8	1650	18.1	212.9

Table 7 summarises the results of logistic regression of the PVY infection on (log) aphid counts. The deviance ratios indicate the level of evidence for an effect or association. Larger values reflect a stronger association and values near 1 mean that there is little evidence for an effect. The residual deviance reflects the level of variability in the PVY infection that is not explained by the aphid counts (and year effects): the smaller the value the better fitting the model. Values near 1 indicate a very good fit.

The counts for many species of aphid have some association with the PVY infection levels. The strongest associations in suction trap counts were found for *M. dirhodum*, *S. avenae,* the aphid vector pressure index, *A. pisum* and *M. euphorbiae*. The strongest associations in YWT counts were found for: *M. dirhodum*, the aphid vector pressure index, *S. avenae, M. euphorbiae* and *A. pisum.* The suction trap data tended to have at least as strong associations as the yellow water counts, perhaps in part due to the lower counts in the yellow water traps. The strongest association was for *M. dirhodum* suction trap and YWT counts. In this case there was little evidence that the slope varied from year to year.

Table 7: Logistic model fits for the SASA PVY^{o} infection levels 2000-2011

Species	Suction Trap Deviance ratios			Yellow Water Traps Deviance ratios		
	Relationship with log(count)	Slope changing in each year	Residual deviance	Relationship with log(count)	Slope changing in each year	Residual deviance
A pisum	**95.5**	**1.3**	**12.4**	**72.7**	**1.2**	**13.8**
A fabae (group)	21.2	1.8	17.9	12.8	1.0	20.0
A nasturtii						
A solani	3.9	2.2	19.8	0.3	0.7	22.3
B helichrysi	37.0	3.0	15.0	21.5	2.1	17.4
Be brassicae	8.8	1.3	20.3			
C aegopodii	12.7	3.6	16.6	1.9	2.8	19.3
C pastinaceae	4.8	1.4	20.6	9.9	0.4	21.4
H pruni	10.8	1.6	19.3			
Hs lactucae	37.8	1.0	16.9	26.9	1.8	17.2
M euphorbiae	**79.3**	**2.9**	**12.3**	**74.1**	**1.4**	**13.7**
M dirhodum	**342.6**	**1.1**	**6.0**	**222.9**	**1.1**	**8.0**
M ascalonicus	2.0	2.8	19.5			
M certus	12.3	0.6	20.5	5.2	0.7	21.4
M ornatus	1.6	1.5	20.9			
Ms persicae	42.9	1.8	15.7	57.5	1.0	15.2
R latysiphon	2.9	1.2	21.3			
R insertum	13.7	2.2	18.2	2.1	0.9	21.8
R padi	30.2	2.8	15.8	26.9	2.1	17.1
S avenae	**136.9**	**2.2**	**10.1**	**136.9**	**2.1**	**10.2**
Vector Pressure	**105.8**	**2.0**	**11.5**	**198.4**	**1.9**	**8.4**

As the effect of *M. dirhodum* using the suction trap data is so strong, the effect of each species counts after first allowing for year and the *M. dirhodum* counts was explored. In the logistic models here, there was no allowance for differing slopes from year to year. Although these effects were relatively minor (compared to the *M. dirhodum* effect), significant residual effects were found for*, A fabae*, *S. avenae, M. certus* and *B. brassicae*, although the latter two species both have very low counts and should thus be treated with caution.

Figure 14 explores the relationship between the REF (denoted as PVY Vector Pressure Index), the numbers of aphids caught in the suction trap and the association found with suction trap counts. Each circle relates to a species (indicated by its initials) with the size of the circle related to the strength of association with PVY infection (through the deviance ratio). There is some indication that higher counts are necessary to find a stronger association but that this does not lead to a stronger association (see e.g. *R. padi*, a species that has been reported as a major vector of PVY in Sweden (Sigvald, 1992)). On the other hand *S. avenae* has a strong association even though the REF value currently used is low.

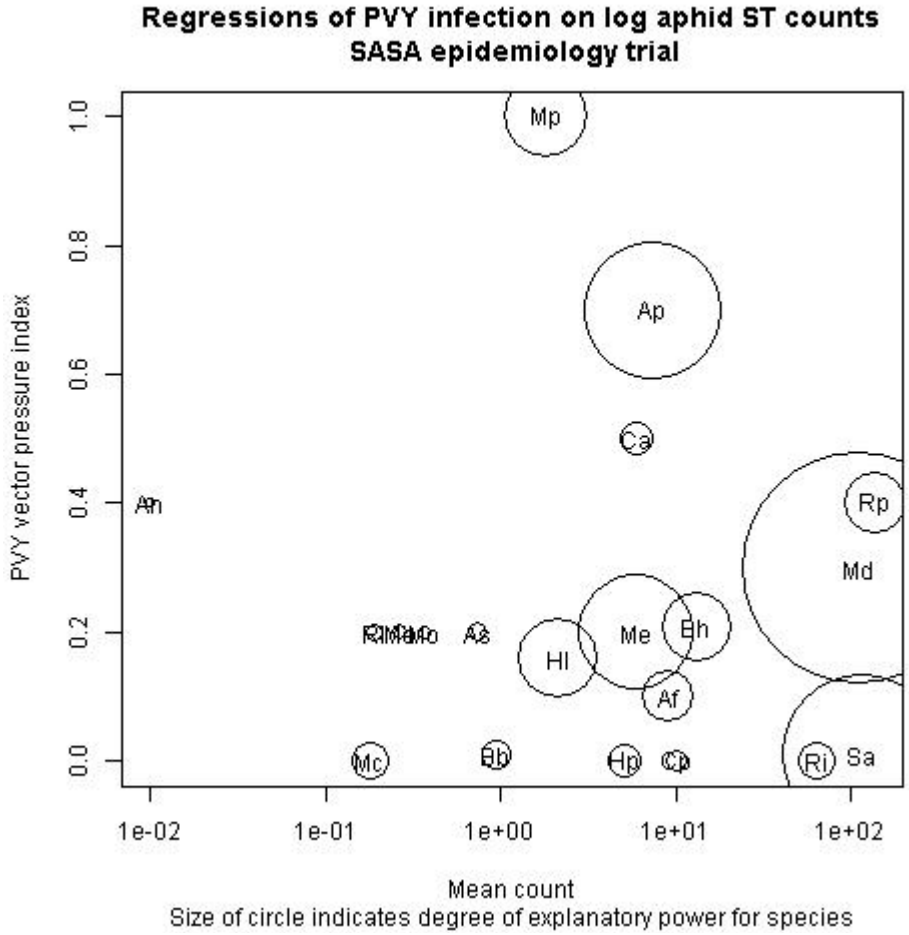


Figure 14: Plot showing the relationship between relative transmission efficiencies and mean aphid counts in the suction trap and the strength of association with PVY infection levels (SASA epidemiology trial 2000-2011).

Fera Results: The degree of fit will be found to be the same whether we are predicting Fera PVY infection levels based on a SASA model or a Fera model; it only depends on the aphid counts at SASA. Table 8 gives the deviance ratios for the effect of log count based on Fera aphid counts (the model did not allow for variability in slope by year this time).

The fits are distinct from those at SASA. Here the yellow water trap data tends to provide the stronger associations. For the two years, the strongest associations are with the Vector Pressure Index and *M. persicae.* Using yellow water trap data *A. fabae, H. lactucae* and *S. avenae* each have a stronger association with PVY transmission than does *M. dirhodum*. Using the suction trap data, the strongest associations are with *A. fabae, S. avenae, R. padi, C. pastinaceae* and then the Vector Pressure Index.

Table 8: Aphid species with summary statistics for the Fera traps and logistic regression model fits for the Fera PVY^{o} infection levels 2010-2011

	Suction Trap		Yellow Water Traps		Logistic Regression	
Species	Mean	Max	Mean	Max	Suction Trap	YWT
Acyrthosiphon pisum	66.9	762	80.4	1425	8.9	20.2
Aphis fabae (group)	13.5	62	298.1	2307	43	92
Aphis nasturtii	0	0				
Aulacorthum solani	0	1	0	1	1.8	0.5
Brachycaudus helichrysi	14.3	126	14.9	105	1.8	27.4
Brevicoryne brassicae	0.7	4			8.5	
Cavariella aegopodii	9.7	42	16.4	110	0.4	0.8
Cavariella pastinaceae	18.9	128	3.9	35	12.5	12.8
Hyalopterus pruni	4	38	0	0	3.8	
Hyperomyzus lactucae	4.2	28	105.3	841	3.9	68.2
Macrosiphum euphorbiae	1.9	8	118.5	1683	5.8	33
Metopolophium dirhodum	728.5	3760	1421	14640	5.6	40.5
Myzus ascalonicus	0.1	2	0	0	0.4	
Myzus certus	0.1	1	0	0	2.9	
Myzus ornatus	0	0	0	0		
Myzus persicae	17.1	134	509	2077	8.8	134.5
Rhopalosiphoninus latysiphon	0.1	2	0	0	0	
Rhopalosiphum insertum	10.9	48	0.5	12	7.1	2.5
Rhopalosiphum padi	145.6	680	145.7	637	21.5	19.3
Sitobion avenae	228.8	1430	34.7	184	30.7	56.2
Vector Pressure	353.3	1672	1132	7296	9.9	146.4

These results show that the relationship between PVY transmission in Edinburgh and York may differ. In Edinburgh there is a clear indication that *M. dirhodum* was the key species over the duration of the SASA epidemiology trials (2000-2011) and that the suction trap provided as good, if not better, relationship between aphid abundance and virus transmission, when compared to yellow water traps. In Yorkshire, over the duration of this project (2010-2011) a very different relationship was found, with the abundance of several species of aphids showing a stronger relationship with PVY transmission than does *M. dirhodum*. In addition, the aphid data from yellow water traps showing a stronger relationship than the data collected by the suction trap. This may in part be due to the aphid trap at Askham Bryan being some 28 miles from the field site. However, the data collected at the two sites indicates that there may be differing relationships between yellow water trap catches and suction traps in different parts of the UK. This variation in the data collected by the two methods requires further investigation. Comparing historical aphid catches from the suction trap network with those from the yellow water trap network funded by Potato Council should help elucidate this variation.

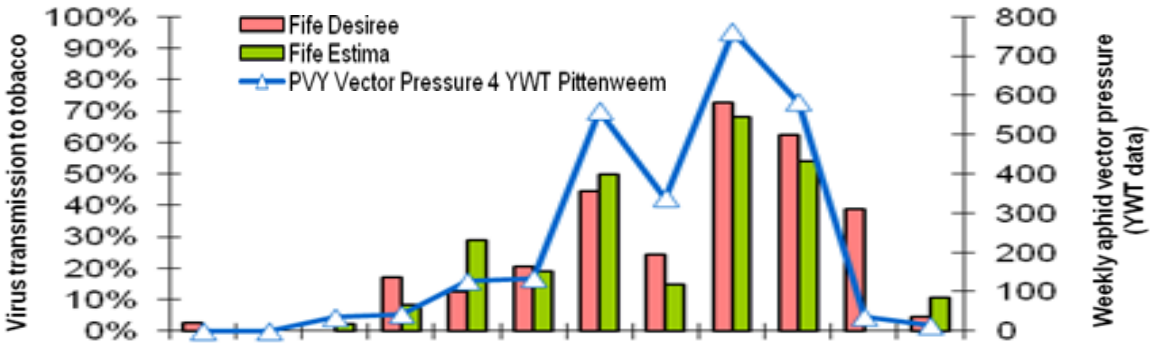
3.2.2. Spatial distribution of transmitted PVY and PVA isolates.

Results for the SASA and Scottish Agronomy sites for both 2010 and 2011 are presented together below. Results from the Fera site (2010 and 2011) are provided later in this section.

SASA and Scottish Agronomy

The weekly frequency of distribution of transmission at the SASA and SA sites was assessed by determining the distribution and frequency of infected tobacco bait plants each week (*i.e.,* distance and frequency of transmission expressed as a percentage of tobacco bait plants infected at a given position in relation to the infector row). Representative examples of weekly spatial distribution are presented in Figures 15 and 16.

In the majority of the cases, the highest transmission rate was observed in bait plants located in the vicinity of the infector row (mainly between rows 1 to 3). An increased distance of transmission was observed in weeks of a high transmission rate (Figure 15 and Figure 16: 4.9, weeks 7, 9 and 10) and suction trap aphid vector pressure (from 8% to 50% of transmission rate in row 12). It is to be noted that in the PVA Estima plot (Figure 15 lower pane), a large number of PVA infected plants were found to be co-infected with PVV. Several lines of evidence suggest that PVV inoculum source is likely to originate from Estima PVA infectors plants (lack of PVV transmission in bait plants outside the trial, short-range transmission within the Estima plot and opposed to neighbouring Desiree plot). Taken together, this suggests that in these conditions, a relatively short distance of transmission of PVY and PVA (and PVV) is observed, confined largely inside the same plot.



Desiree plot

	W1	W2	W3	W4	W5	W6	W7	W8	W9	W10	W11	W12
R1	0	0	0	50	75	100	100	100	100/25	100	75	0
R2	0	0	0	0	50	50/25	100	50	100	100	100	25
R3	33	0	0	25	0	25	75	0	100	75	50	0
R4	0	0	0	25	0 / 25	0	67	0	75	100	50	0
R5	0	0	0	0	0	0	50	0	75	75	0	0
R6	0	0	0	0	0	0	67	0	100	100	25	0
R7	0	0	0	25	0	0	50/25	50	67	50	33	0
R8	0	0	0	25	25	0	0	0	75	50	0	0
R9	0	0	0	0	0	25	25	50	67	0	33	0
R10	0	0	0	0	0	25	0	25	33	50	0	0
R11	0	0	0	50	0	0	25	0	25	75	50	25
R12	0	0	0	0	0	0	25	0	50	25	0	0

PVA	
0	
< 26%	
27-40%	
41-60%	
61-80%	
> 80%	

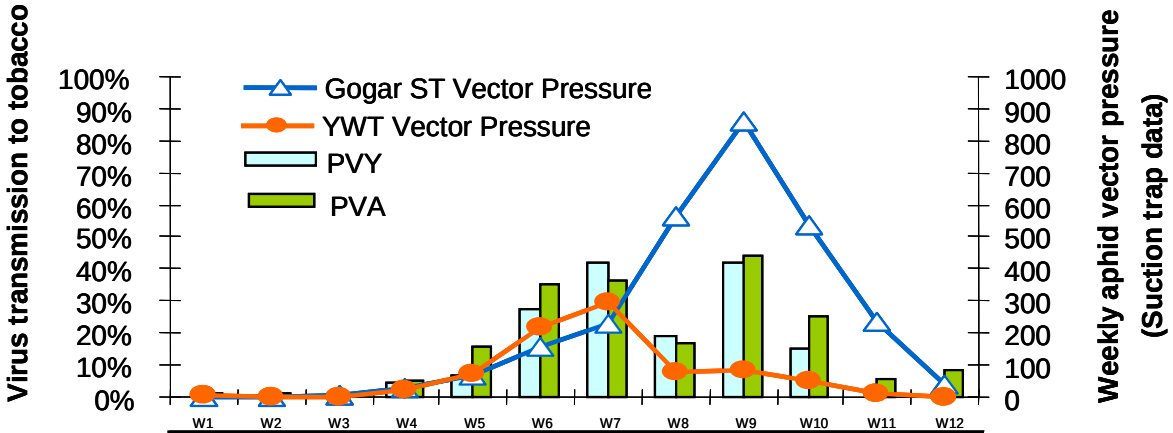
PVA
PVV
PVA+PVV

Estima plot

	W1	W2	W3	W4	W5	W6	W7	W8	W9	W10	W11	W12
R1	0	0	25	25 / 25	75 / 100	100 / 100	100 / 100	75 / 25	75 / 50	100 / 100	0	50 / 75
R2	0	0	0	0 / 25	75 / 25	50 / 75	100 / 75	50 / 25	75 / 100	100 / 75	0	25 / 25
R3	0	0	0	25	33	66	75 / 50	0	100 / 100	50 / 50	0	0
R4	0	0	0	0	66 / 33	50 / 25	100 / 75	0 / 50	100 / 50	50 / 50	0	25
R5	0	0	0	0	0	0	50 / 25	25	100 / 75	50 / 25	0	0 / 25
R6	50	0	0	0 / 25	25	0	25 / 25	0	100 / 25	25 / 50	0	0
R7	0	0	0	0	25	0	0	0	50 / 50	50 / 25	0	0
R8	0	0	0	0	0	0	50	0	0 / 33	25	0	0
R9	0	0	0	25	33	0	25	0	75 / 75	50	0	0
R10	0	0	0	0	0	0	25	0	75 / 25	50 / 50	0	0
R11	0	0	0	0	0	0 / 25	25 / 25	0	25	0 / 25	0	0
R12	0	0	0	0	25 / 25	0	25	0	25	50	0	0

Figure 15. Example of weekly distance and frequency of transmission to tobacco bait plants is reported for both PVA and PVV and expressed as a weekly percentage of total cases of infection and plotted by distance (row number) from the infector plants for each of the Desiree (central panel) and Estima plots (lower panel; 2010). Weekly aphid vector pressure

from yellow water traps within each Desiree and Estima PVA plots at SA site (Pittenweem, Fife) (upper panel).



PVY^{O}

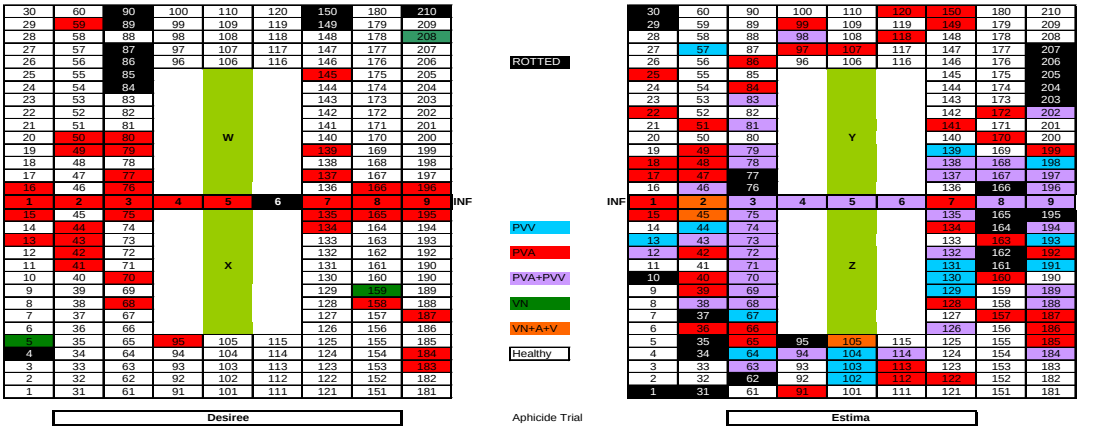
	W1	W2	W3	W4	W5	W6	W7	W8	W9	W10	W11	W12
R1	0	0	0	8	0	42	45	8	42	17	9	8
R2	0	0	0	0	25	17	18	0	20	8	9	0
R3	0	0	0	0	0	0	20	0	25	17	0	0
R4	0	0	0	0	0	17	0	9	25	18	9	0
R5	0	0	0	0	0	17	25	0	0	0	0	0
R6	0	0	0	0	0	0	22	0	17	10	18	0
R7	0	0	0	0	0	0	0	11	8	0	0	0
R8	0	0	0	0	0	0	9	0	18	0	0	0
R9	0	0	0	0	0	0	11	0	0	18	8	0
R10	0	0	0	0	0	0	0	0	8	0	0	0
R11	0	0	0	0	0	0	17	0	9	8	18	0
R12	0	0	0	0	0	0	33	0	0	8	0	0

PVY^{N}

R1	0	0	0	33	25	58	64	0	67	67	27	17
R2	0	0	0	0	17	33	45	33	60	33	9	8
R3	0	0	0	0	0	42	60	30	25	42	0	8
R4	0	0	0	0	17	17	27	36	58	64	0	0
R5	0	0	0	8	0	25	38	8	42	27	0	0
R6	0	0	0	0	0	33	33	18	25	40	0	0
R7	0	0	0	0	0	17	30	11	50	9	0	0
R8	0	0	0	0	0	0	18	18	36	25	0	0
R9	0	0	0	0	0	8	22	9	33	27	0	0
R10	0	0	0	0	0	0	20	20	25	25	0	0
R11	0	0	0	0	0	18	33	8	9	17	0	0
R12	0	0	0	0	8	17	25	0	8	17	0	0

Figure 16. Example of weekly distance and frequency of transmission (middle and lower panels) to tobacco bait plants is reported for PVY isolates (serotypes N and O are presented) and expressed as a weekly percentage of total cases of infection and plotted by distance (row number) from the infector plants (see plot layout Figure 2). Weekly aphid vector pressure from yellow water traps (YWT) and suction trap (ST) are presented together with the overall PVY and PVA weekly transmission rate) at SASA site (Gogarbank).

The position of infected potato bait plants in each plot was determined by post-harvest testing of 3 tubers from each plant in every plot. Examples of spatial distribution of PVA and PVY isolates at the SASA and Scottish Agronomy sites are presented in Figure 17 (2010 PVA trials SASA and SA top-middle-lower panels), Figure 18 (2011 PVA trials SASA and SA) and Figure 19 (2010 and 2011 SASA PVY trials). The frequency of overall PVA transmission is comparable between sites (approximately 12% at SASA's site and above 15% at Scottish Agronomy's site for each Desiree plot). The frequency of transmission and spatial distribution in potato is also comparable to the distribution in tobacco bait plants where the highest frequency of transmission is observed within rows 1 to 3 (Figure 17 lower panel).

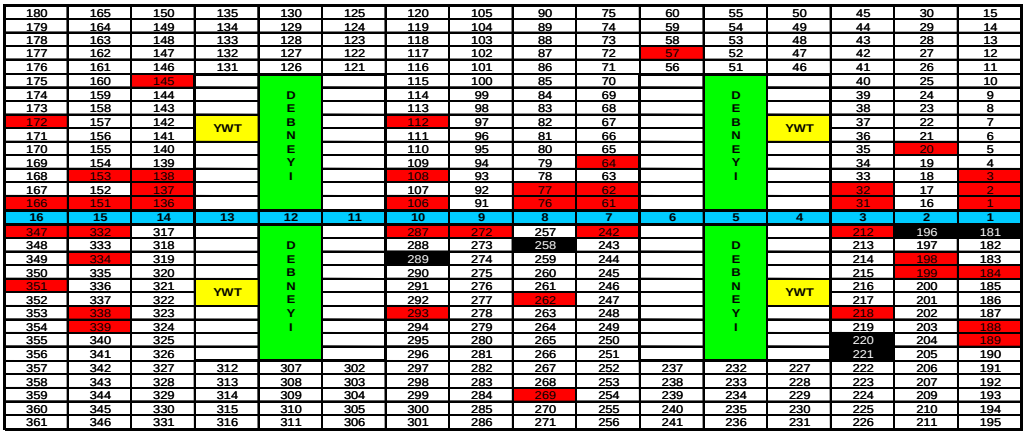


% Infection - Desiree

PVA	15.5%
PVYN	1.5%

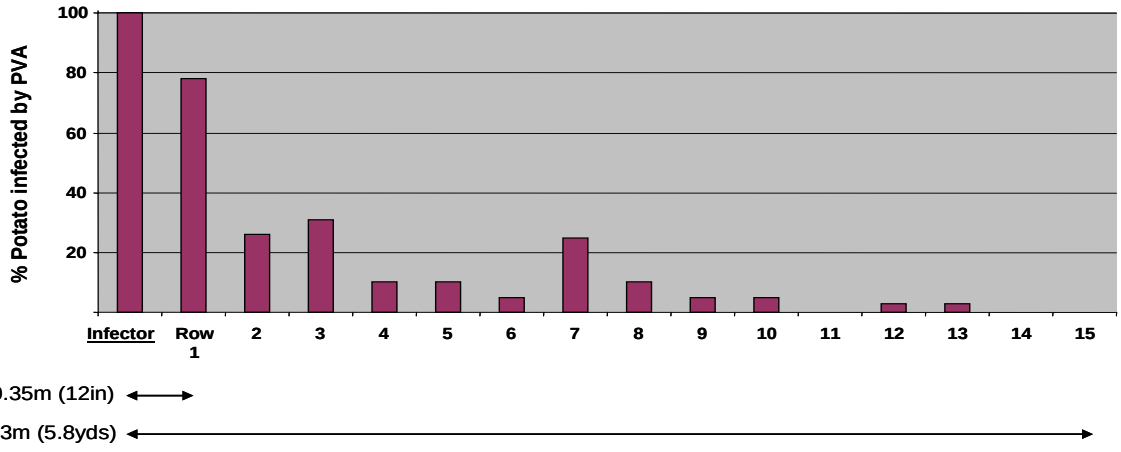
% Infection - Estima

PVA	21.2%	PVA total 40.1%
PVA+PVV	18.2%	
PVV	8%	PVV total 29.1%
PVYN+PVA+PVV	1%	



% Infection - Desiree

PVA 11.9 %



0.35m (12in) ←→

5.3m (5.8yds) ←——————————→

Figure 17. Spatial distribution of infected potato plants at the Scottish Agronomy site (top panel, right PVA-Desiree plot, left PVA-Estima plot) and SASA site (middle panel, PVA-Desiree plot) in 2010. Each potato plant infected by a virus is colour coded (red-PVA, light blue-PVV, green-PVYN, purple-PVA+PVV, orange-PVYN+PVV+PVA, black-rotted not tested). The percentage of infected plants per virus is indicated. The frequency of infected PVA plants and distribution (rows 1 to 12 numbered from the infector row) in SASA's PVA plot is presented (lower panel).

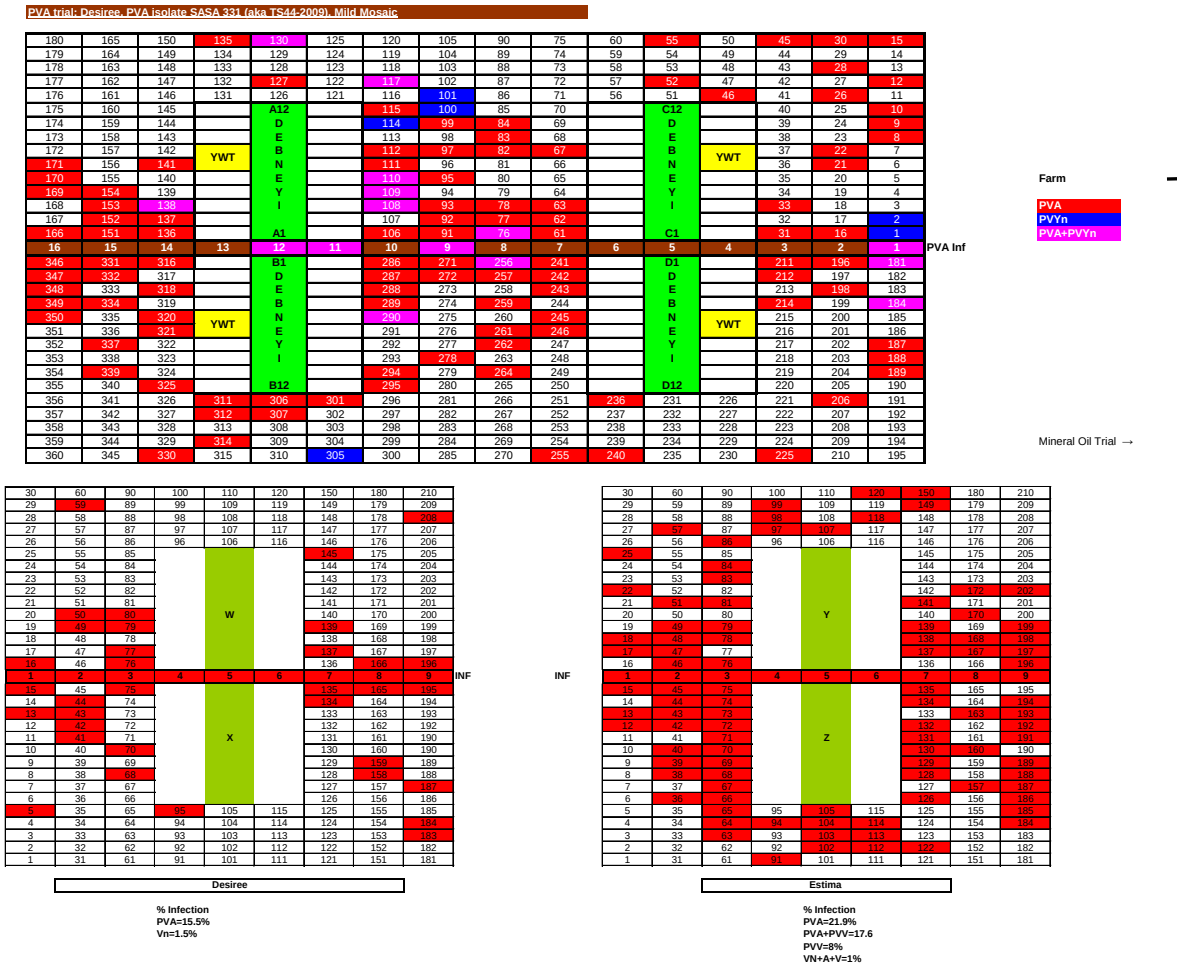


Figure 18. Spatial distribution of PVA infected potato plants in the PVA plot at SASA (upper panel) and SA (Pittenweem, Fife, lower panel) sites (2011).

The PVY trial at SASA's site was designed to monitor and study possible interactions between two different PVY^{N} isolates (PVY$^{EU\text{-}NTN}$ and PVY$^{NA\text{-}NTN}$) together with a PVY^{O} isolate within the same plot in relation to the timing of transmission and distribution in potato plants. For each isolate, 7 infector plants were distributed alternately in the plot. In total 14 infected plants with PVY^{N} serotype isolates and 7 of PVY^{O} serotype as presented in Figure 19. Weekly transmission to tobacco of PVY^{N} and PVY^{O} serotypes followed the same pattern (Figures 9 and 10). Over the season, the overall transmission rate was of 70% for PVY^{N} and 30% for PVY^{O}. As there were a total of 14 infectors of N-serotype as opposed to 7 of O-serotype we conclude that a comparable transmission rate was observed for both PVY^{N} and PVY^{O} serotypes.

The transmission of PVY^{N} and PVY^{O} to potato bait plants was assessed. A much higher proportion of plants tested positive for PVY^{N} than for PVY^{O} (33 plants and 3 plants respectively in 2010 Figure 19, upper panel). The proportion of potatoes that tested positive for PVY^{N} was 92% which contrasts with the weekly transmission rate to tobacco for both PVY^{N} and PVY^{O}. A similar result was found in 2011 (Figure 19 lower panel).

These results suggest that these PVY isolates (PVY^{O}, PVYEU-NTN and PVY$^{NA\text{-}NTN}$) are likely to be transmitted in a comparable fashion by similar aphid species. Contrastingly, frequency of tubers infection was found to differ significantly between PVY^{O} and PVY^{N} isolates (and as well between PVY$^{EU\text{-}NTN}$ and PVY$^{NA\text{-}NTN}$ strains Figure 20 (Davie *et al*, 2012). PVY^{N} incidence in tubers is higher than for PVY^{O} in field conditions. This suggests that PVY^{N} might be fitter

than PVY^{O} isolates resulting in greater distribution and translocation to daughter tubers, potentially explaining the prevalence of PVY^{N} over PVY^{O} serotype. Further experimentations are on-going to understand the basis of PVY strain distribution and dynamics in potato plants (Davie *et al*, 2012).

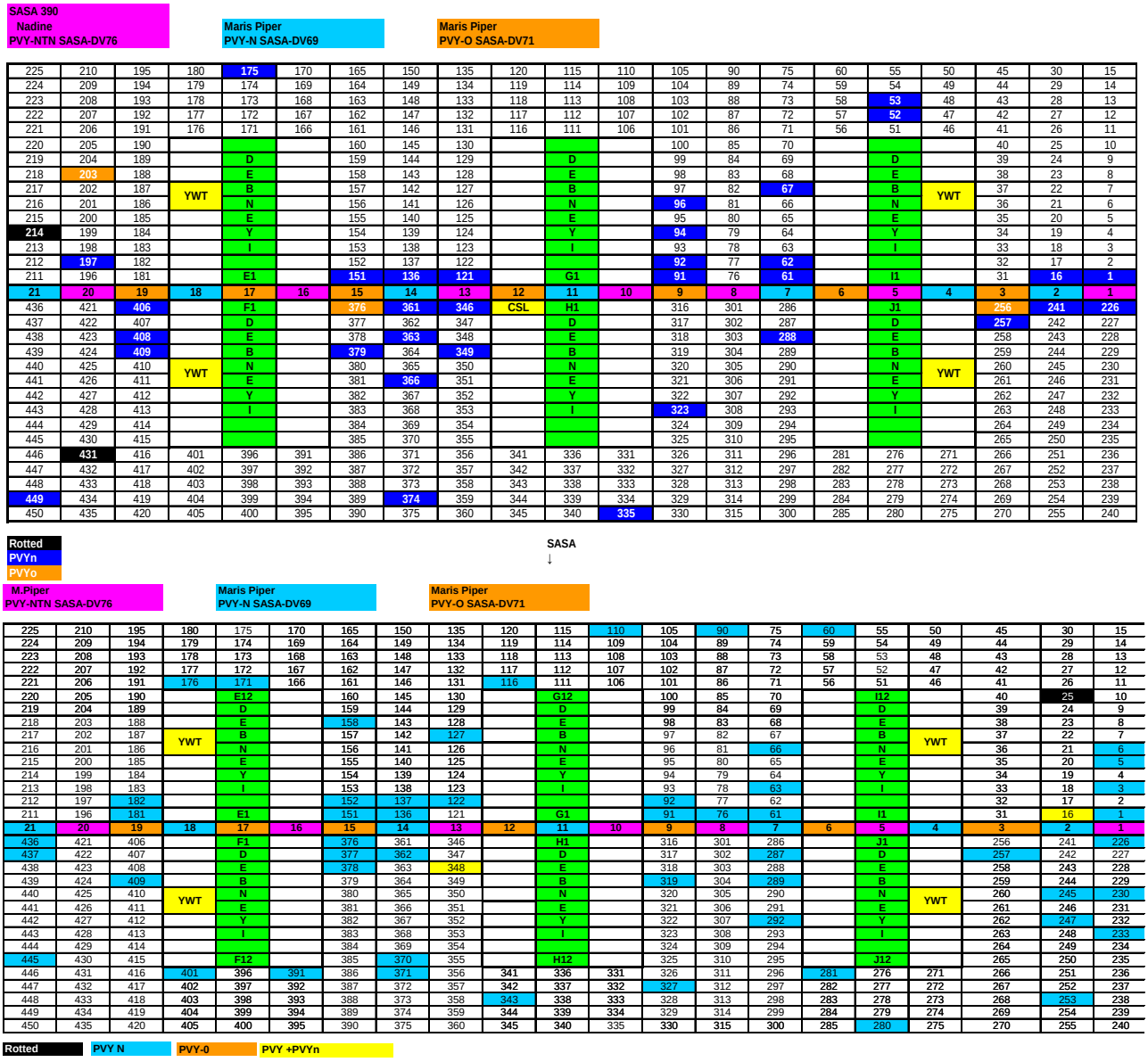


Figure 19. Spatial distribution of PVY isolates in potato plants (SASA trials 2010 –upper panel 2011 lower panel). (blue: PVY^{N}, orange: PVY^{O} positive, black: rotted non-tested tubers).

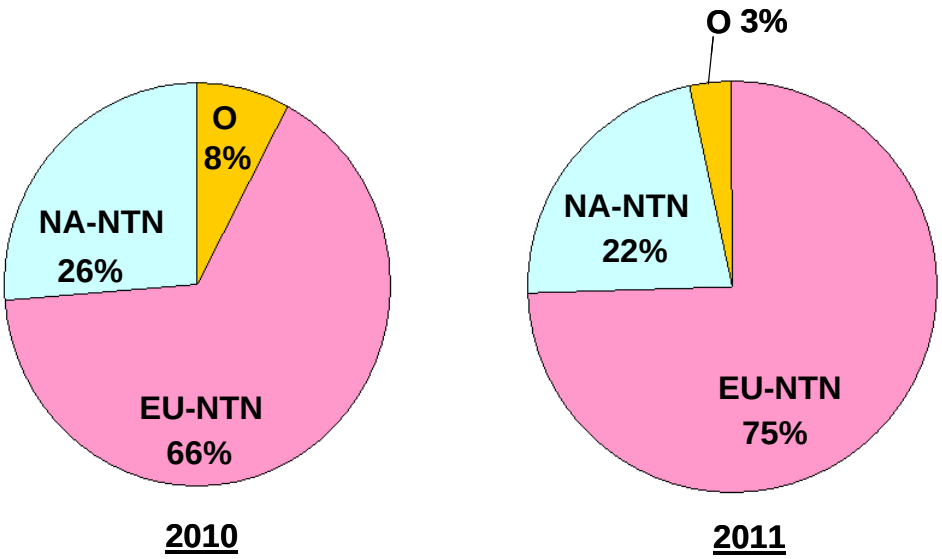


Figure 20. Relative proportion of $PVY^{EU\text{-}NTN}$, $PVY^{NA\text{-}NTN}$ and PVY^{O} in infected potato bait plants (2010-2011).

Fera 2010

At FERA's site, the spatial distribution of the transmission and translocation of PVY and PVA was measured by taking a single tuber from each plant, growing on and then testing the plant for virus infection. The results are presented in Figures 21 and 22, respectively. There is a significant amount of transmission of PVY across the plot. It is likely that the surrounding and within plot King Edward ware crop contributed to the source of PVY and hence overestimates the spread from the infector row.

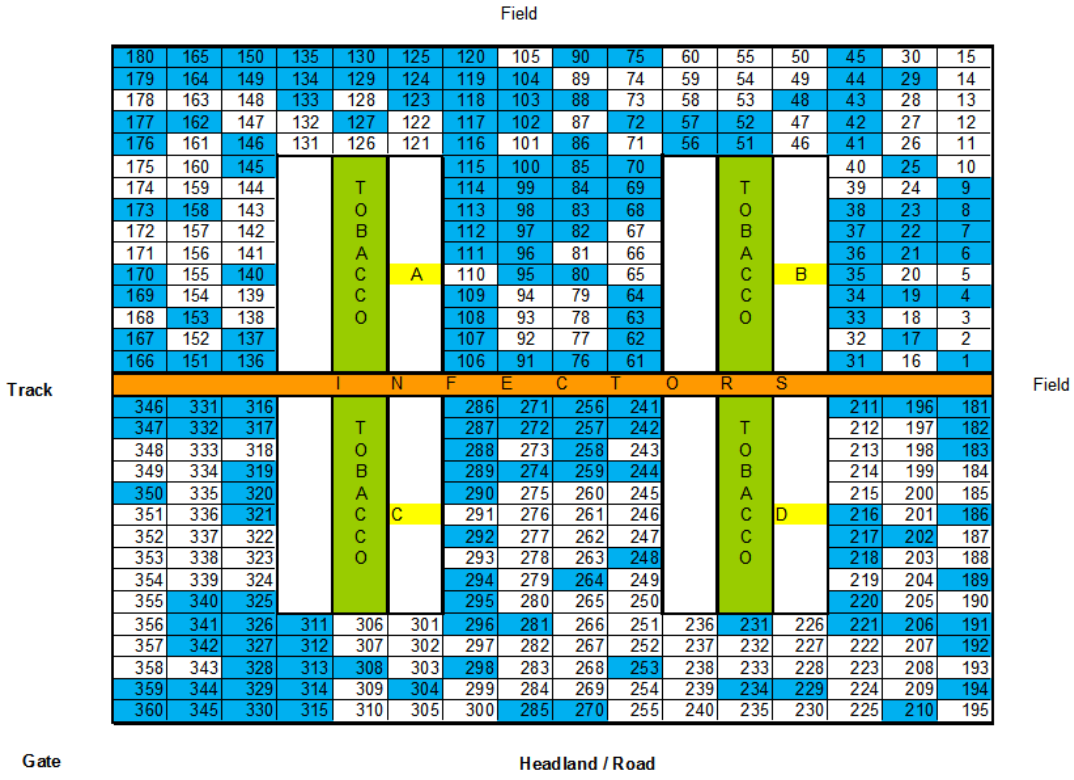


Figure 21. Spatial distribution of PVY infected potato plants in the PVY plot at the Yorkshire epidemiology trial 2010

The amount of transmission and translocation of PVA (6%) through the PVA plot is much less than that of PVY (50%) through the PVY plot, though both had nearly 60% of the infected tubers on the 'field' side of the infector row. The infector row was running approximately west – east so the prevailing south-westerlies would perhaps give a greater chance of infection to the north of the infectors.

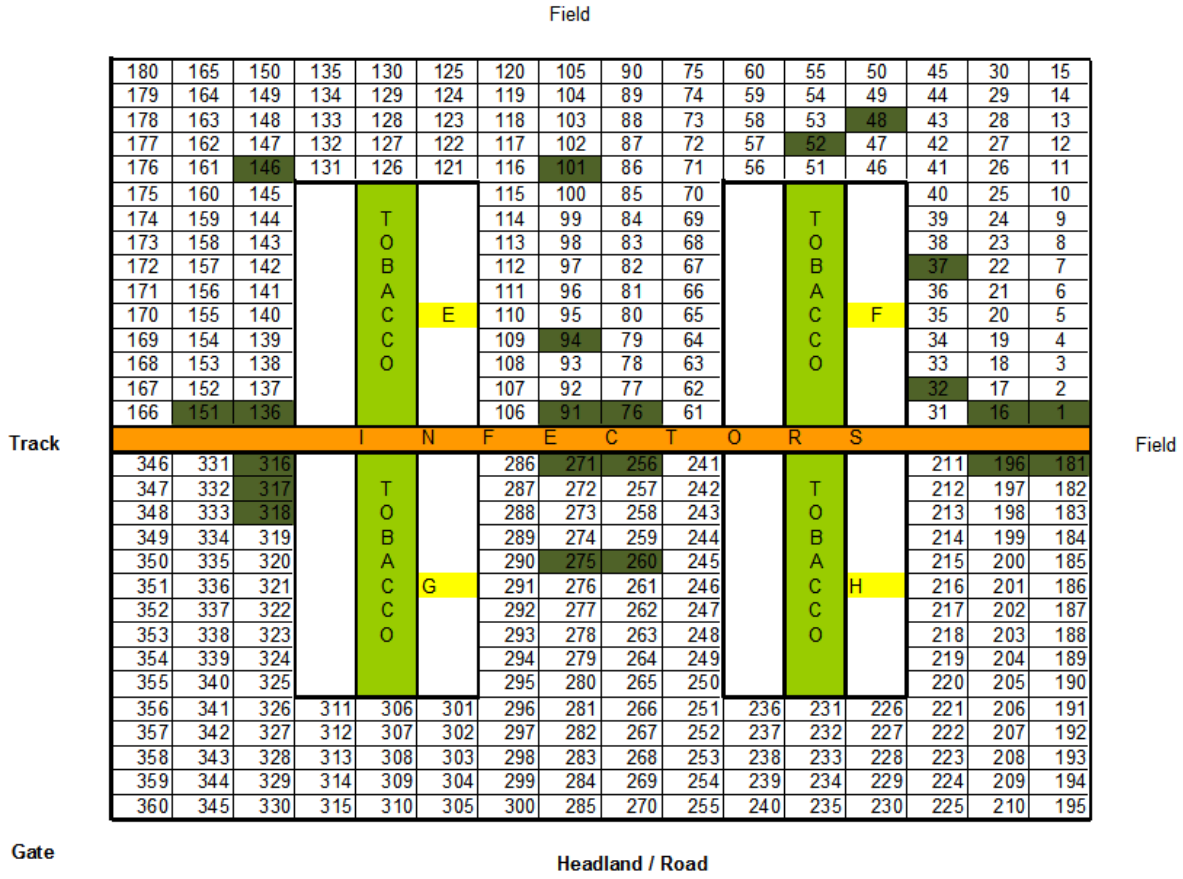


Figure 22. Spatial distribution of PVA infected potato plants in the PVA plot at the Yorkshire epidemiology trial 2010.

Fera 2011

The plots were in a field with a similar orientation to the previous season. Over the course of the season 97 bait plants were infected with PVY. This equates to an infection rate in the plot of 26.9% (Figure 23). A further 2 plants were infected with PVY^O, probably originating from the surrounding crop of ware potatoes. By comparison PVA appears to have been transmitted at a much lower rate (Figure 24a) with 14.4% of bait plants infected at the end of the season (52 plants of 360).

As mentioned previously, the plots were planted in a ware field of cv. King Edward which contained plants exhibiting both severe and mild mosaics. These were shown to be positive for PVY^N and PVY^O, with some plants carrying dual infections. Although this was at a relatively low level (estimated to be <5%) the effect of this residual infection in the surrounding crop can be seen in the effect on the infections in the PVA plot (Figure 24b). In addition to the 52 plants with PVA (14.4%) there were 59 plants infected with PVY^N (16.4%). Eleven plants (3%) were found to be dual infection with PVA and PVY^N and 3 plants (0.8%) were infected with PVY^O.

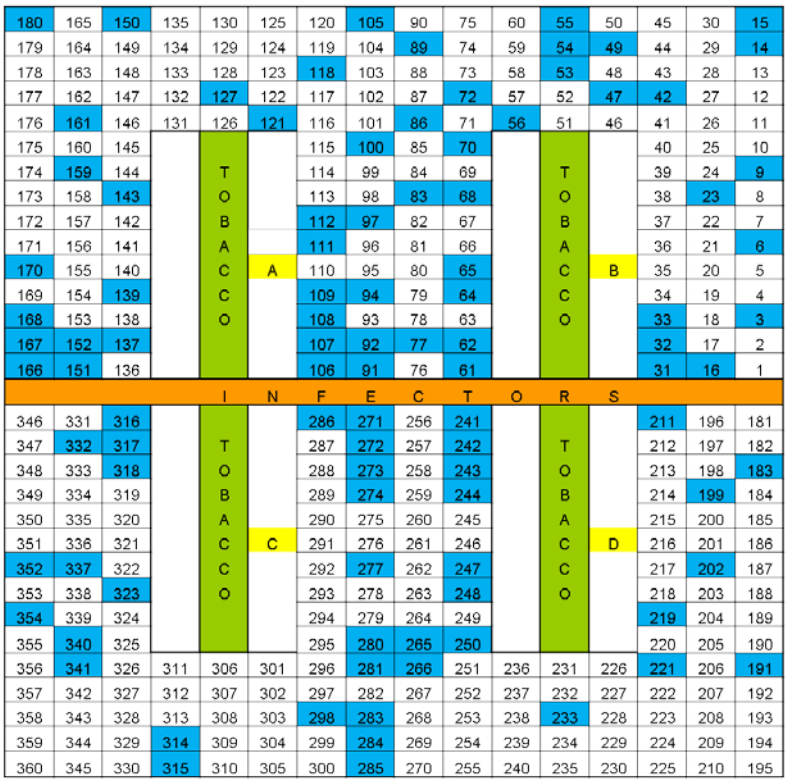


Figure 23. Spatial distribution of PVY infected potato plants in the PVY plot at the Yorkshire epidemiology trial 2011

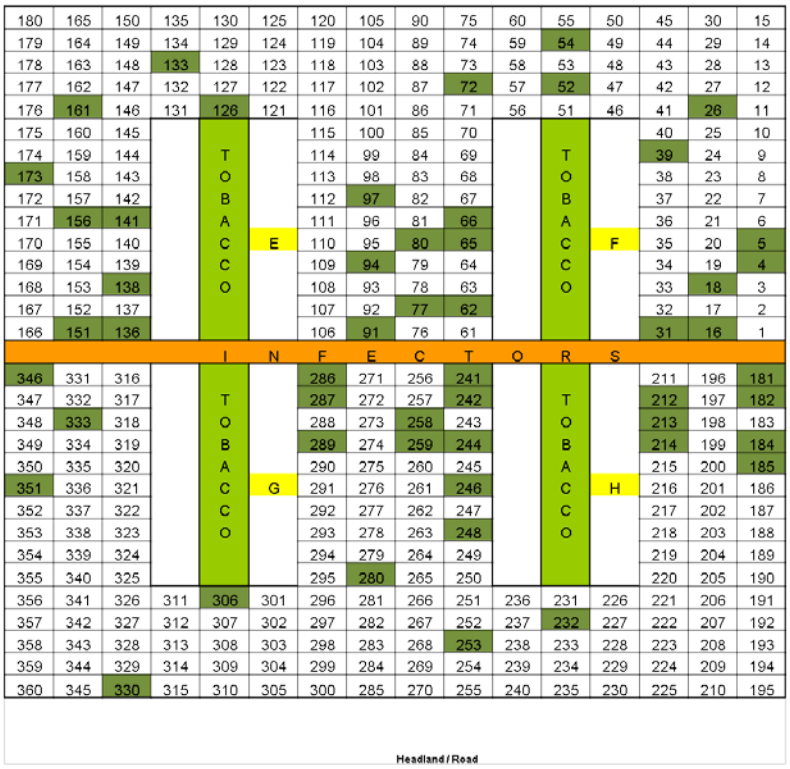


Figure 24a. Spatial distribution of PVA infected potato plants in the PVA plot at the Yorkshire epidemiology trial 2011.

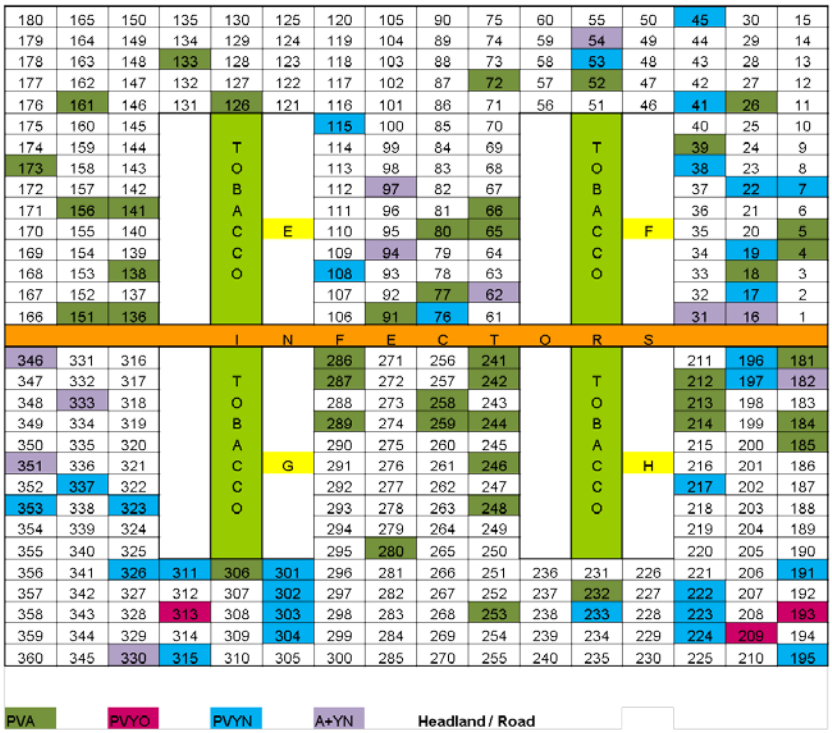


Figure 24b. Spatial distribution of all infected potato plants in the PVA plot at the Yorkshire epidemiology trial 2011. Data are presented for PVA, PVY^{N} and PVY^{O} showing dual/multiple infections.

Objective 4: Provide an improved understanding of the Estima-PVA interaction

The outcome of interactions between viruses (such as PVA) and their potato hosts is conditioned by both virus pathogenicity (*i.e.,* ability to infect, accumulate inside the plant and elicit symptoms) and genetic background of the host (Rajamaki *et al*., 1998). This leads to a range of possible combinations spanning from extreme resistance (inhibition of virus accumulation) to susceptibility and disease symptoms development (virus accumulation in most plant organs and transmission to progeny tubers) (Pallas and Garcia, 2011). Assessment of potato variety susceptibility to viruses relies on the monitoring of virus incidence in progeny tubers. In order to understand the basis of rapid crop health degeneration of variety Estima, the incidence, distribution and translocation of PVA in Desiree and Estima crops were assessed. Data from epidemiology trials were collected over a 4 year period (2008 to 2011) therefore including 2 years preceding the start of this project (SASA and Scottish Agronomy, unpublished data). As presented above comparable weekly timing and frequency of PVA transmission in Desiree and Estima plots was observed (Figures 11 and 13, respectively) indicating that virus uptake from source plants and transmission to bait plants were comparable. However, assessment of the incidence of virus in tubers revealed that the averaged transmission rates to Estima and Desiree were ~40% and ~17%, respectively (Figure 25). Analysis of the frequency of tuber infection from infected Estima and Desiree plants by virus indexing of all individual grown-on plants from each individual PVA positive bulk (3 tubers bulked) showed that the overall percentage of infected tubers was comparable (66.5% and 63% for Estima and Desiree, respectively). However, Estima displayed a greater proportion of plants with all tested tubers infected (39%) over Desiree (28%) (Figure 26). Conversely, Desiree displayed a greater proportion of plants with a lower tuber infection rate (33% of plants with 66% of Desiree tuber infected as opposed to 22% for Estima). This suggests that the rate of PVA tuber translocation is higher in Estima than for Desiree.

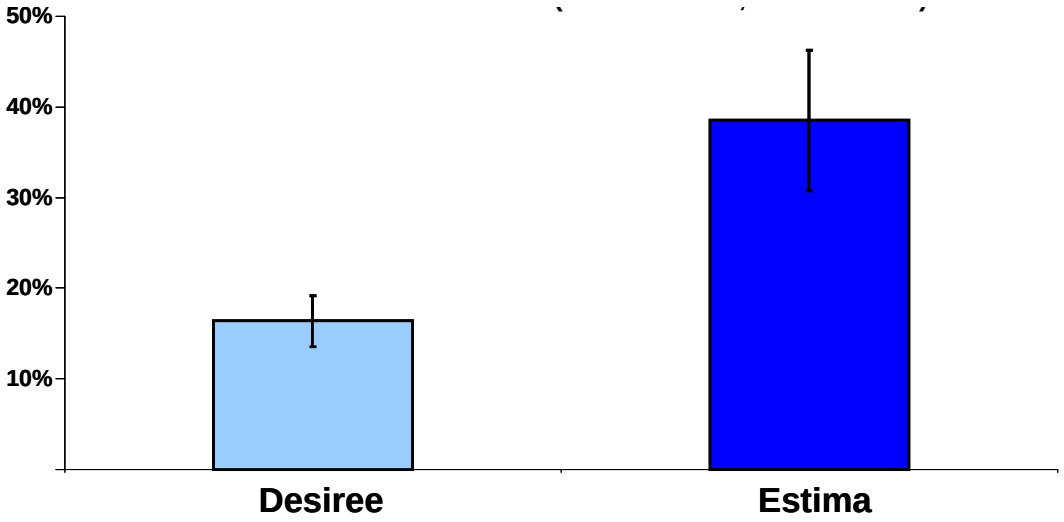


Figure 25. Percentage of PVA-infected Desiree and Estima bait plants at post-harvest testing (Mean +/-SE calculated from four years' data, P=0.003).

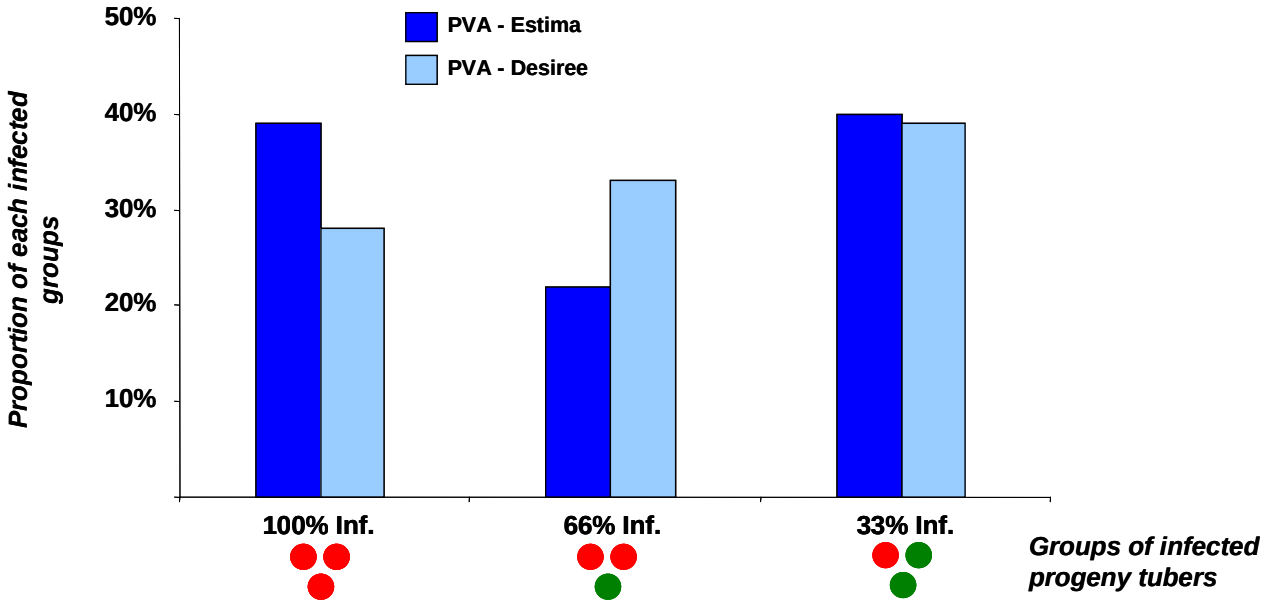


Figure 26. Proportion of tuber groups displaying different incidence of PVA infection from infected Estima and Desiree plants. All positive bulks of Estima and Desiree plants from Fife PVA epidemiology trial were re-analysed by testing individual grown-on plantlets from each PVA positive bulk (bulk of 3 tubers). Results are from season 2010 and 2011 from 101 Estima and 54 Desiree PVA positive bulks (total of 303 tubers from cv Estima and 162 tubers from cv Desiree). Red: infected tubers, Green: non-infected tubers.

The higher susceptibility to PVA infection between Estima and Desiree (more than a two-fold difference, Figure 25) observed in this study was confirmed in independent trials (Table 6, National List Trials, J. Thomas, NIAB, personal communication) whereby PVA incidence in Estima tubers was found to be 2.5-fold higher than Desiree (Table 9). PVY^N incidence in Estima and Desiree was comparably high. Statutory post-harvest testing of Estima crops have revealed that PVA incidence represent the large majority of virus cases (up to 85% in 2012, SASA unpublished data). Taken together the high level of susceptibility of Estima to PVA combined with the higher frequency of PVA incidence in Estima tubers is likely to account for the rapid virus health degeneration observed in Estima crops.

Table 9: Relative infectivity of selected potato crops to PVA and PVY^N observed in UK National List Trials 2009-2012 (J. Thomas, NIAB, personal communication).

	Relative Incidence (%)	
Variety	**PVA**	**PVY^N**
Estima	100	95
Maris Piper	0	89
Desiree	38	100
Record	0	97
Sante	0	0
Lady Rosetta	0	39

Objective 2: Develop systems to allow aphid monitoring data to be effectively utilised to provide growers with the best quality information on which to base their virus management programmes

A separate report addressing objective 2 is provided in Appendix 2. The report considers how the relationships between yellow water trap catches and suction trap catches, and the variation between them, can be utilised in an integrated data delivery system. Consideration is also given to the utilisation of other sources of data, providing recommendations on how the integration of these data sources should be undertaken, what should be included and what further information is required.

Objective 3: Identify sources of potyvirus inoculum and investigate their importance in the spread of virus to seed crops

3.2.3. Survey of Symptomatic Plants (England & Wales)

The results in this summary are presented as cases. A case equates to a finding of virus within a crop. Where more than one virus was recorded from a crop this is counted as one case of each virus, consequentially there are more cases of virus than crops sampled. A negative finding equates to a single crop.

Virus	**2009**	**2010**
Potato virus $Y^{O/C}$	61	78
Potato virus Y^N	129	186
Potato virus A	44	14
Potato virus V	13	11
Potato virus M	4	3
Potato virus S	1	3
Potato virus X	5	3
Total Positive cases	**257**	**298**

Table 10. Symptomatic virus surveys of seed crops (England and Wales 2009 and 2010). The values represent the total number of positive cases of virus of the non-persistent viruses and PVX.

General incidence of the viruses recorded in the surveys can be seen in Figure 27. The most commonly intercepted virus was PVY, representing over 75% of virus detected. The relative incidence of the PVY strains, as defined by their serology, was approximately 42% PVY^O to

58% PVY^{N}. When compared to Scotland and mainland Europe, it would appear that England & Wales has a higher incidence of PVY^{O} than would be expected, which could be a reflection of the varietal makeup of the English and Welsh seed potato crops. On the continent there has been a gradual genetic drift to the tobacco necrosis strain of PVY (PVY^{N}) over the last couple of decades and also an associated increase in the incidence of tuber necrosis inducing strains (PVY^{NTN}). In 2009, PVA represented 17% of positive findings whereas in 2010 it was present in fewer than 5% of cases. It is not known at this time whether this decline is a reflection of the efforts to chase PVA positive crops, primarily Estima, out of seed production chains or a more generalised move away from growing PVA susceptible cultivars (e.g. Desiree or Estima).

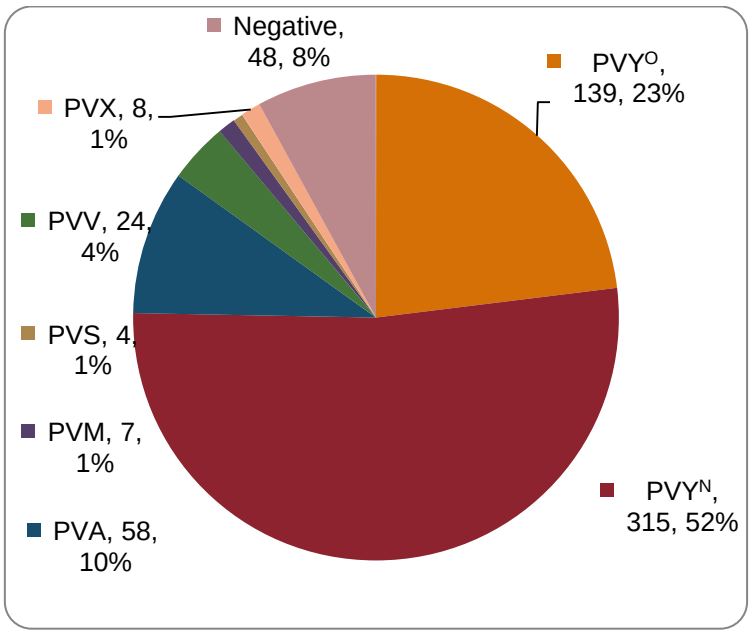
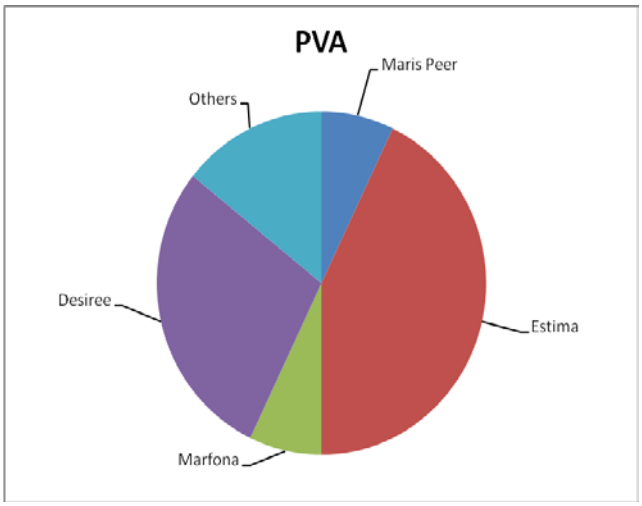


Figure 27 (above). Relative incidence of each virus recorded in the 2009- 2010 surveys of England and Wales

a)



b)

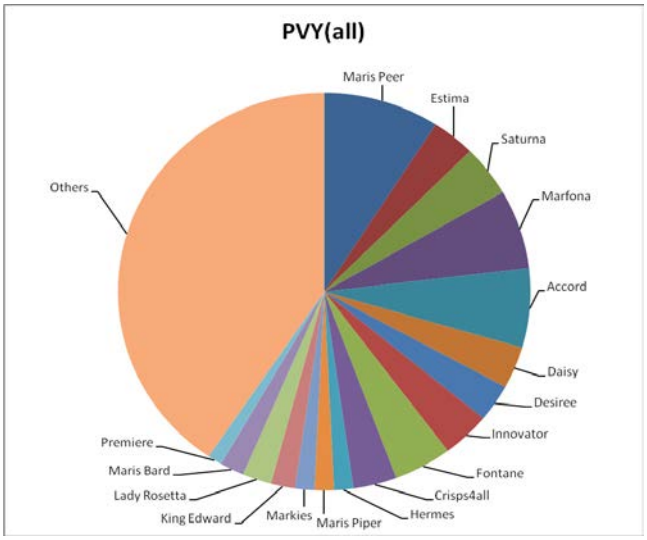


Figure 28. a) Chart of varietal incidence of PVA. b) Chart of varietal incidence of PVY (all strains). Only cultivars with samples submitted from 5 or more crops have been included in these figures (2010 Data)

The varietal distribution of the major viruses (PVY and PVA) is shown in Figure 28 (a & b above). Estima and Desiree are most commonly intercepted with PVA, with small amounts of this virus being found in Maris Peer, Marfona and a few other varieties. This is of note as Marfona is thought to have a high resistance to this virus. The distribution of PVY is more homogenous. Without propensity data (see section 3.2.5 below), it would be difficult to know whether the relative incidence of PVY in Maris Peer, Estima, Saturna, Marfona and Accord are a reflection of general poor virus health in these crops or simply a reflection of the amount of these varieties which are grown.

Samples were submitted from 81 cultivars, including samples from breeding material (Table 11). Few conclusions can be drawn from varieties where only a few crops had samples submitted for testing. The variety Maris Peer represents the largest sample subset and there appears to be a strong affinity of this cultivar to PVY^N. Estima was the second most commonly submitted variety and as expected represented the largest proportion of PVA and PVV findings, although the relative incidence of PVA to the other virus in this variety has dropped markedly.

Table 11. Cases of viruses found in common cultivars, only varieties where greater than 4 crops had samples submitted to the laboratory are listed (2010 England and Wales data).

Variety	No of Crops	PVY^O	PVY^N	PVA	PVV	PVM	PVS	PVX	-VE
Maris Peer	22	3	21	1	1				
Estima	19	3	6	6	7				7
Saturna	14	3	8					1	4
Marfona	13	4	13	1	1		1		
Accord	12	5	12						
Daisy	8	2	7						
Desiree	8	2	6	4					
Innovator	8	6	4						
Fontane	7	5	7						
Crisps4all	6	5	4						
Hermes	6		4						2
Maris Piper	6		4						2

Markies	6	3	1						2
King Edward	5	2	3						1
Lady Rosetta	5	2	4						1
Maris Bard	5	1	4						1
Premiere	5		3		2				
Others	103	32	75	2	0	3	2	2	12
Total	258	78	186	14	11	3	3	3	32

3.3. Survey of symptomatic plants within the Scottish Potato Certification Scheme (SSPCS).

Within the SSPCS during the reporting period 2009-2011, a total of 4,117 leaf samples were collected and tested for eleven viruses (PVY strains PVY^{N}, $PVY^{O/C}$, PVA, PVV, PVM, PVS, PVX, PLRV, TRV, PMTV, TBRV) by ELISA for a maximum of 8 samples per crop (Table 12).

Table 12. Cases of virus detected in samples of Scottish seed crops 2006-2011. During the 2009-2010-2011 period the number of samples received for each of these growing crop season was respectively 1504, 1726 and 887.

Virus	Cases of Virus					
	2006	**2007**	**2008**	**2009**	**2010**	**2011**
Potato Leaf Roll Virus	51	48	107	160	57	20
Potato Virus YO/C	49	52	32	35	61	29
Potato Virus YN (VN)	117	153	184	299	376	174
Potato Virus A	56	103	108	75	78	58
Potato Virus V	11	32	30	13	23	12
Potato Virus M	0	0	0	0	0	0
Potato Virus S	0	2	2	1	0	1
Potato Virus X	23	38	18	19	20	25
Tomato Black Ring Virus	1	7	1	2	0	1
Tobacco Rattle Virus	32	53	19	3	9	1
Potato Mop Top Virus	10	52	40	17	23	49
Total	**350**	**540**	**541**	**624**	**647**	**370**

Data on incidence of virus within varieties (2011) is summarised in Table 13 (below). Samples were received from 128 varieties, with samples from 100 varieties testing positive. The varieties most commonly submitted for testing were Maris Piper and Maris Peer (8% of tested crops); followed by Valor (7%); Desiree (6%), Estima, Atlantic and Hermes (5%) and King Edward (4%).

The strongest virus/variety associations were Estima with PVV; Maris Piper with PLRV; Desiree, Estima and Hermes with PVA; Desiree, Maris Piper, Maris Peer and Valor for PMTV. PVV was detected in 50% of the Estima crops submitted for testing, which accounted for 75% of all PVV findings. PLRV was detected in 28% of the Maris Piper crops submitted for testing, which accounted for 35% of all PLRV findings. PVA was detected from 65% of Desiree crop samples, with a comparable figure of 40% for Hermes and 33% for Estima. Desiree, Hermes and Estima were responsible for 26%, 14% and 10% of all PVA detected from seed crops respectively. PVY (PVY^{N} and $PVY^{O/C}$) was most prevalent in Maris Peer (10%), Atlantic (9%), Maris Piper (8%), King Edward (8%) and Desiree (4%)

Table 13. Cases of virus detected in samples of seed crops by variety (2011) (crops with at least 6 confirmed cases of virus infection are presented for the 11 virus species commonly monitored in Scotland).

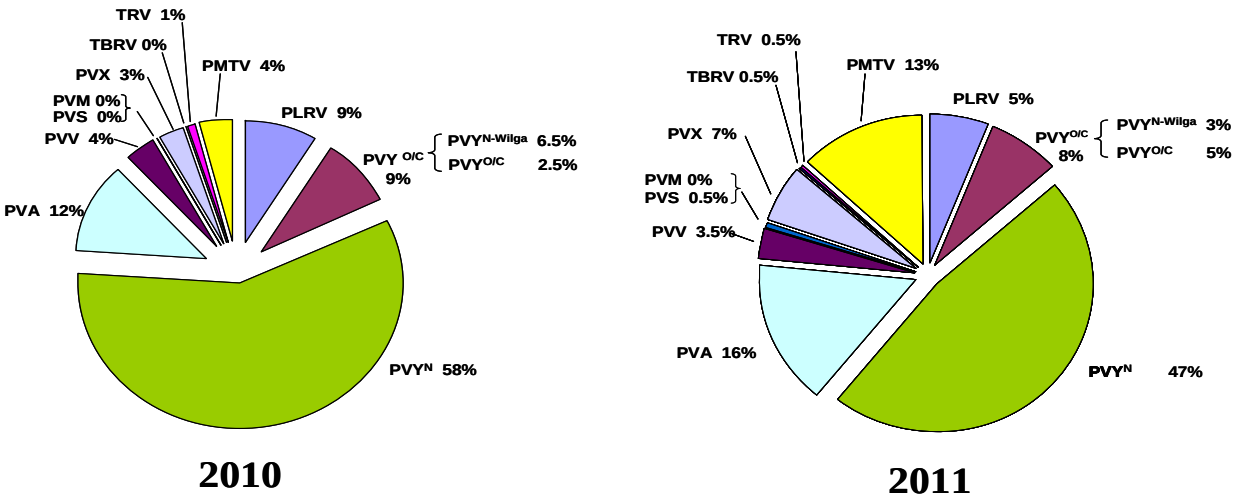
2011		VIRUS PRESENT												
CULTIVAR	No. of crops	Positive	PLRV	$PVY^{O/C}$	PVY^{N}	PVA	PVV	PVM	PVS	PVX	TBRV	TRV	PMTV	Negative
MARIS PEER	33	25	2	1	20	0	0	0	0	2	0	0	5	8
MARIS PIPER	33	25	7	1	15	0	0	0	0	1	1	0	4	8
VALOR	29	27	0	5	19	0	0	0	0	0	0	0	4	2
DESIREE	28	23	1	0	9	15	0	0	0	3	0	0	5	5
ESTIMA	22	18	0	1	0	6	9	0	0	1	0	1	1	4
ATLANTIC	20	17	0	5	14	0	0	0	0	0	0	0	2	3
HERMES	20	12	0	0	0	8	0	0	0	1	0	0	3	8
KING EDWARD	17	16	0	1	16	0	0	0	0	0	0	0	2	1
MARFONA	9	5	0	0	3	0	0	0	0	2	0	0	0	4
MARKIES	7	5	0	0	0	4	0	0	0	0	0	0	1	2
CASABLANCA	6	4	0	1	0	2	0	0	0	0	0	0	3	2
CHARLOTTE	6	4	0	1	3	0	0	0	0	2	0	0	0	2
WINSTON	6	6	0	0	1	0	0	0	0	5	0	0	0	0
ASTERIX	5	3	0	0	2	2	0	0	0	0	0	0	0	2
CABARET	5	4	0	0	2	3	0	0	0	0	0	0	0	1
GOLDEN WONDER	5	5	0	1	1	3	0	0	0	0	0	0	0	0
SHEPODY	5	3	0	0	2	0	0	0	0	0	0	0	0	2
VALE SOVEREIGN	5	3	1	0	1	1	0	0	0	0	0	0	0	2
WILJA	5	3	0	0	2	0	0	0	0	0	0	0	1	2
OTHERS	167	107	9	12	64	14	3	0	1	8	0	0	18	60
Grand Total	433	315	20	29	174	58	12	0	1	25	1	1	49	118

The data presented in Tables 12 - 13 and Figure 29 are an indication of the population dynamics for 11 viruses commonly found in potato growing areas worldwide, based on leaf symptoms of growing crops. Potyvirus is the most prevalent virus group with PVY being the most prevalent over PVA and PVV, together accounting for 83% and 75% of virus cases in 2010 and 2011, respectively (Figure 29).

Over the past two years, PVY^{N} was the most commonly detected virus in symptomatic leaf samples (PVY^{N} and $PVY^{O/C}$ represent 67% and 55% of cases in 2010 and 2011). $PVY^{O/C}$ was found in 8% - 9% of cases. Biotyping of intercepted $PVY^{O/C}$ isolates (i.e. monitoring the induction of vein necrosis on tobacco host plant in a comparable fashion as for PVY^{N} isolates), indicates that $PVY^{N\text{-}Wilga}$ necrotic PVY^{O} variants account for 3% to 6.5% of all virus cases.

PVA was the next most commonly detected virus (12% and 16% of cases), overtaking PLRV (9% and 5% of cases in 2010 and 2011) in sharp decline since 2009 (26% of cases) (Figure 30).

Figure 29. Virus species distribution in symptomatic leaves 2010 and 2011 (SPCS).



From the data presented in Figure 29 a significant increase in the PVY^N incidence is observed since 2007. Analysis of the ratio of PVY^N to PVY^O and PVY^C strains (Figure 30) indicates that this trend is continuous over the past 6 years and is more marked in the past 4 years.

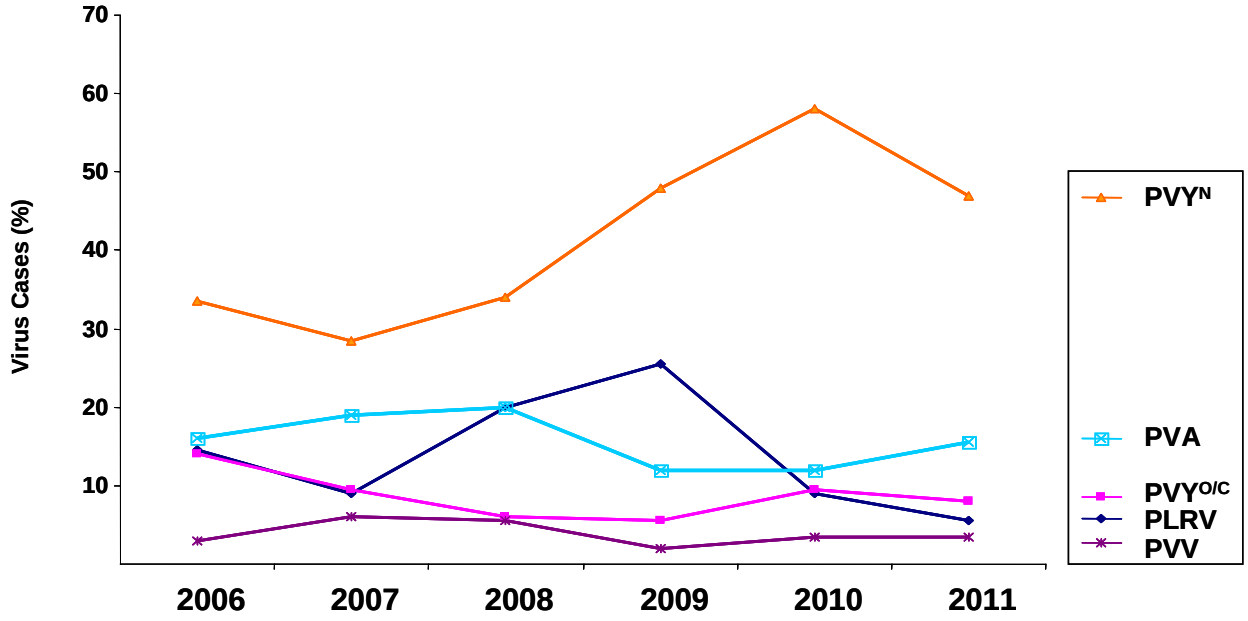


Figure 30. Proportion of aphid transmitted virus cases in seed crops (SSPCS) 2006-2011.

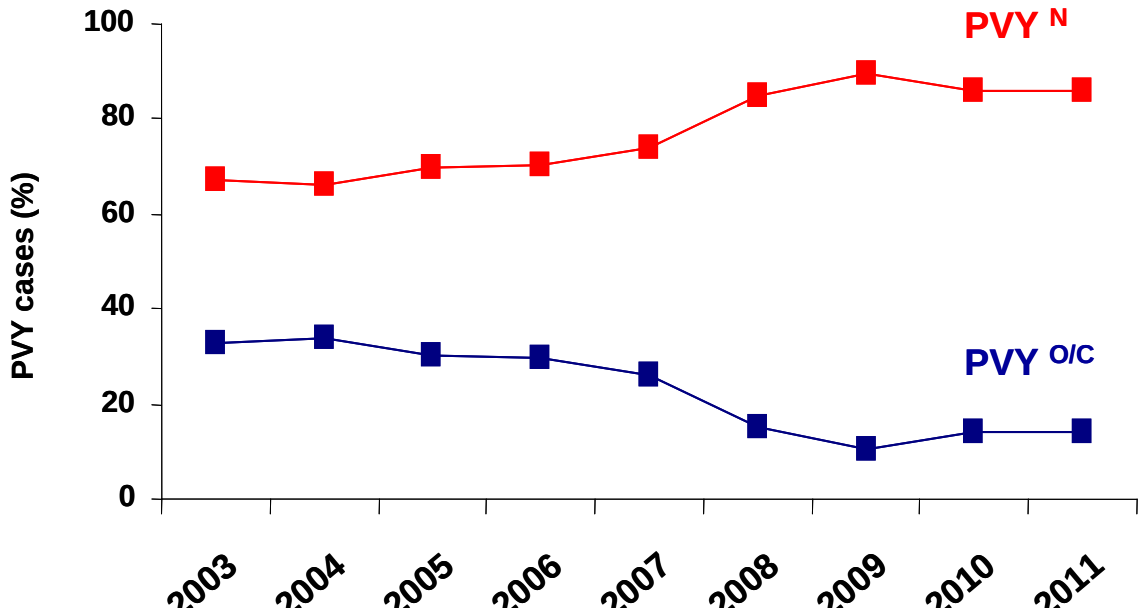


Figure 31. Proportion of PVY strain based on the serology of intercepted cases (PVY^N and $PVY^{O/C}$) in seed crops between 2003 and 2011.

The result of growing crop survey in England and Wales, Scotland (SSPCS) and the overall relative incidence of intercepted viruses ("Overall UK" percentage of total cases per virus

relative to the total number of cases) for 2009 and 2010 is presented below (Table 14). Only the cases found positive for the same 7 mosaic-causing viruses tested are reported. Overall, PVY strains account for 78% of all viruses detected during this survey. PVY^N account for 80% of PVY cases, confirming the prevalence of the tobacco necrotic strain PVY^N in the UK. A higher proportion of $PVY^{O/C}$ to PVY^N serotype was found in England & Wales (Figure 27) in comparison to Scotland (Figure 29). Other potyviruses such as PVA and PVV are less prevalent than PVY^N and $PVY^{O/C}$ in the UK.

Table 14. Total number of virus cases and relative incidence of mosaic-causing viruses in seed crop in the UK (Scotland, England & Wales) in 2009-2010.

	2009		2010		
	# cases	**%**	**# cases**	**%**	**Overall %**
PVYO	96	13.5	139	16	**15**
PVYN	428	61	562	65.5	**63.5**
PVA	119	17	92	10.5	**13.5**
PVV	26	37	34	4	**4**
PVM	4	0.5	3	0.5	**0.5**
PVS	2	0.5	3	0.5	**0.5**
PVX	24	3.5	23	2.5	**3**

Non-persistently aphid transmitted viruses (PVY^N, $PVY^{O/C}$, PVA and to a lesser extend PVV) as opposed to persistently transmitted virus (PLRV) are therefore a common threat for the UK seed potato industry UK wide.

3.4. Survey of symptomatic plants within the Scottish Potato Certification Scheme (SSPCS)- Varietal Propensity Analysis.

Rationale

The overall incidence of virus symptoms seen at crop inspection varies from year to year and between varieties. We are proposing the term 'propensity' to be used to describe whether symptoms observed within a variety are above or below the average across the whole Scottish seed crop.

The extent to which virus symptoms will be observed at classification inspection, and hence the propensity of that variety, will depend on a number of factors. Firstly there is the susceptibility of the variety to the viruses that produce the symptoms: for leafroll this is just one virus (PLRV) but many viruses may be responsible for producing mosaic symptoms and the susceptibility of a variety to each of these viruses will vary. Secondly, the degree to which symptoms are expressed at the time of crop inspection may vary between varieties: those which produce obvious symptoms will be more easily observed by the inspector and varieties where symptoms are more subtle or typically develop later in the season may be recorded less frequently. Varietal husbandry may also be a factor as some varieties may be grown in areas where their exposure to external sources of virus inoculum differs from the norm. Newer varieties may also have fewer crops at lower grades with a lower number of field generations. The propensity of such varieties may be expected to increase as more seed crops are grown with more field generations. Chance may also play an important part and therefore this approach is best taken for only the more popular varieties where there is the opportunity to look at a larger number of crops and ideally needs to be looked at over a period of several years.

Methods

Seed potatoes produced and marketed in Scotland must be classified under the Seed Potato Classification Scheme (SPCS). SASA is the Certifying Authority for seed potatoes in Scotland and administers the Scheme. SASA is part of SGAFRC (Scottish Government Agriculture, Food and Rural Communities Directorate) which also undertakes SPCS inspections.

All field grown seed crops entered for classification are inspected by Scottish Government potato inspectors on at least two inspections which take place from late June to early August. During these inspections the incidence of a range of faults including symptoms of virus infection are recorded on the crop inspection cards. Virus symptoms are recorded as Leafroll, Mild Mosaic and Severe Mosaic. These data are then transferred to the SPUDS (Seed Potato Unified Data System) database administered by SASA. As Leafroll symptoms are caused by a single virus, Potato Leafroll Virus (PLRV) and both Mild and Severe Mosaic symptoms can be caused by a range of viruses the data are separated into Leafroll and Mosaics for the purpose of analysis. A crop exhibiting either or both Mild and Severe Mosaic symptoms is considered as expressing Mosaic symptoms. To compare the incidence of symptoms of virus infection recorded at inspection between varieties, data have been extracted from SPUDS and the number of crops within which plants exhibiting Leafroll and Mosaic symptoms have been collated for all varieties over the years 2009 to 2011. To limit chance effects, only those varieties for which an average of over 40 crops p.a. have been entered for classification over the period 2009-2011 have been used for this analysis. The results from the classification inspections are based on 5539 crops grown on 11,873 ha in 2009; 5519 crops grown on 11,806 ha in 2010; and 5450 crops grown on 11,823 ha in 2011.

During the inspections of all field grown crops in Scotland, SASA also conducts a survey of viruses affecting seed potato crops by requesting all inspectors to submit samples from plants affected by mosaic symptoms. Samples received at the SASA laboratory are tested by ELISA for a total of eleven viruses for a maximum of 6 samples per crop. The results allow a similar 'propensity' analysis to that used on the leafroll and mosaic symptoms to be carried out using data for the respective viruses. This has been carried out for the four most prevalent aphid transmitted viruses, i.e. the PVY strains PVY^{N} and $PVY^{O/C}$; PVA and PVV. The results of this survey are based on 1504 samples for virus testing from 664 seed crops in 2009, 1726 leaf samples from 684 seed crops in 2010 and 887 leaf samples from 433 seed crops in 2011.

Results

Propensity to leafroll symptoms

Leafroll symptoms were recorded at inspection in 358 crops out of the total of 16,361 crops inspected during 2009-2011 (Table 15). Symptoms were recorded in 70 varieties, but only in 19 varieties were symptoms recorded on 5 or more occasions. For leafroll only four varieties have consistently produced a propensity value greater than unity over each of the 3 years 2009-2011. The most significant of these is Maris Piper which makes up 8.5% of the total seed crops planted in Scotland over this period. With an average propensity of 4.2, this variety was responsible for 36% of the total crops in which leafroll symptoms were seen during crop inspection. Lady Balfour, Vales Sovereign and Desiree were the other three varieties with a propensity consistently over unity. The following varieties showed a very low propensity to Leafroll over the 3 –year period, these were Hermes, Maris Peer, Markies, Saxon, Lady Rosetta, Saturna, Charlotte, Atlantic, Burren, Rooster, Wilja and Melody. Valor and, to a lesser extent, Maris Bard, are varieties of concern as the propensity of both to leafroll increased markedly in 2011.

Variety	Leafroll 2009	Leafroll 2010	Leafroll 2011	Leafroll 2009-11	Total Crops with Leafroll	Total Crops
MARIS PIPER	4.5	3.4	3.6	4.2	128	1390
HERMES	0.4	0.4	0.0	0.3	9	1274
DESIREE	1.4	1.5	1.2	1.4	24	775
MARIS PEER	0.6	0.0	0.8	0.5	6	536
ESTIMA	1.2	2.3	0.0	1.4	15	483
MARKIES	0.2	0.5	0.0	0.3	2	326
KING EDWARD	0.2	3.5	1.6	1.3	9	315
MARFONA	1.0	0.5	0.0	0.9	6	305
PENTLAND DELL	0.5	3.2	0.0	1.2	7	267
CABARET	0.7	0.0	0.0	0.5	3	266
SAXON	0.2	0.0	0.0	0.2	1	261
LADY ROSETTA	0.3	0.8	0.0	0.4	2	249
VALOR	0.3	0.7	5.3	1.0	5	236
SATURNA	0.0	0.0	0.0	0.0	0	227
CHARLOTTE	0.0	0.0	0.0	0.0	0	226
ATLANTIC	0.0	0.8	0.0	0.2	1	224
HARMONY	1.1	0.9	1.8	1.1	5	207
WINSTON	0.9	0.8	0.0	0.7	3	203
CARA	1.8	2.0	0.0	1.7	7	186
BURREN	1.0	0.0	0.0	0.5	2	173
ROOSTER	0.5	1.0	0.0	0.5	2	172
RUSSET BURBANK	2.5	1.0	2.6	2.1	8	171
KERR'S PINK	1.6	1.0	2.7	1.6	6	171
MARIS BARD	0.0	0.0	2.2	0.3	1	167
VALES SOVEREIGN	2.7	2.6	2.7	2.9	10	159
WILJA	0.5	0.0	0.0	0.3	1	131
KENNEBEC	0.0	1.4	0.0	0.4	1	128
MELODY	0.0	0.0	0.0	0.0	0	127
TOTAL	1.0	1.0	1.0	1.0	358	16361

Table 15. Propensity to leafroll of the varieties more widely grown as seed within the Scottish SPCS (only varieties averaging over 40 crops p.a. over the period 2009-2011). Propensity values above unity are shaded red.

Propensity to Mosaic Symptoms

Mosaic symptoms were recorded at inspection in 2208 crops out of the total of 16,361 crops inspected during 2009-2011 (Table 16). Symptoms were recorded in 183 varieties, with symptoms recorded on 5 or more occasions in 66 varieties. For mosaics, eleven of the more commonly grown varieties have consistently produced a propensity value of over unity over the three years 2009-2011. Nine of these eleven varieties showed consistently high propensity values across the three years, averaging over 1.5. These were Valor, King Edward, Harmony, Winston, Desiree, Maris Peer, Atlantic, Maris Piper and Wilja. Unlike the interaction between leafroll and Maris Piper, there is no predominant variety for mosaics. Valor is the most significant variety, making up 1.4% of the total number of crops and being responsible for 5.1% of the total crops in which mosaic symptoms were seen during crop inspection. The following varieties showed a consistently low propensity to Mosaics over the 3 –year period, these were Saxon, Kennebec, Lady Rosetta, Markies, Burren, Saturna, Cara and Vales Sovereign.

Variety	Mosaics 2009	Mosaics 2010	Mosaics 2011	Mosaics 2009-11	Total Crops with Mosaics	Total Crops
MARIS PIPER	1.9	1.8	1.0	1.7	318	1390
HERMES	0.5	0.5	0.7	0.6	97	1274
DESIREE	1.9	2.1	2.1	2.0	214	775
MARIS PEER	1.6	2.0	2.7	2.0	144	536
ESTIMA	1.0	1.1	1.0	1.0	68	483
MARKIES	0.1	0.3	0.6	0.3	14	326
KING EDWARD	2.4	2.2	2.2	2.4	100	315
MARFONA	1.0	0.9	0.9	1.0	40	305
PENTLAND DELL	0.6	0.8	0.4	0.6	23	267
CABARET	1.1	1.2	1.1	1.1	41	266
SAXON	0.1	0.1	0.3	0.1	4	261
LADY ROSETTA	0.3	0.1	0.0	0.2	6	249
VALOR	2.5	3.0	6.0	3.5	112	236
SATURNA	0.6	0.4	0.5	0.5	14	227
CHARLOTTE	0.9	1.0	0.9	1.0	30	226
ATLANTIC	1.8	1.6	2.5	1.9	56	224
HARMONY	3.2	2.4	1.2	2.3	65	207
WINSTON	2.6	1.9	2.7	2.3	63	203
CARA	0.7	0.5	0.2	0.5	12	186
BURREN	0.3	0.4	0.3	0.3	8	173
ROOSTER	1.4	1.2	0.2	1.0	24	172
RUSSET BURBANK	1.0	1.0	1.3	1.1	25	171
KERR'S PINK	0.9	0.8	1.1	0.9	21	171
MARIS BARD	1.3	0.8	0.0	0.7	16	167
VALES SOVEREIGN	1.0	0.2	0.2	0.5	11	159
WILJA	1.4	1.7	1.1	1.5	26	131
KENNEBEC	0.0	0.3	0.3	0.2	3	128
MELODY	0.3	0.0	0.0	0.1	1	127
TOTAL	1.0	1.0	1.0	1.0	2208	16361

Table 16. Propensity to mosaics (severe or mild symptoms) of the varieties more widely grown as seed within the Scottish SPCS (only varieties averaging over 40 crops p.a. over the period 2009-2011). Propensity values above unity are shaded red.

Propensity analysis of the major viruses that produce Mosaic Symptoms

In contrast to the previous analyses which use data on symptoms seen at classification inspections, the following analysis is based on the laboratory diagnosis of viruses detected in leaf samples taken from plants exhibiting symptoms of mosaics at crop inspection.

PVY^N was diagnosed in leaf samples from 856 (from 114 varieties) of the 1780 seed crops sampled (Table 17). PVY^N infects a wide range of the most widely grown varieties. Propensity values of greater than unity were consistently recorded for King Edward, Atlantic, Maris Peer, Harmony, Wilja and Maris Piper. In contrast the following varieties showed a very low propensity to PVY^N over the 3 –year period, these were Hermes, Estima, Markies, Saxon, Lady Rosetta, Kennebec and Melody. The propensity of Valor showed a marked increase from below unity in 2009 and 2010 to the highest value recorded for this strain of virus in 2011.

Variety	PVY^N 2009	PVY^N 2010	PVY^N 2011	PVY^N 2009-11	Crops with PVY^N 2009-11	Total Crops
MARIS PIPER	2.2	1.6	1.1	1.7	126	1390
HERMES	0.0	0.2	0.0	0.1	8	1274
DESIREE	0.8	1.4	1.1	1.2	47	775
MARIS PEER	1.8	2.3	3.1	2.2	63	536
ESTIMA	0.2	0.4	0.0	0.2	6	483
MARKIES	0.0	0.1	0.0	0.1	1	326
KING EDWARD	4.6	3.9	5.9	4.6	76	315
MARFONA	1.3	0.9	1.2	1.2	19	305
PENTLAND DELL	0.8	1.6	0.4	1.1	15	267
CABARET	1.1	1.9	0.7	1.4	19	266
SAXON	0.2	0.0	0.0	0.1	1	261
LADY ROSETTA	0.0	0.0	0.0	0.0	0	249
VALOR	1.0	0.9	8.0	2.4	30	236
SATURNA	0.9	0.4	0.4	0.6	7	227
CHARLOTTE	2.0	0.9	1.3	1.4	16	226
ATLANTIC	3.6	3.8	6.3	4.3	50	224
HARMONY	3.0	1.8	1.6	2.1	23	207
WINSTON	1.3	0.2	0.4	0.6	6	203
CARA	0.8	0.5	0.0	0.5	5	186
BURREN	0.4	0.2	0.9	0.4	4	173
ROOSTER	1.7	0.5	0.0	0.8	7	172
KERR'S PINK	0.6	0.7	0.0	0.6	5	171
RUSSET BURBANK	0.6	0.5	0.0	0.4	4	171
MARIS BARD	1.2	1.5	0.0	1.0	9	167
VALES SOVEREIGN	0.6	0.0	0.6	0.4	3	159
WILJA	2.3	2.1	1.4	2.0	14	131
KENNEBEC	0.0	0.0	0.0	0.0	0	128
MELODY	0.0	0.0	0.0	0.0	0	127
TOTAL	1.0	1.0	1.0	1.0	856	16361

Table 17. Propensity to PVY^N based on virus diagnoses conducted at SASA on leaf samples from plants exhibiting mosaic symptoms at crop inspection. Data are only presented for those varieties averaging over 40 crops p.a. over the period 2009-11.

$PVY^{O/C}$ was found in far fewer samples (121) and varieties (47) than PVY^N (Table 18) which may reflect more varieties with high resistance to this strain or more simply that over the period of this study it has simply become the less prevalent strain of PVY and therefore has less chance to be recorded in as many varieties. Only in 8 varieties was $PVY^{O/C}$ diagnosed on 5 or more occasions. Therefore, care should be taken in reaching conclusions over

propensity based on such a limited quantity of data. Only one variety, Maris Peer, consistently recorded propensity values of above unity across the three years. PVY$^{O/C}$ was not recorded in the varieties Markies, Pentland Dell, Saxon, Lady Rosetta, Burren and Rooster, Kennebec and Melody.

Variety	PVY$^{O/C}$ 2009	PVY$^{O/C}$ 2010	PVY$^{O/C}$ 2011	PVY$^{O/C}$ 2009-11	Crops with PVY$^{O/C}$ 2009-11	Total Crops
MARIS PIPER	1.3	1.1	0.5	1.1	11	1390
HERMES	0.4	0.6	0.5	0.5	5	1274
DESIREE	0.0	0.0	2.7	0.5	3	775
MARIS PEER	3.1	2.8	2.5	2.8	11	536
ESTIMA	0.0	0.0	1.4	0.3	1	483
MARKIES	0.0	0.0	0.0	0.0	0	326
KING EDWARD	2.8	4.6	0.0	3.4	8	315
MARFONA	0.0	2.5	6.0	2.2	5	305
PENTLAND DELL	0.0	0.0	0.0	0.0	0	267
CABARET	0.0	3.1	0.0	1.5	3	266
SAXON	0.0	0.0	0.0	0.0	0	261
LADY ROSETTA	0.0	0.0	0.0	0.0	0	249
VALOR	12.4	2.2	0.0	4.6	8	236
SATURNA	0.0	0.0	3.0	0.6	1	227
CHARLOTTE	0.0	1.1	6.0	1.8	3	226
ATLANTIC	4.1	7.4	0.0	4.8	8	224
HARMONY	0.0	1.4	0.0	0.7	1	207
WINSTON	0.0	0.0	15.5	3.3	5	203
CARA	0.0	1.5	0.0	0.7	1	186
BURREN	0.0	0.0	0.0	0.0	0	173
ROOSTER	0.0	0.0	0.0	0.0	0	172
RUSSET BURBANK	0.0	0.0	4.0	0.8	1	171
KERR'S PINK	0.0	0.0	4.2	0.8	1	171
MARIS BARD	0.0	1.6	0.0	0.8	1	167
VALES SOVEREIGN	2.5	0.0	0.0	0.9	1	159
WILJA	3.3	0.0	0.0	1.0	1	131
KENNEBEC	0.0	0.0	0.0	0.0	0	128
MELODY	0.0	0.0	0.0	0.0	0	127
TOTAL	1.0	1.0	1.0	1.0	121	16361

Table 18. Propensity to PVY$^{O/C}$ based on leaf samples submitted to SASA from plants exhibiting mosaic symptoms at crop inspection. Data are only presented for those varieties averaging over 40 crops over the period 2009-11.

Although PVA was recorded in 214 samples and 37 varieties, 66% of the records came from just 4 varieties: Desiree, Hermes, Estima and Cabaret. , PVA was found more than once in just 8 of the 29 more widely grown varieties (Table 19).

Variety	PVA 2009	PVA 2010	PVA 2011	PVA 2009-11	Crops with PVA 2009-11	Total Crops
MARIS PIPER	0.0	0.1	0.0	0.1	1	1390
HERMES	1.9	2.4	1.6	2.0	33	1274
DESIREE	7.2	4.4	6.3	5.9	60	775
MARIS PEER	0.0	0.0	0.0	0.0	0	536
ESTIMA	4.4	6.6	4.2	5.1	32	483
MARKIES	0.0	0.6	3.4	1.2	5	326
KING EDWARD	0.7	0.0	0.0	0.2	1	315
MARFONA	0.6	0.0	0.0	0.3	1	305
PENTLAND DELL	0.8	0.0	0.0	0.3	1	267
CABARET	5.9	4.1	3.3	4.6	16	266
SAXON	0.0	0.0	1.1	0.3	1	261
LADY ROSETTA	0.0	0.0	0.0	0.0	0	249
VALOR	0.0	0.0	0.0	0.0	0	236
SATURNA	0.0	0.0	0.0	0.0	0	227
CHARLOTTE	0.0	0.0	0.0	0.0	0	226
ATLANTIC	0.0	0.0	0.0	0.0	0	224
HARMONY	0.0	0.0	0.0	0.0	0	207
WINSTON	0.0	0.0	0.0	0.0	0	203
CARA	0.0	0.0	0.0	0.0	0	186
BURREN	0.0	0.0	0.0	0.0	0	173
ROOSTER	0.0	0.0	0.0	0.0	0	172
RUSSET BURBANK	0.0	0.0	0.0	0.0	0	171
KERR'S PINK	0.0	2.4	1.7	1.3	3	171
MARIS BARD	4.7	3.7	0.0	2.7	6	167
VALES SOVEREIGN	2.3	0.0	1.7	1.4	3	159
WILJA	0.0	0.0	0.0	0.0	0	131
KENNEBEC	0.0	1.7	0.0	0.6	1	128
MELODY	0.0	0.0	0.0	0.0	0	127
TOTAL	1.0	1.0	1.0	1.0	214	16361

Table 19. Propensity to PVA based on leaf samples submitted to SASA from plants exhibiting mosaic symptoms at crop inspection. Data are only presented for those varieties averaging over 40 crops over the period 2009-11.

PVV was recorded in 50 samples and from just 9 named varieties. Estima was the only variety which consistently recorded a propensity value of above unity, and was responsible for 74% of the PVV cases diagnosed at SASA over the 3-year period. (Table 20).

Variety	PVV 2009	PVV 2010	PVV 2011	PVV 2009-11	Crops with PVV 2009-11	Total Crops
ESTIMA	20.6	27.0	28.4	25.1	37	483
PREMIERE	9.2	5.9	0.0	5.6	2	116
BANBA	0.0	0.0	28.3	9.5	2	69
ARGOS	0.0	10.0	0.0	5.0	1	65
ARRAN PILOT	42.2	0.0	0.0	8.2	1	40
PINK FIR APPLE	0.0	30.0	0.0	12.1	1	27
GOLDEN NUGGET	70.3	53.3	0.0	37.8	3	26
MAYAN TWILIGHT	70.3	0.0	0.0	23.4	1	14
SHETLAND BLACK	0.0	80.0	0.0	32.7	1	10
TOTAL	1.0	1.0	1.0	1.0	50	16361

Table 20. Propensity to PVA based on leaf samples submitted to SASA from plants exhibiting mosaic symptoms at crop inspection. Data are only presented for those named varieties in which PVV was observed over the period 2009-11.

Summary of Propensity

Table 21 shows the propensity values obtained from the leaf testing in the context of the propensity values obtained using the observations of symptoms at crop inspection. This allows the propensity to mosaic symptoms to be explained by the propensity to the respective viruses/strains. The most widely grown variety, Maris Piper has a propensity to both Mosaics and Leafroll, with the propensity to Mosaics largely explained by a propensity to PVY^N. Whilst Hermes and Desiree have a propensity to PVA, the higher propensity of Desiree to mosaic symptoms is explained by a greater propensity to PVA and probably also to PVY^N. Maris Peer has a propensity to Mosaics explained by a propensity to both strains of PVY. Estima has a moderate propensity to Mosaics, with a very low propensity to PVY offset by a high propensity to PVA and PVV. Varieties such as Markies, Pentland Dell, Saxon, Lady Rosetta, Saturna, Burren, Kennebec and Melody all show a low propensity to potyviruses and Leafroll. This approach also allows some of the more inconsistent propensity values from leaf tests to be placed into greater context. Rooster and Russet Burbank show a relatively average propensity to mosaics but their propensity to the main aphid transmitted viruses is generally low. Therefore, their propensity to mosaics may be due to a propensity to PVX.

Propensity and Varietal Resistance

Testing varieties for resistance to viruses is time consuming and costly. Furthermore, it is only feasible to test varieties to a limited number of viruses and strains. These strains should be representative of field populations which in turn requires extensive surveillance and characterization work. Collecting data on propensity, which is at least partly dependent upon virus/strain susceptibility/resistance (see 'rationale' above), provides a cost effective method for maintaining up to date information on varietal behaviour in relation to a full range of viruses present under field conditions. Table 22 compares the propensity data presented in Table 21 with the varietal resistance scores recorded on the British Potato Variety Database.

Variety	Crops	Mosaics	PVY^{N}	PVY$^{O/C}$	PVA	PVV	Leafroll
MARIS PIPER	1390	1.7	1.7	1.1	0.1	0.0	4.2
HERMES	1274	0.6	0.1	0.5	2.0	0.0	0.3
DESIREE	775	2.0	1.2	0.5	5.9	0.0	1.4
MARIS PEER	536	2.0	2.2	2.8	0.0	0.0	0.5
ESTIMA	483	1.0	0.2	0.3	5.1	25.1	1.4
MARKIES	326	0.3	0.1	0.0	1.2	0.0	0.3
KING EDWARD	315	2.4	4.6	3.4	0.2	0.0	1.3
MARFONA	305	1.0	1.2	2.2	0.3	0.0	0.9
PENTLAND DELL	267	0.6	1.1	0.0	0.3	0.0	1.2
CABARET	266	1.1	1.4	1.5	4.6	0.0	0.5
SAXON	261	0.1	0.1	0.0	0.3	0.0	0.2
LADY ROSETTA	249	0.2	0.0	0.0	0.0	0.0	0.4
VALOR	236	3.5	2.4	4.6	0.0	0.0	1.0
SATURNA	227	0.5	0.6	0.6	0.0	0.0	0.0
CHARLOTTE	226	1.0	1.4	1.8	0.0	0.0	0.0
ATLANTIC	224	1.9	4.3	4.8	0.0	0.0	0.2
HARMONY	207	2.3	2.1	0.7	0.0	0.0	1.1
WINSTON	203	2.3	0.6	3.3	0.0	0.0	0.7
CARA	186	0.5	0.5	0.7	0.0	0.0	1.7
BURREN	173	0.3	0.4	0.0	0.0	0.0	0.5
ROOSTER	172	1.0	0.8	0.0	0.0	0.0	0.5
KERR'S PINK	171	0.9	0.6	0.8	1.3	0.0	1.6
RUSSET BURBANK	171	1.1	0.4	0.8	0.0	0.0	2.1
MARIS BARD	167	0.7	1.0	0.8	2.7	0.0	0.3
VALES SOVEREIGN	159	0.5	0.4	0.9	1.4	0.0	2.9
WILJA	131	1.5	2.0	1.0	0.0	0.0	0.3
KENNEBEC	128	0.2	0.0	0.0	0.6	0.0	0.4
MELODY	127	0.1	0.0	0.0	0.0	0.0	0.0
TOTAL	16361	1.0	1.0	1.0	1.0	1.0	1.0

Table 21. Collation of varietal propensity information collected over the period 2009-2011 using data on symptom expression at crop inspection (Mosaics and Leafroll) and laboratory virus diagnoses on leaf samples submitted to SASA from plants exhibiting mosaic symptoms at crop inspection (PVY^{N}, PVY$^{O/C}$, PVA and PVV).

Variety	Leafroll Propensity	PLRV resistance
MARIS PIPER	4.2	4
VALES SOVEREIGN	2.9	1
RUSSET BURBANK	2.1	2
CARA	1.7	5
KERR'S PINK	1.6	5
ESTIMA	1.4	3
DESIREE	1.4	4
KING EDWARD	1.3	5
PENTLAND DELL	1.2	5
HARMONY	1.1	6
VALOR	1.0	6
MARFONA	0.9	4
WINSTON	0.7	5
ROOSTER	0.5	7
BURREN	0.5	8
CABARET	0.5	3
MARIS PEER	0.5	4
LADY ROSETTA	0.4	6
KENNEBEC	0.4	N/A
WILJA	0.3	7
HERMES	0.3	7
MARKIES	0.3	6
MARIS BARD	0.3	6
ATLANTIC	0.2	6
SAXON	0.2	8
SATURNA	0.0	6
CHARLOTTE	0.0	5
MELODY	0.0	3

Table 22. Varietal propensity to leafroll and resistance to leafroll taken from the British Potato Variety Database (1-9 scale where 1 is highly susceptible and 9 is highly resistant). Only varieties with an average of over 40 crops planted p.a.

Leafroll and Resistance to PLRV

Whilst there is a general relationship between high propensity values and low resistance scores, there are anomalies with five of the ten varieties with a propensity of above unity scoring 5 or 6 for PLRV resistance, and Maris Piper scoring 4 despite having the highest propensity to leafroll (and being responsible for 36% of all crops exhibiting leafroll symptoms at classification inspections). No leafroll was seen in crops of Saturna, Charlotte and Melody which also have PLRV resistance scores of 6, 5 and.3 respectively

Mosaics and Resistance to $PVY^{O/C}$

Varietal resistance scores recorded on the British Potato Variety Database are limited to resistance to $PVY^{O/C}$ and do not show any clear relationship to propensity to mosaics (Table 23). This is not surprising as $PVY^{O/C}$ is not a particularly prevalent virus amongst those responsible for producing mosaic symptoms. $PVY^{O/C}$ shows a better relationship between high $PVY^{O/C}$ propensity values and low resistance scores than was found with PLRV, with eight of the ten varieties with a propensity of above unity scoring 2 or 3 for $PVY^{O/C}$ resistance. Of the other two of these ten varieties,

Winston presents the biggest anomaly, with a propensity to PVY$^{O/C}$ of 3.3 and a resistance score of 7. It is interesting to note that Maris Piper scores 2 for resistance to PVY$^{O/C}$ compared with 4 to PLRV, scores which contrast with the propensity of this variety to the two viruses. No positive laboratory diagnoses of PVY$^{O/C}$ were recorded for eight of the varieties with over 40 crops p.a. and scoring between 4 and 9 for resistance to PVY$^{O/C}$.

Variety	Mosaics Propensity	PVY$^{O/C}$ Propensity	PVY^{O} resistance
ATLANTIC	1.9	4.8	3
VALOR	3.5	4.6	3
KING EDWARD	2.4	3.4	2
WINSTON	2.3	3.3	7
MARIS PEER	2.0	2.8	3
MARFONA	1.0	2.2	4
CHARLOTTE	1.0	1.8	2
CABARET	1.1	1.5	3
MARIS PIPER	1.7	1.1	2
WILJA	1.5	1.0	2
VALES SOVEREIGN	0.5	0.9	4
MARIS BARD	0.7	0.8	6
RUSSET BURBANK	1.1	0.8	4
KERR'S PINK	0.9	0.8	6
CARA	0.5	0.7	7
HARMONY	2.3	0.7	3
SATURNA	0.5	0.6	4
HERMES	0.6	0.5	7
DESIREE	2.0	0.5	7
ESTIMA	1.0	0.3	2
ROOSTER	1.0	0.0	5
PENTLAND DELL	0.6	0.0	4
BURREN	0.3	0.0	7
MARKIES	0.3	0.0	9
LADY ROSETTA	0.2	0.0	5
KENNEBEC	0.2	0.0	N/A
SAXON	0.1	0.0	5
MELODY	0.1	0.0	8

Table 23. Varietal propensity to mosaics and PVY$^{O/C}$ and resistance to PVY$^{O/C}$ taken from the British Potato Variety Database (1-9 scale where 1 is highly susceptible and 9 is highly resistant). Only varieties with an average of over 40 crops planted p.a. No varietal resistance measures are currently available for viruses other than PVY$^{O/C}$ and PLRV.

Conclusions

Providing up to date information on the propensity of a variety to virus symptoms (Leafroll and mosaics) and to specific viruses that produce mosaic symptoms can provide growers and agronomists with a valuable tool for virus management. The data differs to some extent from the information available on resistance and it is difficult to assess which data set provides the more reliable information for virus management. However, with PVY^{N} the dominant virus within the Scottish classification scheme, the propensity figures at least provide some information on the incidence of this virus strain (as well as information on other viruses e.g. PVA and PVV) within the Scottish seed production system. Propensity data are relatively

cheap to acquire and maintain, the information required is already collected by SASA in relation to symptom expression and maintaining the surveillance by taking leaf samples during inspection and submitting these for laboratory diagnoses is relatively cost effective in comparison to carrying out extensive varietal resistance testing as part of the varietal assessment programme (e.g. National List and Independent Variety Trials). Propensity data also have the ability to track changes in resistance that may occur over time as the viruses evolve and the diversity of the virus population changes. As the reliability of the propensity data depends upon the inspection or sampling of an extensive number of crops, it is less reliable for varieties with relatively few crops which are only grown over a relatively small area, e.g. new varieties

3.5. Analysis of Scottish SPCS data- Mosaic data 2009 to 2011

Contingency tables have been used to separate out the effects of vertical transmission (infected parent to infected daughter) from horizontal transmission (clean parent, infected daughter) in Scottish seed crops. The data presented below are a preliminary analysis as only the primary parent stock and not any secondary parent stocks are considered as sources of infection.

From Table 24 which relates to daughter crops grown in 2009, vertical transmission is estimated at 44% (71 crops with mosaics from 161 crops grown from seed stocks in which virus symptoms had been observed in 2008) and horizontal transmission is estimated at 15% (624 crops with infection grown from 4134 seed stocks in which no virus symptoms had been observed in 2008).

Table 24. The incidence of mosaic symptoms in parent (2008) and daughter (2009) crops as observed in the growing crop by RPID potato inspectors.

	2009 Mosaics				
2008 Mosaics	**Yes**	**No**	**Grand Total**	**Vertical Transmission**	**Horizontal Transmission**
Yes	71	90	161	44%	
No	624	3510	4134		15%
Grand Total	695	3600	4295		

From Table 25 which relates to daughter crops grown in 2010, vertical transmission is estimated at 65% and horizontal transmission is estimated at 17%

Table 25. The incidence of mosaic symptoms in parent (2009) and daughter (2010) crops as observed in the growing crop by RPID potato inspectors.

	2010 Mosaics				
2009 Mosaics	**Yes**	**No**	**Grand Total**	**Vertical Transmission**	**Horizontal Transmission**
Yes	252	138	390	65%	
No	735	3506	4241		17%
Grand Total	987	3644	4631		

From Table 26 which relates to daughter crops grown in 2011, vertical transmission is estimated at 43% and horizontal transmission is estimated at 7%

Table 26. The incidence of mosaic symptoms in parent (2010) and daughter (2011) crops as observed in the growing crop by RPID potato inspectors.

	2011 Mosaics				
2010 Mosaics	**Yes**	**No**	**Grand Total**	**Vertical Transmission**	**Horizontal Transmission**
Yes	170	230	400	43%	
No	309	3839	4148		7%
Grand Total	479	4069	4548		

These data may be used as a baseline for comparing the effects of field generation, variety and the geographical region in which the parent stock had been grown.

Effect of Field Generation

Field generation 1 is omitted from Tables 27 to 29 (below) because the parent stocks were not field grown. Crops which were produced from imported seed are also omitted. The infection incidence is the overall incidence for the field generation. 'Vertical transmission' gives the proportion of crops showing mosaic symptoms in the year of classification that were grown from stocks which had shown symptoms in the previous year. 'Horizontal transmission' gives the proportion of crops showing mosaic symptoms in the year of classification that were grown from stocks which had **not** shown symptoms in the previous year. The final column gives the proportion of crops at each generation that are grown from parent stock in which no virus had been seen.

Table 27. Variation in the proportion of seed crops in which mosaic symptoms were observed in the 2009 seed crop by field generation. The data are split into the two categories of vertical and horizontal transmission according to whether the primary parental seed stock had exhibited mosaic symptoms at inspection in 2008.

2009 data

Field Generation	**Total Crops**	**Infection Incidence**	**Vertical Transmission**	**Horizontal Transmission**	**Proportion of crops from clean seed**
2	477	1%		1%	100%
3	596	3%	0%	3%	99%
4	989	10%	67%	9%	98%
5	1021	20%	28%	19%	97%
6	767	30%	44%	29%	92%
7	330	29%	47%	27%	89%
8	103	33%	78%	29%	91%
9	11	36%		36%	100%
10	1	100%	100%		0%
Grand Total	4295	16%	44%	15%	96%

Table 28. Variation in the proportion of seed crops in which mosaic symptoms were observed in the 2010 seed crop by field generation.

2010 data

Field Generation	Total Crops	Infection Incidence	Vertical Transmission	Horizontal Transmission	Proportion of crops from clean seed
2	795	10%	55%	8%	96%
3	641	9%	50%	8%	100%
4	1075	13%	58%	12%	98%
5	1061	30%	59%	26%	90%
6	552	31%	67%	25%	85%
7	350	44%	71%	33%	71%
8	109	45%	65%	40%	79%
9	40	55%	75%	42%	60%
10	6	67%	100%	0%	33%
Grand Total	4629	21%	65%	17%	92%

Tables 27 to 29 show similar analyses of data for the 2009 to 2011 growing seasons. Each table shows no clear pattern of change over field generations in the extent of vertical transmission (although the sample size is relatively small as only 4% of crops were grown from seed stocks exhibiting virus in the previous season in 2009, c.f. 8% in 2010 and 9% in 2011). A marked increase in the extent of horizontal transfer with field generation is seen between field generations 4 and 5.

Table 29. Variation in the proportion of seed crops in which mosaic symptoms were observed in the 2011 seed crop by field generation.

2011 data

Field Generation	Total Crops	Infection Incidence	Vertical Transmission	Horizontal Transmission	Proportion of crops from clean seed
2	598	1%	50%	1%	99.7%
3	861	6%	42%	4%	93%
4	1159	6%	44%	4%	96%
5	1090	13%	30%	12%	93%
6	578	21%	39%	17%	80%
7	169	22%	49%	13%	76%
8	61	41%	59%	26%	56%
9	19	47%	62%	17%	32%
10	10	60%	71%	33%	30%
Grand Total	4545	10%	42%	7%	91%

When comparing between field generations, less emphasis should be placed on the later generations (generations 7 and above) due to the relatively low number of crops of these generations grown each year (Figure 32).

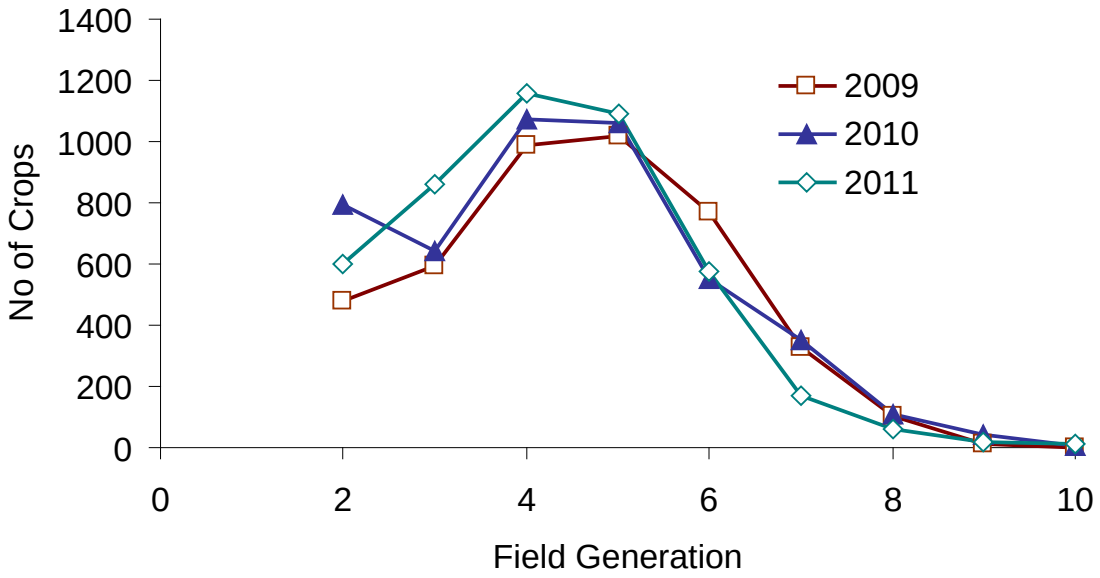


Figure 32. The number of classified seed crops grown at each field generation in 2009, 2010 and 2011.

It is clear from Tables 26 to 28 that the parent stock is always an important source of virus. Increasing percentages for subsequent field generations are probably more indicative of the increasing levels of virus within crops of later generations. This may, in part, be, due to the greater tolerances that are permitted for later generation material within the classification scheme. Horizontal transmission rates increase with increasing field generation indicating that there may be a greater external source of virus inoculum in areas where this later generation material is produced. The change between field generation 4 and 5 appears quite marked. These findings are summarised in Figure 33, which shows that although the overall incidence of infection increases with field generation, this is driven by the increasing amount of horizontal transmission in later field generations. Over field generations 2 to 7, the generations at which the vast majority of classified crops are grown, vertical transmission remains relatively constant at between 40 and 60%.

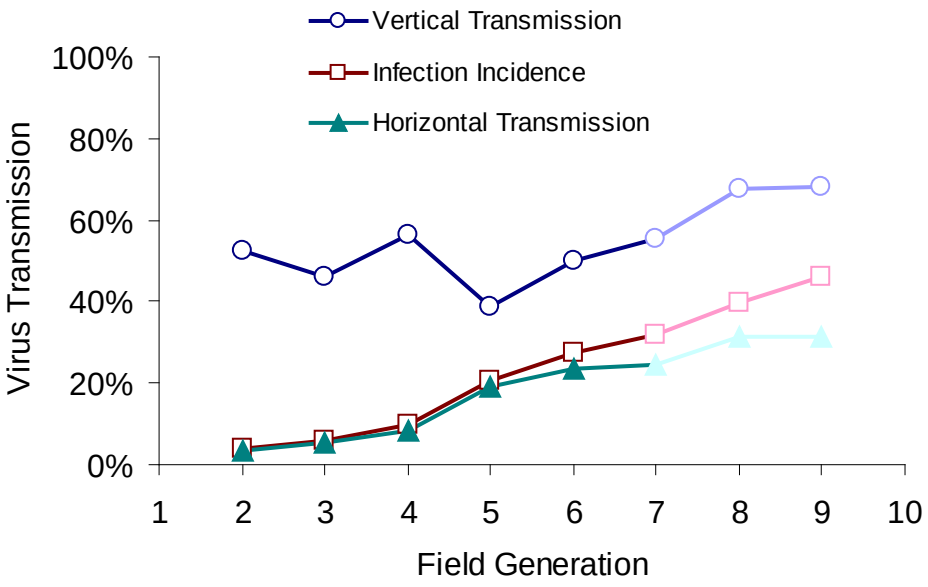


Figure 33. Summary of the effect of field generation on the variation in vertical and horizontal transmission of viruses producing mosaic symptoms at crop inspection of classified seed crops grown at each field generation in 2009, 2010 and 2011. The overall infection incidence (resulting from both horizontal and vertical; transmission) is included. Paler colours are used to denote generations 8 & 9 where the points are based on far fewer data (see Figure 32).

The proportion of crops grown from clean seed declines with field generation, presumably due to the increasing levels of virus found in later generations (Figure 34). This helps explain why the incidence of infection diverges from the incidence of horizontal transmission for later field generations in Figure 33.

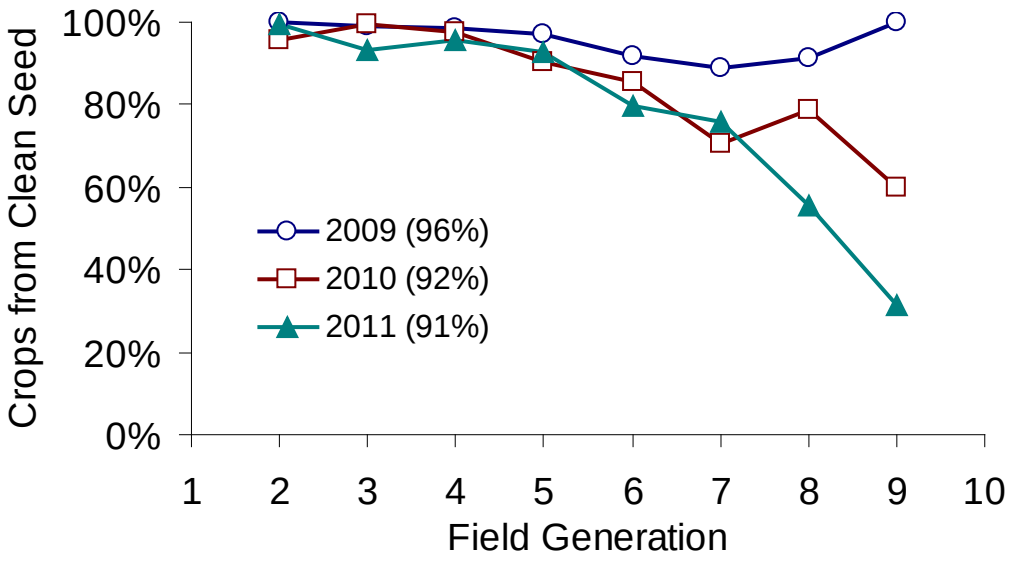


Figure 34. The percentage of seed crops by field generation grown for classification from parent stocks in which no virus symptoms had been seen in the previous year. Data for 2009, 2010 and 2011.

Effect of Variety (See the previous section on Propensity Analysis)

Effect of Geographical Area (District)

A similar approach has been taken for analysing the effects of geographical area, which for ease of analysis has been done on a district basis. Table 30 lists the 23 districts growing the highest number of seed crops for classification (at least 70 crops grown in 2009). The order of the table is sorted in decreasing order of the incidence of infection. Tables 31 and 32 provide comparable data for 2010 and 2011 for the same districts

The districts that are consistently at the top of these three tables are those in which virus symptoms are most frequently observed at inspections. Vertical transmission rates in these districts do not appear to show any great difference from the average of for each year. However, the top eight districts: Carnoustie, Monifieth, Laurencekirk, Kirriemuir, Brechin, Perth Eastern, Perth and Forfar all have markedly higher horizontal transmission rates that are nearly or more than twice the average value of 15%. In contrast, whilst districts such as Avoch, and Muir of Ord, may have similar vertical transmission rates, the horizontal transmission rates are less than a third of the average value .

Table 30. Variation in the proportion of seed crops in which mosaic symptoms were observed in the 2009 seed crop by District. The data are split into the two categories of vertical and horizontal transmission according to whether the primary parental seed stock had exhibited mosaic symptoms at inspection in 2008.

2009 Data

Origin District	Total Crops	Infection Incidence	Vertical Transmission	Horizontal Transmission	Proportion of crops from clean seed
ANGUS (Carnoustie)	87	51%	38%	52%	91%
PERTH (Eastern)	163	41%	44%	41%	90%
ANGUS (Kirriemuir)	134	39%	43%	38%	90%
ANGUS (Montrose)	72	36%	100%	34%	97%
ANGUS (Monifieth)	79	30%	0%	31%	97%
KINCARDINE (Laurencekirk)	151	28%	20%	29%	93%
KINCARDINE (St Cyrus)	60	27%	20%	28%	83%
ANGUS (Brechin)	150	25%	78%	22%	94%
ANGUS (Forfar)	220	24%	38%	23%	94%
PERTH (Perth)	247	21%	50%	19%	92%
PERTH (Central)	181	21%	90%	17%	94%
FIFE (St Andrews)	80	15%		15%	100%
ABERDEEN (Garioch)	69	14%		14%	100%
ABERDEEN (Aberdeen)	83	14%		14%	100%
BANFF (Banff)	192	14%		14%	100%
ABERDEEN (Turriff)	433	9%	17%	9%	99%
ABERDEEN (Ellon)	248	8%	60%	7%	98%
ABERDEEN (Deer)	213	5%	0%	5%	100%
ROSS & CROMARTY (Fortrose)	211	5%		5%	100%
NAIRN	70	4%		4%	100%
MORAY (Forres)	61	3%	0%	4%	93%
ROSS & CROMARTY (Avoch)	197	3%		3%	100%
ROSS & CROMARTY (Muir of Ord)	175	2%		2%	100%
Grand Total	4295	16%	44%	15%	96%

Table 31. Variation in the proportion of seed crops in which mosaic symptoms were observed in the 2010 seed crop by District. The data are split into the two categories of vertical and horizontal transmission according to whether the primary parental seed stock had exhibited mosaic symptoms at inspection in 2009.

2010 Data

Origin District	Total Crops	Infection Incidence	Vertical Transmission	Horizontal Transmission	Proportion of crops from clean seed
ANGUS (Monifieth)	95	48%	80%	43%	84%
KINCARDINE (Laurencekirk)	170	44%	69%	38%	81%
ANGUS (Carnoustie)	72	43%	50%	42%	83%
ANGUS (Brechin)	160	39%	56%	38%	90%
ANGUS (Forfar)	217	39%	84%	33%	88%
PERTH (Perth)	311	38%	58%	36%	92%
ANGUS (Kirriemuir)	163	36%	50%	33%	87%
PERTH (Eastern)	96	35%	81%	19%	73%
PERTH (Central)	218	33%	78%	25%	85%
KINCARDINE (St Cyrus)	94	29%	52%	22%	78%
ABERDEEN (Garioch)	76	24%	29%	22%	78%
ABERDEEN (Aberdeen)	70	20%	63%	15%	89%
BANFF (Banff)	226	19%	59%	15%	90%
ABERDEEN (Turriff)	376	12%	50%	10%	96%
BANFF (Cullen)	73	10%	0%	10%	99%
MORAY (Elgin)	79	8%	50%	6%	97%
ABERDEEN (Ellon)	391	5%	55%	4%	97%
ROSS & CROMARTY (Fortrose)	287	5%		5%	100%
ABERDEEN (Deer)	154	5%	67%	3%	98%
ROSS & CROMARTY (Muir of Ord)	215	4%		4%	100%
MORAY (Duffus & Drainie)	101	4%	0%	4%	99%
NAIRN	134	3%		3%	100%
ROSS & CROMARTY (Avoch)	167	1%	0%	1%	99%
Grand Total	4631	21%	65%	17%	92%

Figure 32. Variation in the proportion of seed crops in which mosaic symptoms were observed in the 2011 seed crop by District. The data are split into the two categories of vertical and horizontal transmission according to whether the primary parental seed stock had exhibited mosaic symptoms at inspection in 2010.

2011 Data

Origin District	Total Crops	Infection Incidence	Vertical Transmission	Horizontal Transmission	Proportion of crops from clean seed
DUMFRIES (Annan)	65	37%	88%	20%	75%
ANGUS (Brechin)	164	21%	41%	18%	87%
PERTH (Eastern)	116	19%	24%	18%	82%
ANGUS (Carnoustie)	89	21%	46%	17%	85%
KINCARDINE (Laurencekirk)	190	25%	50%	15%	73%
PERTH (Central)	194	19%	45%	15%	89%
ANGUS (Monifieth)	93	17%	36%	14%	85%
ABERDEEN (Garioch)	72	15%	60%	12%	93%
PERTH (Perth)	279	18%	46%	11%	80%
KINROSS	78	21%	48%	11%	73%
ANGUS (Kirriemuir)	170	11%	40%	9%	94%
ANGUS (Forfar)	221	10%	23%	8%	88%
BANFF (Banff)	113	12%	44%	6%	84%
ABERDEEN (Ellon)	323	6%	100%	5%	99%
ABERDEEN (Turriff)	409	5%	43%	4%	98%
ABERDEEN (Deer)	209	4%	67%	3%	99%
MORAY (Forres)	66	5%	25%	3%	94%
ROSS & CROMARTY (Fortrose)	333	3%		3%	100%
NAIRN	148	5%	60%	3%	97%
MORAY (Elgin)	105	2%	0%	2%	99%
ABERDEEN (Aberdeen)	70	3%	20%	2%	93%
ROSS & CROMARTY (Avoch)	156	1%	0%	1%	99%
ROSS & CROMARTY (Muir of Ord)	237	0%	0%	0%	100%
Grand Total	4547	11%	42%	7%	91%

Horizontal transmission and other potato crops as the Source of Inoculum
The area of ware and other seed potatoes in the respective districts is probably the most likely source of external inoculum for horizontal transmission. Comprehensive data on the ware area is available from SASA for both the 2010 and 2011 crops, but not for 2009 so the 2010 data for both seed and ware has been used to assess the relative proportions of ware and seed crops by district (Table 33).

Table 33. Variation in the incidence of mosaic symptoms in 2009-2011 seed crops grown from primary parental stocks in which symptoms had not been observed in the previous year in relation to the total areas of potato production (seed and ware data for 2010 and 2011) in the District in which the primary parental stock was grown.

Origin District	2009	2010	2011	Mean	Mean Ware Area	Mean Seed Area	Mean Potato Area
ANGUS (Carnoustie)	51%	43%	21%	37%	1394	438	1832
ANGUS (Monifieth)	30%	48%	17%	29%	725	269	994
KINCARDINE (Laurencekirk)	28%	44%	25%	27%	323	728	1051
ANGUS (Kirriemuir)	39%	36%	11%	27%	615	605	1220
ANGUS (Brechin)	25%	39%	21%	26%	422	869	1291
PERTH (Eastern)	41%	35%	19%	26%	1347	474	1821
PERTH (Perth)	21%	38%	18%	22%	613	848	1461
ANGUS (Forfar)	24%	39%	10%	22%	1035	1079	2113
PERTH (Central)	21%	33%	19%	19%	167	386	553
BANFF (Banff)	14%	19%	12%	12%	51	377	428
ABERDEEN (Turriff)	9%	12%	5%	8%	325	516	841
ABERDEEN (Ellon)	8%	5%	6%	5%	37	301	338
ROSS & CROMARTY (Fortrose)	5%	5%	3%	4%	3	191	194
ABERDEEN (Deer)	5%	5%	4%	4%	226	187	413
NAIRN	4%	3%	5%	3%	29	122	151
MORAY (Elgin)	1%	8%	2%	3%	30	198	228
ROSS & CROMARTY (Muir of Ord)	2%	4%	0%	2%	26	76	102
ROSS & CROMARTY (Avoch)	3%	1%	1%	1%	14	157	171
Grand Total	**16%**	**21%**	**11%**	13%	15136	11733	26869

Figure 35 shows a clear relationship between the mean horizontal transmission and the area of potato production within the district, whether it be seed, ware or the total potato area. The weakest relationship is with the seed area (adjusted r2 = 0.36, p=0.004), a stronger relationship is found with the ware area (adjusted r2 = 0.67, p<0.0001), and the strongest is with the total potato area (adjusted r2 = 0.76, p<0.0001). This indicates the importance of other potato crops as a source of virus inoculum for horizontal transmission. Whilst ware crops produce a stronger relationship with within a district than seed crops, the relationship with area of seed crops is also significant and therefore the relationship with the total area of potatoes is the most significant.

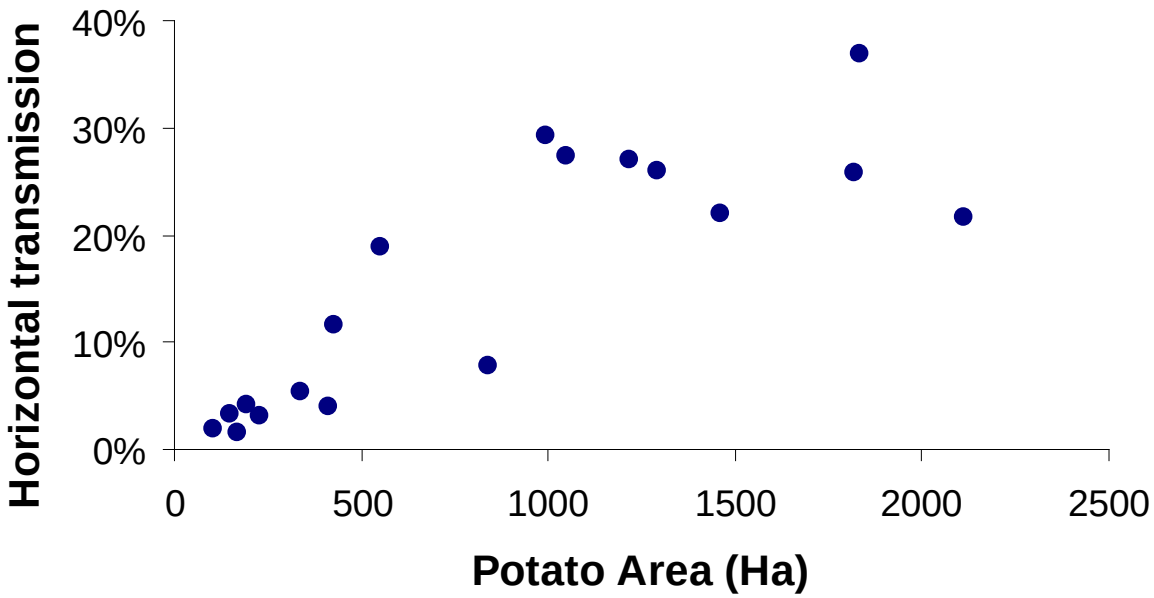


Figure 35. The effect of total area of potato production within a District on the incidence of horizontal transmission of mosaic causing viruses to daughter seed crops.

Conclusions

Variety clearly has a very important effect on the incidence of mosaic symptoms observed at classification inspections. The presence of virus in the parental stock also has a very significant effect. Over the period 2009-2011, whilst virus symptoms were observed in 16% of the crops grown, the virus incidence was 52% for stocks grown from infected parental material, and 13% for crops grown from parent stock in which no symptoms had been seen at the previous year's classification inspections. These data indicate a four-fold difference in the likelihood of mosaic being seen in a daughter crop depending upon whether virus had been observed in the parent crop.

Looking solely at horizontal transmission*, i.e.,* where symptoms occur in the daughter stock when grown from a clean parental stock, there is a clear increase associated with increasing field generation. However, generation *per se* is unlikely to have any direct effect on the likelihood of virus transmission, except for later generation crops tending to be larger and hence more likely to exhibit at least one plant showing virus symptoms at inspection. The location where later generation crops are grown is more likely to have an effect, with such crops grown in areas where more commercial stocks are grown. The presence of other potato crops within a geographical district has a highly significant effect on the likelihood of horizontal transmission, with the area of ware potato crops having a more significant effect than the area of seed crops.

3.6. Survey of potential sources of virus inoculum - Groundkeepers

The results of the sampling and subsequent virus testing of groundkeepers carried out in 2009, 2010 and 2010 are provided in Tables 34 to 37 below.

Table 34. Summary of the information on groundkeeper sample collection and the results of virus testing of groundkeeper samples in 2009. The values for viruses detected (incidence) are based on a sample of 100 randomly selected plants per location. (Unless otherwise indicated).

Location	Host crop/variety	Groundkeeper variety (if known)	*Year groundkeeper variety last planted as a potato crop	Date of collection of groundkeeper sample	Number of groundkeeper samples (plants) tested	Virus incidence
Angus	Ware /King Edward	King Edward	n/a	June	100	14 % PVY^N
Perthshire	Ware / Harmony	Harmony	n/a	June	100	77% PVY^N 1% PLRV
Fife	Ware / Marfona	Estima	2008	June	100	3.75% PVA
Fife	Ware / Marfona	King Edward	1993	June	100	12.5% PVY^N
Angus	Seed / Hermes	Saturna	n/a	June	100	7% PVX
Fife	Broccoli	Maris Piper	unknown	June	100	25% PVY^N
Fife	Broccoli	Maris Piper	unknown	June	100	1% (PLRV)
Fife	Parsnips	Saxon	unknown	June	100	2.1% PVY^N
Aberdeenshire	Spring Barley	Estima	2006	June	100	0.6% (PVA & PVX)
Aberdeenshire	Spring Barley	Estima	2008	June	100	10.7% PVS
Perthshire	Winter Oats	Maris Piper & Maris Peer	unknown	June	100	28% PVY^N
Fife	Spring Barley	Estima	unknown	June	100	14% PVA

*In some locations samples were collected from multiple fields (100 plants per field unless otherwise stated), in these cases the year the ground keeper variety was last planted as a potato crop is not listed and n/a is entered in the table. Where groundkeeper samples were taken from a single field, and the date that the groundkeeper variety was last planted as a potato crop is known, the year is provided in the table. If the year is unknown this is indicted as unknown in the table.

Table 35. Summary of the information on groundkeeper sample collection and the results of virus testing of groundkeeper samples in 2010. The values for viruses detected (incidence) are based on a sample of 100 randomly selected plants per location (unless otherwise indicated).

Location	Host crop/variety	Groundkeeper variety (if known)	Year groundkeeper variety last planted as a potato crop	Date of collection of groundkeeper sample	Estimated number of groundkeepers per hectare	Number of ground keeper samples (plants) tested	Virus incidence
Angus	Brussel Sprouts	Rooster	2009	June	8,667	100	Negative
Angus	W. Wheat	Rooster	unknown	July	9,310	100	Negative
Angus	S. Barley	Rooster/Osprey	2007	July	1,200	100	Negative
Angus	S. Barley	Nicola		June	1,000	100	Negative
Angus	W. Wheat	Charlotte	2000	July	50	10	Negative
Angus	S. Barley	Marfona	2009	June	7,000	100	Negative
Angus	S. Barley	P. Dell	2008	July	400	20	Negative
Angus	W. Barley	Charlotte	2008	June	1,100	100	Negative
Aberdeen	S. Barley	Rooster	2008	June	800	20	Negative
Aberdeen	S. Barley	Wilja	2008	June	330	20	Negative
Aberdeen	Carrots	M. Piper	2009	July	914	20	Negative
Aberdeen	Xmas trees	Kerrs Pink	2008	July	2,340	100	Negative
Perth	W. Wheat	Cultra	2009	June	10,000	100	1% PVY^N
Perth	S. Barley	Burren	2009	July	3,300	100	Negative
Perth	S. Barley	Unidentified		July	2,500	100	Negative
Perth	W. Wheat	Winston	2009	June	8,000	100	Negative
Perth	W. Barley	Apache	2009	June	4,500	100	2% PLRV
Angus	SE Kerrs Pink	Cara	unknown	June	925	100	Negative
Angus	SE Harmony	Kerrs Pink	unknown	June	42,425	100	Negative
Angus	SE Cara	Cara	unknown	June	1,736	100	Negative
Angus	SE Winston	Charlotte	unknown	June	4,000	100	Negative
Angus	SE Hermes	Saturna	unknown	June	1,250	100	Negative
Angus	SE Harmony	Cultra	unknown	June	49,255	100	Negative

Angus	SE Estima	Estima	unknown	June	820	100	Negative
Angus	SE Estima	Estima	unknown	June	900	100	5% PVY^N, 17% PVV, 10% PVA, 1% PVX
Angus	SE Rooster	Cara	unknown	June	1,654	100	2% PVY^N, 2% PVS
Fife	Ware/Saxon	Nadine	unknown	June	50,833	100	0
Fife	Ware/Nadine	Nadine	unknown	June	11,833	100	0
Fife	Ware/Maris Piper	Maris Peer	unknown	June	7,847	100	0
Angus	Ware/Maris Peer	Unknown	unknown	June	569	100	0
Angus	Ware/Saxon	Osprey	unknown	June	850	100	0
Angus	Ware/Maris Piper	Rooster	unknown	June	32,525	100	17%PVY^N, 11% PVX, 4% PVX + PVY^N
Angus	Ware/Osprey	Nadine	unknown	June	46,250	100	0
Angus	Ware/Osprey	Cara	unknown	June	32,200	100	0
Angus	Ware/Wilja	Cara	unknown	June	320	100	1% PVY^N
Angus	Ware/Wilja	Charlotte	unknown	June	150	100	1% PVY^N
Fife	Carrots	Maris Piper	unknown	June	27,513	100	3%PVY^N
Fife	Kale	Maris Piper	unknown	June	14,416	100	0
Fife	Kale	Osprey	unknown	June	639	100	1%PVY^N
Fife	Kale	Nadine	unknown	June	9,305	100	2%PVY^N
Angus	Broccoli	Cara	unknown	June	20,152	100	2%PVY^N
Angus	Carrots	Cara	unknown	June	29,333	100	0
Angus	Broccoli	Harmony	unknown	June	19,180	100	50%PVY^N
Angus	Broccoli	Maris Piper	unknown	June	1,775	100	0
Angus	Carrots	Unknown	unknown	June	46,665	100	0
Angus	Spring Barley	Russet Burbank	unknown	June	6,202	100	0
Roxburgh	Winter Wheat	King Edward	unknown	June	5,300	100	58% PVY^N, 4% PVY, 2% PVY + PVY^N

Table 36. Summary of the information on sample collection from once grown seed for ware and the results of virus testing of the samples in 2010. The values for PVY^N incidence are based on a sample of randomly selected plants per location (unless otherwise indicated).

County	Variety	Date Sampled	Number of plants tested/field	% PVY^N incidence
Angus	Harmony	June	100	58% PVY^N, 2% PVS + PVY^N
Angus	Harmony	June	100	41% PVY^N
Angus	Harmony	June	100	39% PVY^N, 4% PVS, 4% PVS + PVY^N, 2% PVY+ PVY^N
Angus	Wilja	June	100	41% PVY^N
Angus	Valor	June	100	13% PVY^N
Aberdeenshire	Rooster	June	100	41% PVX, 4% PVY^N, 2% PVX + PVY^N
Aberdeenshire	Rooster	June	100	26% PVX, 26% PVY^N, 2% PVX + PVY^N
Aberdeenshire	Rooster	June	100	43% PVX, 20% PVY^N, 4% PVX + PVY^N,
Ross & Cromarty	Red Duke of York	June	100	21% PVX, 30% PVY^N, 21% PVX + PVY^N
Perthshire	Golden Wonder	June	100	7% PVA
Fife	Estima	June	100	0
Angus	Harmony	June	100	2% PVX, 45% PVY^N, 2% PVX + PVY^N, 2% PVY, 4% PVS, 2% PLRV
Angus	Harmony	June	100	26% PVY^N
Angus	Harmony	June	100	41% PVY^N, 4% PVY
Angus	Harmony	June	100	41% PVY^N, 6% PVY
Angus	Valor	June	100	11% PVY^N
Angus	Rooster	June	100	13% PVY^N, 2% PVX
Angus	Vales Sovereign	June	100	0

Table 37. Summary of the information on groundkeeper sample collection and the results of virus testing of groundkeeper samples in 2011. The values for viruses detected (incidence) are based on a sample of 92 randomly selected plants per location (unless otherwise indicated).

County	Host crop/variety	Groundkeeper variety (if known)	Year groundkeeper variety last planted as a potato crop	Date of collection of groundkeeper sample	Estimated number of groundkeepers per hectare	Number of groundkeeper samples (plants) tested	PVY^N incidence*
Aberdeen	Seed Potato	Unknown	>10 years	June	14	2	Negative
Aberdeen	Carrots	Charlotte	2008	June	2,542	100	Negative
Aberdeen	W. Wheat	Burren/Slaney	2010	June	0	0	N/A
Aberdeen	Grass	Charlotte	2006	June	0	0	N/A
Aberdeen	W. Wheat	Maris Peer	2009	June	167	17	Negative
Aberdeen	Seed Potato	Unknown	>10 years	June	14	0	N/A
Aberdeen	Seed Potato	Unknown	>10 years	June	83	10	Negative
Aberdeen	W. Barley	M. Bard/M. Piper	2005	June	0	0	N/A
Aberdeen	W. Wheat	M. Piper	2004	June	0	0	N/A
Aberdeen	W. Wheat	Desiree/M. Piper	2006	June	28	2	Negative
Aberdeen	W. Barley	K. Edward	2008	June	83	8	Negative
Aberdeen	Seed Potato	Estima	2004	June	0	0	N/A
Aberdeen	Seed Potato	Maris Bard	2004	June	0	0	N/A
Aberdeen	W. Wheat	Hermes/ Casablanca	2010	June	472	57	Negative
Aberdeen	W. Wheat	Saxon	2009	June	9,710	100	Negative
Aberdeen	W. Wheat	Bonnie/Cabaret	2009	June	2,056	100	Negative
Aberdeen	W. Wheat	Maris Bard	2010	June	2,709	100	Negative
Aberdeen	W. Wheat	Maris Peer	2003	June	7,848	100	Negative
Angus	Spring Barley	Marfona	2003	7 June	4,472	92	4.30%
Angus	Carrots	Desiree	2008	7 June	17,958	92	3.30%

Angus	Spring Barley	Saturna/ Hermes	2003 - Saturna (Unknown for Hermes)	8 June	3,569	92	9.80% PVY^{O}
Angus	Carrots	King Edward	2009	8 June	9,944	92	10.90%
Angus	Carrots	Courlan/ Shepody	2007 - Courlan 1998 - Shepody	8 June	9,375	92	Negative
Angus	Grass	Pentland Dell	2004 or 2003	9 June	4,125	92	Negative
Angus	Spring Barley	Estima/ Romano	2008	10 June	4,542	92	1.00%
Angus	Spring Barley	King Edward	2005	10 June	2,681	92	9.80%
Angus	Winter Wheat	Harmony	2010	13/ June	8,097	92	43.50%
Angus	Winter Wheat	Harmony	2010	13 June	2,486	92	66.30%
Angus	Seed Potato	Wilja	1997	13 June	4,278	92	Negative
Angus	Spring Barley	Wilja	2005	13 June	5,472	92	31.50%
Angus	Spring Barley	Marfona	2009	13 June	3,403	92	6.50%
Angus	Carrots	Lady Rosetta	2009	13 June	3,083	92	10.90%
Angus	Spring Barley	Maris Peer	2005	15 June	9,972	92	11.90%
Angus	Grass	Maris Piper	2008	18 June	7,792	92	4.30%
Angus	Broccoli	Unknown	2007	18 June	13,375	92	2.20%
Angus	Winter Oats	Russet Burbank	2010	18 June	2,847	92	2.20%
Angus	Grass	Mixed Varieties	2008	18 June	1,347	92	2.20%
Angus	Spring Barley	Maris Piper	2009	19 June	5,042	92	Negative
Angus	Spring Barley	Estima	2005	19 June	3,042	92	5.40%
Angus	Carrots	Orla/ Lady Balfour	2010	19 June	3,736	92	1.10%
Angus	Carrots	Sante	2009	19 June	7,750	92	10.90%
Angus	Ware Potatoes	Orla	2011	25 June		92	2.20%
Angus	Wheat	Unknown	2010	25 June	7,403	92	6.50%
Angus	Winter Oats	Hermes/ Pentland Dell	2010	25 June	2,361	92	3.30%
Angus	Spring Barley	Mixed Varieties	Unknown	25 June	2,264	92	Negative
Angus	Spring Barley	Hermes	2010	25 June	1,611	92	1.10%

Angus	Ware Potatoes	Harmony	2011	26 June	-	92	75.00%
Angus	Ware Potatoes	Valour	2009	26 June	-	92	7.60%

*N/A indicates that samples were not tested for potyvirus infection. Unless indicated otherwise the values refer to % PVY^N.

Survey of potential sources of virus inoculum - ware crops

In 2009, during a small survey of ware crops in Perthshire and Angus, high levels of virus were detected in two ware crops grown from home saved seed with virus levels ranging from 14-85%.

Case Studies

2009 Study of a high health seed farm in Aberdeenshire

Aphid monitoring

Throughout the 2009 growing season, in all four traps, aphid activity was extremely low. Just 23 aphids were trapped over an 8 weeks period, with only one potato aphid caught.

Virus evaluation in groundkeepers

Groundkeepers were found in only three fields of thirteen monitored. The largest numbers of groundkeepers were found in fields where potatoes were grown in the previous year (2008). A very small number (6 groundkeepers) were found in a field in which potatoes were grown in 2007 but in all other fields, groundkeepers were not detected.

Two, of the three fields, were selected in the vicinity of the crop of Maris Piper. Both had crops of potatoes in 2008 and a high number of groundkeepers were observed in each field.

Field 1 was two fields away from the 2009 Maris Piper crop to the south-west. There were fourteen tramlines in total across field 1. Groundkeepers were sampled from three sampling areas to give a total of 100 samples from each field (Table 38).

Field 2 was one field away from the 2009 Maris Piper crop to the south-east. There were 12 tramlines in total across field 2. Groundkeepers were not sampled from tramlines 10-12 as the sampling area was not long enough. Groundkeepers were sampled from 3 sampling areas to give a total of 100 samples form each field (Table 39).

All groundkeepers were negative for both PVA and PVY.

Table 38. Sampling details for field 1 (Previous crop Maris Piper)

Tramline no. sampled	Total no. of groundkeepers	No. of groundkeepers sampled	Estimated groundkeeper population/ha
4	108	35	5,400
8	126	30	6,300
12	243	35	12,150
		Av. Groundkeeper population	7,950

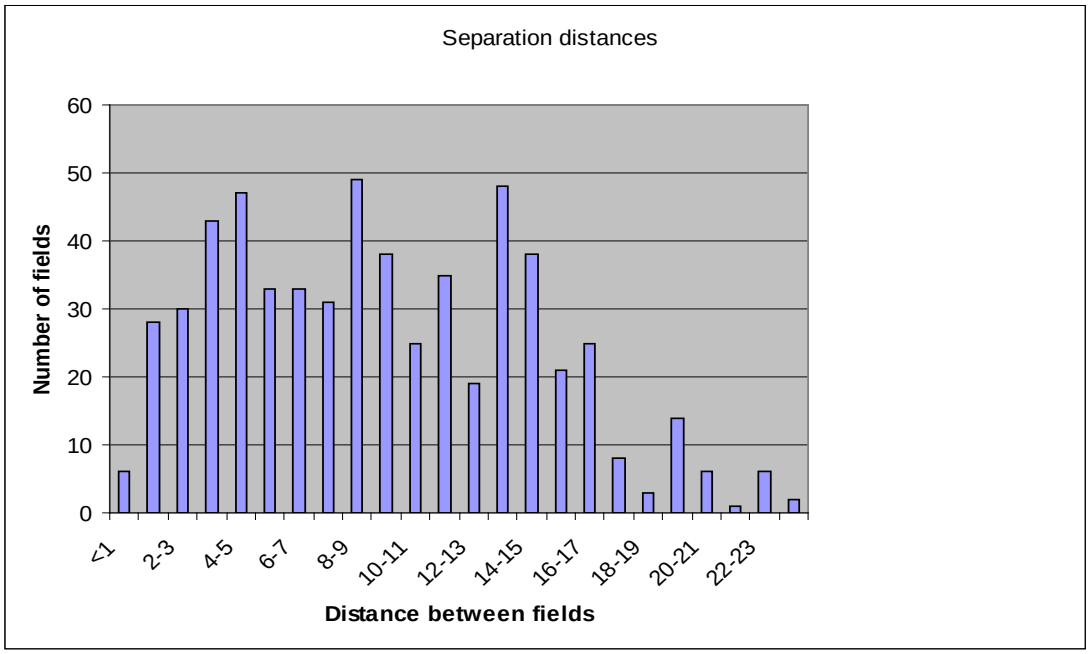
Table 39. Sampling details for field 2 (Previous crop Wilja and Rooster)

Tramline no. sampled	Total no. of groundkeepers	No. of groundkeepers sampled	Estimated groundkeeper population/ha
1	275	40	13,750
4	310	40	15,500
8	23	20	1,150
		Av. Groundkeeper population	10,133

2011 Study of a high health seed farm in Angus

The SPUDS database was utilised in combination with the laboratory results of virus testing to assess the location of the current seed crop in relation to the location of fields where groundkeepers had been found. This analysis was carried out for all of the available fields. Figure 36 shows a summary of the distances between the centres of each field which had previously been used to grow a potato crop and in which groundkeepers were recorded and the centre of the 2011 current seed field. Fields were separated anywhere between less than 1 to more than 20km. Only six fields were separated by less than one km. However, of those six fields two represented situations where there could be a threat to a seed crop. Mixed variety groundkeepers totalling 30 PVY^N infectors per hectare were found in the field adjacent to a Pre Basic field in 2011. These had arisen from seed planted in 2008 but failed to attain a Pre Basic Grade. In a further example, a total of 1,187 PVY^N infectors per hectare were found 3.8km from the centre of a Pre Basic field in 2011.

Figure 36. Summary of separation distances (km) between fields where groundkeepers were sampled and the centre of a pre basic seed crop in the 2011 case study.



3.7. Survey of potential sources of virus inoculum and aphids potentially carrying potyviruses

3.7.1. Groundkeeper counts

The experiments at JHI were aimed at understanding virus transmission over a number of seasons and at a scale between plot and landscape. The first of these experiments used a pre-existing mini-rotation field system to carefully map the occurrence of potato groundkeepers and follow virus levels within them (see Table 4 in Material and Methods section). Where possible the cultivar of the groundkeeper was identified and sub samples were also tested for PVA and PVY. It is important to note that the generation of potato plants from true potato seed is described and it is abbreviated to TPS.

PVA was deliberately introduced into the mini-rotation area in 2006 by growing a seed crop known to contain PVA. The numbers of groundkeepers counted over three seasons in all plots is presented in Figure 37(a). It is clear that in all areas the numbers of groundkeepers fell between 2009 and 2010 and this may correspond with the very cold winter of 2009/2010. However, unusually large numbers of uniformly distributed potato plants appeared simultaneously in the SE plot in 2010. It was believed that these represented true seed from the Estima crop and this was confirmed by carefully digging up of samples of the young plants and confirming that there were no mother tubers in the root systems. In this experimental system TPS germinated under a Swede crop two years after the Estima crop that probably produced the seed (2008) had been grown. Estima was also grown in the SW plot in 2009 and this area remained fallow in 2010. However, there was no evidence of germination of TPS in this area in 2010. Germination of true seed will therefore contribute plants in a season, although this is unpredictable and the seed could remain dormant for some time.

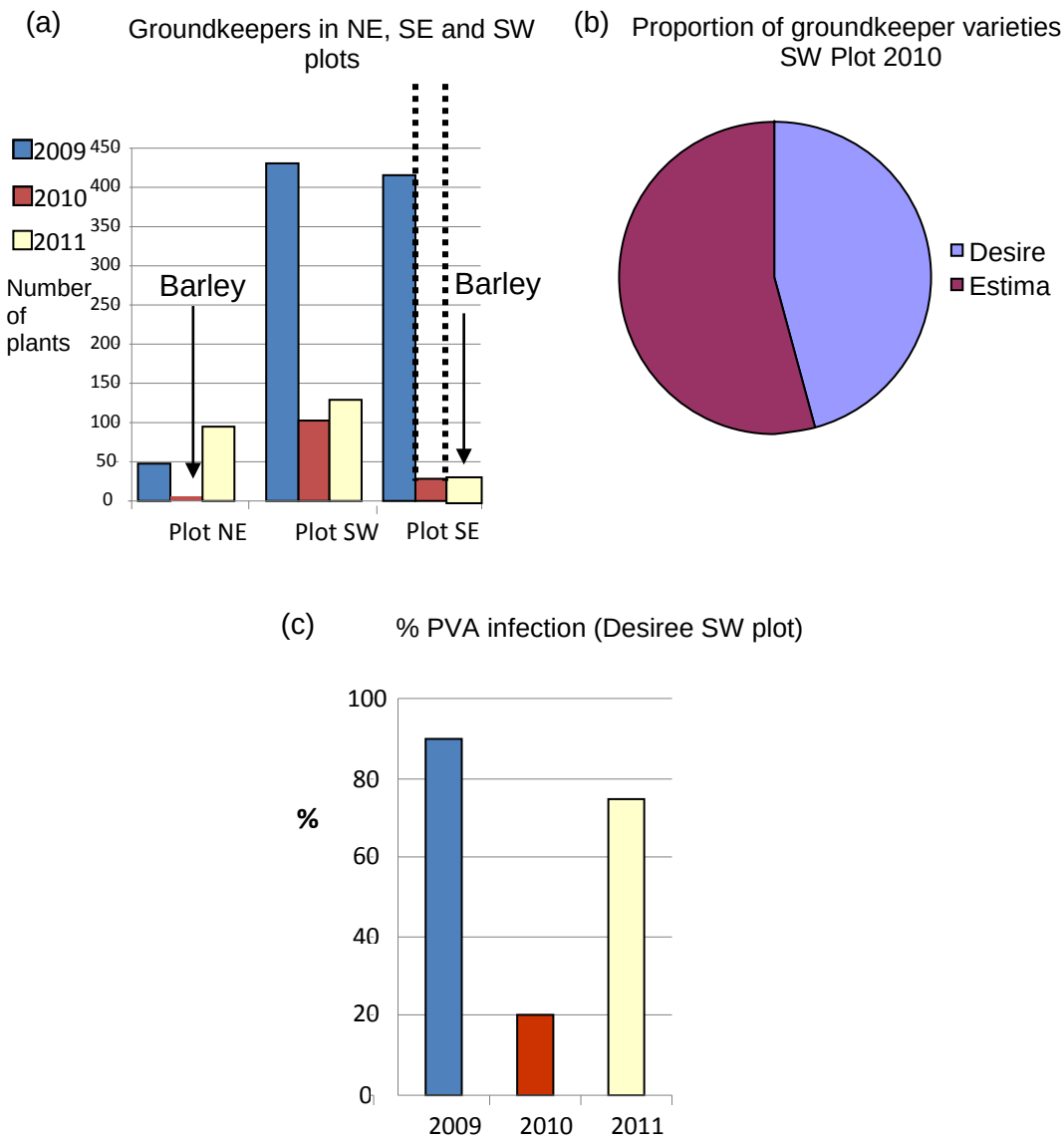


Figure 37. (a) The number of groundkeepers present in the plots from 2009 to 2011. The bar with a hatched line indicates large numbers of volunteers (seedlings) in the SE plot. The NW plot was a complicated mixture of varieties and groundkeeper identification proved difficult in 2010. The number of groundkeepers in 2010 dropped to ~10%, 14% and 30% of the previous year (2009) in the NE, SE and SW plots. [This is a similar drop in groundkeeper numbers to a large field identified at Sauchenloan by SAC in 2010 (~10%).]
(b) Proportions of groundkeeper varieties year 1 after an Estima and year 5 after a Desiree crop. The Desiree appears to produce robust tubers which maintain a population well after it has been grown.
(c) The percentages of PVA infected plants for three years in the SW plot.

While Estima appeared to produce considerable quantities of true seed under favourable conditions, it was much less able to produce groundkeepers from left over tubers. The SW plot had grown a crop of Desiree in 2005, but had not grown this variety since. Estima was grown in this plot in 2009. It was hypothesised harvesting Estima would leave many more tubers of this variety and it would dominate the groundkeepers in the following season, but this was not the case, as almost half of the plants were Desiree.

There was a clear trend across all the plots for a reduction in groundkeepers and two factors could have played a part. The winters of 2009/2010 and 2010/2011 were very cold and frost should have damaged and killed potatoes in the ground. Secondly, potatoes trying to grow in cereal crops are denied light and competition for resources. While these are also difficult to count, estimates made after harvest suggest there is a reduction in the numbers of groundkeepers within these crops. This is encouraging for agricultural systems using seven year rotations for potato where cereals make up the remainder of the rotation.

It was also possible to assess the levels of PVA virus in the Desiree groundkeepers in the SW plot (Figure 37 (b)). In 2009 the infection was sizeable at 90%. In 2010 this level had fallen to 20%, but in 2011 the virus had increased again and was found in 75% of the sample. There was less impact on virus infection by ambient conditions and the Desiree groundkeepers would be a particularly effective source of infection. It could be anticipated with only a few potato plants, and many of these carrying virus, there would be constant re infection of healthy plants, particularly from colonising species which would seek out these plants if there were no other hosts around.

Two additional field experiments were carried out in 2010, one at the JHI site and a smaller variant at the Scottish Agronomy field site. The field at the Scottish Agronomy site had a very small plot size with the target area being plots of 5 x 5 (25 plants), surrounded by 56 barrier plants further embedded within PVA infectors Figure 38 (a). All 25 bait plants were tested and the results were that five plants became infected in the protected area and four in the unprotected area. The numbers are small, but are so close to each other that it seems that there is no protective effect under these very stringent conditions.

The larger plots at JHI were replicates of 25 by 36, four of Desiree and four of Estima (Figure 31 (b)). Between them were larger blocks of Maris Piper (50 x 36). Only one plant, an Estima from position B12, became infected with PVA.

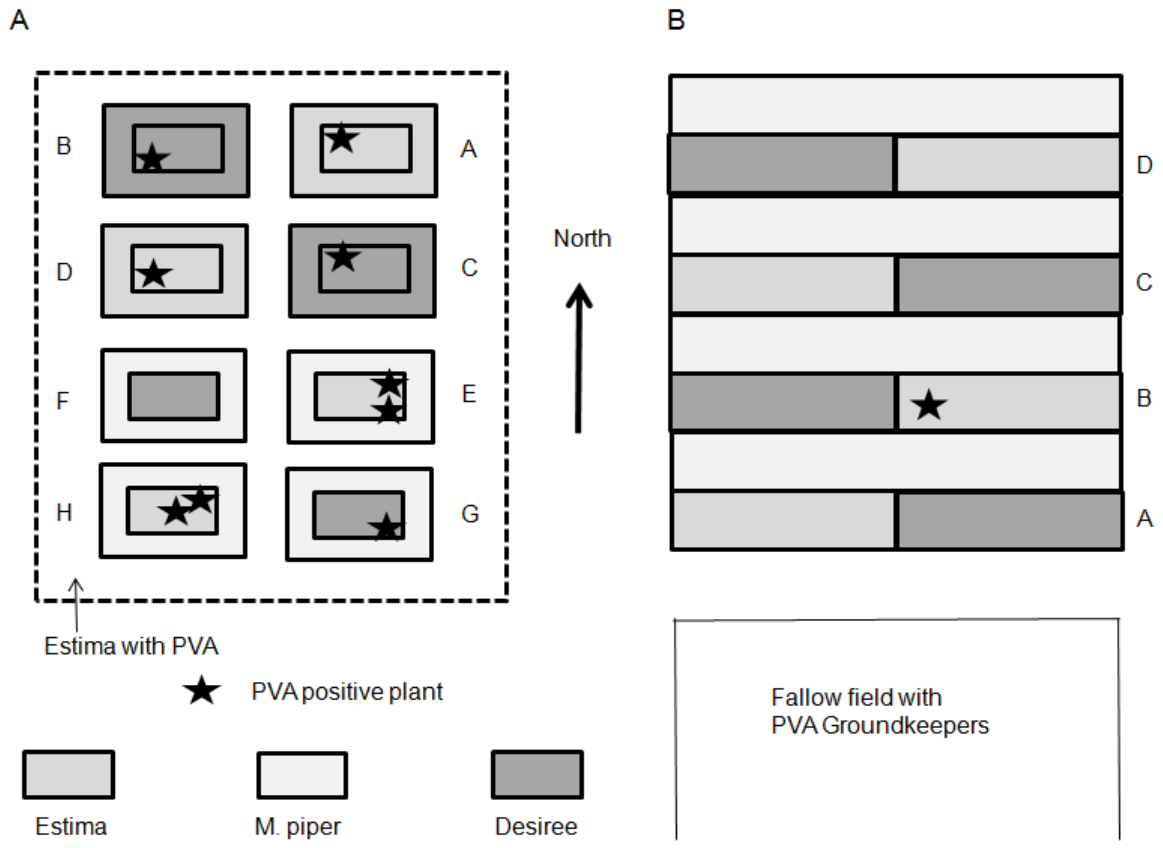


Figure 38. Field design for potato variety mixtures. Plants that scored positive for virus are indicated with a star.

To follow the large scale 2010 experiments, further use was made of the JHI site in 2011. The design comprised two sizes of inoculum source within a virus free crop (established from clean stock, but also rogued Figure 39 (a) and (b). It was hypothesised there would be a numerical relationship, with the area containing approximately three times as many infected tubers producing three times more new infections in the neighbouring clean stock. However, the small area produced ten infected plants and the large area produced nine and the hypothesis was rejected (χ^2 = 7.44, P < 0.01). This result was unexpected. One technical explanation was that the potato plants used as a source of virus were not ideal for planting as seed. Due to limited availability of seed, the tubers used were small and any large tubers were split into smaller pieces. This resulted in weak plants in the field, many of which failed to establish.

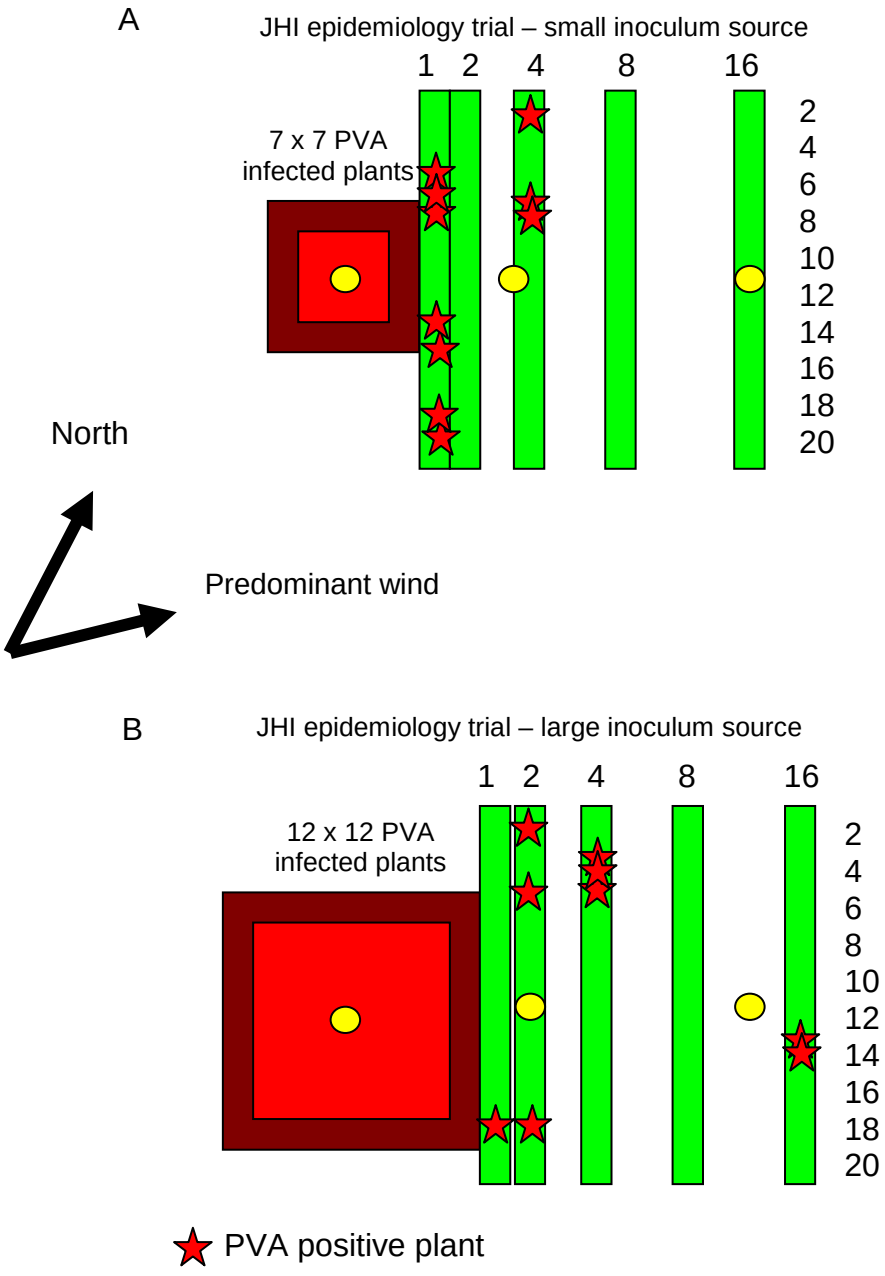


Figure 39. Twenty Estima plant samples per row (three tubers/sample) were grown on and post harvest tested by ELISA. Rows are 0, 2, 4 and 8 drills apart. Plant 1 is at the north end

Positional effects

Sampling was carried out on the east side of the plots which was downwind of the predominant winds in the area (Figure 39). Five rows of 20 plants were sampled, stored and grown on for ELISA tests. The rows were separated by increasing distances (Figure 39). Nineteen plants were found to have been infected and the position of these plants (as indicated by red stars in the figure above) gave some indication of what was likely to be occurring during aphid transmission.

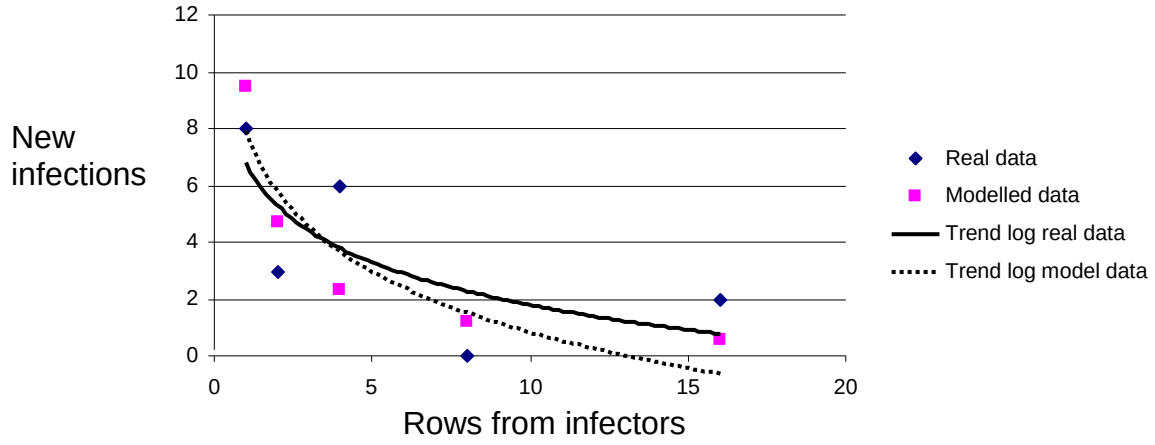


Figure 40. Total number of new infections in the clean potato stock by row distanced from the infection source.

The infected plants were not evenly distributed east to west as there were significantly more new infections in rows 1, 2 and 4 than in the remaining rows ($\chi^2 = 6.9$, $P < 0.01$; DF = 1; Figure 40). Row one, adjacent to the plots, had the most new infections, but this was mostly accounted for in plants next to the 7 x 7 plot, which had seven of the eight new infections found in row one. This observation was consistent with wingless colonising aphids crawling from the infected block and probing the first uninfected plants they encountered. Once the aphids had probed and fed on an unifected plant they would rapidly lose their infectivity (Bradley, 1959). This would be the case even after uninfected plants had become infected during the season as these plants would take time to become infectious to aphids.

The infected plants were also not evenly distributed north to south. In particular six infected plants were found in the northern parts of row 4. This is approximately 30% of the total new infections. Assuming the 19 infected plants were randomly distributed north south and east west then approximately one plant would be found in each half row (twenty half rows $P = 0.05$). Thus the probability of finding six in this area by chance alone would be 2.32×10^{42}. A second calculation based only on an even distribution in the first three rows (six half rows) would give an expectation of 1.6 plants in each half row. This equates to a probability of 0.08 for each infected plant and thus a cluster of six would have a probability of 2.9×10^{35}. Given these low probabilities it seems more likely an event has created a cluster of infections in this area in both the north and south plots. This would be consistent with flying aphids encountering the PVA infected plants and then moving a short distance before landing and probing an uninfected plant. As aphids are weak fliers and are likely to be blown more than actively fly then a cluster would occur downwind of the source of virus. It is possible this clustering effect continues into the unsampled area to the north-east.

In this case the result appears consistent with an inverse square law relationship. Figure 40 shows a graphical comparison between the expected numbers from an inverse square relationship and those observed. However, a chi square test finds there is a significant difference between the observed and expected values ($\chi^2 = 11.2$, $p < 0.025$, DF4). This can

be accounted for by the cluster found in row 4. In this case the distribution is not likely to be due to one process operating uniformly but two: 1. Increased levels of transmission will occur close to the virus source by crawling, colonising aphids. 2. Flying aphids will provide longer distance virus movement. Exactly how flying aphids contribute is difficult to determine as to make a flight they will have to propel themselves into the air and this may result in a minimum distance travelled before they alight into the canopy. The clustered results in row 4 may indicate this is the minimum distance of a flight.

These experiments represented a compromise between what was ideal and what was technically and financially achievable. It would have been better to have worked on both the east and west sides of the plots. However, it was considered more likely that prevailing wind would carry winged aphids further to the east and it was this maximum spread that was to be investigated. Likewise working on plants in the north and south would have yielded information, but this would have simply replicated results from the epidemiology trials. More replication of 7 x 7 and 12 x 12 plots would have provided more confidence in the numbers and this is absolutely necessary before attempting any form of calculation to determine a mathematical formula. Nonetheless, the observations are consistent with the expected behaviour of aphid virus transmission.

3.7.2. Molecular analysis of flying aphid populations

During 2010 and 2011 aphid samples were collected from field sites in different ways: 1. Preserved in YWTs containing propylene glycol, 2. Alive using sweep netting of the crop or 3. Alive using an Ashby trap to collect flying specimens in a bottle. In 2010, 6465 winged aphids (sampled as 961 individual aphids or in bulk samples containing 2-20 aphids) were tested for virus (Table 40).

PVA was detected in 0.8% and PVY in 0.3% of *M. dirhodum* collected at the Invergowrie site. The aphid was collected in enormous numbers at this site. Other aphids were collected by the traps in very low numbers. The small number of specimens of the two colonising aphid species of potatoes, the potato aphid *M. euphorbiae* and *M. persicae*, collected at Pittenweem did not contain detectable quantities of the viruses. As described in other parts of the report, the field season of 2010 was unusual compared to many other years, as it was dominated by a single species of aphid *M. dirhodum* whereas other species were in low numbers. This could be accounted for by the exceptionally cold winter favouring species that overwinter as eggs, such as *M. dirhodum*, at the expense of others that overwinter as live forms, such as *M. persicae*.

Table 40. Summary of the location of collection of aphid samples and the species composition of the collected aphids that were tested for viruses in 2010.

Site (2010)	Species	Individuals	PVA	PVY	% PVA	% PVY
Pittenweem	*C. pastinaceae*	2	-	-	-	-
	M. euphorbiae	35	-	-	-	-
	M. persicae	2	-	-	-	-
	H. lactucae	16	-	2	-	12.5
	M. dirhodum	2266	45	2	2	0.09
Invergowrie	*M. euphorbiae*	7	-	-	-	-
	H. lactucae	3	-	-	-	-
	M. dirhodum	3032	24	9	0.79	0.3
	B. helichrysi	13	-	-	-	-
Strathkinness	*C. pastinaceae*	2	-	-	-	-
	M. euphorbiae	7	-	-	-	-
	H. lactucae	11	-	-	-	-
	M. dirhodum	756	6	17	0.79	2.25
	A. fabae	208	-	-	-	-
	A. pisum	9		1		11.11
Grand total		6369	75	31		

In 2011, flying aphid samples were collected from the air above the field experiment shown in Figure 39. Six YWTs were distributed amongst the sampling area, three associated with the 7 x 7 infector grid and three with the 12 x 12 grid. Samples were collected in standard detergent fluid twice a week. The One trap was placed in the centre of each plot and the other two equal distances away from the centres of each plot, amongst the sampling rows on the east. This meant that the traps next to the 12 x 12 infectors were closer to the edge of the infected plot than those in the 7 x 7 plot. The aphids (Table 41) were analysed using molecular techniques to determine if, and how many, had encountered PVA infected plant material.

Table 41. Summary of the location of collection of aphid samples and the species composition of the collected aphids that were tested for PVA in 2011.

Site (2011)	Species	Individuals	PVA	PVY	% PVA	% PVY
Invergowrie	*A. rubi*	1	-	n/a	-	n/a
	A. solani	1	-	n/a	-	n/a
	Aphis sp	12	8	n/a	67	n/a
	B. helichrysi	3	1	n/a	33	n/a
	C. pastinaceae	3	1	n/a	33	n/a
	Capitophorus sp	3	2	n/a	67	n/a
	H. lactucae	2	1	n/a	50	n/a
	M. cerasi	1	-	n/a	-	n/a
	M. dirhodum	78	21	n/a	27	n/a
	P. fagi	3	-	n/a	-	n/a
	R. padi	9	3	n/a	33	n/a
	S. avenae	4	1	n/a	25	n/a
	Unknown	6	4	n/a	67	n/a

The results, which are shown in Figure 41 (below), indicate that up to 50% of the aphids encountered PVA. It was hypothesised the original experimental design would produce more positive aphids within and next to the 12 x 12 plot and this would diminish with distance. This was not reflected in the results as both the 7 x 7 and the 12 x 12 plots had similar PVA levels in the aphids and there was no decrease the further they were collected from the source. However, the former observation was consistent with the number of new plants infected during the season, where there was also a negligible difference between the infectious spread from the different sized plots (see Figure 39). The levels of PVA detected in the aphids in 2011 were considerably greater than those of 2010, but this could partly be accounted for by improvements in the technology. While these results are still preliminary and need to be interpreted with caution, they do indicate that aphids that have encountered viruliferous plants are likely to spread quite far. However, their infection status cannot be assumed only by the fact they have fed on virus infected plant material. Further work calibrating the patterns of virus and virus carrying aphid spread is required before any suggestions can be made about the risk of spread *vs* separation distance.

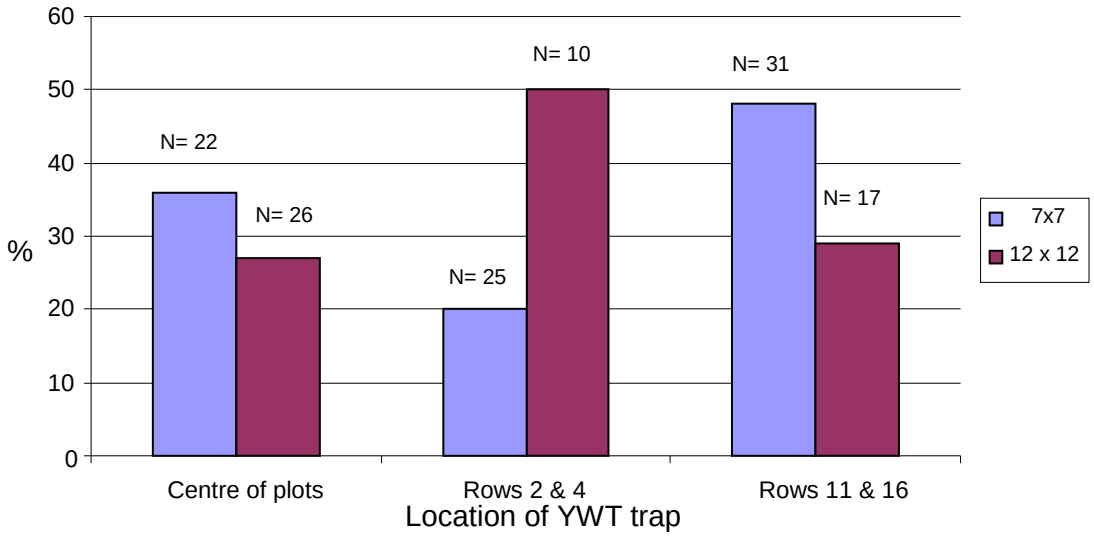


Figure 41. Summary of the percentage of aphids carrying PVA, at different distances from a PVA inoculum sources (see Figure 39 for the layout of the rows relative to the inoculum source.

Objective 5: Review of the Role of Insecticides and Mineral Oils in Minimising Virus Transmission

The review cited 207 refereed papers or other relevant literature. The full review is available at the Potato Council website. The summary points are provided below.

- There is overwhelming evidence that mineral oils work in minimising spread of potyviruses and this is beyond reasonable doubt.
- Prior to mineral oil use in the UK, consideration has to be given to the confidence with which visual inspection methods used by the Certifying authorities can be undertaken. In France and Netherlands, where oil is commonly used, crops are subjected to minimal growing crop inspection and are post-harvest tested instead.
- Phytotoxicity and reduced crop yields are reported in many mineral oil studies and this occurs at concentrations of more than 1%.
- A policy on the impact of mineral oils for visual seed inspection has to be developed prior to their use in the UK seed potato industry.
- Further work is required on the environmental fate of mineral oils.
- Oil effectiveness during irrigation and intense rainfall should be established.
- Studies should not be biased by a focus on insecticide resistant *M. persicae* as there are many more abundant aphid species which vector potyviruses that are sensitive to insecticides.
- The majority of literature has examined application of mineral oil as a separate spray. To be practicable the effect of tank mixing oils with fungicides needs to be investigated with respect to biological efficacy of reducing potyvirus and any unintentional increase caused in foliar blight.
- In addition to mineral oils, many reports found that pyrethroids insecticides have good activity in preventing potyvirus spread.

- Maintaining a low environmental inoculum is the most effective method of controlling potyviruses.

4. Discussion

4.1. Objective 1: Identify the most important potyvirus vector aphids suing a combination of lab and field studies

4.1.1. Virus Transmission: Aphid Relative Efficiency Factors

The transmission experiments have provided interesting information on the ability of the species tested to transmit PVY and PVA, showing, for the first time, that *Aphis fabae, Metopolophium dirhodum, Sitobion avenae, Acyrthosiphon pisum and Cavariella aegopodii* are able to transmit PVA and highlighting that *Cavariella aegopodii* is potentially an important vector of PVY and *Sitobion avenae* may be more significant than previously thought. In comparison with REF's for PVY^N and PVY^{NTN} determined by Verbeek *et al.* (2009) and earlier studies, the REFs determined in this study were generally higher (Table 42). The most notable differences are *S. avenae*, *M. dirhodum, M. euphorbiae, C. aegopodii, R. padi* and A*. pisum.* The reasons for these differences are unclear but the most likely explanation is that different biotypes (clones) of aphids and UK virus isolates were used.

Table 42. Comparison of REF values listed in previous published studies with results from the current study.

Species	REF 1980's (from Verbeek *et al.* 2009)[a]	REF used in current UK PVY control system	REF from this study PVY^N	REF PVY^N from Verbeek *et al.* 2009	REF from this study PVY^{NTN}	REF PVY^{NTN} from Verbeek *et al.* 2009	PVYave (including (PVY^O)
Sitobion avenae	-(-)	0.01	1.288	0.00	0.400	0.00	0.678
Aphis fabae	0.10 (0.07)	0.01	0.00	0.03	0.131	0.04	0.064
Brevicoryne brassicae	-(0.00)	0.01	0.00	0.00	0.00	0.00	0.00
Acyrthosiphon pisum	0.05 (0.11)	0.70	0.335	0.08	0.500	0.07	0.646
Metopolophium dirhodum	0.01 (0.10)	0.30	1.028	0.02	0.077	0.00	0.368
Myzus persicae	1.00 (1.00)	1.00	1.000	1.00	1.000	1.00	1.000
Macrosiphum euphorbiae	0.10 (0.07)	0.20	0.767	0.00	0.389	0.00	0.489
Cavariella aegopodii	-(0.00)	0.00	0.577	0.00	0.977	0.00	0.781
Rhopalosiphum padi	0.02 (0.14)	0.40	0.668	0.00	0.971	0.01	0.811
Drepanosiphum platanoides	-(-)	0.00	0.00	-	0.00	-	0.00
Hyperomyzus lactucae	- (0.16)	0.16	0.00	0.00	0.00	0.00	0.00
Microlophium carnosum	-(-)	0.00	0.00	-	0.00	-	0.00

[a]From Verbeek *et al.* 2009: REF used in the current Netherlands PVY control system and determined by Van Harten (1983) and between brackets De Bokx & Piron (1990), -: REF was not determined.
PVYave = average value including values for PVY^O

4.1.2. Epidemiology Field Trials

The purpose of the epidemiology plots at SASA, Fera and SA was to investigate the timing of transmission of PVY and PVA. This built upon the trials which had been running at SASA over the previous decade. The purpose of running these trials at a range of sites allowed a

validation of the trials at SASA, at sites representing the different geographic locations in Scotland and England where seed potatoes are produced.

In both years (2010 and 2011), the English trials saw broadly similar periods where both PVY and PVA were being transmitted. There were some differences in the patterns of transmission between PVA and PVY in both years however, these cannot be easily explained through differences in vector pressure. In 2011, the YWTs picked up PVY and PVA transmission later in the season but the suction trap at Askham Bryan did not. The Askham Bryan suction trap picked up *M. persicae* up to and including 7th Aug 2011 and the YWTs also picked up *M. persicae* during every week until the end of the study. A similar pattern was observed during 2010: the last date on which the suction trap picked up *M. persicae* was 22nd August but they continued to be detected in YWTs up to the end of the season. This suggests that the YWTs are picking up lower altitude, local flights of *M. persicae* late in the season and that these are not detected by the high level suction trap.

Using the new virus transmission factors (PVYave reported in Table 42 above) and trap data from the Yorkshire site resulted in higher aphid vector pressure figures from YWT and suction trap data for PVY in mid-July 2010 but made little difference to the vector pressure figures for PVA. In 2011, using the new virus transmission factors again produced higher aphid vector pressure figures from YWT and suction trap data for PVY in mid-July. The increase for ST vector pressure was particularly noticeable. Neither the old nor new REF values reflected the transmission of both PVY and PVA later in the season (mid-August onwards in both 2010 and 2011).

The PVY trial at SASA's site was designed to monitor and study possible interactions of two different PVY^{N} isolates ($PVY^{EU\text{-}NTN}$ and $PVY^{NA\text{-}NTN}$) together with a PVY^{O} isolate within the same plot in relation to the timing of transmission and distribution in potato plants. A comparable timing of transmission (following aphid vector pressure from the Gogarbank suction trap) and weekly transmission rate to bait plants was observed for both PVY^{N} and PVY^{O} serotypes. However, the proportion of potatoes tested positive for PVY^{N} (in particular $PVY^{EU\text{-}NTN}$) was far higher in comparison to other strains ($PVY^{NA\text{-}NTN}$ and PVY^{O}), which contrasts with the weekly transmission rate observed for PVY^{N} and PVY^{O} isolates. This suggests that PVY^{N} transmission and detection in tubers is more readily observed for PVY^{N} ($PVY^{EU\text{-}NTN}$) than for PVY^{O} in potato plants in field conditions.

Each of the virus life cycle steps from (i) transmission by an aphid vector, (ii) genome replication, (iii) local and (iv) systemic movement resulting in the invasion of whole plant tissues including tubers, represents possible population bottlenecks during the infection of their host (Garcia-Arenal *et al.,* 2001). For each of the PVY isolates assessed, multiple aphid feeding episodes leading to multiple transmission events of either one or several isolates might have occurred within the same potato plant during the whole season. This apparent discrepancy between frequency of transmission and the prevalence of a specific PVY strain type could be explained by the ability of specific PVY^{N} variants to out-compete others (such as PVY^{O}) during the infection process. Genotyping of PVY strains indicates that the $PVY^{EU\text{-}NTN}$ variant account for the larger proportion of virus cases (66% and 75% respectively in 2010 and 2011 trials). This suggests that $PVY^{EU\text{-}NTN}$ variant may be fitter and out-competed $PVY^{NA\text{-}NTN}$ and PVY^{O} variants. Further analysis is on-going to determine their respective biological properties in terms of replication, local and long distance movement *in planta* (Davie et al, 2012, unpublished data).

4.2. Objective 2: Comparison of methods used to monitor vector aphid populations

Since the project has completed, discussions have begun on the logistics of the provision of a joint aphid alert system, which collates data from a range of sources. As this develops further updates on progress will be provided via the Potato Council website.

4.3. Objective 3: Identify sources of potyvirus inoculum and investigate their importance in the spread of virus to seed crops

4.3.1. Survey of Symptomatic Plants

The results of this survey show that virus incidence in seed potato crops in England and Wales is comparable to virus incidence in Scotland, with PVY^{N} being the most prevalent virus. The main caveat with this type of survey is that the sampling concentrated on symptomatic material and some viruses and strains of viruses will be under represented. PVA, and to some extent PVV, in certain varieties can be difficult to see at visual inspection. Other viruses, such as PVM and PVS, are also known to be latent in some cultivars. Primary infection, that is infection in the season of growth, may also be difficult to see in the field. However, this survey does give a guide as to the inoculum that would have been in stock material as planted.

PVY^{N} represent more than 80% of PVY cases, confirming the prevalence of the tobacco necrotic strain PVY^{N} in GB. A trend observed worldwide and often associated with the occurrence of necrotising (PVY^{NTN}) variants. Partial sequencing of recombination junctions of PVY^{N} field isolates and phylogenetic analysis has indeed confirmed that a vast majority of PVY^{N} field isolates belong to the EU-NTN recombinant group, of which selected individual isolates trigger PTNRD in susceptible cultivars (SASA-PCL PhD studentship, unpublished data).

Regional variation in the proportion of $PVY^{O/C}$ serotype was observed that may be due to regional differences in the area grown of varieties susceptible to PVY^{O}. A higher proportion of $PVY^{O/C}$ to PVY^{N} serotype was found in England and Wales (30%) in comparison to Scotland (14%) in 2010, confirming a trend observed in 2009 (33% for England & Wales, 10.5% Scotland). The causes of this discrepancy in the proportion of $PVY^{O/C}$ and PVY^{N} are not known. This may be due to regional differences in inoculum sources (seed or ware crops) and in the number of PVY^{O} susceptible varieties grown (Maris Peer, King Edward, Valor).

Biotyping of intercepted of $PVY^{O/C}$ serotypes within the Scottish SPCS, indicates that a significant proportion (between 33% to 66%) belong to the $PVY^{N\text{-}Wilga}$ biotype that are characteristized by the elicitation of vein necrotic symptoms in tobacco. $PVY^{N\text{-}Wilga}$ is biologically closely related to PVY^{N} strains. $PVY^{N\text{-}Wilga}$ recombinants have the potential to cause tuber necrosis and are increasingly found in seed crops in mainland Europe and worldwide, presenting a potential threat for certification programmes. The identification of these different PVY biotypes demonstrates the dynamic nature of PVY population and the prevalence of fitter necrotizing recombinant PVY^{NTN} and $PVY^{N\text{-}Wilga}$ variants that are displacing common PVY^{O} strains (Gray *et al.,* 2011).

Other potyviruses such as PVA and PVV are less prevalent than PVY^{N} and $PVY^{O/C}$ in England and Wales. PVA incidence was found to vary from year to year (17% in 2009, 5% in 2010). As PVA and PVV are found to be associated with a limited numbers of crops (Lacomme C and Pickup J, 2010), their relative incidence may reflect differences in inoculum sources (seed or ware crops) and in the amount of susceptible varieties grown every year (Hermes, Estima, Desiree) in England-Wales and Scotland.

4.3.2. Analysis of Scottish SPCS data - Mosaic data 2009 to 2011.

Data from the Scottish SPCS and the Scottish survey of symptomatic plants were included in a data mining exercise with the aim of examining the contribution of different potential inoculum sources to virus transmission. The study makes a distinction between **horizontal transmission**, i.e. where symptoms occur in the daughter stock when grown from a clean parental stock; and **vertical transmission** ie where symptoms occur in the daughter stock when grown from virus infected parental stock. The factors that have been examined are: Field generation; variety, geographical area; and the presence of other potato crops.

Field generation

Over field generations 2 to 7, the generations at which the vast majority of classified crops are grown, vertical transmission remains relatively constant at between 40 and 60%. Horizontal transmission rates increase with increasing field generation indicating that there may be a greater external source of virus inoculum in areas where this later generation material is produced. The change between field generation 4 and 5 appears quite marked. These findings are summarised in Figure 33 (shown again below) which shows that although the overall incidence of infection increases with field generation, this is driven by the increasing amount of horizontal transmission in later field generations.

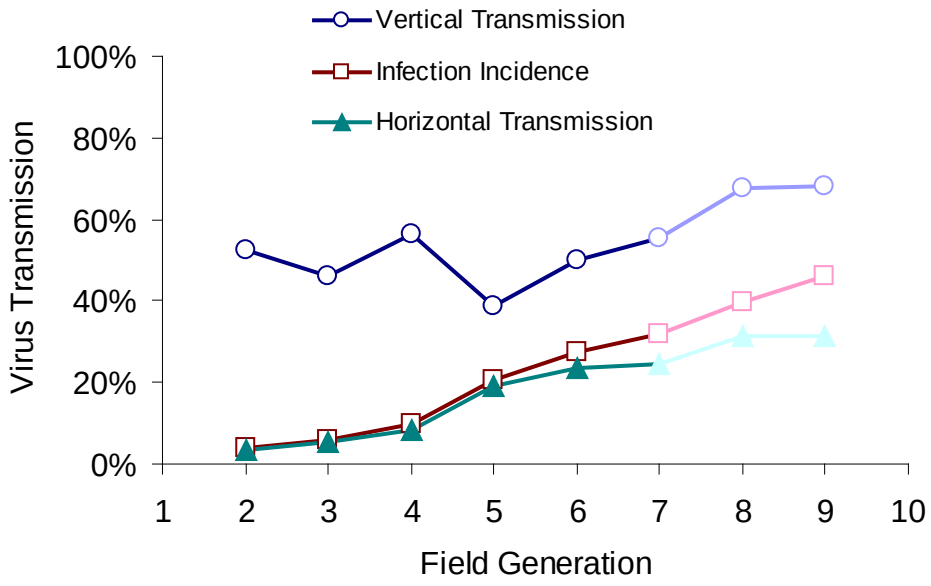


Figure 33. Summary of the effect of field generation on the variation in vertical and horizontal transmission of viruses producing mosaic symptoms at crop inspection of classified seed crops grown at each field generation in 2009, 2010 and 2011. The overall infection incidence (resulting from both horizontal and vertical; transmission) is included. Paler colours are used to denote generations 8 & 9 where the points are based on far fewer data.

Effect of Variety

The term 'varietal propensity' is used in this report to describe whether symptoms observed within a variety are above or below the average across the whole Scottish seed crop. Two sources of information are available to study varietal propensity: laboratory diagnosis of viruses detected in leaf samples taken as part of the symptomatic surveys; and the observations of symptoms at crop inspection.

Table 21 (provided again below) shows the propensity values obtained from the leaf testing in the context of the propensity values obtained using the observations of symptoms at crop inspection. This allows the propensity to mosaic symptoms to be explained by the

propensity to the respective viruses/strains. The most widely grown variety, Maris Piper has a propensity to both Mosaics and Leafroll, with the propensity to Mosaics largely explained by a propensity to PVY^N. Whilst Hermes and Desiree have a propensity to PVA, the higher propensity of Desiree to mosaic symptoms is explained by a greater propensity to PVA and probably also to PVY^N. Maris Peer has a propensity to Mosaics explained by a propensity to both strains of PVY. Estima has a moderate propensity to Mosaics, with a very low propensity to PVY offset by a high propensity to PVA and PVV. Varieties such as Markies, Pentland Dell, Saxon, Lady Rosetta, Saturna, Burren, Kennebec and Melody all show a low propensity to potyviruses and leafroll. This approach also allows some of the more inconsistent propensity values from leaf tests to be placed into greater context. Rooster and Russet Burbank show a relatively average propensity to mosaics but their propensity to the main aphid transmitted viruses is generally low. Therefore, their propensity to mosaics may be due to a propensity to PVX.

Variety	Crops	Mosaics	PVY^N	$PVY^{O/C}$	PVA	PVV	Leafroll
MARIS PIPER	1390	1.7	1.7	1.1	0.1	0.0	4.2
HERMES	1274	0.6	0.1	0.5	2.0	0.0	0.3
DESIREE	775	2.0	1.2	0.5	5.9	0.0	1.4
MARIS PEER	536	2.0	2.2	2.8	0.0	0.0	0.5
ESTIMA	483	1.0	0.2	0.3	5.1	25.1	1.4
MARKIES	326	0.3	0.1	0.0	1.2	0.0	0.3
KING EDWARD	315	2.4	4.6	3.4	0.2	0.0	1.3
MARFONA	305	1.0	1.2	2.2	0.3	0.0	0.9
PENTLAND DELL	267	0.6	1.1	0.0	0.3	0.0	1.2
CABARET	266	1.1	1.4	1.5	4.6	0.0	0.5
SAXON	261	0.1	0.1	0.0	0.3	0.0	0.2
LADY ROSETTA	249	0.2	0.0	0.0	0.0	0.0	0.4
VALOR	236	3.5	2.4	4.6	0.0	0.0	1.0
SATURNA	227	0.5	0.6	0.6	0.0	0.0	0.0
CHARLOTTE	226	1.0	1.4	1.8	0.0	0.0	0.0
ATLANTIC	224	1.9	4.3	4.8	0.0	0.0	0.2
HARMONY	207	2.3	2.1	0.7	0.0	0.0	1.1
WINSTON	203	2.3	0.6	3.3	0.0	0.0	0.7
CARA	186	0.5	0.5	0.7	0.0	0.0	1.7
BURREN	173	0.3	0.4	0.0	0.0	0.0	0.5
ROOSTER	172	1.0	0.8	0.0	0.0	0.0	0.5
KERR'S PINK	171	0.9	0.6	0.8	1.3	0.0	1.6
RUSSET BURBANK	171	1.1	0.4	0.8	0.0	0.0	2.1
MARIS BARD	167	0.7	1.0	0.8	2.7	0.0	0.3
VALES SOVEREIGN	159	0.5	0.4	0.9	1.4	0.0	2.9
WILJA	131	1.5	2.0	1.0	0.0	0.0	0.3
KENNEBEC	128	0.2	0.0	0.0	0.6	0.0	0.4
MELODY	127	0.1	0.0	0.0	0.0	0.0	0.0
TOTAL	16361	1.0	1.0	1.0	1.0	1.0	1.0

Table 21. Collation of varietal propensity information collected over the period 2009-2011 using data on symptom expression at crop inspection (Mosaics and Leafroll) and laboratory virus diagnoses on leaf samples submitted to SASA from plants exhibiting mosaic symptoms at crop inspection (PVY^N, $PVY^{O/C}$, PVA and PVV).

Geographical location

The analyses have identified districts that have markedly higher horizontal transmission rates (nearly or more than twice the average value of 15%). There are also districts where the horizontal transmission rates are less than a third of the average value.

Other potato crops in a district
There is a clear relationship between the mean horizontal transmission and the area of potato production within a district, whether it be seed, ware or the total potato area. The weakest relationship is with the seed area, a stronger relationship is found with the ware area and the strongest is with the total potato area. This indicates the importance of other potato crops as a source of virus inoculum for horizontal transmission. Whilst ware crops produce a stronger relationship within a district than seed crops, the relationship with area of seed crops is also significant and therefore the relationship with the total area of potatoes is the most significant.

Overall, when horizontal transmission is considered, there is a clear increase associated with increasing field generation. However, generation *per se* is unlikely to have any direct effect on the likelihood of virus transmission, except for later generation crops tending to be larger and hence more likely to exhibit at least one plant showing virus symptoms at inspection. The location where later generation crops are grown is more likely to have an effect, with such crops grown in areas where more commercial stocks are grown. The presence of other potato crops within a geographical district has a highly significant effect on the likelihood of horizontal transmission, with the area of ware potato crops having a more significant effect than the area of seed crops.

4.3.3. Survey of groundkeepers, ware crops

Field based sampling was carried out to supplement the information provided by the analyses of the Scottish SPCS data. This included sampling of groundkeepers and ware crops for potyviruses.

All field grown seed crops entered for classification are inspected by Scottish Government potato inspectors on at least two inspections that take place from late June to early August. Pre-monitoring inspections take place at or around the 2nd week of June each season. Before this point in time the farm roguing teams have normally removed the majority of groundkeepers. At this juncture inspectors do not record officially the presence of groundkeepers. The second inspections usually take place from early July with a third growing crop inspection 14 days later. It is only at this point that inspectors log the presence of groundkeepers or off types, or virus. Therefore it is possible that analyses of the data recorded in the scheme may underestimate the role of groundkeepers as an early season inoculum source of virus.

Groundkeepers were sampled in three years, at a range of times during the growing season and from a range of crops/fields. The samples were not collected as part of a stratified survey therefore the results can only give an indication of the prevalence of potyvirus infection in groundkeepers. In some areas (e.g., the Aberdeenshire case study) no virus was found in the groundkeepers sampled. In other locations in excess of 50% of a random sample of groundkeepers tested positive for PVY^N when sampled in early/mid June. The samples where high percentages of groundkeepers tested positive for PVY^N were from crops other than seed potatoes (eg winter wheat, sugar beet).

The case study in Angus highlighted that fields in which groundkeepers (infected with potyvirus) occur can be in close proximity to pre basic crops. Although the design of the sampling in the current study does not allow a direct link between virus in groundkeepers and virus transmission to be drawn, the results have highlighted the percentage of groundkeepers that can be infected with potyvirus.

The results from the long term rotation experiment at JHI have demonstrated that groundkeepers remain in the soil over a number of seasons. The longest surviving groundkeeper populations are from Maris Piper crops grown at least six years prior to sampling. In the first year of this project, a population of King Edward was also identified that had survived for 16 years in fields. This expands work carried out in an earlier project

(Turley, 2000) which tracked groundkeepers for four years. Turley found that the crops grown around the groundkeepers had a strong influence on their fate. More competitive crops, such as oilseed rape restricted numbers, whereas more open crops such as field beans would allow survival of more groundkeepers. The numbers of groundkeepers did reduce by approximately 90% between the years 2009 and 2010 in both commercial fields and the experimental fields at JHI in the current study. Turley (2000) also found that numbers declined but in the first years post cultivation they were very high. In most situations groundkeepers were present throughout the study, although some rotations did eliminate them. However, in some crops and years low numbers could suddenly increase for no clear reason. Comparing this phenomenon to our study it is possible that this was caused by TPS germination.

Turley (2000) found that true potato seed (TPS) was viable, but the role that it played in the field was uncertain. He reported that the cultivar Estima consistently produced the most viable seed which sometimes reached levels of 90% viability. In our study, we found a clear case of germination of Estima seed two years after its cultivation. In this case it is possible that the cultivation of the ground for the swede crop produced ideal conditions for the young seedlings to germinate and grow. The swede would not compete with the seedlings in the first months of its growth. In terms of the virus reservoir, the contribution of plants arising from true potato seed is considered to be low (PVY is not known to be transmitted through a botanical seed pathway).

In the current study, a limited number of ware crops were sampled for potyvirus infection. Considerable levels of virus PVY^N infection were detected in some of the crops. This observation is supported by the fact that out of 370 ware crops inspected by Scottish Government inspectors in 2010, 11 were found to have more than 4% virus. It can be assumed that groundkeepers arising from these crops will at least initially represent sources of potyvirus inoculum. Results from the levels of PVA virus in groundkeepers in the JHI experimental fields showed that infection incidence dropped from 2009 to 2010 corresponding to the very cold winter. However, for the same plot in 2011, the incidence returned to almost the same levels as in 2009. The rate at which infection incidence declines and the factors affecting the rate of decline are not well understood but cold weather may kill tubers in the soil and virus infected tubers may be more vulnerable to freezing.

Virus in field collected aphids

The molecular analysis of aphids from traps or collections in fields did detect potyviruses in aphid species. In 2010 collections were made from the Fife field trials where the inoculum was low relative to the size of the field. Three species were collected which contained virus and *M. dirhodum* was caught in sufficient numbers to give a reasonable estimate of the frequency with which it carried virus (0.5 - 1.5%). While it is not possible to assess the transmission capabilities of these individuals, the frequencies are close to the low REFs reported in field based studies, such as Harrington and Gibson (1989). These results are consistent with the observation by Wang and Ghabrial (2002) that viral detection frequencies are correlated with transmission frequencies in non-colonising aphids. In 2011 a different approach was taken and the JHI field site was modified to contain large blocks of PVA infected plants. The detection rate for virus positive aphids in this experiment were greater than in 2010. Eight species were collected which were positive for PVA, ranging between 20 and 40% of individuals. While some were in low numbers and this has to be interpreted with care, the increase in detection rates from the field in 2011 corresponds to the increased transmission efficiencies calculated in the new REF values, particularly when looking at individual clones. It is important to consider REFs are corrected against a standard and so these too are not a clear measurement of virus transmission efficiency, *i.e.,* in some experiments individuals would be exposed to standard transmission conditions, yet they did not transmit virus. It will not be known if this occurred at the acquisition or transmission stage. It may be field detection results are influenced by multiple factors including: the presence of particular clones in a local area, the ambient conditions (temperature, humidity), the concentration of infected plants in the immediate vicinity, the total numbers of each

species in the air (a dilution effect), the source potato varieties, the length of time during and after feeding etc. In terms of the influence of the concentrations of infected plants on aphid acquisition, the JHI experiment was designed to investigate this, yet there was no difference in detection rates between the large and small plots. This is probably due to the quality of the plant material used.

4.4. Objective 4: Provide an improved understanding of the Estima-PVA interaction

Assessment of virus incidence in Estima plants have provided important information on the factors contributing to the more rapid degeneration of the health of Estima crops. Data from field transmission trials revealed that a significantly higher percentage of Estima plants were infected with PVA in comparison to other varieties. Moreover, infected Estima plants were found to display a higher tuber infection rate in comparison to infected Desiree plants. As PVA is largely the most prevalent virus found in Estima crops in Scotland (high propensity value), the main cause for the rapid health degeneration of Estima crops is likely to be due to the combination of Estima high susceptibility level (horizontal transmission) and high PVA infection frequency to tuber progeny (vertical transmission).

5. Conclusions

5.1. Importance of potyviruses in GB seed crops

Prior to the start of the project in 2009, the estimated incidence of aphid transmitted viruses causing mosaic symptoms (ie potyviruses) had been increasing steadily in seed crops in GB. The results show that:

- PVY^{N} represent more than 80% of PVY cases, confirming the prevalence of the tobacco necrotic strain PVY^{N} in the UK. A trend observed worldwide and often associated with the occurrence of potato tuber necrotising (PVY^{NTN}) variants.
- The regional variation in the proportion of $PVY^{O/C}$ and PVY^{N} serotypes might be due to regional differences in inoculum sources (seed or ware crops) and in the number of PVY^{O} susceptible varieties grown (such as Maris Peer, King Edward, Valor).
- The timing of transmission and distribution of a selection of PVY isolates suggest that they are likely to be transmitted by the same aphid species. Discrepancy between virus incidence at post-harvest and transmission frequency for the PVY^{N} and PVY^{O} serotypes, suggests that PVY^{N} ($PVY^{EU\text{-}NTN}$) transmission in tubers is more readily observed than for PVY^{O} in potato plants. This difference in fitness might explain the prevalence of PVY^{N} over the PVY^{O} serotypes in UK seed crops.
- Assessment of virus incidence in Estima plants has provided important information on Estima/virus interactions whereby the combination of Estima relative high susceptibility level (horizontal transmission) and high PVA infection frequency to tuber progeny (vertical transmission) are likely to be the cause of the rapid degeneration of Estima crops to viruses.

5.2. Aphid vectors of potyviruses

Two approaches have been taken to study the aphids which are involved in the transmission of potyviruses. These have been glasshouse studies to determine aphid Relative Efficiency Factors (REFs) and field trials in which the occurrence of different aphid species (as monitored by suction traps and yellow water traps) has been compared with weekly estimates of potyvirus transmission (monitored using tobacco bait plants).

- The glasshouse studies have shown for the first time that *Aphis fabae, Metopolophium dirhodum, Sitobion avenae, Acyrthosiphon pisum and Cavariella*

aegopodii are able to transmit PVA. The results also highlighted that *Cavariella aegopodii* is potentially an important vector of PVY.

- In 2012, *C. aegopodii* was been allocated a PVY index of 0.5 for the purposes of the aphid monitoring scheme for seed potato crops. This is accompanied by a note in the weekly summary stating that *C. aegopodii* transmits PVY and PVA and is present early in the season when the potato plants have not yet developed mature plant resistance to virus infection. A note is also included in the weekly summary stating that *A. fabae* is a good vector of PVA so growers of PVA susceptible potato varieties should take this into account or consult their agronomist.

Using data from the epidemiology field trials, a logistic regression model based on binomial response data was used to relate virus transmission to aphid counts for individual aphid species. These results show that the relationship between PVY transmission in Edinburgh and York may differ.

- In Edinburgh there is a clear indication that *M. dirhodum* was the key species over the duration of the SASA epidemiology trials (2000-2011) and that the suction trap provided as good, if not better, relationship between aphid abundance and virus transmission, when compared to yellow water traps.
- In Yorkshire, over the duration of this project (2010-2011) a very different relationship was found, with the abundance of several species of aphids showing a stronger relationship with PVY transmission than does *M. dirhodum*. In addition, the aphid data from yellow water traps showed a stronger relationship than the data collected by the suction trap. This may in part be due to the aphid trap at Askham Bryan being some 28 miles from the field site.
- The data collected at the two sites indicates that there may be differing relationships between yellow water trap catches and suction traps in different parts of the UK.

5.3. Sources of potyvirus inoculum

- Variety clearly has a very important effect on the incidence of mosaic symptoms observed at classification inspections.
- The presence of virus in the parental stock also has a very significant effect.
- Over the period 2009-2011, whilst virus symptoms were observed in 16% of the crops grown, the virus incidence was 52% for stocks grown from infected parental material, and 13% for crops grown from parent stock in which no symptoms had been seen at the previous year's classification inspections.
- These data indicate a four-fold difference in the likelihood of mosaic being seen in a daughter crop depending upon whether virus had been observed in the parent crop.

Horizontal transmission is the term used to describe the situation where mosaic symptoms occur in the daughter stock when grown from a clean parental stock. In this situation an external source of virus inoculum is assumed to be the origin of the potyvirus infection. Analyses of SSPCS data (2009 -2011) have shown that there is a clear increase in horizontal transmission associated with increasing field generation. However, generation *per se* is unlikely to have any direct effect on the likelihood of virus transmission, except for later generation crops tending to be larger and hence more likely to exhibit at least one plant showing virus symptoms at inspection. The location where later generation crops are grown is more likely to have an effect, with such crops grown in areas where more commercial stocks are grown. The presence of other potato crops within a geographical district has a highly significant effect on the likelihood of horizontal transmission, with the area of ware potato crops having a more significant effect than the area of seed crops.

The collection and testing of leaf samples from groundkeepers has highlighted the prevalence of potyvirus infection in some groundkeepers. This information should be used to re-iterate the importance of the management of groundkeepers.

5.4. Knowledge Gaps

- A review of literature on the use of mineral oils to minimise virus spread has highlighted knowledge gaps relating to the use of mineral oils in GB. These are currently being addressed as part of a separate research project.
- Better knowledge of varietal susceptibility to virus infection for the most prevalent potyvirus species and variants (*i.e.* current prevalent PVY^N variants and PVA strains) and susceptibility to potato tuber necrotic ringspot disease (PTNRD) development.
- Understanding the mechanisms that are driving the dynamics of PVY variant population and PVA prevalence in Scotland/Northern Europe (including virus acquisition/retention/transmission by aphids, varietal genetic diversity associated with endogenous virus resistance and mature plant resistance)
- Epidemiological trial data collected in Yorkshire and Edinburgh indicates that there may be differing relationships between yellow water trap catches and suction traps in different parts of the UK. This variation in the data collected by the two methods requires further investigation. Comparing historical aphid catches from the suction trap network with those from the yellow water trap network funded by Potato Council may help elucidate this variation.

6. ACKNOWLEDGEMENTS

The authors wish to thank Adrian Roberts (BioSS) and colleagues for their input into the various statistical analyses, particularly the analysis of the epidemiology trials data and the analyses of data held in the SPUDS database.

7. References

Details of published sources of material referred to or quoted in the text (including URL addresses of any websites used).

Berger PH, Zeyen RJ, Groth JV. 1987. Aphid retention of maize dwarf mosaic virus (potyvirus): epidemiological implications. *Annals of Applied Biology* **111(2)**:337-34.

Bradley, RHE. 1959. Loss of virus from the stylets of aphids. *Virology*, **8**: 308 – 318.

Chrzanowska M. 1991. New isolates of the necrotic strain of potato virus Y (PVY^N) found recently in Poland, *Potato Research* **34 (2)**: 179-182.

De Bokx JA and Piron PGM. 1990. Relative efficiency of a number of aphid species in the transmission of potato virus Y^N in the Netherlands. *Netherlands Journal of Plant Pathology*, **96**: 237-246.

Davie, K., M. Dickinson, and C. Lacomme. Biodiversity and Epidemiology of PVY in Scotland. 2012. *In Proceedings Crop Protection in Northern Britain* 255-260.

Fox A, Evans F and Browning I. 2005. Direct tuber testing for *Potato Y potyvirus* by real-time RT-PCR and ELISA: reliable options for post-harvest testing? *EPPO Bulletin* **35**: 93-97.

Gibson RW; Payne RW and Katis N. 1988. The transmission of potato virus Y by aphids of different vectoring abilities. *Annals of Applied Biology*, **113**: 35-43.

Garcia-Arenal F, Fraile A and Malpica JM. 2001. Variability and genetic structure of plant virus populations. *Annu. Rev. Phytopathol*. **39**: 157-186.

Gray S, De Boer S, Lorenzen J, Karazev A, Whitworth J, Nolte P, Singh R, Boucher A and Xu H. 2011. Potato virus Y: an evolving concern for potato crops in the United States and Canada. *Plant Disease* **94:** 1384-1397.

Katis N and Gibson RW 1985. Transmission of potato virus Y by cereal aphids. *Potato Research*. **28**: 65-70.

Kostiw M. 1979. Transmission of *Potato virus Y* by *Rhopalosiphum padi* L. *Potato Research*. **22**: 237-238.

Harrington R and Gibson RW. 1989. Transmission of potato virus Y by aphids trapped in potato crops in southern England (1989) Harrington, R.; Gibson, R. W. *Potato Research* **32(2)**:167 -174

Hull R 2002. Nomenclature and Classification of plant viruses, from *Matthew's Plant Virology*, 4th edition, Academic Press, Chapter 2, pp13-19

Jones DAC, Woodford JAT, Main SC, Pallet D and Barker H. 1996. The role of volunteer potatoes in the spread of potato virus Y^N in ware crops of cv. Record. *Annals of Applied Biology* **129(3)**: 471–478.

Kanavaki O,Margaritopoulos, J, Katis, N, Skouras, P and Tsitsipis, J. 2006. .Transmission of Potato virus Y in tobacco plants by *Myzus persicae nicotianae* and *M. persicae* s.str. *Plant Disease* **90(6)**: 777 - 782

Nolte, P., Whitworth, J.L., Thornton, M.K. and McIntosh, C.S., 2004. Effect of seed borne Potato virus Y on performance of Russet Burbank, Russet Norkotah and Shepody potato. *Plant Disease*. **88**, 248-252.

Pallas, V and Garcia, JA. (2011). How do plant viruses induce disease? Interactions and interference with host components. *Journal of General Virology.* **92**, 2691-2705.

Pickup, J; Davie, K; Fox, A; Highet, F; Holmes, R. 2009. Epidemiology of viruses in Scottish seed potatoes. *Aspects of Applied Biology* **94**, 5-10.

Piron PGM. 1986. New aphid vectors of potato virus Y^N. *Netherlands Journal of Plant Pathology*. **92**: 223-229.

Rajamaki, M, Merits, A, Rabenstein, F, Andrejeva, J, Paulin, L, Kekarainen, T, Kreuze, JF, Forster, RLS, and Valkonen, JPT. (1998). Biological, serological, and molecular differences among isolates of Potato A potyvirus. *Virology.* **88**, 311-321.

Sigvald, R. 1984. The relative efficiency of some aphid species as vectors of potato virus Y^O (PVY^O). *Potato Research.* **27**: 285-290.

Sigvald, R. 1992. Progress in aphid forecasting systems. *Netherlands Journal of Plant Pathology*. **98**: 55-62.

Singh, R. 1998. Reverse-transcription polymerase chain reaction for the detection of viruses from plants and aphids. *Journal of Virological Methods*. **74**: 125-138.

Singh, R. 1999. A solvent-free, rapid and simple virus RNA-release method for potato leafroll virus detection in aphids and plants by reverse transcription polymerase chain reaction. *Journal of Virological Methods.* **83**: 27-33.

Singh,R, Valkonen JPT, Gray SM, Boonham N, Jones RAC, Kerlan, C and Schubert J. 2008. Discussion paper: The naming of Potato virus Y strains infecting potato, *Archives of Virology* **153:** 1–13,

Turley, D. 2000. Understanding the biology and incidence of potato volunteers. Project 807/151. Report to the British Potato Council.

Van Harten A. 1983. The relation between aphid flights and the spread of Potato virus YN (PVYN) in the Netherlands. *Potato Research,* **26**: 1-15

Verbeek, M; Piron, PGM; Dullemans, AM; Cuperus C; van der Vlugt, RAA. 2010. Determination of aphid transmission efficiencies for N, NTN and Wilga strains of *Potato virus Y*. *Annals of Applied Biology* **1**: 39-49

Wang, R.Y; Gabrial; S.A. 2002. Effect of aphid behaviour on efficiency of transmission of *Soybean mosaic virus* by the Soybean-colonising aphid, *Aphis glycines*. Plant Disease 85: 1260 - 1264.

8. Appendix 1

Table 1. Values for each aphid clone tested, corrected using its internal MP2 control, with each virus strain.

S. avenae				
Clone	PVYN	PVYO	PVYNTN	PVAStrong
11	0.737	0.222	0.436	0.000
N	0.751	0.533	0.332	0.836
E	0.294	0.200	0.053	0.557
Average	0.594	0.319	0.273	0.465

A. fabae				
Clone	PVYN	PVYO	PVYNTN	PVAStrong
1	0.000	0.167	0.250	0.600
2	0.000	0.000	0.000	0.563
C	0.000	0.000	0.111	0.091
Average	0.000	0.056	0.120	0.418

B. brassicae				
Clone	PVYN	PVYO	PVYNTN	PVAStrong
1	0	0	0	0
2	0	0	0	0
Average	0	0	0	0

A.pisum				
Clone	PVYN	PVYO	PVYNTN	PVAStrong
1	0.000	1.063	0.067	0.000
2	0.250	1.235	0.882	0.500
3	0.333	0.765	0.429	0.000
Average	0.194	1.021	0.459	0.167

M. euphorbiae				
Clone	PVYN	PVYO	PVYNTN	PVAStrong
Me1	0.676	0.000	0.927	0.769
Me3	0.000	0.000	0.000	1.125
Me4	0.656	0.862	0.143	0.600
Average	0.444	0.287	0.357	0.831

C. aegopodii				
Clone	PVYN	PVYO	PVYNTN	PVAStrong
1	0.429	0.462	1.385	0.625
2	0.240	1.000	0.410	0.348
Average	0.334	0.731	0.897	0.486

R. padi				
Clone	PVYN	PVYO	PVYNTN	PVAStrong
1	0.579	0.889	0.927	0.000
2	0.235	0.692	1.174	0.000
3	0.346	0.621	0.571	0.048
Average	0.387	0.734	0.891	0.016

D. platanoidis				
Clone	PVYN	PVYO	PVYNTN	PVAStrong
1	0	0	0	0

H. lactucae				
Clone	PVYN	PVYO	PVYNTN	PVAStrong

M. dirhodum				
Clone	PVYN	PVYO	PVYNTN	PVAStrong
A	0.833	0.000	0.000	0.000
B	0.952	0.000	0.000	0.000
C	0.000	0.000	0.214	0.067
Average	0.595	0.000	0.071	0.022

M. persicae				
Clone	PVYN	PVYO	PVYNTN	PVAStrong
B	0.879	1.176	1.083	1.000
D	0.714	0.957	0.619	1.375
E	0.143	0.645	1.053	0.286
Average	0.579	0.926	0.918	0.887

1	0	0	0	0

M. carnosum				
Clone	PVYN	PVYO	PVYNTN	PVAStrong
1	0	0	0	0
2	0	0	0	0
Average	0.000	0.000	0.000	0.000

9. APPENDIX 2.

An Assessment of the Work Required to Incorporate Other Sources of Aphid Data into a Potato Virus Risk Assessment Scheme

Ref: R428

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Date report submitted: September 2010

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CONTENTS

10. SUMMARY

This report details the work undertaken to produce an assessment of the tasks required to incorporate complementary sources of aphid data into a potato virus risk assessment scheme and make recommendations on the optimum combination of data required to provide a cost effective risk assessment. An investigation into the available sources of data and the subsequent derivation of relationships between suction trap and yellow water trap data via statistical analyses of key data subsets highlighted that it would take a greater level of investigation than available within the scope of this element of the project to reach a conclusion on the optimum combination of data required. The recommendation is therefore to undertake further analyses, with more vector species and region combinations, to facilitate the understanding of the optimum level of monitoring. A review of the aphid data delivery systems highlighted a range of possible innovations that should be considered by industry and it is recommended that a single website enables ease of access to the various data sets, with integration and explanation where appropriate.

11. AIMS AND APPROACHES

11.1. Aim

Produce an assessment of the work required to incorporate complementary sources of aphid data (e.g. Potato Council (PCL) funded and British Beet Research Organisation (BBRO)) funded yellow water trapping and the Rothamsted/SASA suction trap network) into a potato virus risk assessment scheme and make recommendations on the optimum combination of data required to provide a cost effective risk assessment.

11.2. Approaches

1. Undertake statistical investigations of a subset of the available data from the Rothamsted/SASA suction traps (STs), the Fera yellow water traps (YWTs) and the Broom's Barn YWTs.
2. Derive relationships between YWTs and STs for *Myzus persicae* and *Metopolophium dirhodum* using STs from Broom's Barn, Askham Bryan and Dundee and YWTs within 100km of each of these traps.
3. Consider how this relationship and the variation between traps could be utilised in an integrated data delivery system.
4. Undertake an independent review of the current aphid data delivery systems (SASA and Rothamsted STs and the Fera/PCL YWTs) and make recommendations on future delivery mechanisms.
5. Consider what other sources of data could be utilised.
6. Consider how best to integrate these various sources into one delivery system
7. Make recommendations on how the integration of these data sources should be undertaken, what should be included and what further information is required before it can be delivered.

11.3. Caveat

1. For the purposes of this report, it has been assumed that the monitoring of aphid populations is an integral part of the risk assessment for virus transmission. Therefore the direct evaluation of the use of aphid data (as collected by any available means of monitoring) as a means of assessing the risk of virus transmission has been considered external to this report. The evaluation of aphid monitoring methodologies in relation to available information on virus transmission has been covered within a review commissioned by the BPC (Northing & Pickup, 2009). It is considered that the much of the work carried out within project R428 (Aphids and virus in seed potatoes) will provide valuable information that will allow improve any evaluation of the different methodologies for monitoring aphids in relation to virus risk. This will be reported upon in due course.
2. Further information from recent work carried out by SASA using aphid suction trap catches is available in an addendum to this report.

12. STATISTICAL INVESTIGATIONS OF TRAP CATCHES

12.1. Introduction

Two trapping technologies are used routinely for aphid monitoring in Great Britain for delivery of aphid data to the farming industry: suction traps (STs) and yellow water pan traps (YWTs). YWTs operated by Fera are used in support of the potato industry and those operated by Broom's Barn are used in support of the sugar beet industry. STs, run by Rothamsted Research and SASA, are used to record all aphid species and so are relevant to the potato crop. In some areas where seed potatoes are grown there are STs, Fera-maintained YWTs and Broom's Barn-maintained YWTs. Each of these has a level of bias inherent within it (e.g. aphid colour preference in the YWTs and typical flight height in the STs) and are currently utilised in different ways. It is possible that by synergising data from these systems, overall trapping effort could be reduced or enhanced information obtained. By examining the relationships between data from the different systems, an insight into how these data might be integrated in the future can be obtained.

12.1.1. Suction traps (STs)

A network of suction traps (Macaulay et al., 1988; Taylor, 1986; Harrington and Woiwod, 2007) has been operated in the UK since 1965. Currently 16 traps are emptied daily from March until November and weekly at other times. Samples from the 12 traps in England are sent to Rothamsted and those from the 4 traps in Scotland are sent to SASA. All aphids are identified to species (occasionally species group or genus). Samples 100km or more apart are strongly correlated (Taylor, 1979; Cocu et al., 2005) and the traps give a landscape-scale overview of what is flying (http://www.rothamsted.bbsrc.ac.uk/insect-survey/).

12.1.2. Yellow water pan traps (YWTs) Broom's Barn

Within a 100km radius of the ST at Broom's Barn 22 to 25 YWTs were operated during the beet-growing season each year between 2004 and 2009 (Figure. 2 shows 2009) and will continue in coming years. The traps (`FLORA' traps, Nickerson Brothers Ltd) are 26cm in diameter and 10cm deep, two thirds filled with water and a few drops of detergent. Three YWTs are set up in each field at least 15m apart and at least 15m from the field margin, and results totalled for each field. At the start of the season the YWTs are placed at ground level but they are gradually raised on stands as the plants grow, keeping them at crop height (eventually 60-70cm above ground). The YWTs are emptied twice a week on Mondays and Thursdays.

12.1.3. Yellow water pan traps (Fera)

The Potato Council has funded the analysis and delivery to industry of approximately 100 YWTs per year since 2004. These are located in seed potato fields and maintained by growers or their advisors. They are placed in the field at crop emergence, emptied on a weekly basis until haulm destruction and the contents sent to Fera for analysis each week. However, growers do not always have time to empty traps according to a regular weekly

schedule and the full season's trapping it not always managed. On average around 800 samples from 100 sites are analysed each year (Northing *et al*, 2003, Northing, 2009).

12.2. Materials and Methods

12.2.1. Analyses

In order to investigate the potential complementarity of the trap networks, three STs (Broom's Barn, Askham Bryan and Dundee) were selected on the basis that they had the most YWTs within 100km and represented southern and northern England, and Scotland. Two aphid species were selected. *Myzus persicae* is identified from all the YWTs and STs and is an important vector of potato viruses (both PLRV and PVY). *Metopolophium dirhodum* has been implicated in the spread of PVY, however, it is not identified from the Broom's Barn YWTs. Thus comparisons were made between ST and YWT samples from all three ST sites for *M. persicae* and from Dundee and Askham Bryan for *M. dirhodum.* For each comparison, separate analyses were done for YWTs at distances of 0-25km, 25-50km and 50-100km from the STs.

For each comparison, the number of aphids caught in the ST was summed for each day of each time span between emptying YWTs (usually approximately 7 days) for the seasons 2004 to 2009. Numbers of aphids were logged (base 10 n+1) and the data for STs regressed on data for YWTs. Thus for each ST there were several data points for YWTs according to how many of them were operating with the given distances from the STs for each time period. Similar analyses were done but using the arithmetic mean number of aphids in the YWTs for a given ST/distance/time period (again using log 10 n+1 of the mean), resulting in one YWT point corresponding to one ST point.

12.3. Results

Figure. 3 shows the relationship between the abundance of aphids in YWTs and STs for *Myzus persicae* and *Metopolophium dirhodum* for YWTs at different distances from STs. The correlation coefficients were highly significant ($P<0.001$) in all cases. However there was very large variability in the abundance in YWTs.

Figure. 4 shows the same relationship but for the log of the mean count in all YWTs. The relations are again highly significant ($P<0.001$).

Figure. 5 suggests that in each season (2004 as an example) the profile of each of the YWTs is broadly similar to the ST (i.e. approximating a bell curve) but that the maximum point of the curve varies greatly between traps.

FIGURE. 1. TWO TYPES OF APHID TRAP
A) SUCTION TRAP B) YELLOW WATER-PAN TRAP.

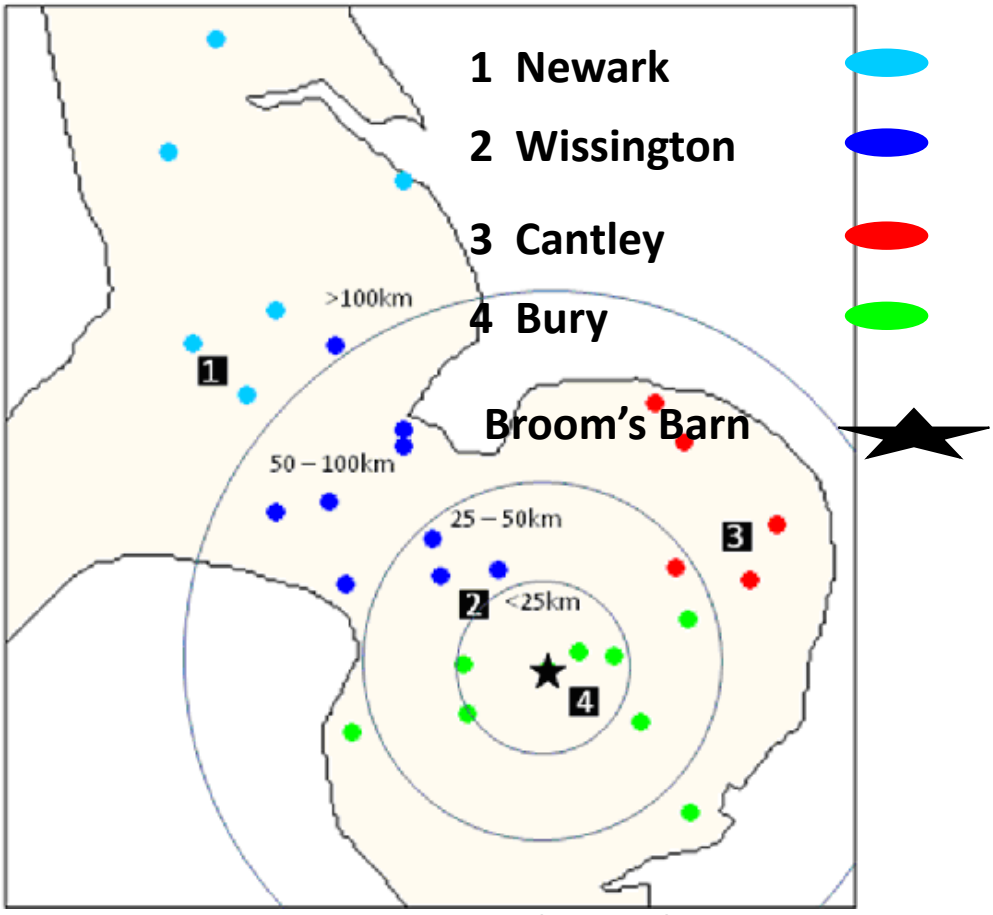


FIGURE. 2. LOCATION OF SUGAR BEET FACTORIES (NUMBERED) AND THEIR ASSOCIATED YELLOW WATER-PAN TRAP SITES 2009, WITH DISTANCES FROM BROOM'S BARN SUCTION TRAP

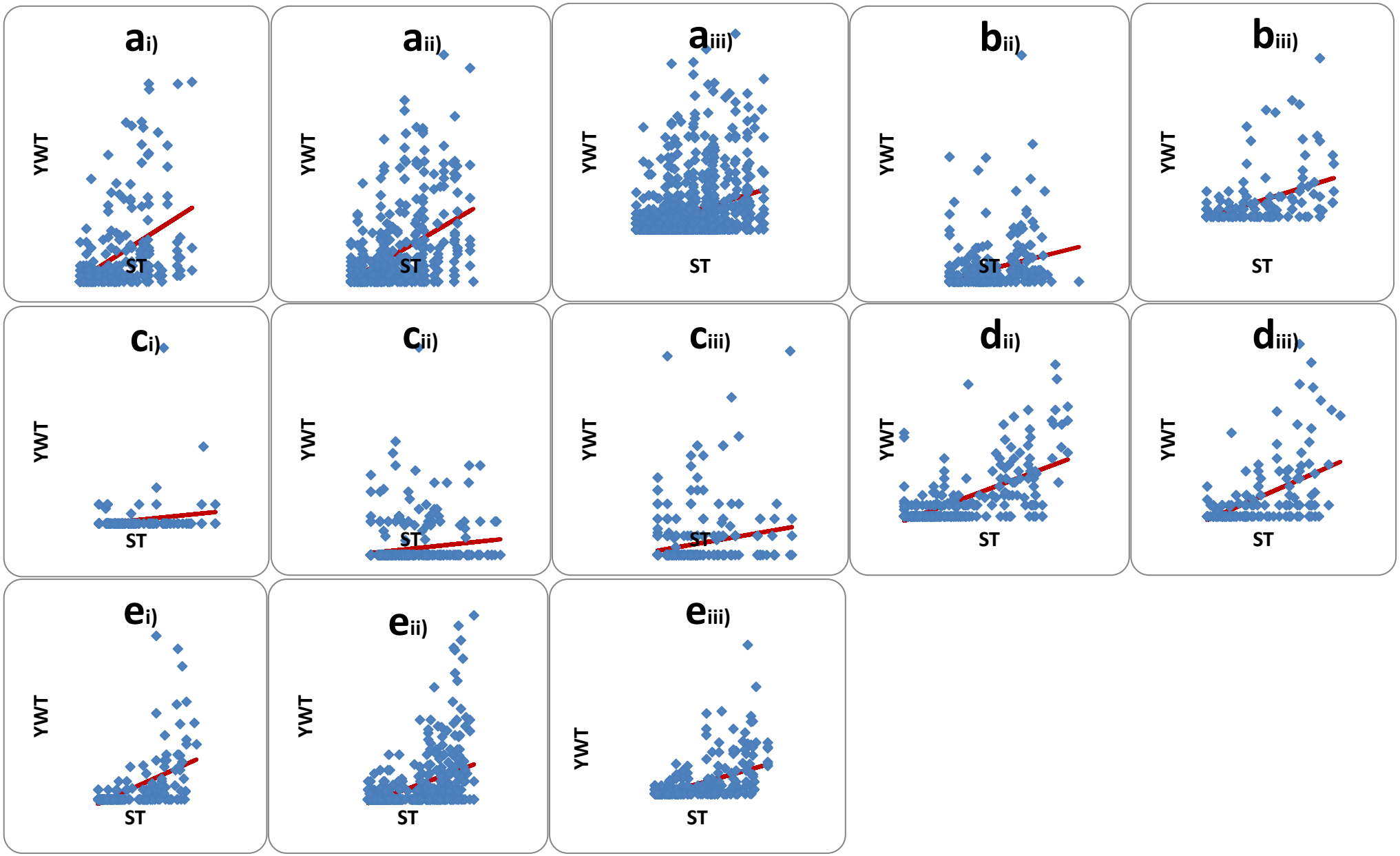


FIGURE. 3. NUMBERS OF APHIDS (LOG_{10} N+1) CAUGHT IN YELLOW WATER PAN TRAPS (YWT, ONE POINT FOR EACH YWT) VS NUMBERS CAUGHT IN SUCTION TRAPS (ST).

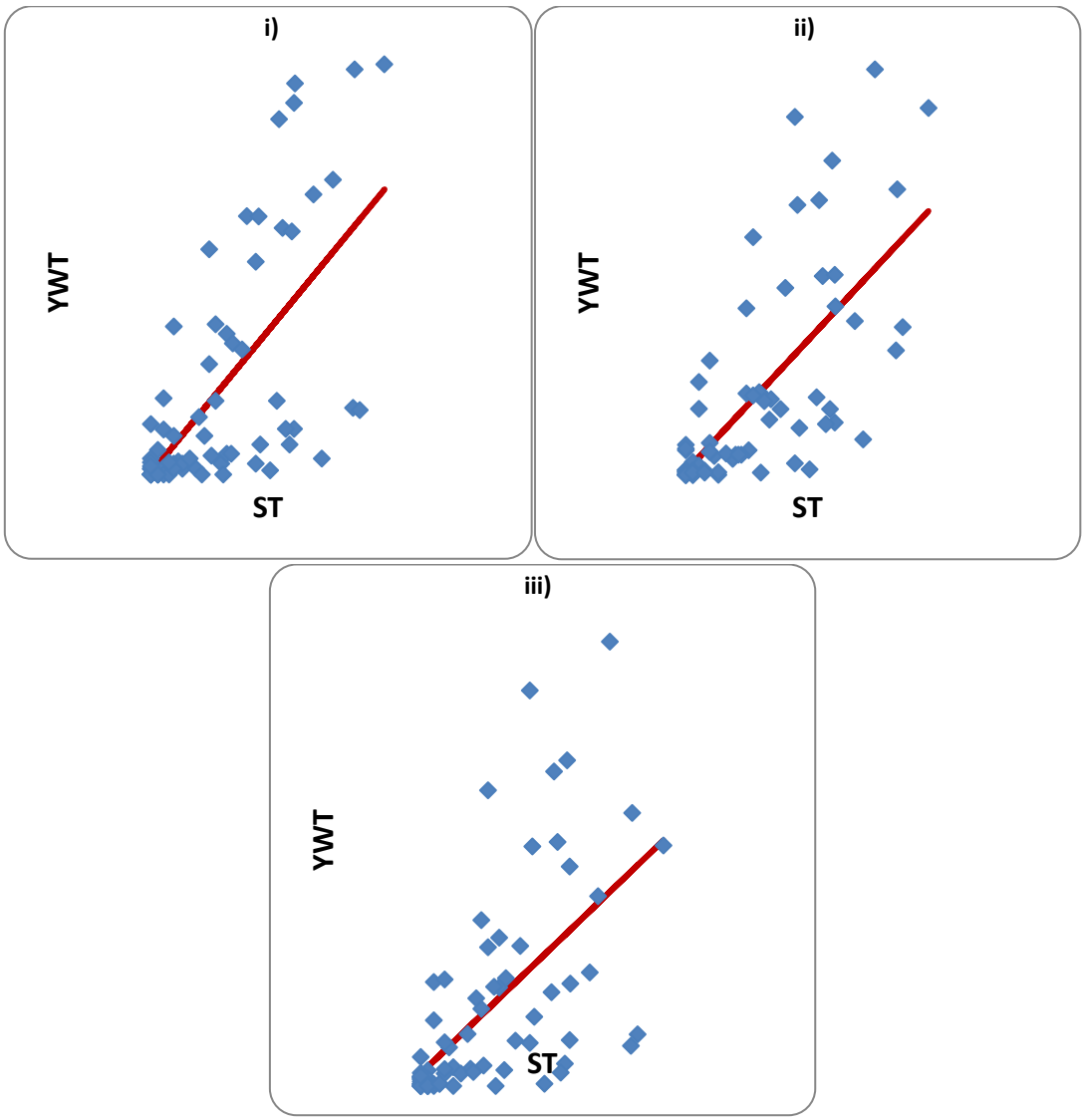
(Continued on next page)

Key

a) *M. persicae* at Broom's Barn
b) *M. persicae* at Askham Bryan (only 1 YWT 0-25km from ST and it caught only 1 *M. persicae*)
c) *M. persicae* at Dundee
d) *M. dirhodum* at Askham Bryan (only 1 YWT 0-25km from ST and it caught no *M. dirhodum*)
e) *M. dirhodum* at Dundee
i) YWTs 0-25km from ST
ii) YWTs 25-50km from ST
iii) YWTs 50-100km from ST

Statistical Table

	n	Intercept	Standard Error	Slope	Standard Error	Adjusted R Square	P-value
ai)	267	0.024	0.030	0.351	0.040	0.226	<0.001
aii)	550	0.020	0.019	0.339	0.024	0.268	<0.001
aiii)	1314	0.014	0.009	0.187	0.012	0.167	<0.001
bii)	332	0.025	0.018	0.194	0.034	0.087	<0.001
biii)	183	-0.006	0.019	0.268	0.038	0.211	<0.001
ci)	212	-0.001	0.004	0.046	0.015	0.036	<0.001
cii)	621	0.003	0.002	0.029	0.007	0.029	<0.01
ciii)	422	0.013	0.005	0.090	0.020	0.046	<0.001
di)	11	0.000	0.000	0.000	0.000	1.000	-
dii)	359	-0.023	0.008	0.133	0.008	0.421	<0.001
diii)	183	-0.019	0.016	0.127	0.015	0.275	<0.001
ei)	212	-0.025	0.012	0.100	0.011	0.290	<0.001
eii)	621	-0.022	0.007	0.087	0.006	0.236	<0.001
eiii)	422	-0.024	0.012	0.152	0.012	0.288	<0.001



(i) YWTs 0-25km from ST
(ii) YWTs 25-50km from ST
(iii) YWTs 50-100km from ST

Statistical Table

	n	Intercept	Standard Error	Slope	Standard Error	Adjusted R Square	P-value
i)	74	0.006	0.051	0.518	0.068	0.442	<0.001
ii)	74	0.013	0.043	0.475	0.056	0.489	<0.001
iii)	74	0.036	0.038	0.332	0.050	0.370	<0.001

FIGURE. 4. NUMBERS OF APHIDS (LOG_{10} N+1) CAUGHT IN YELLOW WATER PAN TRAPS (YWT, MEAN FOR ALL YWTS) VS NUMBERS CAUGHT IN BROOMS BARN SUCTION TRAP (ST).

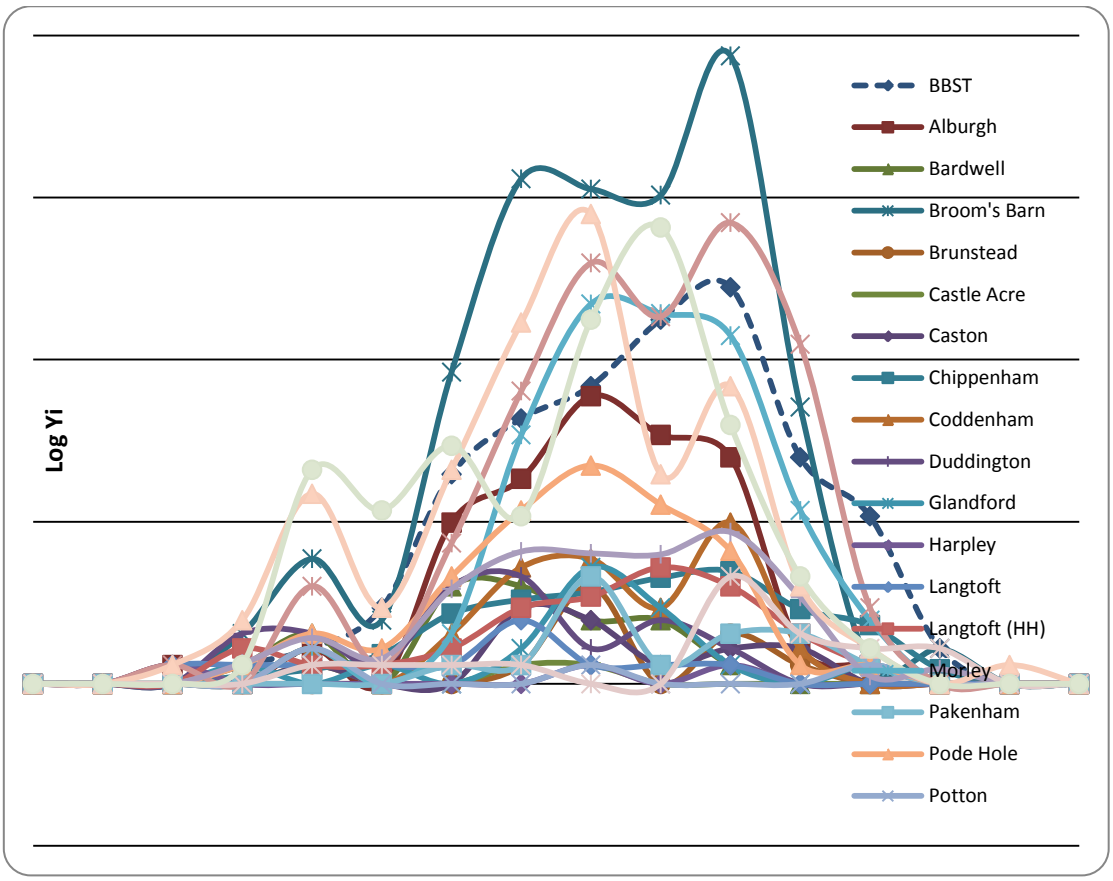


FIGURE. 5. NUMBERS OF APHIDS (LOG_{10} N+1) CAUGHT IN YELLOW WATER PAN TRAPS (AND BROOM'S BARN SUCTION TRAP) VS SAMPLING WEEK IN 2004.

12.4. Discussion

There is a significant positive linear relationship between the numbers of aphids caught in STs and numbers caught in YWTs up to at least 100km away. Several hundred curvilinear models were also tested but linear relationships were found to describe the data best. There was much variability in the number of aphids caught in YWTs at given distances from STs. This variability is likely related to field characteristics, a hypothesis reinforced by the fact that given YWTs tend to record relatively high numbers of aphids throughout the season whilst others tend to record consistently low numbers. However, between seasons, relative numbers in particular YWT locations are not consistent. This is probably because the fields used for YWTs on a particular farm (and hence with the same location identifier) vary between years and each field is likely to have different characteristics such as crop sowing date, field size, slope, aspect, surrounding vegetation, neighbouring crops. For example, work on vectors of *Barley yellow dwarf virus* in cereals (Foster et al., 2004) showed that field characteristics could potentially be used to link ST data to risk of BYDV in individual fields, and it would seem worthwhile investigating whether this can be achieved for aphids and virus in potatoes. Some field characteristics data are already available for the Broom's Barn YWTs from 2004 to present. Even when mean aphid data for the different YWTs within a certain distance of an ST were plotted against aphid data for STs, the scatter around the linear relationship was large and hence

the variance accounted for fairly low. It is important to determine whether the variance accounted for can be increased as a result of incorporating data on field characteristics.
If it is assumed that the STs provide a consistent approximation of the regional patterns of aphid flight, we can utilise these relationships to put the field specific YWT catches into a more regional context. For example, figure 6 shows a portion of figure 2(aii) with 4 new YWT samples (in yellow). Clearly, in this situation, the limited number of samples does not encompass the full scope of the possible trap catches in the region. In the current PCL system, these 4 points would be presented on a map with a colour denoting their weekly risk index. A future system should also do this, include the suction trap data and highlight how these trap catches fit into the historical risk for that particular region given the approximate level of ST catch, for example, by providing a graphic similar to figure 6.

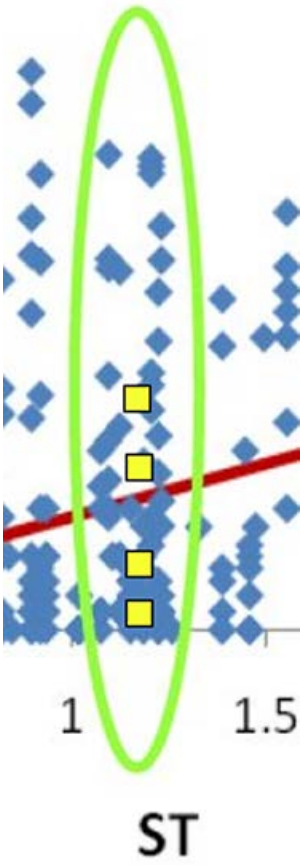


FIGURE 6: EXAMPLE OF HOW CURRENT INDIVIDUAL YWT DATA COULD BE VISUALISED IN THE CONTEXT OF THE WHOLE REGION.

The way these data are provided should be developed in consultation with industry, as they need to be provided in an easily understandable and accessible format with clear information about what can and can't be intimated from them.

So far, relationships between ST and YWT aphid samples have only been examined for two aphid species. *Myzus persicae* is known to be a highly efficient vector of potato viruses and *Metopolophium dirhodum* has been implicated as an important vector of PVY in Scotland. There is the potential to

look in a similar way at a number of other vector species and ST site combinations. In order for these relationships to be presented in terms of virus risk indices rather than individual aphid species they will need to be amalgamated into one overall relationship for each region.

There is clearly much scope for synergising the information obtained from the different monitoring systems, even though this is complicated by funding issues. In addition to the points discussed above, it would be useful if, instead of throwing all the aphids from the Broom's Barn YWT other than *M. persicae* away, they could be sent to Fera for identification as part of the PCL monitoring scheme. Furthermore, *M. persicae* from some of the STs are tested for their insecticide resistance status. These data would be of direct use to the potato industry but, because the work is funded by the BBRO, only reach the sugar beet industry. Pragmatic solutions to these problems could improve the service provided to both sectors. In turn a more pragmatic approach to service delivery could also expand the range and use of these valuable data for use by the field vegetable sector, as well as other sectors with a clear aphid vector-virus relationship.

13. REVIEW OF APHID DATA DELIVERY SYSTEMS

13.1. Introduction

As part of the current Potato Council project with Fera, Rothamsted and SASA, I (Professor Bill Hutchison from the University of Minnesota) was asked to provide an independent review of the existing web sites developed to assist potato growers and crop advisors with timely aphid and virus management.

Each of the existing web sites has many strengths, in large part due to their use of real-time data collections of numerous aphid species, and an emphasis on those species that are the most efficient vectors of economically damaging viruses (particularly PVY).

13.2. Current Web Sites and Overview

13.2.1. Food and Environment Research Agency (Fera): Aphid Monitoring

URL: http://aphmon.csl.gov.uk/levy/

This is the delivery system for the trap catches from the 100 sites that the Potato Council fund. The results are added to a database on a daily basis, which automatically updates this dedicated website, and are sent via email/fax to the grower. The results from over 98% of samples are reported on the day the sample arrives at Fera. The website reports all aphids found in a sample and uses relative vector efficiency factors (RVEF) to provide a risk index for PVY which increases cumulatively over time.

Users of the service can also sign up to receive e-mail and SMS alerts when Peach–potato aphids are first found in their region or when aphid catches in any trap in their region exceed a weekly threshold. Comparative information with previous seasons is also available. This website is restricted to those who already have access to the PCL website (i.e. Potato Council levy payers and corporate members).

The PCL has produced a poster that helps users understand what the results do and do not take into account, providing a basis for considering these results within the rest of their decision making processes.

13.2.2. Aphid Bulletin, Rothamsted Insect Survey (RIS)

URL: http://www.rothamsted.ac.uk/insect-survey/STAphidBulletin.php

This web site is based on data from the network of sixteen suction traps and is designed to provide up to date news on the distribution and abundance of pest aphids at a regional scale. Each trap is representative of what is flying over an area of radius approximately 80 km, but there is considerable local variation in aphid density at ground level. The data are used for fundamental studies on factors affecting the dynamics of aphid populations and to provide

sponsors with information that aids aphid control decisions. The bulletins provide counts of 20 important aphid species (including the significant PVY vector species) across a week and are released weekly from around the beginning of April to the end of November. This website is not restricted to specific users, but tailor-made interpretative bulletins are issued to industry sector sponsors. A forecast of the first date of capture of important pest aphids and of numbers caught in late spring and early summer is issued to industry sponsors in early March on the basis of relationships with temperature in January and February.

13.2.3. SASA

URL: http://www.sasa.gov.uk/seed_potatoes/aphids/index.cfm

This web site is based on data from the four Scottish suction traps that contribute to the sixteen of the RIS. The bulletin is released on a weekly basis and details all aphids trapped. This is also a wider information provision system and incorporates predictions of the 1st flight of *Myzus persicae* and *Macrosiphum euphorbiae* at the Edinburgh and Dundee traps, cumulative vector pressures utilising RVEFs and comparisons with historical data. This website is not restricted to specific users.

13.2.4. Potato Council

URL: http://www.potato.org.uk/ (home page; without obvious connect to Aphid Survey Results)
URL:
http://www.potato.org.uk/department/knowledge_transfer/aphid_monitoring/index.html?menu_pos=knowledge_transfer
(via: “Knowledge Transfer,” Aphid Survey Link)

The Potato Council website provides a hub for both levy payers and the public to find detail on the PCL’s activities and current issues for the potato industry.

13.3. Common Objectives Relevant to Growers and Crop Advisors

With an overall goal to support producers of potatoes and other crops (small grains, sugar beet), and the consultants (agronomists) who advise growers, particularly the seed-potato growers, there are several common goals implied or clearly defined by the web sites, including:

- Near real-time aphid trap catch data during the growing season, whether it be Suction Trap (ST) or Yellow Water-pan Trap (YWT) data.
- The Fera and SASA sites, tailored to the potato industry, also integrate weekly aphid catches with virus vector efficiencies (e.g., PVY) to provide a weighted aphid/virus risk measure for growers and agronomists.
- Additional resource information is available that provides more in-depth publications and “fact sheets” on production practices and overviews of the

major virus pathogens (e.g., SASA, Potato Council), as well as detailed “fact sheets” on all major aphid species (e.g., Rothamsted, RIS).

13.4. Recommendations for Further Integration and Improvements

The current web sites have their unique strengths, with the information tailored to specific audiences. After reviewing these sites, and given the needs of potato producers (seed, and general producers), I offer some ideas for future development and enhancement of the existing web sites.

13.4.1. "One-stop-shop" Potato Home Page

The three groups most involved in aphid pest monitoring, and working directly with potato growers (Fera, SASA, Rothamsted) should consider seeking funding to pool further their efforts, to develop a "One-stop-shop" site, where all key players in the industry can go to locate similar information. For example, this could include a "clickable map" home page, similar to what we use in the Midwest U.S. (www.vegedge.umn.edu), where one can view newsletters from all surrounding states (production regions). This page should have a clean design, easy to navigate for growers and agronomists, and then link to specific Fera, SASA and RIS pages, where appropriate. A central home page might also be preferable to the Potato Council, as they can then maintain one link for all aphid and virus IPM information. Another very basic, yet functional, example of a central page approach, in use with co-operators from many states in the U.S., is the ZEAMAP page, for flight monitoring, migration forecasting and resistance monitoring data, for the corn earworm (*Helicoverpa zea*) (see: http://www.vegedge.umn.edu/ZeaMap/zeamap.htm).

13.4.2. Direct Coupling of RIS Suction Trap to Yellow Water Trap Networks

Given the results of the recent correlation analysis of ST and YWT data for *M. persicae* (Harrington et al. 2010) and reported above, the weekly RIS Aphid Bulletin could be expanded (e.g., beyond the Cereal Newsletter) to include a brief "Potato Aphid News," that for *M. persicae*, would reflect a "Phase I" Early Warning (e.g., when *M. persicae* is ≥3/week/ST), with instructions for users to watch closely YWTs in specific regions (and alerts early season to be sure YWTs are operational).

Once the user is looking at this link on the central home page, it would then be easy to navigate to Phase II, warnings about specific 'hot spots' based on YWT data. The weekly integration of multiple aphid species counts, coupled with vector efficiencies (e.g., on Fera site), use a good combination of graphical interface (clickable map), and easy-to-read tables of aphid-vector risk, that provide a foundation for further improvements.

The existing clickable maps on the Fera site, with colour-coded (Red, Yellow, Green, reflecting, high, medium, and low risk, respectively) for aphid catch, are excellent. If not already included for all SASA locations, the same Aphid Risk Index, weighted for aphid species and vector efficiencies, should be used for the English and Scottish locations (again, the same index would be best

for consistency; however, in Scotland, with a high percentage of seed potatoes, the risk may have to be adjusted, to being more conservative).

13.4.3. Introduce or Expand the use of Geospatial ("contour") Aphid Maps

Although not necessary on a weekly basis, the development of region-wide Aphid Maps, showing "hot spots" relative to low-density areas, using basic GIS or contour (isocline) graphics can further enhance the web sites. For example, following the peak of *M. persicae*, a Cumulative Aphid Map, from ST or YWTs, for each major potato production region could be added to the web site. This would quickly give growers a better idea of the extent of aphid risk, and/or weighted vector/virus risk. If time permitted, 4-5 such maps could be linked together, to show the animation of population change over 4-5 weeks, respectively. A good example of such maps was provided by Mark Stevens, based on 2008 data for the Broom's Barn region.

13.4.4. Audience Interaction, Dialogue

The addition of an Email contact to the home page, for questions, adds a personal, interactive component. This depends on current staff, and budget capability.

13.4.5. Video

Consider having your colleagues assist in filming brief videos (e.g., 5-10 min), in the field, how to set up YWTs, what is counted, what's not, etc. Or, for example, an interview with Jon Pickup, regarding how these data can be used to reduce grower risk, etc. These could be updated, or added as needed given changes in aphid insecticide resistance, new potato varieties, or new IPM technologies, to keep the web presence fresh and educational. One example of a recent popular IPM video in the U.S. was developed and placed on You-Tube for ease of access, and compatibility on nearly all personal computers (see, Cullen, 2009; Western bean cutworm IPM, Univ. of Wisconsin).

13.4.6. Mobile Access-Smart Phones

The use of Smart phones with "mobile access" web sites, and "apps" (I-Phone®) are increasingly being used worldwide. Such applications are intriguing and will likely show utility, if a high percentage of the target audience (growers and particularly farm advisors), are using these phones in the UK. Unless, the IPhone is readily used in the UK, I am not currently proposing an IPhone App, as these are specific to the IPhone. However, mobile access web sites are available for downloading and viewing web sites that have been scaled appropriately for smart phones. Thus, existing web sites can be viewed, without the need to develop a new app. Estimates for IPhone Apps and Mobile Access web sites (a modification of an existing web site), were recently estimated at $15,000 and $10,000 (U.S.$; private marketing firm), respectively, for the *VegEdge* site at the University of Minnesota.

13.4.7. Aphid and Virus Pest "Profiles"

The RIS site includes an excellent series of Aphid Pest "fact sheets" or Pest Profiles that could be featured on the central web page, for users who seek more detailed information about a given aphid species or complex. The focus of the fact sheets should primarily be limited to the most recent information on the biology and ecology of each pest, as this information does not need to be updated frequently. Information about IPM and management recommendations would be provided elsewhere on the web site. Existing fact sheets may need to be reviewed and updated. New fact sheets, particularly for specific viruses and/or a virus complex, should also be added.

In summary, the existing web sites all have their advantages in terms of unique information that is useful to potato growers and farm advisors. However, all of the information may not be readily apparent to these audiences. The proposal for a "One Stop Shop", fully integrated web site, might be a key step forward to make the aphid/virus IPM information more easily, and rapidly accessible. All new ideas of course should be gauged by those active with the industry, and will be dependent upon future budget opportunities. Finally, prior to moving forward, it may be time to conduct a brief survey of growers and farm advisors, to assess objectively their needs about improvements to the existing web sites, and the information they require. Such surveys could be handed out at annual potato meetings, with the audience given the time to fill these out at the meeting, and thus ensure a high response rate and rapid turnaround time. Moreover, by conducting the survey at one or more grower/agronomist meetings, time could be scheduled for a follow-up discussion as a large group or smaller focus groups depending on the time available. Verbal feedback from the target audience may provide additional perspectives not gained from written surveys only.

14. RECOMMENDATIONS

Brackets after each recommendation detail i) season in which results become usable and ii) relative resource required to achieve this (Low = <£2.5k; Medium = <£30k; High > 30k).

1) Examine the relationship between aphid numbers in STs and YWTs for a broader range of vector species and trap sites to ensure that there is a usable relationship in each region for overall vector aphid pressure between the two trapping methods. (2011, Medium)

2) Discuss with industry how to utilise effectively this information. (2011, Low)

3) Examine the relationship between numbers of aphids in YWTs and field characteristics, and the potential for using this to make ST samples relevant to individual fields rather than large regions. (2012, Medium).

4) Pass unused aphids from carefully targeted Broom's Barn YWTs to Fera for inclusion in the PCL aphid monitoring scheme. (2010, Low).

5) Pass data on insecticide resistance in *Myzus persicae* to Fera for inclusion in the PCL aphid monitoring scheme. (2010, Low).

6) Produce a single website to unite aphid and virus data from a range of sources for a range of industry sectors. (2011, Medium or high depending upon the scope).

7) In conjunction with industry, investigate other methods of interpretation and communication of relevant information. (2011, Medium (for implementation of investigation recommendations)).

All this would entail excellent collaboration between interested levy boards, other industry users and research organisations.

15. REFERENCES

Cocu, N., Harrington, R., Hullé, M. and Rounsevell, M.D.A. (2005) Spatial autocorrelation as a tool for identifying the geographical patterns of aphid abundance. *Agricultural and Forest Entomology* 7, 31-43.

Cullen, E. 2009. Western bean cutworm, University of Wisconsin-Madison; On-line:
http://www.youtube.com/watch?v=PAT2d_S6QwY (accessed, 10-02-2010)

Foster, G.N., Blake, S., Tones, S.J., Barker, I. and Harrington, R. (2004) Occurrence of barley yellow dwarf virus in autumn-sown cereal crops in the United Kingdom in relation to field characteristics. *Pest Management Science* 60, 113-125.

Harrington, R. and Woiwod, I. (2007) Foresight from hindsight: the Rothamsted Insect Survey. *Outlooks on Pest Management* February 2007, 9-14.

Harrington, R., Stevens, M., Mallott, M., Taylor, M., Hallsworth, P. and Hutchinson, W. (2010) There's more than one way to skin an aphid. *British Sugar Beet Review* in press.

Macaulay, E.D.M., Tatchell, G.M. and Taylor, L.R. (1988) The Rothamsted Insect Survey 12-metre suction trap. *Bulletin of Entomological Research* 78, 121-129.

Northing, P, Walters, KFA, Barker, I and King, L. (2004) Crop Specific Virus Risk Assessment: A cost effective management tool for the seed potato growing industry. *Proceedings Crop Protection in Northern Britain 2004* 297-302.

Northing, P and Pickup, J. (2009). A Review of Aphids and Virus Transmission in Seed Potato Crops. Report for the Potato Council.

Northing, P. (2009). Extensive field based aphid monitoring as an information tool for the UK seed potato industry. *Aspects of Applied Biology* **94**, 31-34.

Taylor, L.R. (1979) The Rothamsted Insect Survey – an approach to the theory and practice of synoptic pest forecasting in agriculture. *Movement of Highly Mobile Insects: Concepts and Methodology in Research* (ed. by R.L. Rabb and G.G. Kennedy), pp. 148-185. University Graphics, Raleigh, North Carolina.

Taylor, L.R. (1986) Synoptic dynamics, migration and the Rothamsted Insect Survey. *Journal of Animal Ecology* 55, 1-38.