APHIDS AND VIRUS MANAGEMENT IN POTATOES

Q&A SUMMARY PUBLISHED FEBRUARY 2020

VIRUSES

- The main virus species in GB potato crops is currently Potato Virus Y (PVY)
- There are different strains and variants of PVY (e.g., PVY^{O}, PVY^{C}, PVY^{N}, PVY^{NTN}). These reflect differences that can be detected primarily according to their biology (e.g., the symptoms they cause), antibody-based detection methods like ELISA and using molecular techniques. More than one method is often needed to identify the viruses.
- It is generally accepted that isolates of the PVY^{N} strain group cause milder mosaic symptoms on most potato cultivars than isolates of the PVY^{O} strain group.

SYMPTOMS

- Primary infection occurs in the growing season and is aphid-borne. Secondary infection is tuber-borne.
- Symptoms of primary infection can sometimes be seen but this probably varies with the variety, environment/season and timing of infection. Diseased (symptomatic) plants are generally the result of secondary transmission from infected tubers.
- Symptoms include chlorotic mosaics in the haulm with possible pallor, leaf deformation, reduced leaflet size and overall reduction in vigour. Susceptible varieties could also produce smaller tubers.
- Mixed infections are when a plant is infected by different virus species and this generates more severe symptoms (i.e. severe mosaic, stunting).

ROLE OF APHIDS

- PVY is a non-persistent virus. Aphids pick up and spread the virus quickly (i.e. less than a minute of contact on the plant).
- The Peach-potato aphid, *Myzus persicae,* is considered the most efficient vector of PVY (i.e. it is more effective at transmitting PVY between potato plants than other aphid species). Winged forms of non-potato aphids such as cereal aphids can also be important in spreading the virus.
- The relative importance of the different aphids depends upon the respective abundances of colonizing aphids (e.g., *M. persicae*) within the crop and non-colonizing aphids (e.g., cereal aphids, Willow-carrot aphid) visiting the crop.
- Aphids are not believed to carry PVY over long distances and therefore the most likely sources of virus are the input seed and/or neighbouring potato crops and groundkeepers that are already infected with virus.
- Information on aphid flights is available via the suction trap network reported in AHDB Aphid News and from yellow water traps reported by Fera on behalf of AHDB.

- Suction traps give a regional indication of aphid flights. Field traps, like the yellow water traps, tell you what is moving on a local scale.

- Winged aphids tend not to be active below~10^{o}C.

VIRUS TESTING METHODS

- Direct tuber molecular tests and growing-on ELISA tests can both be used to detect PVY and other virus species in tubers.

- The two tests use different tissues from different parts of the tuber and so there will be variability related to virus distribution in the dormant tuber especially in plants infected during the growing season, but overall, they give comparable results.

- National List testing of potato varieties reports a resistance rating (1-9 scale) associated with the proportion of daughter tubers that are infected with viruses. It doesn't report symptom expression/yield loss.

- Variety propensity values are based on symptoms seen in Scottish seed crops during inspection. Values greater than 1 indicate that symptoms are more likely to be found in that variety and values less than 1 indicate that they are less likely to be found in that variety.

MANAGEMENT

- The elimination of sources of virus inoculum, such as groundkeepers, is very important. (e.g., every 300-400 infected tubers per ha equates to an equivalent additional 1% increase in seed infection).

- Quick acting insecticides (pyrethroids, flonicamid, acetamiprid) would be preferred to slow acquisition of PVY from any infected plants and hinder flights to neighbouring non-infected plants.

- Some aphids (*M. persicae*, *Sitobion avenae* [Grain aphid]) that spread PVY are known to be resistant to pyrethroids.

- Mineral oils are used in mainland Europe/Canada to reduce virus transmission. They may be adjuvants to be applied with plant protection products (PPP) or in some cases paraffin oils are registered as PPP themselves.

- The mechanism of action of oils is not fully understood but it's possible that oil on the aphid mouthparts reduces the acquisition and/or retention of PVY by the aphids.

- The number or frequency of mineral oil applications seem to be more important than the rate of each application. Overseas the focus is on the frequency of applications on young plants to protect leaves that are constantly developing.

- Field trials carried out in GB indicated that mineral oils can reduce virus transmission (up to a 2-fold (50%) reduction in the best-case scenario), but under high infectivity pressure (vector and virus source) may not always provide the necessary levels of prevention of virus infection for certified seed crops.

- Historically mature plant resistance (MPR) was considered to come into effect ~4 weeks after emergence and result in fewer infected daughter tubers/less yield loss in plants infected later in the growing season. It is known that the strain of virus is important and recent unpublished work indicates that although MPR still applies when a plant is infected with PVY^{O}, it can be less efficient when a plant is infected with variants of PVY^{NTN}. Other aspects such as varietal differences in MPR onset have been reported.

- MPR is still a tool in virus management in GB. However, given the nature of PVY strains that are currently the most common and their ability to infect daughter tubers late in the season, early haulm destruction and control of aphids all through the growing season are also important management options.

APHIDS AND VIRUS MANAGEMENT IN POTATOES

Q&A DETAILS

TYPES OF VIRUS TRANSMITTED BY APHIDS

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). This distinction is important in determining how long it takes an aphid to acquire the virus from an infected host plant and transmit it on to another plant. This in turn has an impact on which aphids can transmit the virus and how to manage them using insecticides or other means.

Persistent virus

The virus is picked up by potato colonising aphids during prolonged feeding (~12 hours) on an infected plant. Once an aphid acquires the virus it is infective for life. The peach-potato aphid (*Myzus persicae*) is regarded as the most efficient vector (i.e it is most efficient at transmitting the virus from one plant to another)

Non-persistent virus

Aphids can pick up and spread PVY very quickly (no prolonged feeding period is required). This means that non-colonising aphid species can transmit PVY. These include Willow-carrot aphid and cereal aphids that do not fulfil their life cycle on potato but do alight on potato plants and probe the leaves. For these aphids, it is the alatae (winged forms) that are the vectors. Laboratory methods have been used to compare the ability of different aphid species to transmit PVY and the results are taken into account in the aphid monitoring scheme (see below).

Non-persistent viruses in potatoes: different strains and names

In virology, strains of virus are members of a virus species with differing but distinct characteristics. Traditionally these have been based on biological (e.g., symptoms on a range of plant species) or biochemical properties (antibody/coat protein specificity as used in ELISA tests). More recently with advances in molecular biology (genome sequencing) subgroups have been identified based on differences at the molecular level. The different approaches

have resulted in different strains and strain variants being identified and referred to, often with different abbreviations/subscripts. In some cases, differences that can be distinguished at the molecular level aren't picked up using other techniques (e.g., antibodies used in ELISA tests). The table below gives an indication of the complexity involved.

Table 1. PVY strains and variants and their characteristics**.**

ABBREVIATION OFTEN USED	DEFINITION	SEROTYPE (ANTIBODY-BASED TEST [ELISA])
PVY Strain		
PVY^{o} PVY^{C}	PVY Ordinary (PVY^{O}) and C (PVY^{C}) strain group. PVY^{O} is more commonly found affecting potato in the UK compared to PVY^{C} which is rarely found affecting UK potatoes.	$PVY^{O/C}$
PVY^{N}	PVY^{N} Tobacco veinal Necrosis strain induces a necrotic reaction on tobacco.	PVY^{N}
$PVY^{N\text{-}Wilga}$	PVY^{N} isolates originally detected in potato cultivar Wilga. This strain has a coat protein similar to PVY^{O} but induces a necrotic reaction on tobacco.	$PVY^{O/C}$
PVY^{NTN}	PVY^{N} isolates able to cause Potato Tuber Necrotic Ringspot Disease. PVY^{NTN} is an heterogenous group of genetically related variants.	PVY^{N}
PVY Strain Variants		
$PVY^{NA\text{-}NTN}$ $PVY^{EU\text{-}NTN}$	PVY^{NTN} isolates able to cause Potato Tuber Necrotic Ringspot Disease that are genetically related originally defined as North American ($PVY^{NA\text{-}NTN}$) and European ($PVY^{EU\text{-}NTN}$) species. Both species are found in every potato growing area.	PVY^{N}

Other strains are known, such as PVY^{E} and PVY^{Z}, but are not routinely diagnosed by laboratories in GB. As diagnostic technology continues to develop it is likely that further strains will be reported.

What are the main viruses found in potatoes in GB and are the prevalent strains changing?

PVY remains the most prevalent virus although in some varieties PVA remains a concern. In terms of strains, there is information collected in Scotland but not England and Wales. Overall, it's believed that the EU-NTN type of PVY is most common.

VIRUS DETECTION/TEST METHODS

There are different approaches to virus assessment. Samples of tubers can be tested directly using a molecular test based on the polymerase chain reaction (real-time PCR methods often termed qPCR). Alternatively, plants are grown from the tuber sample and sap from the leaves

of each test plant is tested using an antibody- based technique (ELISA). The latter has a longer turn-around time as breaking dormancy, growing plants and testing usually takes 4-6 weeks. The direct tuber testing of a single crop sample usually requires ~ 2-5 days.

Do the direct tuber testing and growing-on tests give the same result or is one more/less sensitive?

The two tests use different tissues from different parts of the tuber and so there will be variability related to virus distribution in the dormant tuber, especially in tubers from plants infected late during the growing season (late primary infections). Overall, they should give comparable results.

Technically, the ELISA test is less sensitive in terms of analytical sensitivity (compared to the molecular technique) but the growing on of the tissue results in an amplification of the virus in the growing plant, resulting in an increase of the virus level, compensating for the inherent differences in sensitivity between the two tests.

Does it matter when direct tuber tests are done?

Early work suggested that the type of molecular techniques used initially (conventional PCR) dropped off in efficiency up to 20 weeks, but this is not something seen by the labs now. Based on current information it is thought that growing-on and direct tuber testing qPCR are relatively comparable when they have been done side by side throughout the off-season.

Where can I get tubers virus tested?

NIAB - NIAB Potato Disease Testing
Fera - https://www.fera.co.uk/crop-health/plant-clinic
SASA -https://www.sasa.gov.uk/diagnostics/virus-testing

How do we interpret test results?

Commercial testing labs will be able to provide more information about the test results. The information below is provided courtesy of Fera and refers to a 100 tuber sample where, 25 sub-samples (of four tubers each [referred to as bulks]) are tested for virus.

Software is used to give a mean calculated result (% virus). It assumes that if a number of bulks are tested, and only a few of these are positive, then in each of those positive bulks there will only be a low number of positive tubers. As the number of positive bulks increases it is assumed that a greater number of individual tubers in each bulk are also positive.

If 0 bulks out of 25 are positive, then there is 95% confidence that the stock has less than 4% virus. If 24 out of 25 bulks are positive, the value will be estimated as 55% virus content (with lower and upper confidence intervals of 32% and 82%, respectively. This is shown in the graph below:

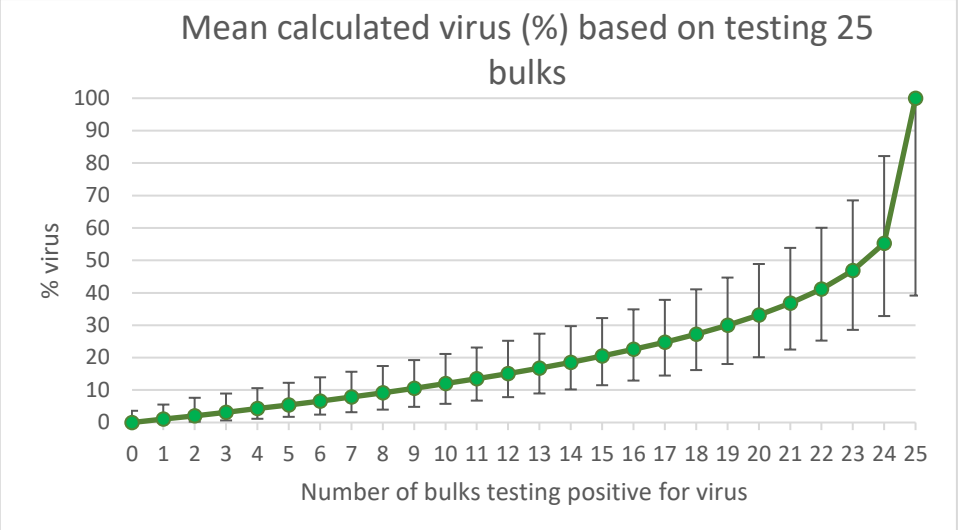

Fig. 1. Calculated % virus based on the number of bulks (out of 25) testing positive for virus.

How do % virus values translate into effects on yield and quality?

This will vary with virus strain, potato variety and whether infection is primary or secondary. There isn't much information publicly available for GB varieties. A review from 2007 quoted that estimated yield losses of 10-15% would be anticipated if the incidence of PVY-infected seed tubers was 30% (in Spain). Unpublished work from Switzerland suggests a mean figure of just over 0.2 t/ha per % virus infection, but the varieties studied my not reflect those grown in GB or the PVY strains that predominate here. A similar figure (~ 0.18t/ha in each variety) was reported from North America for secondary infections of PVY in Russet Burbank, Russet Norkotah and Shepody.

SYMPTOMS

What sort of symptoms would I expect to see in (a) haulm and (b) tubers if my crop had PVY?

There will be a range of symptoms from almost asymptomatic through mild to severe chlorotic mosaics in the haulm with possible pallor, leaf deformation, reduced leaflet size and overall reduction in vigour. This will depend on the PVY strain and the potato variety.

Susceptible varieties could produce smaller tubers. The most obvious tuber symptom associated with potato viruses is Potato Tuber Necrotic Ring Disease associated with infection of susceptible varieties with PVY^{NTN} type isolates. Work at SASA also correlated the presence of mosaic symptoms in haulms with the presence of tuber cracking. However, tuber cracking (also known as "elephant hide") can also be caused by the fungus *Rhizoctonia solani* and other stresses that affect the development of the plant such as drought stress.

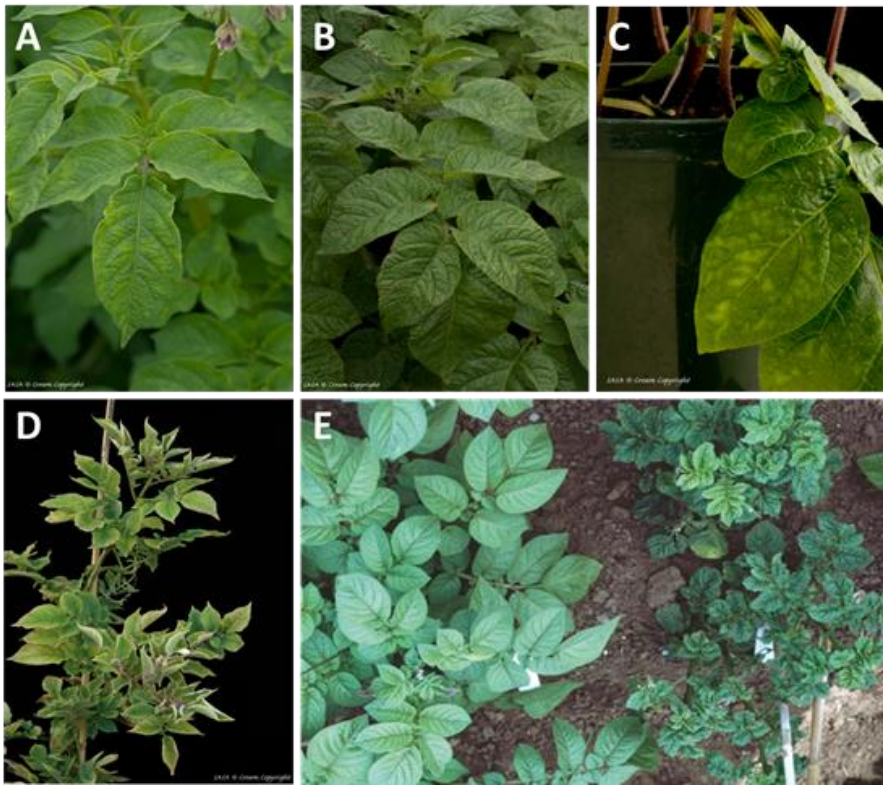

Fig. 2. Potato plants displaying mild mosaic symptoms (A, B, C), leaf roll symptoms (D), severe mosaic and stunting (E).

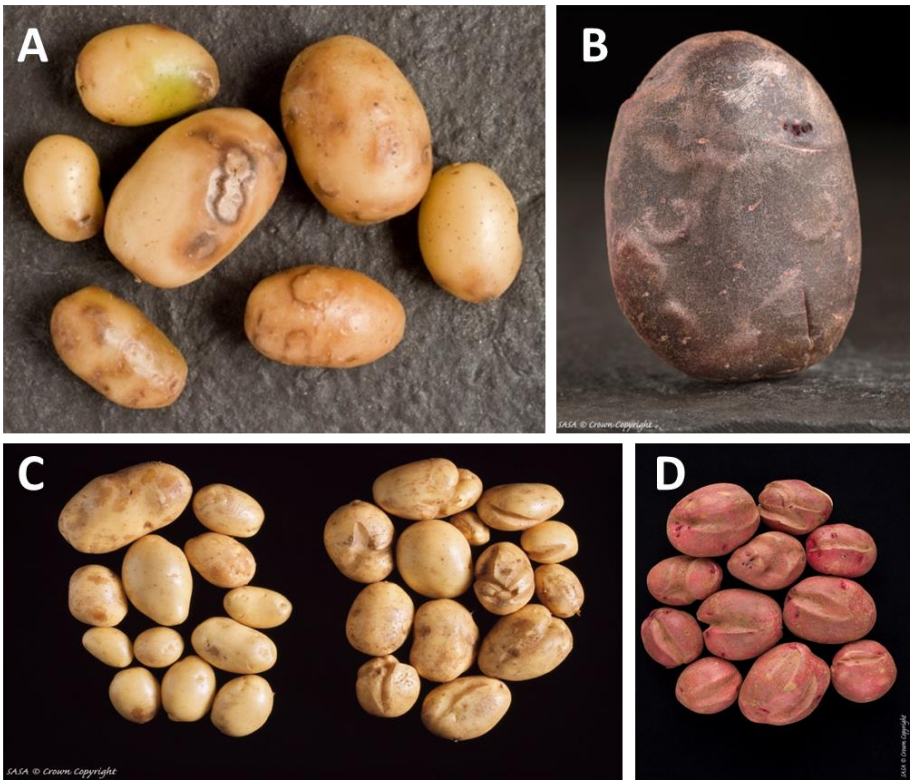

Fig. 3. Potato tubers displaying potato tuber necrotic ringspot disease (PTNRD) symptoms (A, B), growth cracking symptoms (C, D).

Do we see symptoms of primary infection in crops?

(Primary infection occurs in the growing season and is aphid-borne. Secondary infection is tuber-borne). Conventional wisdom says that the virus you see this year was spread last year, though in years with early transmission, it is possible that virus could be seen in the year of infection (i.e. primary infection) and there is some anecdotal evidence to support this.

Are any particular varieties more susceptible than others?

National List (NL) testing includes assessments of variety susceptibility to $PVY^{O/C}$, PVY^{N}, PVA and PLRV. Infected tubers are used to introduce virus inoculum into the trial plots that are planted with virus-free tubers of test varieties as well as known resistant and susceptible control varieties. The amount of virus infection in the tubers of the test plants is assessed at the end of the growing season, using a growing-on test. The incidence of infected tubers in relation to the susceptible and resistant control varieties is used to determine a resistance rating (scale of 1 – 9; with 9 = high resistance). This doesn't provide information on symptom expression.

In Scotland, SASA report information on variety propensity. The term has been adopted 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 propensity values are calculated from the results of laboratory virus diagnoses on leaf samples submitted to SASA from plants exhibiting virus symptoms during crop inspections (PVY^{N}, $PVY^{O/C}$, PVA and PVV). Values greater than 1 indicate that a 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. 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. However, propensity can be collected over many years and maybe statistically more robust than the virus tests that are carried out as part of the NL programme. It is also up to date in relation to assessments against the virus strains present in the field in recent years. Information is not available for England and Wales as laboratory tests are not carried out on symptomatic plants seen during seed crop inspections there.

Do some varieties have high levels of virus but no symptoms in leaves/ no effect on yield /tuber quality?

There is probably a complex interaction between the virus strain(s), potato variety and timing of infection on virus symptom expression. Importantly, the level of resistance or susceptibility to PVY of a variety and its ability to display symptoms of infection will impact on the virus distribution in the whole plant, its capacity to affect the development of the plant tuber formation and, ultimately, yield. Some varieties do not display symptoms of infection and their yields might not be affected. However, these varieties represent a source of virus inoculum that can be transmitted to, and affect, neighbouring susceptible varieties.

MATURE PLANT RESISTANCE

What is it, how long does it last, is it the same in all varieties, does it vary with environmental factors?

Reports of Mature Plant Resistance (MPR) date back over 30 years and were based on observations that plants inoculated with virus (PVY^O or PVY^N) during the first 4 weeks following emergence had more daughter tubers infected with virus than plants inoculated in the subsequent 4 to 6 weeks. Overall, delayed infection in relation to the plant developmental stage reduced tuber infection and yield losses. The onset of flowering is considered a good indication of when MPR begins to take effect.

MPR varies with variety but the underlying mechanism is unknown. It is known that the strain of virus is important and recent unpublished work indicates that although MPR still applies when a plant is infected with PVY^O, it is less efficient when a plant is infected with PVY^{NTN} or $PVY^{N\text{-}Wilga}$. (PVY^{NTN} is still able to infect daughter tubers up to 9-10 weeks post emergence which is about 2 weeks later in comparison to PVY^O).

APHIDS AND VIRUS TRANSMISSION

What are the most important aphids? Does it vary between England and Scotland?

Over 500 aphid species have been reported in GB. Various researchers have trapped and tested winged aphids in GB and the Netherlands for their ability to transmit one or more strains of PVY. When these species lists are combined, there are around 30 species that have been found to transmit PVY. The aphids vary in the efficiency with which they transmit viruses. This is defined as the relative transmission efficiency, or relative efficiency factor (REF). It is a measure of how often an aphid species will transmit the virus relative to the 'best' vector, the Peach-potato aphid, *M. persicae*. It is given a value of 1.0 and the values for the other species are proportional to this. For example, the Black bean aphid has a relative transmission efficiency of 0.1, meaning that in the same conditions, this species transmits the virus only 10% of the time compared to *M. persicae*.

AHDB funds an Aphid Monitoring Scheme and the results are reported as a vector pressure index. It is designed to give the user an assessment of the risk of PVY spread. It is calculated using the catches of aphid species and their respective REF values.

Researchers at SASA have studied the relationship between the numbers of different aphids and PVY transmission. They concluded that the cereal aphids (Rose-grain aphid, *Metopolophium dirhodum,* Grain aphid *Sitobion avenae* and Bird cherry-oat aphid, *Rhopalosiphum padi*) were the key vectors. In other countries, other aphid species are considered to be more important, for example, Black bean aphid, *Aphis fabae,* in Finland and Leaf curling-plum aphid *Brachycaudus helichrysi* in Switzerland.

How important are Willow-carrot aphids in GB?

In laboratory testing the Willow-carrot aphid, *Cavariella aegopodii*, was a moderately efficient transmitter of PVY and PVA, however in the field situation the relative importance of this aphid by comparison to Peach-potato aphid or cereal aphids remains to be demonstrated.

Does the timing of aphid flights matter (early vs late season)?

Recent mathematical modelling work from the US suggests that an early-season peak in the numbers of non-colonizing aphids resulted in the highest number of PVY-infected plants in the end of the season, while mid- and late-season peaks caused relatively little virus spread. We don't know if this work is directly transferable to GB. Epidemiological modelling using Scottish aphid and seed certification data indicates that the inclusion of aphid data up to the end of July is critical in Scotland.

What do suction traps vs in field traps tell us?

Suction trap information is summarised in AHDB's Aphid News. The yellow water trap information is available by an open access website. Suction traps give a stable, long- term, area wide sample of the population of aphids in an area. Field traps, like the yellow water traps, tell you what is moving on a local scale.

Where is the virus coming from?

Aphids are not believed to carry PVY over long distances and therefore the most likely sources of virus are the input seed and/or neighbouring potato crops and groundkeepers that are already infected with virus.

How important is winter temperature in determining aphid numbers? How reliable is the forecasting?

Using the suction trap information researchers at Rothamsted Research have shown strong relationships between winter temperature and the time that *M. persicae* are first caught in traps and their abundance. Relationships for other species are less strong. Compared to 50 years ago, many aphids are flying a month or more earlier.

Can aphids be tested to see if they are carrying PVY?

Not reliably due to the non-persistent nature of virus transmission and the short period of contact with the aphid's mouthparts. Virus particles are believed to dissociate from the mouthparts once aphids are held in collecting fluids, e.g., as used suction and yellow water traps.

MANAGEMENT

Why is this an issue now?

This may be an issue that has been building for a while and has now come to peoples' awareness. Other potato growing areas such as the Netherlands (which implements a post-harvest testing regime) have experienced high levels of downgrades and failures due to virus. The specific reasons are currently not clear and so it isn't possible to predict whether this is a one-off, seasonal effect or a longer-term trend.

Is this related to the banning of neonicotinoids meaning there are more aphids around?

The aphid yellow water trap scheme has been operating since 2004 and reports the numbers of aphids recorded in 100 traps per year. Although the location of the traps varies from year

to year it's probably a good data set to understand trends in aphid numbers. The counts don't show a consistent trend across all aphid species.

Peach-potato aphid counts have increased since 2014 (the first season that neonicotinoid seed treatments were withdrawn on OSR) but the numbers fluctuate year to year.

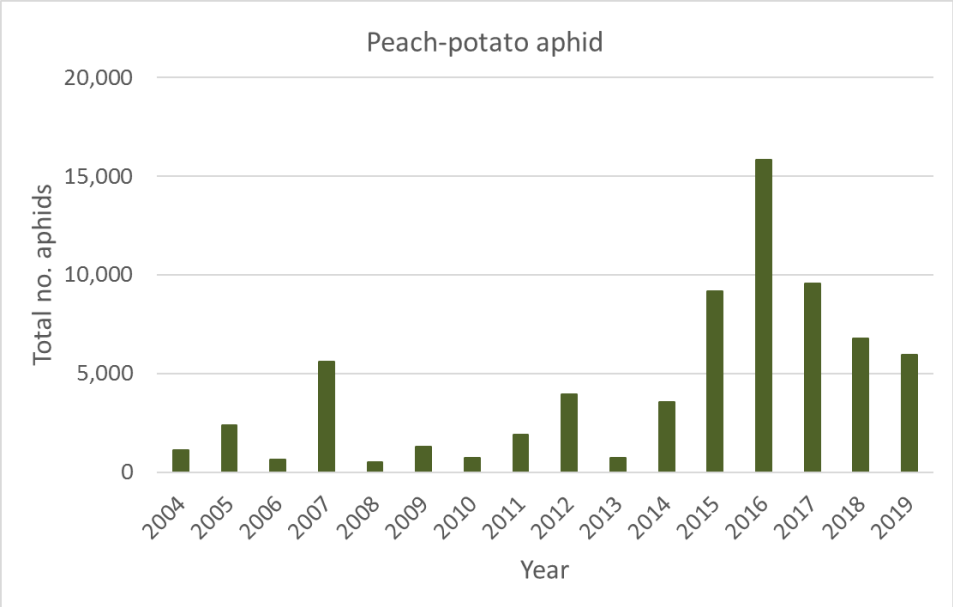

Fig. 4. Peach-potato aphid counts recorded from AHDB yellow water traps (2004-19).

Bird cherry-oat aphid counts haven't tended to show a consistent increase over time. However, 2019 will be the first season that neonicotinoid seed treatments have been withdrawn for use on cereals in UK.

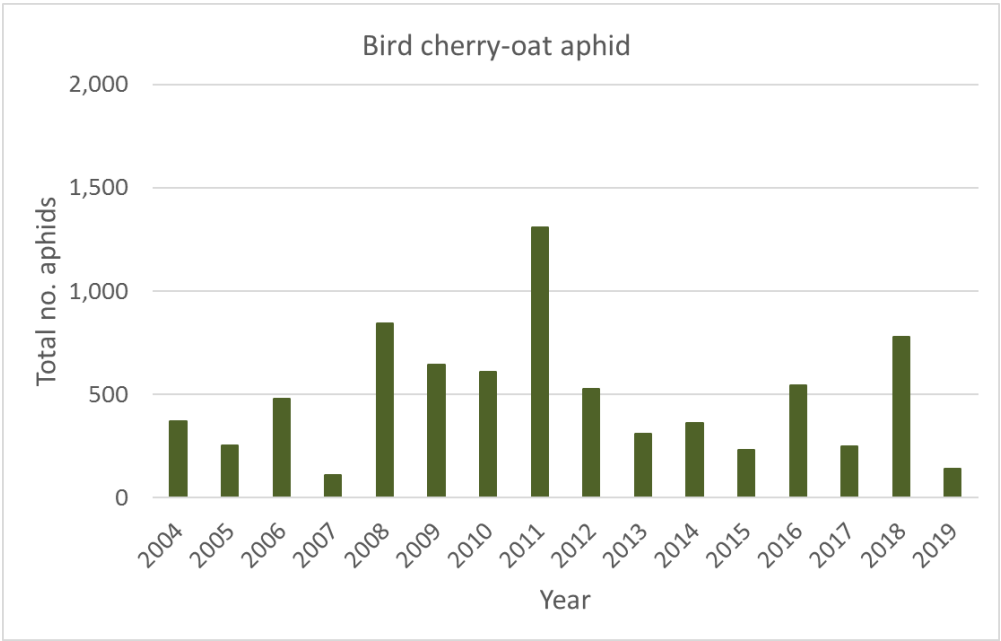

Fig. 5. Bird cherry-oat aphid counts recorded from AHDB yellow water traps (2004-19).

Willow-carrot aphid counts have increased over time, except in 2018. The increase may be related to reports of reduced sensitivity to pyrethroids in this aphid.

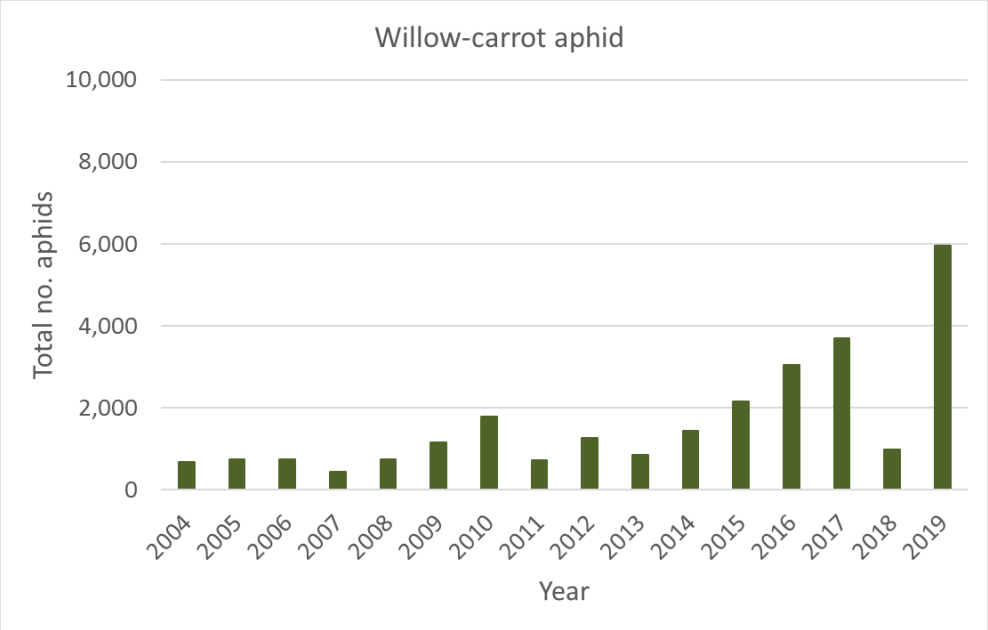

Fig. 6. Willow-carrot aphid counts recorded from AHDB yellow water traps (2004-19).

What can I do differently in 2020 to minimise the risk to my crop?

Choose as high as possible grade of input seed. For seed crops burn down as soon as possible and monitor crops for any regrowth. New growth that develops after haulm destruction can be susceptible to aphid-borne infection especially when significant aphid pressure is still observed late in the growing season. Management of inoculum sources in ware crops and groundkeepers is very important in minimising the risk of virus spread. Ideally do not plant a variety which is high risk (e.g. lower grade/older generation/virus susceptible variety) near to higher grade production. Pay attention to store hygiene and clean and disinfect after store emptying to kill off overwintering aphids.

How do mineral oils work?

It is thought that mineral oils hinder the attachment of virus particles to the aphid's mouthparts. While oil can lower PVY incidence in the field, the magnitude of control can vary considerably from year to year (the reduction was up to 2-fold in an AHDB-funded project on mineral oils). It's likely that the variation is due to factors such as virus inoculum levels, aphid abundance and timing of the aphid flights into the crop relative to spray timings.

Are there issues with mineral oil use in GB?

Mineral oil treatment can alter plant physiology and, in some cases, be phytotoxic. This can have an adverse effect on the appearance of crops and there have been concerns that mineral oil use might affect seed crop inspectability. An AHDB Potatoes project on mineral oils addressed this issue and plots were established to study the effect of spray oil treatments on

a range of virus-infected and healthy plants of various potato varieties. Phytotoxic symptoms (localised necrotic spots (see below) were occasionally observed. They tended to be observed when periods of sunny weather coincided with oil applications. Currently growers are advised that the use of mineral oils is at their own risk and if phytotoxic effects occur that affect inspectability the certifying authorities may refuse to grade the crop.

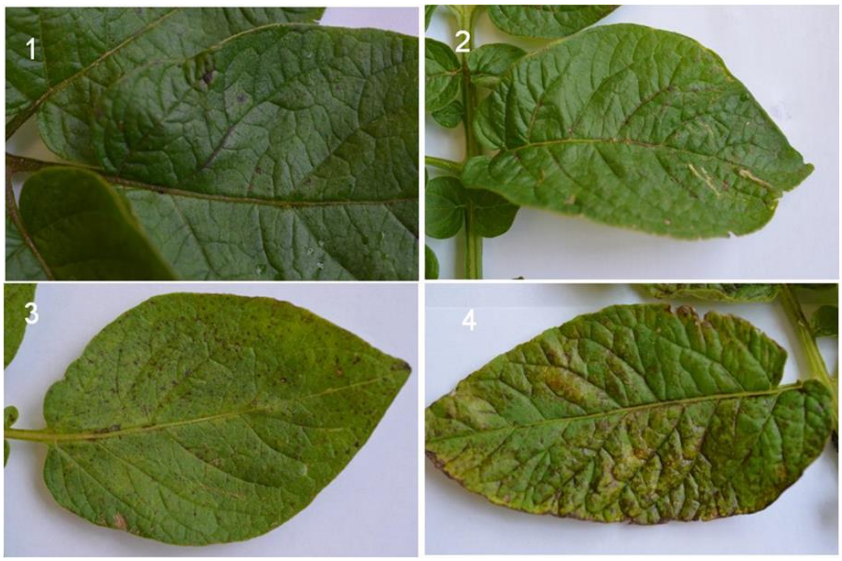

Fig. 7. Representative pictures of the severity of leaf marking associated with mineral oil application (Trial plots at Cambridge, 2012).

OTHER SOURCES OF INFORMATION

Information on the relevant Seed Potato Classification Schemes (SPCS) are available from SASA and APHA. These rely on visual inspection of seed crops and require a minimum area/number of plants to be inspected.
http://www.sasa.gov.uk/seed-ware-potatoes/classification-scheme
https://www.gov.uk/guidance/the-seed-potato-classification-scheme
The Scottish Aphid-Borne Virus Working Group provides an annual update on virus management in seed crops
There are two relevant AHDB projects reports:
R428 Aphids & Virus Transmission in Seed Crops
R449 Effectiveness of Mineral Oils

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