Grower Summary

Investigating the timing of transmission of carrot viruses to improve management strategies

FV 460

Final report

GROWER SUMMARY

Headline

Research has identified the main vectors and timing of transmission of carrot red leaf virus. Transmission of carrot red leaf virus appears to track well with flights of willow-carrot aphid. A vector control trial suggests early season control is key to mitigating against yield loss from aphid transmitted virus in carrots. A day-degree forecast for willow-carrot aphid appears to produce useful information on timing for growers.

Background

Within carrot crops the key viruses of concern are carrot necrotic dieback virus; Carrot yellow leaf virus and the viruses of the carrot motley dwarf complex, the principal virus of which is Carrot red leaf virus (CtRLV). Carrot necrotic dieback virus (CNDBV, formerly Anthriscus strain of *Parsnip yellow fleck virus*) and carrot yellow leaf virus (CYLV) are also viruses which can have a major impact on carrot crops. Previous work (FV 382 a and b) indicated that CNDBV is not a major disease observed in mature carrot crops. This may be the consequence of the virus being associated with seedling death, reducing the incidence of the virus from previous field samples. However, these previous studies indicated that both CtRLV and CYLV can be present at very high incidences (up to 100% of sampled plants). CtRLV is a persistently transmitted virus and facilitates the transmission of two other pathogenic viral agents (carrot mottle virus and carrot red leaf associated viral RNA) of the Carrot Motley Dwarf complex (CMD). CMD is associated with leaf reddening and mottling. There are no available data on yield losses associated with CMD but the complex has been linked to an impact on marketable yield through excessive lateral root hair development and root splitting (kippering). CYLV was the subject of previous AHDB funded studies (FV 382 a and b). Whilst there are no available data on yield losses associated with this virus, the previous studies strongly implicated this virus with quality losses due to development of internal necrosis in carrot root (Adams et al., 2014). Therefore, this study focused on CtRLV as a proxy for transmission of the CMD virus complex, and CYLV as a virus thought to be present in high incidence for which minimal epidemiological information is available.

The aim of this study was to identify the timing of transmission of CtRLV and CYLV throughout the growing season and to correlate this to aphid flight data gathered from yellow water pan traps in the field. A further objective of the project was to compare the different methods used for monitoring aphid flights (suction trapping and in-field yellow water traps), and also to see whether these new data can be used to refine the current models used for predicting flights of willow-carrot aphid (*Cavariella aegopodii*).

Summary

Year 1 Field trial (2019)

Greater virus transmission was recorded in the trials at Warwick than at Stamford Bridge. Most of the virus detected throughout the growing season was carrot red leaf virus (CtRLV) at both sites, with carrot yellow leaf virus (CYLV) being occasionally detected throughout the season. Aphid flights at both sites followed a similar pattern throughout the season, though fewer aphids were caught in the traps at Stamford Bridge. At Stamford Bridge CYLV was detected in a single week, from one bulk sample (Week of 21-May). Peak transmission at the Yorkshire site was just under 4.5% transmission, in the week of the 14 May. The trials at Stamford Bridge did not show a good relationship between aphid flights and virus, a reflection of the limited virus transmission at the Stamford Bridge site.

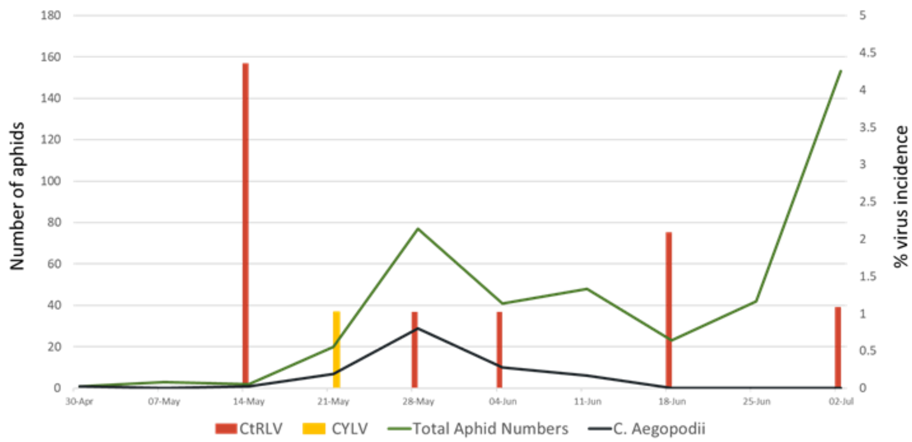

Figure1. Showing the limited virus transmission recorded at Stamford Bridge, Yorkshire. Virus content in plots is shown in the bars (Red for CtRLV, yellow for CYLV), and aphid flight data in the lines on the graph (Green for total aphid flights, Black for willow-carrot aphid).

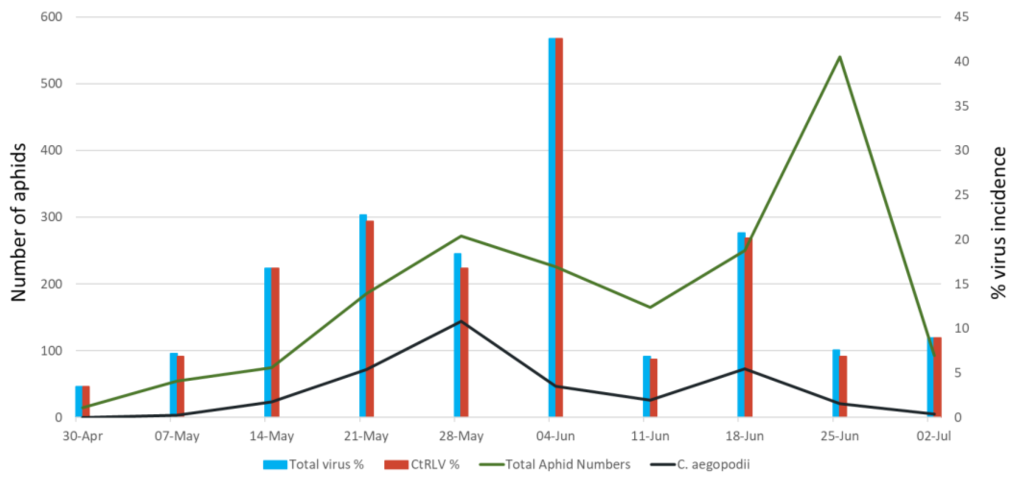

Figure 2. Virus transmission recorded in trial plots at Warwick University. Virus content is shown in the bars (Blue for total virus content, Red for CtRLV), and aphid flights in the lines on the chart (Green for total aphids, Black for willow-carrot aphid)

The trials at Warwick had greater incidence of virus transmission throughout the season, with a peak transmission of 43% in the week 4-June. Carrot yellow leaf virus was only detected sporadically throughout the season, in the weeks 7-May, 21-May, 28-May*, 11-June, 18-June, 25-June*. To reduce diagnostic costs all samples were tested as "pooled leaves", also termed "bulk samples". Each week 100 leaves from the test plot were sampled as 25 4-plant bulks. The percentage of virus incidence was then calculated based on the number of bulks testing positive each week. All findings were a single positive bulk per week, except * where there were two positive bulks detected. From looking at the pattern of flights of the individual aphid species at Warwick, transmission appears to track movements of *Cavariella aegopodii,* but this will be further refined in the coming seasons.

Year 2 Field trial (2021)

Following a year hiatus due to COVID affecting the ability of staff at both Warwick and Fera to conduct field work, the year 2 of the trial was rolled over to 2021. The trial at Fera was conducted at a field in Buttercrambe, less than 2 km North of the Stamford Bridge site used in 2019. The first week of the trial (uncover and aphid trapping) was approximately 2-3 weeks later than in 2019, occurring in the week of 18 May, rather than 30th April, however, this aligned well with the relative aphid predictions and the relative abundance of aphids caught at both the Fera and Warwick site were in line with a similar phenology (timing of the life cycle) of the various species across both years of the trial.

In a similar pattern to the 2019 trial, there was very little transmission recorded in the Fera trial, with a maximum transmission of 1% of any virus across the entire trial in the weeks of

15 June, 6 and 13 July. Aphid numbers were negligible throughout the season. C. aegopodii remained low throughout the entire season rarely getting above single figures in any week. Consequently, with both transmission and vector numbers so low, it is difficult to draw any further conclusions from this part of the trial.

The pattern of virus transmission and aphid captures on the Warwick trial are shown in figure 3. Transmission increased rapidly in the early weeks of the trial (18 May – 8 June), peaking on 1 June, where all plant samples tested were positive for virus, with 95% of the virus detected being CtRLV. Carrot yellow leaf virus was also detected in the weeks of 1 and 8 June, although this was only present at low incidence (~5% of virus detected). Throughout this early part of the trial vector numbers corresponded well to transmission, with the majority of aphids caught in yellow traps being the willow carrot aphid. Later in the trial (29 June onwards) a second peak of virus transmission was recorded, which does not correspond with a rise in numbers of willow-carrot aphid. However, during this period there was a rise in the captures of *C. pastinaceae* (parsnip aphid) representing a large proportion of the small peak in aphid captures at 6 July. It should be considered that this species, not identified as a factor in the previous trial, may be driving this late season transmission.

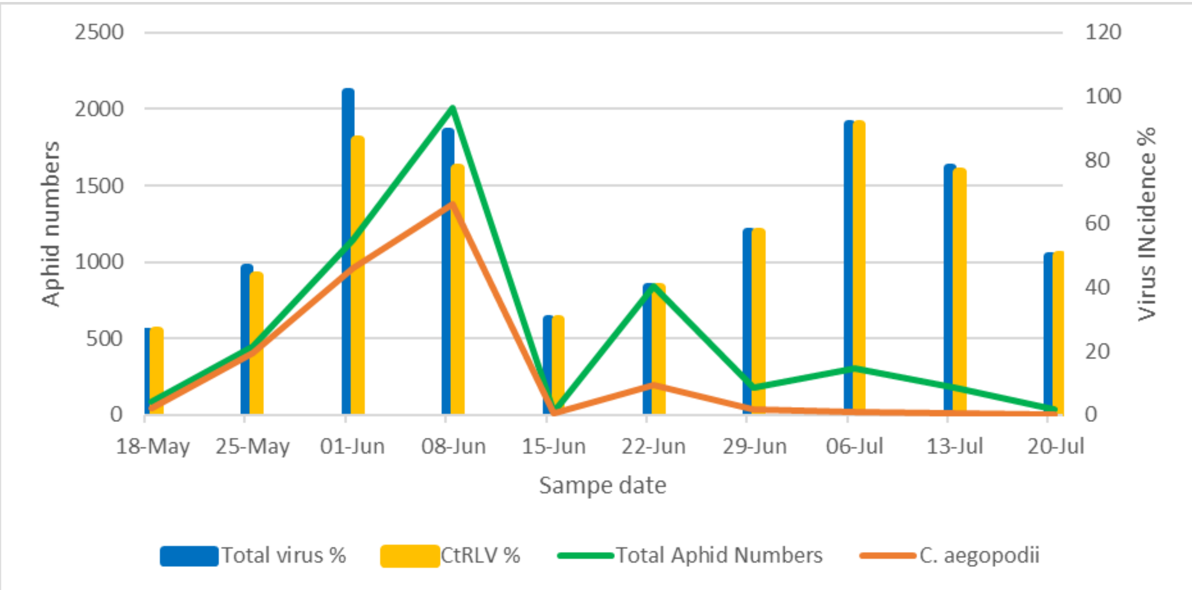

Figure 3. Virus transmission recorded in trial plots at Warwick University. Virus content is shown in the bars (Blue for total virus content, Yellow for CtRLV), and aphid flights in the lines on the chart (Green for total aphids, Orange for willow-carrot aphid)

Comparisons of monitoring data collected in different ways (plant sampling, suction traps, water traps) suggest that all approaches are broadly measuring the ‘same thing’. Additionally, on the strength of these data the day-degree forecast for willow-carrot aphid (*C. aegopodii*) appears to be relatively robust, whereas it may be more difficult to forecast the activity of peach-potato aphid (*M. persicae*) and the parsnip aphid (*C. pastinaceae*).

Year 3 (2022) Vector management trial

The final year of the programme of research switched from investigating the timing of transmission to focus on the control of the vector *C. aegopodii*, the willow carrot aphid. The trial combined currently available and near-market products to investigate their efficacy at controlling both virus infection and disease impact from the virus, including foliar and root symptoms and yield reduction. Throughout the trial transmission of CYLV was below levels needed for reliable detection at the sampled rate, and consequently the focus of the results reported here are on CtRLV.

The treatments were conducted over a 10 week period (9 treatment dates). The treatments and the dates of specific applications are presented in Table 1. First treatment date was on 9 May (T1) and final treatment on 6 July 9 (T9). Peak aphid populations in the trial were recorded the following week, with both willow-carrot aphid and peach-potato aphid numbers peaking in the week of 19 May (week 2 of the trial) and reducing through the period to 16 June (week 6 of the trial) (See section 4.3). Virus content in the untreated plots was monitored through weekly sampling, starting 3 weeks after T1. From the first sampled week 18 of the 20 bulked samples tested were positive for CtRLV (calculated virus content 36%, CI: 20.53-58.47). From the third sampling week all bulked subsamples were positive for CtRLV (calculated virus content 100% CI: 29.97-N/A), indicating the high virus pressure in the initial weeks of the trial.

Table 1. Treatment programmes trialled in spray control trial

Treatment	**T1**	**T2**	**T3**	**T4**	**T5**	**T6**	**T7**	**T8**	**T9**
Timing [1]		**7DAT1**	**7DAT2**	**7DAT3**	**7DAT4**	**7DAT5**	**7DAT6**	**7DAT7**	**7DAT8**
Date	09-May	17-May	25-May	31-May	07-Jun	14-Jun	20-Jun	28-Jun	06-Jul
1	Untreated	Untreated	Untreated	Untreated	Untreated	Untreated	Untreated	Untreated	Untreated
2	Movento 0.3	Movento 0.3	Movento 0.3	Movento 0.3	Movento 0.3	Movento 0.3	Movento 0.3	Movento 0.3	Movento 0.3
3	Movento 0.3		Teppeki 0.14		Movento 0.3		Teppeki 0.14		
4	Teppeki 0.14		Movento 0.3		Teppeki 0.14		Movento 0.3		
5	Gazelle 0.2		Movento 0.3		Teppeki 0.14		Movento 0.3		Teppeki 0.14
6	Movento 0.3		Gazelle 0.2		Teppeki 0.14		Movento 0.3		Teppeki 0.14
7	Movento 0.3	Teppeki 0.14	Movento 0.3	Teppeki 0.14					
8	Movento 0.3		Movento 0.3						
9	Coded 0.25		Coded 0.25						
10	Teppeki 0.14		Teppeki 0.14						
11	Gazelle 0.2		Gazelle 0.2						
12 [2]	Minecto One		Minecto One						

1- 7DATX represents “days after treatment”
2- Minecto One – only carrot fly control is specified on the label.

The prevalence of virus in plots was measured at the mid- and end- points of the trial (Figure 4). Given the lag-time allowed for the bio-amplification of virus within plants to reach detectable levels the “week 5” and “week 10” sample points were three weeks in arrears of the actual treatment weeks. At week 5, all treatment programmes showed a reduction in virus content by comparison to the untreated control to approximately half of the virus content of untreated plots. Some treatments, showed little increase in virus content over the later half of the trial, including the regimes with Movento and Teppeki in the earliest treatment. However, the two programmes with early Gazelle treatments had a marked increase between the mid-point virus content and the virus prevalence recorded at the end of the trial.

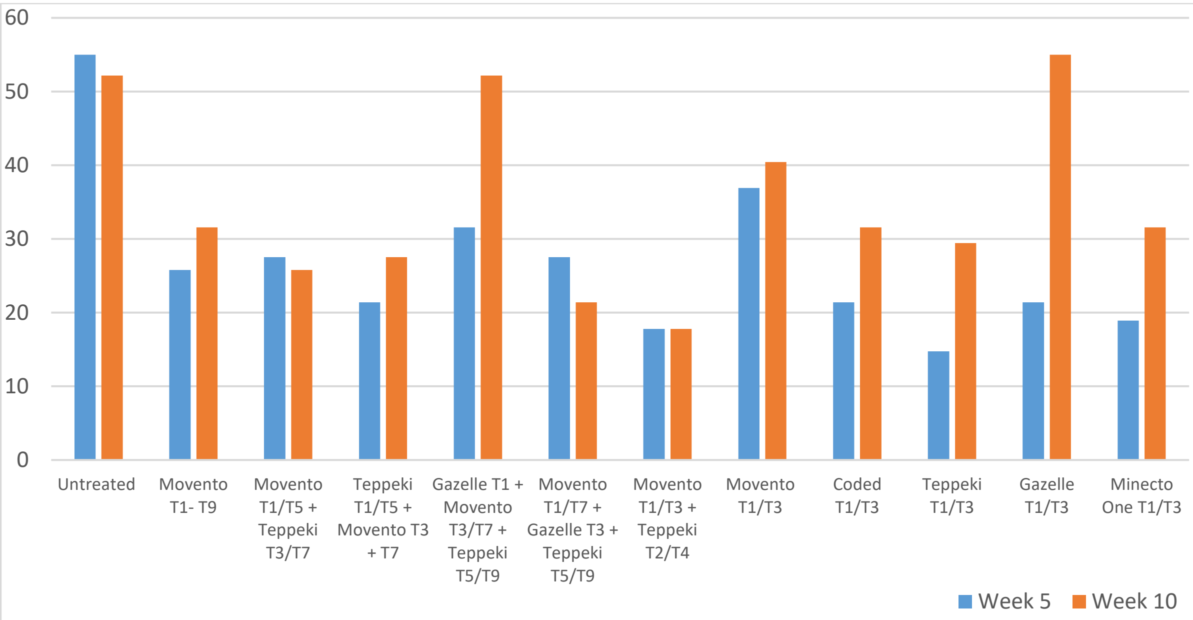

Figure 4. % virus content recorded in plots of virus treatment

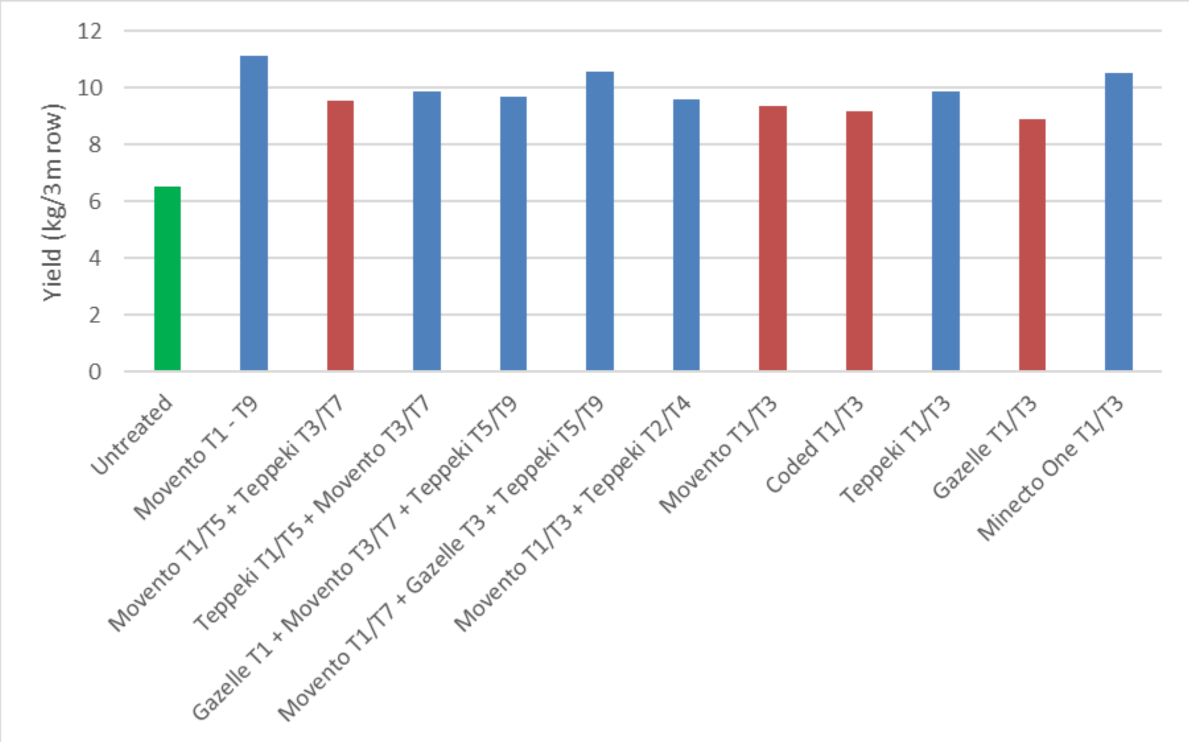

Figure 5. Yield of carrot roots, presented as Kg per 3 m row. Green denotes "untreated control", red where the reduction in yield was significantly reduced from treated control (Movento T1-T9).

The application of chemical controls had a positive impact on foliar symptom development with all treatments (See section 4.3). Similarly, all treatments had the effect of mitigating against yield loss (Figure 5). Although there were little differences between treatments, the yield from some programmes were significantly lower than the treated control (intensive Movento treatment). However there does not appear to be a correlation between the virus content at mid- and end- point and the impact on yield within the trial.

Comparison of methods of monitoring aphid infestations (on plants, suction trap, water traps)

At Wellesbourne, plots of carrots are maintained throughout the year to support the population of carrot fly. The carrots are overwintered, sometimes under covers, and then uncovered. New plots of carrots are sown in late March and then in May each year. Numbers of aphids (primarily willow-carrot aphids) were monitored on these plots throughout each year by counting the number of aphids on a fixed length of row or a fixed number of plants. Records were taken of the numbers of winged, wingless and parasitised aphids. Winged aphids were also monitored in the Rothamsted Insect Survey suction trap located at Wellesbourne and in water traps in the field trials in 2019, 2021 and 2022 – as above. All these data sets were compared.

Figure 6 compares the pattern of captures of willow-carrot aphid in the suction trap and the water traps at Wellesbourne in 2021 with the numbers of winged aphids found on carrot plants. The suction trap captures, water trap captures and numbers of aphids found on the new carrots appear to be reflecting the same pattern. However, winged aphids were present on the overwintered carrots well before they were captured in traps. The same pattern was shown in all three years (2019, 2021, 2022).

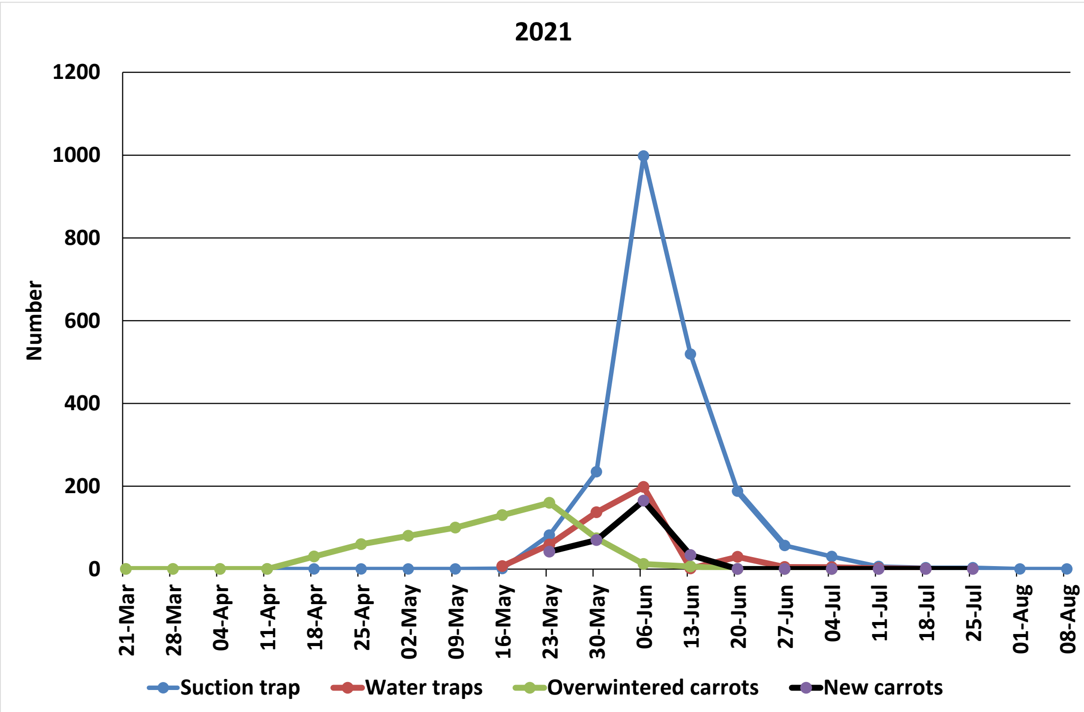

Figure 6. Numbers of winged willow-carrot aphid (C. *aegopodii)* captured in the suction trap, in the 4 yellow water traps in the field trial, on the plot of overwintered carrots and on plots of new carrots at Wellesbourne, Warwick in 2021.

Relationships between suction trap data and weather data

A larger set of suction trap data than available originally was used to refine the day-degree model for willow-carrot aphid. To predict the dates of first and 10% capture, the day-degree sums are 325 and 451 day-degrees respectively from 1 February above a base temperature of 4.4°C. It seems to make little difference to 'accuracy' whether the start date is 1 January or 1 February (although the day-degree sums differ) or whether the base temperature is 4.4 or 4^{o}C (the day-degree sums again differ).

Suction trap data for the parsnip aphids is more limited, partly because they are often less abundant than willow-carrot aphid. Despite the fact that the parsnip aphids are thought to have similar life-cycles to willow-carrot aphid there does not seem to be a 'constant' relationship between the dates of first or 10% capture in suction traps and accumulated day-degrees. The same is true for *M. persicae* (which is not unexpected since it has a different method of overwintering – as mobile aphids rather than cold-resistant eggs on a woody host). For *M. persicae,* the established way to forecast the spring migration is the relationship between the date of first capture etc. with the mean air temperature in January - February, used by the Rothamsted Insect Survey to produce forecasts in early March each year. Using a similar approach for the parsnip aphids produced some statistically-significant relationships but these were not as robust as the day-degree forecast for willow-carrot aphid (this may be partly because there is less data).

Day-degree forecasts

The revised day-degree model using accumulated day-degrees from 1 February was used to predict the start of willow-carrot aphid flight activity at Wellesbourne in each year. This information was also provided to growers in real time through the Pest Bulletin. An example of the Pest Bulletin information (for 2022) is shown in Figure 7.

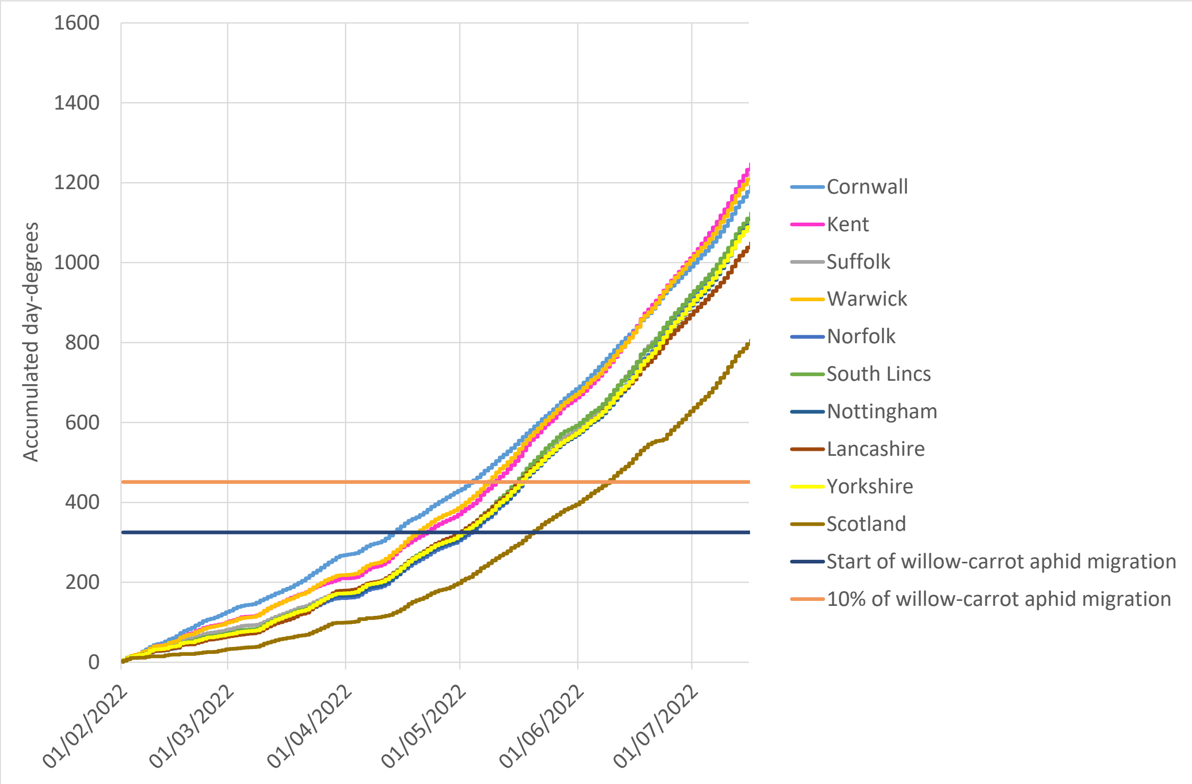

Figure 7. Day-degree forecasts for willow-carrot aphid in 2022. Information from the Rothamsted Suction trap captures have been used to estimate the mean number of D° from 1 February until the first aphid of the year is caught in a suction trap (the start of the migration to carrot) and when 10% of aphids are caught. This is after approximately 325 and 451D° respectively.

Comparisons between years

Figure 8 compares suction trap captures at Wellesbourne in 2019, 2021 and 2022, confirming that willow-carrot aphids were most abundant in 2021 but that the migration was earliest in 2022.

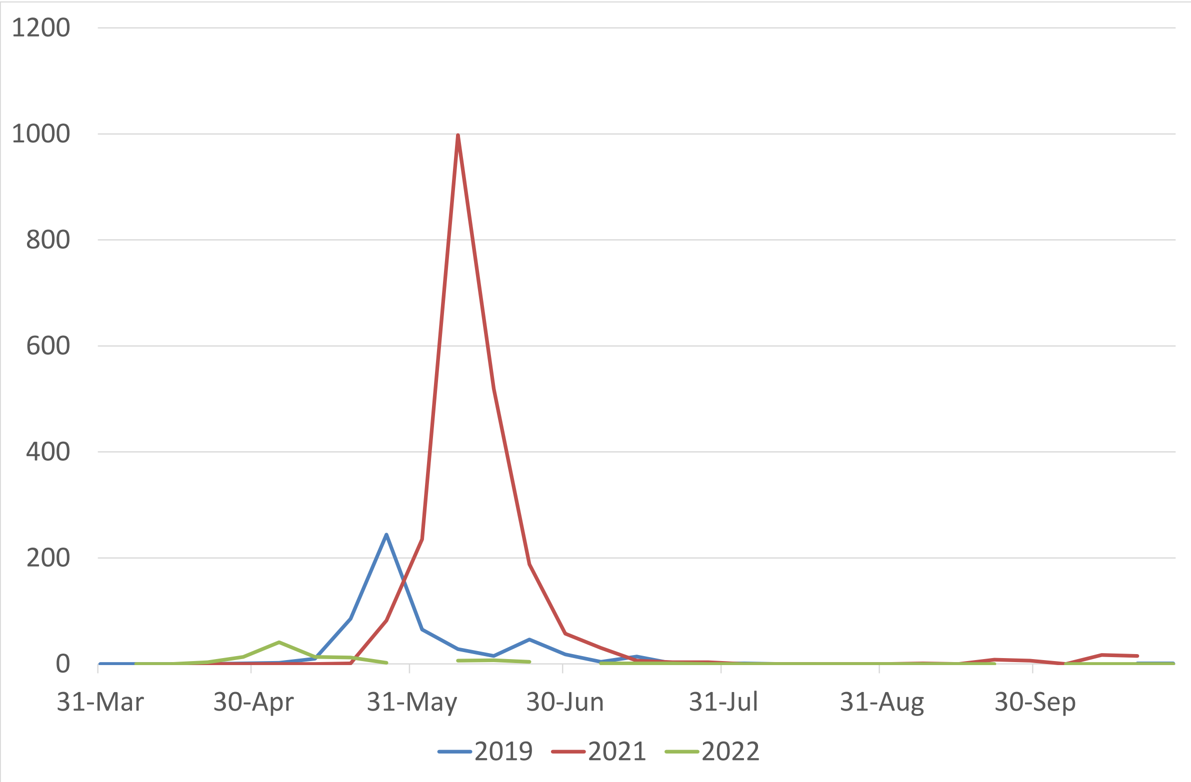

Figure 8. Suction tap captures (number of aphids) at Wellesbourne in 2019, 2021 and 2022 confirming that willow-carrot aphids were more abundant in 2021 than 2019 or 2022 but that the migration was earlier in 2022.

Table 2 compares 2019, 2021 and 2021 with regard to the timing of the migration of willow-carrot aphids at Wellesbourne. Generally, the day-degree forecast gave useful information about the timing of activity in each year and the rankings between years were consistent.

Table 2. Comparisons between 2019, 2021 and 2022 regarding the timing of the migration of willow-carrot aphids at Wellesbourne. Rankings are shown in brackets: (1) = earliest of the 3 years.

	2019	**2021**	**2022**
Forecast start of migration	23 April (2)	9 May (3)	20 April (1)
Date by which first aphid captured in suction trap (weekly samples)	28 April (2)	16 May (3)	17 April (1)

Date by which first aphid captured in water traps (weekly samples)	7 May (2)	18 May (3)	Before 10 May (1)
Forecast 10% migration	16 May (2)	29 May (3)	8 May (1)

Forecast refinement/validation

Fera Science Ltd have a very large historical data set on aphid captures in yellow water traps in commercial crops (2004-2018) and this was sent to Warwick to see if the data could be used for forecast validation. The data set is quite 'fragmented' and there appears to be no information about when trapping started and finished and so it is of limited use for forecast validation (there are no dates with zero captures).

Information available to growers

Throughout the project, including as far as feasible in 2020 (Covid pandemic), information on aphid activity relevant to carrot crops has been available as part of the AHDB Pest Bulletin, hosted in 2019-2022 on the Syngenta UK web site. This has included outputs from the day-degree forecasts, suction trap counts and plant monitoring data at Wellesbourne.

In 2020 and 2021, the Fera/AHDB potato water trap data sets were made available to the AHDB Pest Bulletin on a weekly basis, providing additional information on aphid activity.

In 2021, the aphid forecast was developed by AHDB into a forecasting tool that was hosted on the AHDB Horticulture web site and was available in 2021 and 2022.

Financial Benefits

In year 3 of the project the focus of field work has been on a control trial to look at optimising control strategies through a replicated block trial based at Warwick crop centre. Although these data suggest that current treatment programmes will reduce the impact of virus infections on carrot yield, the initial treatment and intensity of treatment will influence the degree of impact from virus in crops. Impacts have not been quantified due to the limited scope of the trial.

Action Points

- Early treatment may mitigate against impacts of virus, whilst not preventing virus infection over the season.
- The willow-carrot aphid appears to be the primary vector of carrot red leaf virus in the trials carried out within this project. The day-degree forecast should be used as a guide for initiating aphid management.

- In some seasons late season infection may be driven by the parsnip aphid. However, the impact of these late season infections is not known.

