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Progress in aphid forecasting systems

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Abstract

Potato virus Y and many other viruses of potatoes cause major economic losses to seed potato production in many countries. Potato virus Y, which is transmitted in a non-persistent manner, is one of the most important virus diseases of potatoes in many countries in Europe and especially in the northern regions.

During the last decade there has been an increasing interest in developing methods for potato virus forecasting. The abundance of virus vectors is often estimated by yellow water traps (YWT), suction traps or field surveys. In Sweden the relationship between occurrence of alate aphids and the proportion of PVY infected progeny tubers has been studied since 1975. A dynamic simulation model for PVY has been designed for predicting the incidence of PVY. The simulation model describes a system which includes e.g., healthy and PVY diseased potato plants, different aphid species as virus vectors an their efficiency as virus vectors, the susceptibility of the potato crop according to mature plant resistance and date of haulm destruction. There was a good correlation between model output and samples of progeny tubers tested for PVY.

Additional keywords: potyvirus, potato virus Y, PVY, *Aphis* species, *Myzus* species, *Rhopalosiphum padi*, virus vector, vector efficiency, mature plant resistance, seed potato production

Introduction

Many aphid species are important vectors of viruses causing potato diseases. The adverse effects of such diseases on seed potato production have led to large economic losses in many countries. Potato virus Y (PVY) is transmitted by aphids in a non-persistent manner and is generally acquired and transmitted within fields by the probing of winged aphids flying from plant to plant (Hille Ris Lambers, 1972).

In Sweden and in many other countries in northern Europe, PVY is one of the most important virus diseases of potatoes. Its incidence is generally much higher than that of potato leafroll virus (PLRV), probably because the main vector of the latter, *Myzus persicae*, is much less abundant in potato fields compared with other aphid species which can transmit PVY but not PLRV (Sigvald, 1990). Although the spread of PVY^O in Sweden is negligible during most years, outbreaks of this virus have been recorded on a few occasions since 1970, especially in southern and central regions (Sigvald, 1987). In the northern regions of Sweden, which are important areas for seed potato production, the incidence of PVY^O has been very low, mostly because few vectors and few virus sources are present in the fields (Sigvald, 1987).

Although PVY can be transmitted by aphid species that feed preferentially on potatoes, other species that do not colonize potatoes seem to be more important, e.g., *Rhopalosiphum padi*, *Brachycaudus helichrysi*, *Acyrthosiphon pisum* and *Phorodon humuli*

(Edwards, 1963, Van Hoof, 1977, 1980; Kostiw, 1979, 1980; Sigvald, 1984). The relationship between aphid migration and the spread of PVY has been studied by exposing bait plants to vectors in the field (Van Hoof, 1977; De Bokx, 1979; Ryden et al., 1983; Sigvald, 1989). Winged aphids have also been collected and placed on test plants to determine whether or not they are viruliferous (Van Hoof, 1980; De Bokx and Piron, 1984, 1985, 1990; Harrington et al., 1986). There are great differences in virus-transmission efficiency between aphid species (Sigvald, 1984; Katis and Gibson, 1985; Harrington and Gibson, 1989; De Bokx and Piron, 1990).

During the last decade there has been increasing interest in developing methods for PVY forecasting. The main variables used when forecasting the incidence of PVY include the number of winged aphids and their efficiency as vectors, the time of aphid migration in relation to plant age and the availability of virus sources (Gabriel, 1981; Van Harten, 1983; Sigvald, 1985, 1986). Simulation models have also been used to describe the epidemiology of non-persistently transmitted viruses (Ruesink and Irwin, 1986; Sigvald, 1986).In this paper the epidemiology of PVY is described in a simulation model for predicting conditions in potato fields in Sweden.

Epidemiology studies of potato virus Y in Sweden

During the last 15 years epidemiology studies were carried out in Sweden both in field experiments and laboratory studies. The flight activity of winged aphids was monitored by using yellow water traps (YWT) and suction traps. Aphids were collected three times a week, and eight species were identified: *A. pisum*, *Aphis fabae* gr., *Aphis nasturtii* and *Aphis frangulae* together, *Brevicoryne brassicae*, *Metopolophium dirhodum*, *M. persicae*, *R. padi*, and *Sitobion avenae*. All other species were assigned to a category 'other aphid species'. There were large differences in aphid flights between years and regions (Sigvald, 1987).

Aphid migration in Sweden, and in many other countries in western Europe, usually occurs during the growth period of the potato crop. The older the potato plants are at the time of virus inoculation, the lower is the amount of virus eventually reaching the tubers. This relationship is referred to as mature plant resistance. Virus translocation in potato plants and mature plant resistance have been studied in several countries (Sigvald, 1985; Beemster, 1987; Gibson, 1991). The different studies show clearly that mature plant resistance to PVY is important when determining the risk of virus spread. Field experiments carried out in southern Sweden showed that mature plant resistance increased markedly during July, the main period of aphid flight in Sweden (Sigvald, 1985).

It is of great interest to know which aphid species are most important in transmitting PVY. Note, however, that the abundance of each species and its efficiency as vectors are not the only important variables to consider. The level of synchrony between the migration period of each species, the susceptibility period of the crop and the proportion of diseased potato plants as virus sources in the crop must be taken into account when estimating the importance of various aphid species as vectors of PVY.

Aphid species transmit PVY with different efficiencies, and laboratory experiments indicate that *M. persicae*, *Myzus certus*, *A. nasturtii*, *Brachycaudus helichrysi*, *A. pisum* and *Phorodon humuli* are efficient, while *R. padi*, *S. avenae*, *A. fabae* and *M. dirhodum* are less so (Kostiw, 1979, 1980; Van Hoof, 1980; Sigvald, 1984; De Bokx and Piron, 1990). However, results differ greatly, owing in part to differences in methods, test plants, and aphid biotypes. In Sweden the relative efficiency of certain aphid species as vectors of PVY^{O} was investigated by using cages in which winged aphids were allowed to obtain virus from PVY diseased potato plants and then probe young, uninfected potato plants

(Sigvald, 1984)

In Sweden (Sigvald, 1984), in the Netherlands (De Bokx and Piron, 1990) and in England (Harrington et al., 1986) relative efficiency factors have been assigned to various aphid species. There are differences between the different studies, which partly could be explained by differences in methods (De Bokx and Piron, 1990).

In Sweden the importance of certain aphid species as vectors of PVY was also investigated from 1976 until 1984 by comparing the number of winged aphids of each species trapped in yellow water traps (YWT) to the proportion of PVY infected progeny tubers. This was carried out in seven regions of Sweden, representing southern, central, and northern parts of the country. There were a close correlation between the proportion of PVY infected progeny tubers and the number of known vectors when the proportion of diseased potato plants as virus sources and the influence of mature plant resistance were also included in the analyses (Sigvald, 1987). A strong correlation was found between the occurrence of *R. padi* and the proportion of PVY infected progeny tubers, indicating that this species is an important vector of PVY in Sweden. Other studies confirm the strong correlation between the occurrence of *R. padi* and spread of PVY (Sigvald, 1989). It is very important to identify the most important aphid species as vectors of PVY to set up models to forecast the incidence of PVY in seed-potato fields.

Simulation model for PVY

Results from field experiments, laboratory studies and the literature were used to develop the simulation model for PVY^O spread. Data were also collected from a number of potato fields in southern and central Sweden, from 1982 to 1985, to evaluate and verify the model. The data collected at each field were generally as follows: cultivar, planting date, proportion of diseased plants serving as virus sources (field inspection), date of emergence, date of flowering, date of progeny tuber formation, date of removal of PVY^O diseased potato plants and number removed per ha and date of haulm destruction. From each field samples of 300 progeny tubers were collected after harvesting and tested for PVY (glasshouse test). The goal has been to develop a dynamic simulation model for PVY that describes relationship between important variables an parameters and gives a good overview of the epidemiology of PVY^O.

Some of the most important variables and parameters are:

1. healthy potato plants;
2. newly PVY^O infected potato plants not yet acting as virus sources;
3. totally PVY^O infected potato plants acting as virus sources and with PVY infected progeny tubers;
4. spread of PVY^O. This rate variable is proportional to the infection risk, and is influenced by the degree of mature plant resistance, vector efficiency and cultivar-related susceptibility;
5. infection risk. The risk of healthy potato plants to become infected with PVY^O type ? is calculated by multiplying the proportion of healthy potato plants by the proportion of PVY diseased potato plants acting as virus sources. The effect of multiple infection is taken into account (Gregory, 1948);
6. latent period;
7. mature plant resistance. Mature plant resistance increases with the age of the inoculated plant (Sigvald, 1985). From emergence until day 25 a susceptibility factor of 1.0 is used; the factors used during successive weeks thereafter are 0.8, 0.6, 0.4, 0.2, 0.1, and 0.0.;
8. vector efficiency (Table 1). Because YWT are species selective, the flight activity of some aphid species, e.g., will have been underestimated. Therefore, the efficiency factor

Table 1. Potato virus Y^O (PVY^O) vector efficiency factors for eight aphid species and a group of other less common aphids. The factors are used in the simulation model.

Aphid species	Efficiency factor
Myzus persicae	1.0
Acyrthosiphon pisum	0.7
Aphis nasturtii, A. frangulae	0.4
Rhopalosiphum padi	0.4
Metopolophium dirhodum	0.3
Aphis fabae	0.1
Sitobion avenae	0.01
Brevicoryne brassicae	0.01
Other aphid species	0.2

for *R. padi* is higher than results from different experiments indicate;

9. date of haulm destruction;
10. proportion of progeny tubers infected with PVY^O;
11. cultivar susceptibility. Potato cultivars differ in susceptibility and are thus assigned different susceptibility factors: the greater the susceptibility, the higher the factor value, which ranges from 1.4 to 0.6;
12. removal of PVY-diseased potato plants. The risk for spread of PVY^O can be decreased by removing PVY^O-diseased potato plants from the field before the main aphid flight.

Results from testing the simulation model

After constructing the relational diagram (Forrester, 1961) and writing the DYNAMO-code (Pugh, 1977), the program was run several times using a range of aphid numbers, initial proportions of potato plants infected with PVY^O, levels of mature plant resistance, latent period length, etc., to compare the general behavior of the model with the real system.

The predicted proportions of progeny tubers infected with PVY^O were compared with measure values obtained in the 1975–1977 field experiments (Sigvald, 1989). There was good agreement between the model output and data from the field experiments (Sigvald, 1986). When the aphid migration took place in July the model output correctly predicted that the proportion of progeny tubers infected with PVY^O would increase during August, about three weeks later. By changing the date of emergence it was also possible to compare the model output with results from field experiments (Sigvald, 1985) in which mature plant resistance had been studied.

Sensitivity analyses

The importance of different factors within the PVY^O model was assessed by varying different variables and parameters. The magnitude of the changes was restricted to keep values within the ranges determined in the field and laboratory studies, i.e., usually no more than a 50% increase or decrease in most variables. Most of the aphid data used were from the 1975–1977 field experiments. Changing the proportion of PVY^O-diseased plants serving as virus sources had a great influence on the proportion of potato tubers infected with PVY^O: Thus an increase in the former from 0.1% to 0.5% caused the latter to increase from 20% to 60% infected progeny tubers.

Aphid migration differs greatly between years and regions. Therefore data obtained on

Table 2. Sensitivity analyses of the vector efficiency for the aphid species *Rhopalosiphum padi*, *Aphis fabae*, *Acyrthosiphon pisum* and *Myzus persicae*. The percentage potato vitus Y^O (PVY^O) infected progeny tubers (forecast values) for 50% increase or decrease of the initially efficiency factors.

% PVY^O-infected tubers using efficiency factors of Table 1	*R. padi*		*A. fabae*		*A. pisum*		*M. persicae*	
	–50%	+50%	–50%	+50%	–50%	+50%	–50%	+50%
55.4	34.1	72.9	49.3	60.8	54.5	56.2	53.9	56.8
10.5	9.0	12.1	10.3	10.7	7.9	13.4	10.5	10.6
8.2	7.3	9.3	8.1	8.4	6.0	10.6	8.1	8.3
1.3	1.1	1.5	1.3	1.3	1.2	1.3	1.2	1.3
0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6
0.9	0.8	1.0	0.8	1.0	0.9	0.9	0.9	0.9
22.8	16.1	30.2	21.2	24.4	21.2	24.5	22.6	23.1

aphid catches in yellow water traps (YWT) from about 10 different regions and years were used in the sensitivity analyses in which vector efficiency values were varied (50% decrease or increase). Such changes had a great influence on model output for *R. padi*, *A. fabae* and 'other aphid species', but only slightly affected the output for *M. persicae* (Table 2). These simulations indicate that early and large migration of PVY^O vectors are important mainly if the aphid species concerned are not very efficient as vectors of PVY^O, for example *R. padi*. Latent period length, susceptibility of the potato crop, the extent to which PVY^O-diseased potato plants were removed, cultivar-associated susceptibility were also varied in the sensitivity analyses.

Data from about 70 potato fields were used for parameter estimation and for simulations. When testing the validity of the model, however, we used data from 100 other potato fields. There was a good correlation between predicted values and observed results, $r^2 = 0.80$, $p < 0.001$ (arc sin transf). The results are similar to those described earlier (Sigvald, 1986).

Monitoring aphid flights by suction traps

Since 1984 suction traps have been used at eight locations when monitoring aphid flights in Sweden. During seven years relationship between autumn and spring migration of aphids has been studied to investigate the possibility to forecast attacks by aphids in different crops and the risk for spread of virus. Results so far indicate that there is a close correlation between autumn and spring migration.

There is a great variation in aphid numbers in suction traps between different years and different regions, which causes great differences in spread of PVY. In 1989 there were many winged aphids trapped in southern Sweden, but very few in northern Sweden (Table 3). The results from testing of progeny tubers showed that there were a great spread of PVY in southern Sweden that year, but no spread at all in the northern regions. There are also great differences between years (Table 4).

The results also show that a great spring migration of, e.g., *R. padi* will greatly influence the population level in spring cereals. During years when *R. padi* multiply very rapidly on cereals, a great number of winged forms will migrate during July and thereby cause great spread of PVY in seed-potato crops. The results indicate that there is a possibility of using suction traps to forecast during spring the risk for spread of PVY.

Table 3. Number of winged aphids caught in suction traps in southern and northern Sweden, 1989.

Aphid species	Southern Sweden			Northern Sweden		
	May	June	July	May	June	July
Acyrthosiphon pisum	18	77	263	0	0	0
Aphis sp.	7	67	558	0	0	0
Brachycaudus helichrysi	104	400	983	0	0	0
Metopolophium dirhodum	10	158	664	0	0	0
Myzus persicae	0	0	0	0	0	0
Phorodon humuli	2	37	83	0	0	0
Rhopalosiphum padi	45	2405	6482	0	165	136
Other aphid species	234	2161	3646	2	88	136

Table 4. Number of winged aphids caught in suction traps in northern Sweden, 1987 and 1990.

Aphid species	1987			1990		
	May	June	July	May	June	July
Acyrthosiphom pisum	0	0	0	0	0	3
Aphis sp.	0	1	11	0	3	1
Brachycaudus helichrysi	0	0	0	0	0	1
Metopolophium dirhodum	0	0	0	0	0	0
Myzus persicae	0	0	2	0	0	0
Rhopalosiphum padi	0	3	40	3	298	2226
Other aphid species	0	2	228	2	137	286

Discussion

The computer-based simulation model has become an essential tool for use in analyzing results from epidemiological studies. In the present study, there was a close correlation between the predicted proportion of progeny tubers infected and disease incidence estimates made in the 1975–1977 field experiments (Sigvald, 1986, 1989), indicating that the model predictions can be accurate. Similarly, in 1976, when there was a very large aphid migration early in the summer, the model accurately predicted the proportion of progeny tubers infected with PVY^O in early September (measured incidence = 93%, predicted incidence = 96%). Furthermore, in 1977, when vectors populations were low, both predicted and measured values were ca 2%. Thus the model has great flexibility, providing accurate predictions under a variety of conditions.

Simulation models offer many advantages in virus epidemiology work. For example, they can be used to evaluate the relative importance of different variables. The influence of the proportion of PVY^O diseased potato plants serving as virus sources on the proportion of progeny tubers infected with PVY^O can easily be demonstrated for any given level and pattern of vector intensity.

If very young potato plants are inoculated with PVY^O they can act as virus sources relatively early in the season, when many alates are still migrating and thus increase the risk for PVY^O infection of progeny tubers. On the other hand if alates are migrating late the risk for PVY infection of progeny tubers will decrease dramatically because of greater mature plant resistance and a longer latent period. Also in this case there is good agreement between field data (Sigvald, 1985) and model output.

By taking the vector efficiency of a given aphid species into account along with the timing of its main flight period and number of individuals, the importance of the species as a PVY^O vector during a given year can be estimated. Thus an aphid species with a high vector efficiency that migrates early in the season, when the potato plants are very susceptible, may, nevertheless, be given a low vector-importance rating in the model if it generally migrates in low numbers, as is the case for *M. persicae*. Other studies have shown that *R. padi* can occasionally be an important vector under Swedish conditions (Sigvald, 1987, 1989). Hence, by running such simulations we can get a better understanding of the relative importance of different aphid species as vectors of PVY, thereby helping us in developing priorities for future research.

The effects of various cultural practices on disease incidence can easily be simulated. Removal of PVY^O-diseased potato plants before the main flight of the primary vectors can greatly reduce the proportion of progeny tubers infected with PVY^O. However, removal of diseased plants during or after the aphid flight period has little effect. Early haulm destruction decreases the PVY^O infection risk for progeny tubers. Simulations can also predict the effect of planting sprouted seed potatoes early.

Forecasting the incidence of potato virus Y

This study shows that the PVY^O simulation model can be used in forecasting the risk for virus spread. In Sweden, as well as in other countries, there are great differences in virus spread between years and regions (Sigvald, 1987). In Sweden during years when the incidence of PVY is low, there is no need to test progeny tubers after the harvest. Thus by using the simulation model to forecast PVY incidence, farmers would be allowed to not test progeny tubers for PVY during low-disease years, thereby reducing their operational costs. Similarly, disease incidence can be reduced by taking prophylactic measures at an early stage. However, such measures, e.g., mineral oil application, are too expensive to used on a routine basis; thus if the risk for PVY spread could be predicted, such treatments could be used more selectively, thereby reducing costs.

The seed potato grower would also benefit by being able to predict the proportion of progeny tubers infected in late summer. If there is a great risk that the level of infection of the tuber yield will exceed the threshold set for seed potatoes, it may be more profitable to delay haulm destruction and market the potatoes for consumption or industrial use (starch or ethanol). During the last five years the forecasting method presented here has shown great promise when applied under practical conditions.

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