13 Aphid Alert: How it Came to be, What it Achieved and Why it Proved Unsustainable

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Introduction

'Aphid Alert' was the name used to identify a series of research and outreach initiatives undertaken from 1992 to 2003, and in some instances since, to address potato virus problems in seed potato production in the US Northern Great Plains (NGP) of the USA, in particular north-western Minnesota and eastern North Dakota. Aphid Alert was adopted from the name of a pest management advisory newsletter sent to Minnesota and North Dakota seed potato growers in 1994, and again from 1998 to 2003.

The name found popular acceptance and was applied, even retroactively, to a series of related research/outreach activities. This chapter will focus primarily on the areawide aphid-trapping network operated by the University of Minnesota from 1992 to 1994, and again from 1998 to 2003. Data presented here on potato seed lot rejections due to potato viruses were provided by the Minnesota Department of Agriculture Seed Potato Certification Program (courtesy of Willem Schrage, potato programme supervisor). Data presented here on aphids (reported as numbers or percentages of total captures) are from the subset of traps that were located in the NGP portion of the network (see Fig. 13.1).

Virus Management in Seed Potato Production

Access to high quality, disease-free seed potatoes has been described as 'the single most important integrated pest management practice available to potato growers'

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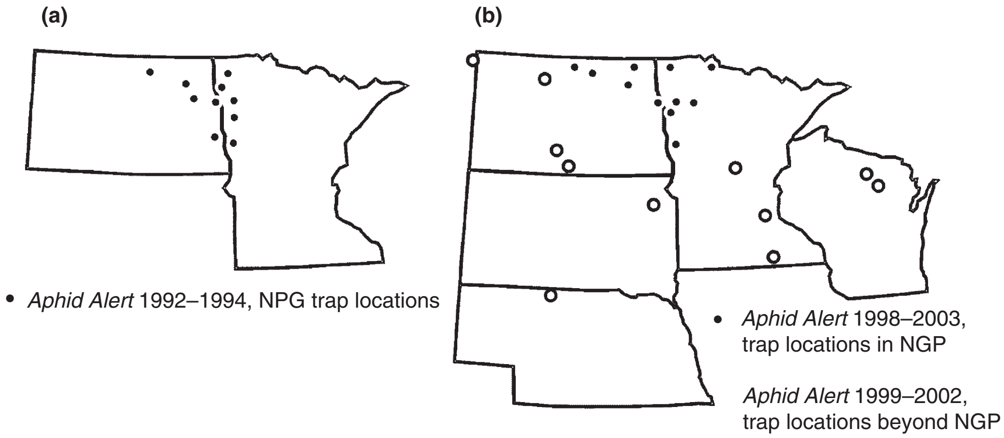

Fig. 13.1. Aphid Alert trap locations, 1992–1994 and 1998–2003.

(Gutbrod and Mosley, 2001) and is essential for successful commercial production. For almost a century, state-regulated seed potato certification programmes have been the primary mechanism for ensuring the cultivar integrity and tuber health of US seed potatoes (Rieman, 1956; Franc, 2001). Seed potato lots can be downgraded or rejected for recertification for a myriad of defects, but aphid-transmitted potato viruses far exceed all others.

Nearly all seed potato certification programmes use a limited-generation production system. Typical production systems permit field increase for five to eight generations. In modern practice, seed potato increase is initiated with tissue culture-derived seedlings tested by enzyme-linked immunosorbent assay (ELISA) to assure freedom from viruses. State seed certification programme personnel inspect seed potato increase fields periodically during the growing season, and representative samples of harvested tubers are indexed in a winter grow-out for virus or other defects. Tolerances for recertification are stringent for all generations (typically ranging from 0.0 to 1.0% total virus) and are usually relaxed incrementally with successive generations of increase.

Potato leafroll virus (PLRV) and Potato virus Y (PVY) are both aphid transmitted (for a discussion of vector biology see Robert and Bourdin, 2001; Radcliffe and Ragsdale, 2002). Transmission of PLRV is persistent and circulative in the body of the vector (Nault, 1997). PLRV can be acquired and transmitted only by aphid species that phloem feed on potato, but not all potato-colonizing species transmit PLRV. *Myzus persicae*, green peach aphid, is the most cosmopolitan, abundant and efficient vector of PLRV (Ragsdale *et al.*, 2001). All other aphid-transmitted potato viruses are non-persistent and borne on the insect's mouthparts (stylets). Many aphid species, including species that do colonize potato, are capable of transmitting PVY. *M. persicae* is the most efficient vector, but other potential vector species are often much more abundant and thus of greater importance in PVY spread in particular locations or years.

Association of the spread of aphid-transmitted potato viruses with aphid flight activity is well documented (Boiteau and Parry, 1985; Sigvald, 1989, 1992; Halbert *et al.* 1990; Pickup and Brewer, 1994). Therefore, trapping networks designed to monitor activity of aphid vectors have been used as decision tools for management of viruses in seed potatoes. In the early development of aphid-trapping networks in seed potato production, the focus was on *M. persicae* (Hille Ris Lambers, 1972). Once researchers recognized the importance of other less efficient but more abundant virus vectors to PVY spread (van Harten, 1983; Harrington *et al.*, 1986; Sigvald, 1987; Harrington and Gibson, 1989; Heimbach *et al.*, 1998), those operating aphid-trapping networks began routinely monitoring these species also. Over the past 50 years, aphid-trapping networks have existed, at least temporarily, in many countries. The oldest and most extensive of these is the EXAMINE (EXploitation of Aphid Monitoring systems IN Europe) network, which presently operates more than 70 suction traps (after the Rothamstead design), 12.2 m tall, in 19 European countries (Harrington and EXAMINE Consortium, 2007).

Generally, aphid-trapping networks are intended to monitor flight of vector species on a regional basis. At any particular location, e.g. an individual farm, flight activity may not be detected because aphid populations are low or the trap site not representative. Other limitations are that the traps may not be monitored frequently enough and that expertise in aphid taxonomy is required to identify the captured aphids to species. However, traps can be effective in detecting sudden influxes of winged aphids into seed potatoes from other crop or weed hosts in the immediate vicinity. This information can be used to time application of foliar aphidicide or crop oil, or in early vine kill where tuber development and yield permit.

Seed Potato Production in Minnesota and North Dakota

Minnesota and North Dakota ranks as the third largest potato-growing region (180,000 ha) in the USA, producing over 2 million t of potatoes per year (USDA/NASS, 2007). Seed potatoes represent an important component, 15–20%, of the on-farm value of this production. Minnesota and North Dakota have had the reputation of being especially favourable for seed potato increase, in part because of a 'northern vigour' imparted by growing conditions, but mostly because historically the region seemed relatively free of aphid-transmitted potato viruses.

In 2006, Minnesota and North Dakota produced 21.7% (12,300 ha) of the seed potatoes certified in the USA (NPC, 2006). However, as recently as 1990, Minnesota and North Dakota produced 31.4% (22,500 ha) of US certified seed potatoes (Slack, 1993). The number of Minnesota and North Dakota farming operations growing seed potatoes has declined to less than half the number that did so in 1990. Many of those who quit were second- and third-generation seed potato growers. The major contributing factor in their decision to quit growing seed was the persistent occurrence of aphid-transmitted viruses, especially PVY. Frequent seed lot rejections make production economically unsustainable, since investment in early-generation seed production cannot usually be recouped before at least three generations of increase.

Aphid/Potato Virus Research at the University of Minnesota

Research on insect-transmitted plant diseases has a long tradition at the University of Minnesota. Entomologist A.A. Granovsky was hired to collaborate with pathologist

J.D. Leach in research on insect-transmitted plant pathogens, and they first co-taught a course on the subject in 1931. In later years, Granovsky became an expert aphid taxonomist and assembled a large reference collection, still maintained at the University of Minnesota. That collection was to prove invaluable in the implementation of Aphid Alert, being used by project personnel to hone skills in aphid identification and as a reference for confirming identifications of less common aphid species.

Much of the early University of Minnesota research on potato viruses (i.e. prior to Aphid Alert) was focused on PLRV and *M. persicae*. With the emergence of PVY as a major concern to the Minnesota/North Dakota seed potato industry in the mid-1980s, attention shifted to PVY. Our first large-scale field experiments on PVY were carried out at Rosemount, Minnesota in 1991. This location, far from any seed potato production, was selected because of seed grower concerns that research using PVY inoculum sources might present a risk to nearby seed potato production. Insecticide efficacy trials were conducted, with all foliar sprays applied by helicopter to avoid risk of mechanical spread of virus by machinery moving through the plots. None of the aphidicides tested in 1991, all products then commonly used on potato, reduced PVY spread. However, in other experiments we found no evidence of mechanical transmission of PVY in seed handling or from machinery moving through the field during cultural operations, thereby allaying that grower concern (Banttari, 1993). Lack of mechanical transmission of PVY has since been confirmed in New Brunswick (Sturz *et al.*, 2000).

Most of our post-1991 aphid/virus research was done in collaboration with the Minnesota/North Dakota potato industry, on grower-owned seed farms or university experiment stations near NGP seed potato production. Significant funding for this research was provided by: (i) the Red River Valley Potato Growers Association (a commodity organization representing NGP potato growers and now known as the Northern Plains Potato Growers Association); (ii) the Minnesota Area II Potato Promotion and Research Council; (iii) Minnesota Certified Seed Potato Growers Association; and (iv) the North Dakota Seed Potato Growers Association. Minnesota Agricultural Experiment Station and competitive grants provided additional funding from USDA/CSREES, NC-IPM. Cooperators, among others, in this effort included the Minnesota Extension Service-IPM Program, plant pathologists at North Dakota State University, the state seed potato certification programmes in Minnesota and North Dakota and a number of leading seed potato growers in Minnesota and North Dakota.

Aphid Alert, 1992–1994

Knowledge of which vector species are present, their abundance and comparative efficiency in transmitting PVY, is necessary to design area-specific management practices to limit spread of the virus. The Aphid Alert trapping network was established to provide this information for the NGP seed potato industry. The first iteration of the Aphid Alert network, operated from 1992 to 1994, was primarily research driven and only secondarily intended for providing seed producers with current-season pest management advisories. Trapping was done each year on five to eight owner-operated seed potato farms and one or two university experiment stations (see Fig. 13.1a).

Traps consisted of green and yellow ceramic tiles (Dal-Tile, Dallas, Texas) placed individually in 1.4 l plastic containers (Servin Saver, Rubbermaid, Wooster, Ohio) partially filled with a 50 : 50 mixture of technical grade propylene glycol and water (DiFonzo *et al.*, 1997). Four traps, two green and two yellow, were used at each location. The green tiles were intended to mimic foliage and provide an unbiased measure of aphid landing rates (Irwin, 1980), whereas yellow was selected because it is attractive to certain aphid species, especially *M. persicae* (Eastop, 1955). Traps were emptied weekly and the collected aphids counted and identified to species, but species identification of other than *M. persicae* was not completed until after the growing season.

To determine the phenology of PVY spread, healthy, potted, indicator plants (equal numbers of *Physalis pubescens* (= *floridana*) and potato) were exposed on bait boards to aphid landing for 1-week intervals at each aphid trapping site (DiFonzo *et al.*, 1997). The bait boards were 1.9 cm plywood with an area of 1.2 m^2, painted either yellow to attract *M. persicae* or brown to mimic soil. One board of each colour was placed at each site. Eight indicator plants were arranged in a circle on each board, with a PVY-infected potato plant placed in the centre. We tested the hypothesis that aphids would land by chance on the infected plant, acquire PVY and then transmit the virus to the adjacent indicator plants.

After exposure, the indicator plants were moved to an aphid-proof screen cage, held for 6 weeks and then tested for PVY by ELISA. This identified the time frame during which PVY transmission occurred most frequently. Comparison of these data with aphid captures in the tile traps was used to infer association of PVY spread with the abundance of specific vector species. For example, across the 3 years, 89% of PVY transmissions to indicator plants occurred between 8 July and 19 August, suggesting that cereal aphids – e.g. bird cherry-oat aphid, *Rhopalosiphum padi*; corn leaf aphid, *R. maidis*; greenbug, *Schizaphis graminum;* and English grain aphid, *Sitobion avenae* – were important PVY vectors in the NGP.

Aphid Alert newsletter

A 1994 USDA/CSREES North Central IPM (NC-IPM) grant funded a University of Minnesota 'research/demonstration' project on use of crop borders to reduce PVY spread in seed potatoes (DiFonzo *et al.*, 1996). A component of this project was distribution of a printed newsletter, *Aphid Alert*, mailed weekly from mid-summer to harvest to all Minnesota and North Dakota seed potato-farming operations. This newsletter was originally envisioned as a vehicle to promote use of crop borders as a means of limiting PVY spread. However, it was also used to provide 'real-time' summaries of aphid capture data from the aphid-trapping network and report other observations, e.g. updates on the status of cereal aphids, thus alerting seed potato growers that these potential PVY vectors were about to leave their cereal hosts and move into adjacent crops.

After the 1994 growing season, with the initial research objectives largely accomplished, the Aphid Alert trapping network was discontinued. Happily for NGP seed potato growers, 1993 was a year of exceptionally low vector pressure (as indicated by aphid captures in the Aphid Alert trapping network) and, that year, potato seed lot rejections were well within historic norms. Unfortunately, this respite proved to be temporary and, by 1997, potato seed lot rejection levels were again considered disastrous, this time with both PVY and PLRV at epidemic levels. Seed potato growers lobbied the University of Minnesota to reactivate the Aphid Alert network and the Minnesota Legislature to provide funding to support research on potato viruses.

Aphid Alert, 1998–2004

In spring 1998, the Minnesota State Legislature authorized the Rapid Agricultural Response Initiative, providing flexible funding to enable University of Minnesota researchers to respond to emerging urgent issues that affected Minnesota's agriculture and natural resource-based industries. An initial allocation of US$1.5 million was provided for designated projects in 1998, and a recurring allocation of US$1 million was created in 1999. One of the first 'Rapid Response' projects funded, 1998–2001, was to develop approaches for managing aphid-transmitted viruses in seed potatoes (Suranyi *et al.*, 1999). Additional projects with Aphid Alert in their title, or that were specifically represented as complementary when proposed, were funded by the Red River Valley Potato Growers Association, the Minnesota Area II Potato Promotion and Research Council and several competitive grants. Sponsors of one or more of these complementary grants included USDA/ARS, NC-IPM, USEPA and the Rapid Agricultural Response Fund. Total extramural funding for Aphid Alert, 1992–1994 and 1998–2004, was in the range of US$1.5 million. Research units participating in Aphid Alert 1998–2003 included all that had participated in Aphid Alert 1992–1994.

In 1998, the aphid-trapping network was re-established, this time using low-volume (2.4 m^3/min) suction traps and green tile traps. Most locations had one suction trap and two green tile pan traps, but from 1998 to 2002 some locations had only pan traps. The suction traps were miniaturized versions (2.3 m tall) of the 8.5 m model designed to monitor wheat aphid, *Diuraphis noxia*, in western USA (Allison and Pike, 1988).

The project began with traps at 12 locations throughout Minnesota and North Dakota in 1998 and, eventually, in 2001 it was introduced in five states and 26 locations. Nebraska, South Dakota and Wisconsin were included from 2000–2002, and a location in Montana was added in 2002. In the final year of the project, 2003, traps were operated at eight Minnesota and North Dakota locations only. A parallel aphid-trapping network was instituted in Manitoba, Canada in 2003, and that network has continued to operate (Manitoba Agriculture, Food and Rural Initiatives, 2007).

Traps of both networks were emptied weekly and within 2 days the aphids were identified to species, counted and the data reported to seed potato growers via a renewed *Aphid Alert* newsletter, this time also published on the Internet (httm://www.ipmworld.umn.edu/alert.htm), and distributed by e-mail to over 800 persons worldwide. The electronic *Aphid Alert* newsletter provided seed potato growers with near real-time information on vector abundance. Information presented in Aphid Alert was used by growers in making pest management decisions, e.g. in timing the application of aphidicide or crop oil or to 'vine-kill' early. Every edition of the newsletter contained information, and often short articles on some aspect of vector/virus biology, ecology and management. Information on the management of other potato pests was included when appropriate. For many growers, and even crop consultants and seed certification personnel, much of this information was both new and of immediate practicality. One grower self-reported keeping every issue of *Aphid Alert* (over 75 in all were produced) for permanent reference.

Aphid captures

More than 57,000 aphids representing 41 species or species complexes were captured during the 9 years of Aphid Alert trapping. Aphid abundance in the NGP, as measured by cumulative captures per trap, varied widely from year to year in both total numbers and species composition. Overall, 95% of the aphids captured were identified to species. About 90% of the identified aphids identified belonged to 16 species reported in the literature as being capable of acquiring and transmitting PVY.

Three potato-colonizing species, *M. persicae*, *Macrosiphum euphorbiae* (potato aphid) and *Aphis nasturtii* (buckthorn aphid), were collected regularly, but most years represented less than 5% of total captures. *Myzus persicae* constituted from 0.2% (2001) to 13.1% (1999) of total aphid captures, but exceeded 2% of total captures only in the years 1998–2000. Cumulative captures of *M. persicae* ranged from a high of 687 in 1999 to lows of 7 (0.4% of total captures in 1993) and 5 (0.04% of total captures in 2001) (see Fig. 13.1).

Abundant among the species captured that do not colonize potato were sunflower aphid, *Aphis helianthi*; turnip aphid, *Lipaphis pseudobrassicae* (= *erysimi*); *R. maidis*; several common cereal aphids including *R. padi*, *S. avenae*, *S. graminum* and soybean aphid, *Aphis glycines*. The latter species, a recent introduction to North America (Venette and Ragsdale, 2004) and an efficient vector of PVY (Davis *et al.*, 2005), was first detected in NPG trap captures in 2001, but has been abundant in the NGP since. Most of the potato non-colonizers were aphids associated with annual crops common to the NGP including small-grain cereals, maize, canola, soybean and sunflower. However, a few, including *Capitophorus* spp., *Hayhurstia atriplicus* and mealy plum aphid, *Hyalopterus pruni*, preferentially colonize various broadleaf weeds and grasses.

Virus Trends in Minnesota and North Dakota Seed Potatoes

For at least 30 years prior to the mid-1980s, Minnesota seed potato lots were seldom rejected for recertification because of PVY (Robinson, 1978). It is possible that the prevalence of PVX in those years made it much easier to identify and rogue infected plants. Multiple infections of PVX and PVY (i.e. strain PVY^{O}, the only variant of PVY known to occur in North America prior to 1990 (Singh, 1992)) tend to be expressed as 'severe mosaic'.

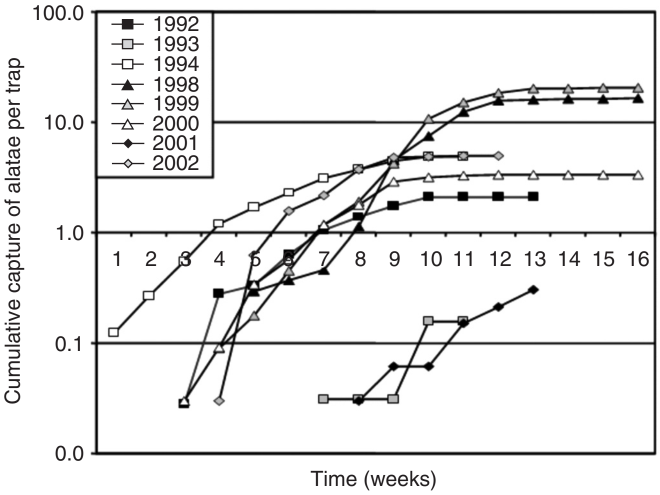

Fig. 13.2. Cumulative capture of *M. persicae* per trap in NPG, 1992–1994 and 1998–2003; week 8 ends on or before 8 August.

PVY first emerged as a major concern for NGP seed potato producers in 1988. That year, 8.2% of seed lots entered into the Minnesota Seed Potato Certification Program winter grow-out were above tolerance for PVY, with nearly twice that percentage in 1989 and 1990 (see Fig. 13.3). The PVY epidemic reached its initial zenith in 1991, when a previously unprecedented 32.1% of Minnesota seed potato lots were not eligible for recertification because of severe mosaic (a classification that supposedly distinguishes PVY from other foliage-mottling viruses, e.g. Potato virus S, that tend to express as 'mild mosaics'). The situation was somewhat better in 1992, when Minnesota seed lot rejections due to PVY dropped to 19.1%. This phase of the epidemic effectively ended in 1993, a year in which the abundance of all vector species was exceptionally low.

However, PVY quickly rebounded, again reaching catastrophic proportions across the region in 1997, this time with PLRV also increasing to epidemic proportions (see Fig. 13.4). That year, 19.3% of Minnesota seed lots were above threshold for PVY and 23.7% were above the threshold for PLRV. Unfortunately, this was but a harbinger of what was to come. The following year, 52.2% of Minnesota seed potato lots were above tolerance for PVY and 31.1% above tolerance for PLRV. On average from 1988 to 2006, 29.1% of all seed lots entered into the annual Minnesota Seed Potato Certification Program winter trials exceeded tolerance for PVY, and from 1997 to 2000, 28.8% of seed lots also exceeded tolerance for PLRV. However, seed potato lots with appreciable PLRV usually also had PVY sufficient to cause rejection even if PLRV had not been present. The PLRV epidemic ended with the 2001 season (a year with low *M. persicae* abundance), but PVY has remained at high prevalence to the present. Since 1997, Minnesota seed lot rejections due to PVY have ranged from 28.3% (2001) to 61.8% (2004).

Prevalence of PVY in the seed potato production system has been persistent and particularly severe in Minnesota, but this problem is not unique to Minnesota and

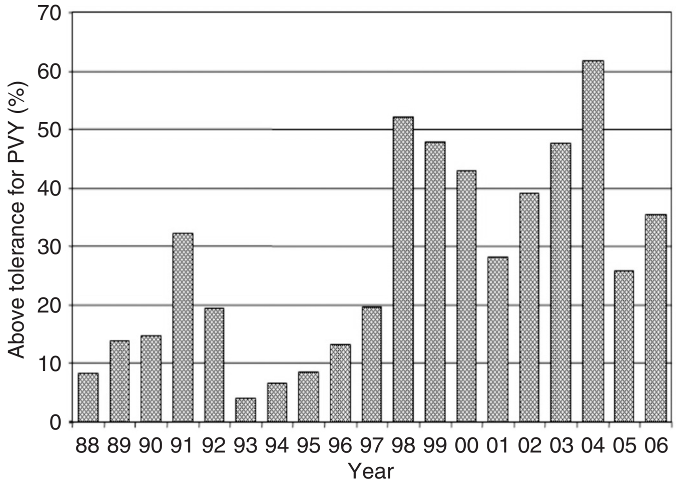

Fig. 13.3. Percentage of Minnesota seed potato lots above tolerance for PVY in winter grow-out, 1988–2006.

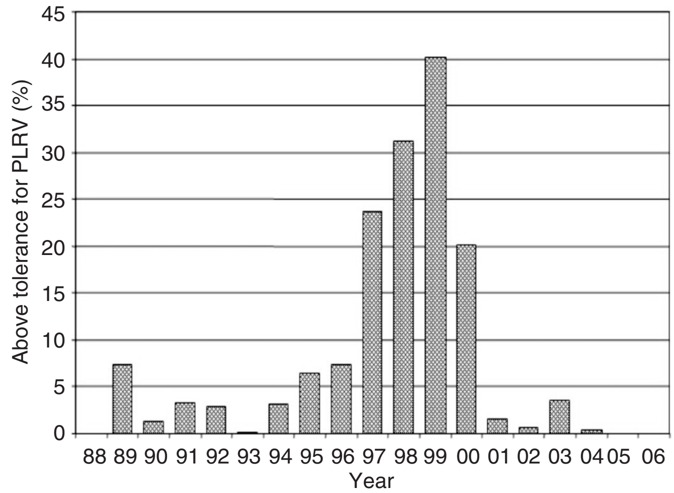

Fig. 13.4. Percentage of Minnesota seed potato lots above tolerance for PLRV in winter grow-out, 1988–2006.

North Dakota. Over the past 20 years, North American seed certification programmes have proved increasingly unsuccessful in purging PVY from state and national seed potato production systems. Many factors are suspected as contributing to this problem, including the emergence of new PVY strains. Since 2004, PVY^{N} (the 'tobacco veinal necrotic strain' of PVY) and $PVY^{N:O}$ recombinants have largely replaced PVY^{O} as the dominant PVY strain in North America (Crosslin *et al.*, 2002; Piche *et al.*, 2004; Davis, 2006). The effects of PVY^{N} and $PVY^{N:O}$ are generally mild, or even undetectable, in most potato cultivars, thus reliance on visual indexing for purposes of seed certification has become problematic (Singh and Singh, 1997; Sturz *et al.*, 1997; Singh *et al.*, 1999, 2003). This has made rouging difficult if not impossible for most growers, and tends to compromise the reliability of current-season virus readings and visual indexing of winter grow-outs by seed potato certification programmes (Davis, 2006). Moreover, it is now recognized that late-season infection with PLRV can go undetected in winter grow-outs, particularly so if indexing is terminated early. In the 2007 Minnesota winter grow-out (2006 crop), no seed lots were rejected for PLRV, but our serological assays showed the virus to be prevalent (data unpublished).

Molecular testing (polymerase chain reaction (PCR)) is the only method that can provide absolute assurance that a potato seedling is free of virus. Serological testing is a more realistic alternative, but even that is time-consuming and expensive compared with visual virus indexing. Serological testing of foliage from all the plants grown in a state seed potato certification programme winter grow-out would be a formidable task, and is perhaps impractical because of the handling time required to collect and process such a high volume of samples. Moreover, present seed certification regulations specify visual indexing as the standard to be used. Also, there could be an economic disadvantage to being the first certification agency to use more sensitive testing methods, especially in situations where there are two states growing seed in the same landscape, as is the case in the NGP.

Other factors suggested as contributing to the present PVY problem include:

- The popularity of certain essentially asymptomatic cultivars (Souza-Dias and Slack, 1987; Russo *et al.* 1999; Mollov and Thill, 2004).
- The introduction of a new vector (*A. glycines*) that has changed the dynamics of PVY epidemiology in the NGP by contributing massive aphid flights in early summer when potatoes are most susceptible to infection (Davis *et al.*, 2005).
- Changing cropping systems (e.g. expansion of canola and soybean production in the NGP).
- Changing pesticide use patterns; for example, the Colorado potato beetle, *Leptinotarsa decemlineata*, developed resistance to all classes of insecticides in common use in the NGP in the 1980s and early 1990s, leading to intensive spray schedules that tended to flare *M. persicae* populations; and emergence of more virulent strains of the potato late blight pathogen, *Phytophthora infestans* DeBary, necessitated greatly increased use of protective fungicides that in turn interfered with aphid entomopathogens, thus favouring *M. persicae* survival (Lagnaoui and Radcliffe, 1998).
- Perhaps even global warming (Davis, 2006). The only element that could end this epidemic would be the development of certain and efficient means of eliminating PVY inoculum from the seed production system and immediate landscape.

In the NGP there are no known perennial hosts of PLRV, and thus potato is the only source of PLRV inoculum. However, there is limited isolation of seed potato production from commercial (ware) production. That, and the fact that seed lots passing summer inspections can be sold for ware production even if they are not tested in a winter grow-out or exceeded tolerance for virus in the grow-out, tends to ensure the presence of virus inoculum in the vicinity of seed production.

The Rise and Fall of Aphid Alert

A review of the origin and eventual demise of Aphid Alert may be instructive to others contemplating development and implementation of areawide pest management programmes. The primary impetus for initiation of this programme of research and outreach came from the potato industry. The support was broad, and initially included not only seed potato growers and state seed certification programmes, but also ware producers and processors. Seed potato production, per se, represents a comparatively small sector of the overall NGP potato industry, whether measured by number of growers, hectares, tuber yield or dollar sales, but all recognized the essential importance of clean seed. There was an imperative for the initiation of the Aphid Alert programme because a seed production system that had seemed relatively secure suddenly presented extreme economic risk.

Potato production is a highly specialized and technically sophisticated form of agriculture. Potato growers tend to be innovators and, not surprisingly, strong supporters of scientific research. The Aphid Alert could not have been implemented on the scale that it was without the substantial funding provided by the various potato grower organizations and the on-site cooperation of participating seed potato growers. Indeed, we had many more invitations to locate traps on farms than we could accept because of the impracticality of our handing a greater number of samples. However, while these groups and individuals provided financial support for the research we considered part of the overall effort to address the problem of PVY, and continued to support virus-related research, grower perception of Aphid Alert tended to be narrower than that. For them, Aphid Alert was the aphid-trapping network and weekly newsletters. Clearly, seed potato growers valued this service. A survey of seed growers at the end of the 1999 growing season indicated that 78% of respondents ($n = 35$) used information presented in the newsletter to make pest management decisions (Radcliffe and Ragsdale, 2002).

Over the 9 years that the Aphid Alert trapping network was in operation, grower organizations and the Minnesota Legislature's Rapid Response Initiative provided more than two-thirds of the funding that directly supported that activity and newsletter. We were able to leverage this support to advantage in competing for extramural grants that permitted accomplishment of a wide range of complementary research studies.

These included research on:

- The use of crop borders to limit PVY spread (DiFonzo *et al.*, 1996).
- The impact of potato fungicides on *M. persicae* populations (Ruano-Rossil *et al.*, 2001).
- The use of crop oils to limit spread of PVY (Suranyi, 2000).
- The role of landscape ecology and aphid behaviour on the dynamics of vector dispersal and virus spread (Carroll, 2005).
- Site-specific targeting of foliar insecticide applications for *M. persicae* control (Carroll *et al.*, 2007).
- The development of meteorological models using the duration of low-level jets to predict *M. persicae* abundance and virus spread (Zhu *et al.*, 2006).
- The transmission efficiencies of vector species (Davis *et al.*, 2006).

- The virus strain presence in Minnesota (Davis *et al*., 2006).
- The reliability of various methodologies of virus detection for purposes of seed certification (Davis *et al*., 2006).

In many respects Aphid Alert was a success. Seed potato growers tended to be strongly supportive and many were quick to adopt new control technologies, e.g. scouting for aphids, using insecticides more selectively, using crop borders, applying crop oils, earlier planting and vine kill and targeting application of insecticides – i.e. a single spray width applied by aircraft to field margins bordering fallowed land (e.g. headlands) for control of newly colonizing *M. persicae* (Carroll *et al*., 2007). The latter provided excellent aphid control while reducing use of foliar aphidicides by over 90%. There seemed to be consensus within the potato industry that the annual benefits of adopting these practices greatly exceeded the research investment (Agricultural Utilization Research Institute, 2002). The trapping network also provided data essential for accomplishing several of the research studies, particularly the third and fourth items on the above list.

So why did the Aphid Alert trapping network prove unsustainable and could its demise have been prevented? Before addressing those questions we must ask: what were the failures or shortcomings of Aphid Alert, and could these have been corrected? The most obvious failure of Aphid Alert is that the current PVY epidemic has persisted in the NGP since 1994. In contrast, the PLRV epidemic of 1997–2000 ran its course and ended. It is obvious that the PVY problem will not be solved quickly, and perhaps will remain intractable so long as growers are obliged to rely on current technologies.

Farmers still tend to think of aphidicides as their primary defence against current-season spread of insect-transmitted viruses, but such use has proved to be of inconsistent benefit (Perring *et al*., 1999). Movement of aphid-transmitted viruses into clean potato fields from outside inoculum sources is almost exclusively by winged aphids (Boiteau, 1997). Insecticides are seldom of any benefit in preventing the spread of either non-persistent viruses (e.g. PVY) (Perring *et al*., 1994; Ragsdale *et al*., 1994) or persistent viruses (e.g. PLRV) by winged aphids already capable of transmission (Hanafi *et al*., 1995). Movement of PVY and other non-persistently transmitted viruses is thought to be almost exclusively by winged aphids because their transmission requires no latent period in the vector, and ability to transmit is lost in the first few feeding probes following acquisition (Ragsdale *et al.* 1994).

In contrast to PVY, within-field spread of PLRV is often by apterae walking from plant to plant (Hanafi *et al*., 1989). Insecticides targeted against aphid vectors, either as systemics at planting or as foliar sprays when needed, tend to be effective in preventing spread of PLRV from within-field sources because the time lag between acquisition of the virus and onset of ability of the vector to transmit is sufficient for the insecticide to have effect (Woodford *et al*., 1988; Hanafi *et al*., 1989; Flanders *et al*., 1991; DiFonzo *et al*., 1995; Boiteau and Singh, 1999).

Weekly application of crop oil can provide considerable protection against the spread of non-persistent viruses (Boiteau and Singh, 1982; Secor *et al*., 2004). Thus, it is useful to know when aphids begin flying, even for PVY. However, since species composition and abundance of aphid populations tends to vary greatly between locations and years (DiFonzo *et al*., 1997, Suranyi, 2000), a more site-specific monitoring of vector populations may be required to be useful as a decision tool in PVY control.

Breeding for aphid and virus resistance offers some promise (e.g. Novy *et al.*, 2002; Davis, 2006), but will take many years to accomplish by conventional plant breeding. Cultivars have been genetically transformed to express resistance to both PLRV and PVY (Brown *et al.*, 1995; Berger and German, 2001). While this novel technology proved far more effective in reducing virus spread than presently available tactics, these cultivars have been withdrawn from the market because they were not accepted for fear of possible public backlash against the technology (Thornton, 2003).

One major shortcoming of the Aphid Alert project was that the service component, i.e. operation of the network, identifying the insects and reporting the trap results to growers on a near real-time basis, fell upon personnel whose professional responsibility was primarily or exclusively research. While undergraduate technicians were used in assisting with some of the more routine aspects of this work, most aspects of establishing and maintaining the network and all of the aphid identification was assumed by graduate students. This worked because the graduate students had dissertation projects that necessitated obtaining aphid capture data. However, as a service function, operation of an aphid-trapping network was not an appropriate activity for a research university.

The benefits to the seed potato industry might have justified the annual investment required, but implementation was not simple. Realistically, this was not an activity a grower organization would want to assume, even if they were prepared to finance the operation. An assessment of ~US$7.50/ha would be adequate to support an aphid-trapping network in the NPG if all Minnesota and North Dakota seed potato growers contributed. The most appropriate agency to operate such a network might be the State Department of Agriculture, possibly as an activity of the potato seed certification programme.

Appreciable seed rejections in the NGP due to PLRV have not occurred since 2000. This made the service of aphid trapping network less of an imperative for seed potato growers. However, considerable PLRV inoculum is still present in the NGP seed potato production system. A year of high *M. persicae* abundance could easily produce a PLRV epidemic comparable to that experienced in the NGP from 1997 to 2000. The seeming intractability of the PVY problem made it inevitable that the grower organizations would eventually want to reprioritize their research investments. Although clean seed is an essential requirement for potato production, the industry faces many other challenges and the dollars available to these associations to support research are mostly from assessments paid by growers producing for processing or fresh market. The fact that seed potato production in this region crosses state, and indeed international, boundaries presents a further complication in the financing and coordinating of an areawide aphid-trapping network.

In spite of the importance of PVY in seed production ware producers have not been unduly impacted, as there is still sufficient certified seed being produced. However, the presence of new PVY strains, especially the recent introduction of PVY^{NTN} (Singh *et al.*, 2003), could make PVY very much of an industry problem; PVY^{NTN} ('tuber necrosis subgroup') infection can cause serious tuber defects (potato tuber necrotic ringspot disease, PTNRD) and breakdown in storage. Effects of PVY^{NTN} are so devastating on tuber health that the disease tends to be self-eliminating. Most NGP seed potato growers would probably like to see restoration of the Aphid Alert network, but to be cost-effective such a network would need to serve a broader group of commodities, e.g. soybean growers and producers of small-grain cereals.

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