Aphids, Their Biology, Relationship to Virus, the Value of Neonicotinoids

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The 2019 Washington-Oregon Potato Conference was marked by the absence of several USDA Agricultural Research Service scientists and their presentations due to the 'partial government shutdown.' The material below was compiled and presented as one of the necessary substitutes. I had hoped to review four subject areas relevant to aphids:

1. Key biological features, excerpted from a recent *Potato Progress* article (Volume 18, Number 12).
2. The important biological relationships between aphids and potato viruses.
3. Some key points about aphid management, including the value of neonicotinoid insecticides in aphid and virus management since the mid-1990s.
4. Monitoring aphids in potato.

The emphasis here is on the commercial crop. Covering aphid and virus management in potato seed is a book-length subject and beyond the scope of this article.

General aphid biology review.

Quite a lot of pest management effort is directed toward aphids on potato. Therefore, as a review for many of you, and to provide a learning resource for people new to aphid biology and their interaction with potato, I thought I would prepare the following primer.

Facts of aphid biology

Aphids have several unusual or unique biological features that are useful for pest managers and crop producers to understand.

Aphids are all parthenogenetic and viviparous, with telescoping generations and seasonal polyphenism.

- Parthenogenesis is the reproductive strategy wherein females produce offspring that are genetic copies of themselves without mating with males. All aphids display parthenogenesis, but most also have one generation per year of sexual reproduction (see below).

- Viviparity is the practice of giving birth to live young. It is in contrast to oviparity, which is the practice of laying eggs. All aphids display at least one generation per year of viviparity, but most also have one generation per year of oviparity (see below).
- Telescoping generations refers to the fact that aphids are developing young inside them from a very early age. In fact, most aphids are pregnant when they are born! In many species, therefore, a female aphid begins to deposit offspring within a few hours of molting to the adult stage.
- Seasonal polyphenism refers to aphids' ability to produce multiple types of adults through the course of the season. Most aphids are completely without wings and are known as apterous. Almost all aphid species can also produce winged females, known as alate. Remember parthenogenesis? It's interesting to bear in mind that a single female aphid can produce offspring that are genetically identical but are a mix of wingless and winged. Other specialized forms include the viviparous female that hatches from the egg in spring, which is known as the fundatrix; the fundatrix can be similar to others of her species or have bizarre morphology and extreme reproductive capacity. Finally, most aphid species can produce males and egg-laying females; males can be either winged or wingless depending on the species, and egg-laying females are almost always wingless.

Figure 1. *Uroleucon sonchi* giving birth on sow thistle. Photo by the author.

Aphid species are generally divided into three life cycle strategies known as heteroecious, autoecious, and anholocyclic.

- Heteroecious aphids are also known as migratory or host-alternating. These species overwinter as eggs on a woody shrub, vine, or tree. Eggs hatch and two or a few generations develop on that host. Then, a generation will form that is mostly or entirely winged, and those females will migrate to completely unrelated species of plants and reproduce on them all growing season. Finally, a special kind of winged female and winged males are produced, which migrate back to the woody host. There, the males mate with egg-laying females. Both common aphids affecting potato in the Northwest are heteroecious:

Figure 2. A *Nearctaphis* fall migrant on mountain ash with her new born young. Photo by the author.

green peach aphid (*Myzus persicae*) and potato aphid (*Macrosiphum euphorbiae*). Green peach aphid uses peach (and some close *Prunus* relatives) as winter host, while potato aphid uses roses, both wild and cultivated, as winter host.

- Autoecious aphids lack this alternation between unrelated host plants, but otherwise have a similar biology of overwintering eggs, wingless and winged females throughout the growing season, then males and egg-laying females in the fall.
- Anholocyclic aphids survive completely without sexual reproduction, having only wingless and winged females. Species with this strategy live in warm climates or indoors. Some aphids can be anholocyclic when living in warm places. For example, both green peach aphid and potato aphid can be anholocyclic in places such as the Willamette Valley of Oregon, and even in the Columbia Basin or southwestern Idaho during mild winters.

Aphids feed on plant sugary sap, which is known as phloem sap (in contrast to the watery sap in the xylem). A few species of aphids feed on non-vascular plants such as mosses. Phloem sap is high in energy but low in nitrogen, a crucial element for production of protein. This means the aphid must process large volumes of sap and excrete the excess sugar in its honeydew.

Most aphids are very host-specific, able to feed and reproduce on only one or a handful of plant species. The most familiar pest aphids, however, are examples of 'polyphagous' feeding biology, that is, they can develop on many plant species. Both potato aphid and green peach aphid are examples of polyphagy and are known to accept hundreds of plant species as hosts.

Some favorite host plants for green peach aphid and potato aphid are also common weeds in potato production (e.g. nightshades, lamb's quarters, pigweeds, tumble mustards and other weedy mustards, stork's bill) or crop plants (e.g. canola and other cole crops). Both species are known to develop on grains like corn or wheat, or legumes like beans, peas, or alfalfa, but do so only **very rarely**.

Important biological relationships between aphids and potato viruses.

Aphids are important pests of potato because they can transmit two important viruses: *Potato leafroll virus* (PLRV) and *Potato virus Y* (PVY). The biology of these two systems differs in extremely important ways that cannot be reviewed often enough. The first of these viruses can be controlled by eliminating or prohibiting aphids from reproducing in the potato crop, while the latter virus *cannot be controlled using insecticides alone*. Below I will explain some of the biology underpinning this difference.

<u>The situation with PLRV.</u>

PLRV is in the category of viruses known as persistent and circulative. This phrase describes the transmission biology of the virus by the aphid, illustrated and described in Figure 3. Briefly, PLRV lives in the phloem system of the plant, a phenomenon called phloem-limited. This means that for an aphid to acquire the virus from an infected plant, it must feed in the phloem system of the plant. Contrary to what might be intuitive, it takes aphids many minutes, up to half an hour or more, to reach the phloem of their host plants. The process is not unlike drilling an oil well, the aphid stylets winding their way among the other kinds of plant cells between the surface of the leaf or stem and the phloem. Once the virus has been consumed by the aphid, it must circulate through the gut wall, into the "blood" (a.k.a. hemolymph) and from there into the salivary glands. This process takes several hours, during which the aphid is exposed to any insecticides present in or on the plant. Once thus infected, an aphid can transmit PLRV for the rest of its life.

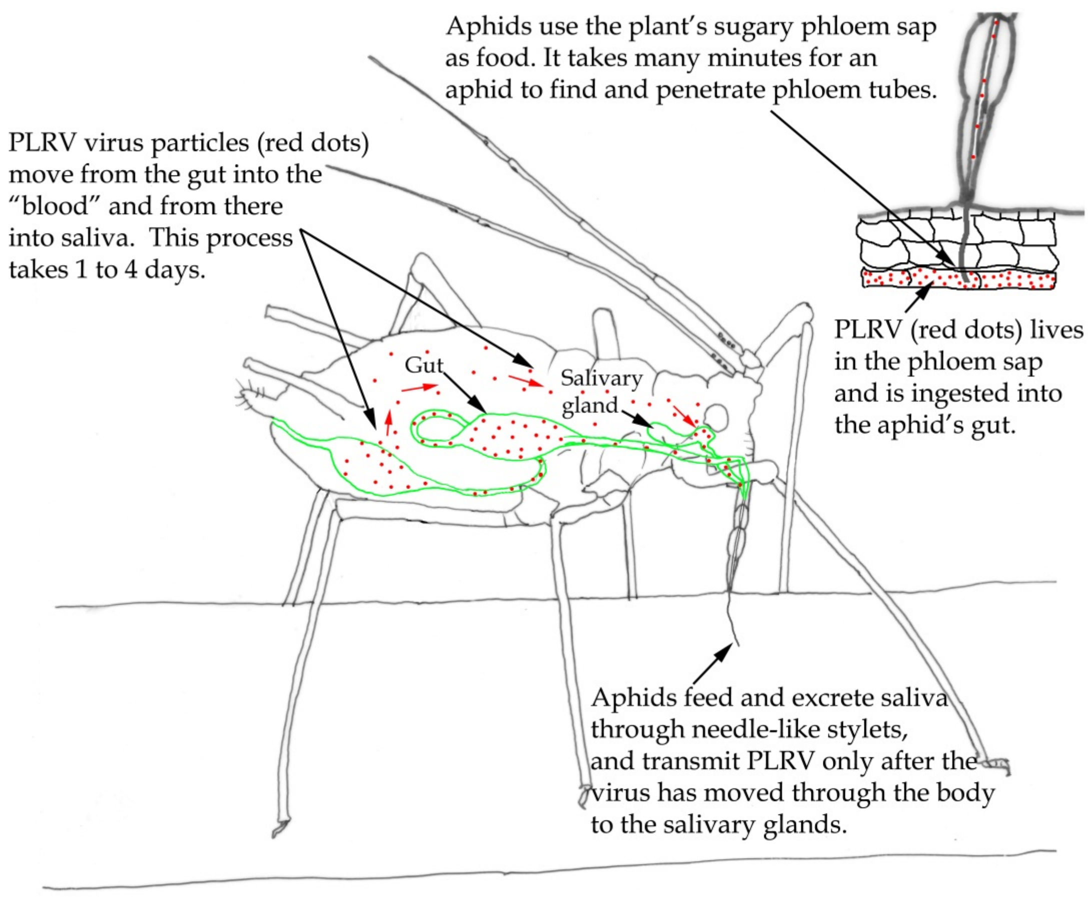

Figure 3. Details of PLRV transmission biology. The most important fact here is that from acquisition to transmission, an aphid must feed on potato for a period measured in days. This means that only aphids that can tolerate potato as food and reproduce on it can transmit PLRV. It also means that insecticides have plenty of time to act before an infected aphid can transmit PLRV. Illustration by the author.

The situation with PVY.
Transmission of PVY, on the other hand, is rapid and infected aphids lose the virus very quickly, a transmission style known as non-persistent (Figure 4). It relies on the fact that as aphids settle on a plant they test it for suitability as a reproductive host by briefly probing the leaf cells with their needle-like mouthparts called stylets. PVY is taken up during these brief tasting probes, adheres to the inside of the stylets and other foregut parts with the help of a specialized viral protein known as helper component, and can immediately be discharged into a plant the next time the aphid probes. It takes only a few probes after acquisition for the aphid to lose all its attached virus particles and become non-infective. The key points here for PVY management include, 1) aphids unable to colonize potato can transmit PVY, but only those aphids whose stylets and foregut can effectively interact with PVY's

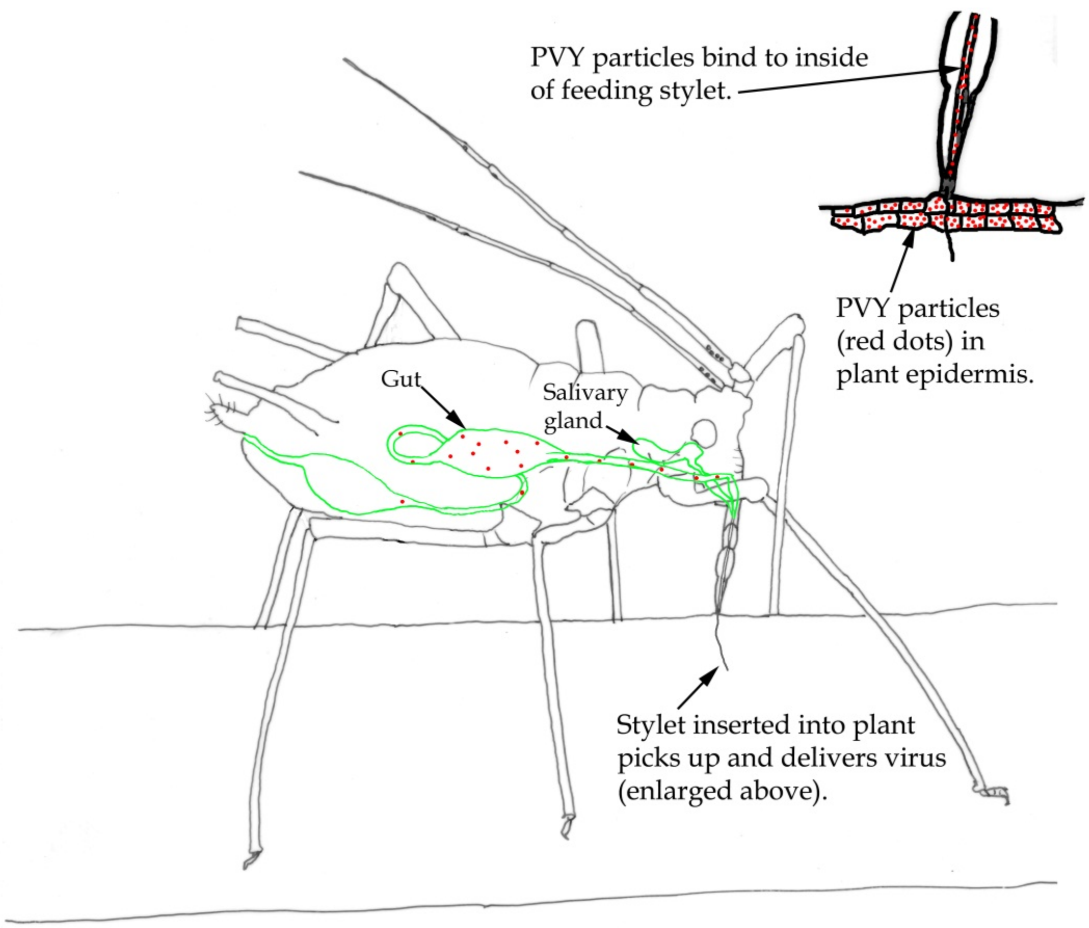

Figure 4. Important aspects of PVY transmission by aphids. Note that in most cases PVY will be transmitted by winged aphids only briefly visiting the crop. A crucial point is that PVY lives in the leaf cells near the surface, as opposed to deep in the phloem, which makes acquisition and transmission of PVY very quick processes. Illustration by the author.

helper component protein; 2) this transmission happens very quickly, much more quickly than any insecticide can act to kill the aphid. PVY management, therefore, must rely on tactics other than aphicides. One common approach in recent years has been mineral oils, sometimes known as stylet oils. The fact that oils at low rates can reduce PVY transmission was discovered in the 1960s (Bradley, Moore, & Pond 1966) and only recently has become commonplace. It is, like all PVY management tools, not a panacea. All tools in PVY management must be considered incremental improvements and must be used carefully and deliberately. For commercial growers by far the best way to control PVY in their harvested crop is to buy seed with little or no PVY.

Key points about aphid management.

Aphids are often managed in commercial potatoes based on a threshold at or near detection – in other words, very aggressively. The key reasons for this risk-averse approach are to 1) control the spread of PLRV and tuber net necrosis it can cause, and 2) limit the spread of PVY and the yield and quality losses it can cause. As many of you know, PLRV used to be common in seed potato, and was a major issue every year in commercial potato production. A look back at the potato conference proceedings and similar publications in the 1970s to early 1990s will show just how serious this problem was. Net necrosis and PLRV, however, have become extremely rare during the 21st century. Why is this? The extreme efficacy of neonicotinoid insecticides such as imidacloprid and thiamethoxam are usually given all the credit, and rightly so. These products can control colonizing aphids in potato almost all season, and extremely effectively (see the red line Figure 5). As described above, keeping colonizing aphids out of potato can and does prevent PLRV infection. The widespread adoption of powerful neonicotinoids in the seed industry has almost eliminated PLRV from seed. Research by Pete Thomas and colleagues in the 1990s showed that by far the most important source of PLRV in the commercial crop is what comes in the seed, as opposed to PLRV that may exist in surrounding environment, weeds, etc. If the seed is free of PLRV, very little will occur in the crop at harvest (Thomas, Pike, and Reed 1997). With neonicotinoids in the commercial crop as well, PLRV is practically eliminated. I should note that although non-colonizing aphids are crucial vectors of PVY, green peach aphid is incredibly capable, and any resident population in your crop can spread PVY.

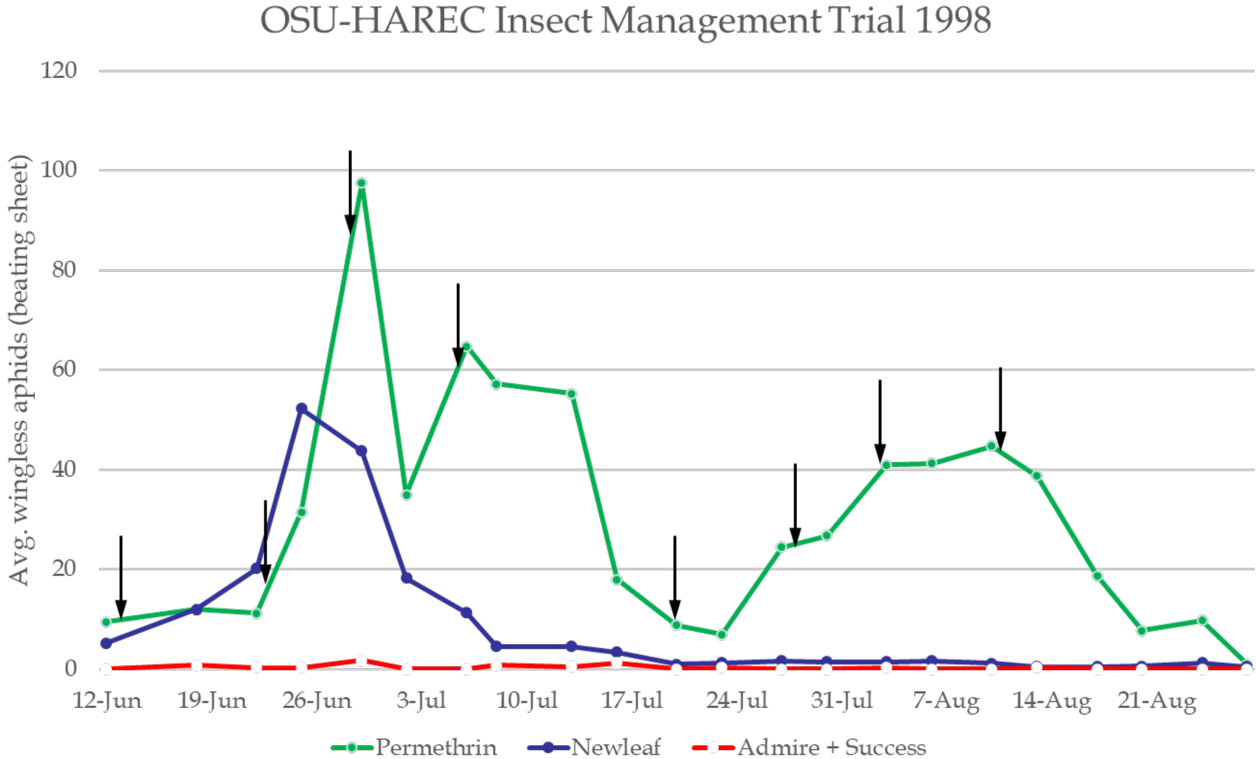

Figure 5. A selection of insecticide treatments from a research report by Gary Reed, OSU Hermiston, 1998. The red line shows the incredible aphid control of imidacloprid applied at planting (Success was used to control beetles). The green line shows what can happen with frequent applications of pyrethroid insecticides (the black arrows showing permethrin application dates): aphid population explosion followed by consistently high numbers. The blue line here is especially interesting. It shows what happened with aphid populations that received no insecticides at all, in plots of the now-defunct transgenic plants called Newleaf that were resistant to beetles. The beating sheets used here were large, so the aphids per sheet represent the number shaken from about 2 plants.

Figure 5 shows two other very important and common phenomena:

1. Pyrethroid insecticides lead to "flaring" of aphid populations. This is almost certainly due to the complete elimination of predators and parasitoids by the insecticide and the fact that pyrethroids are only partially effective at killing aphids. The net result is aphids reproducing faster than can be controlled by the insecticide. Figure 5 is a great illustration of why entomologists constantly discourage the use of pyrethroids!
2. Very often aphid populations that are left untreated will rise briefly early in the season and then drop off to very low numbers. This is the normal course of aphid populations in natural systems. Spring brings on large numbers of aphids as they exploit high quality host plants and low numbers of predators. During summer, predators, parasitoids, heat, and lower host plant quality typically cause aphid populations to crash. When lay people learn that I am an aphid expert, they almost invariably ask me how to control the aphids on

some plant or other in their yard. My first answer is always to wait a week or two and see if they disappear without any control effort. The blue line in Figure 5 shows that this can happen in a potato crop as well.

Monitoring for aphids in potato.

There are no formal treatment thresholds for aphids in commercial potato, but it is still important to look for them in your crop. Reasons include:

1. Determine when/if to spray for aphids. If you did not apply a neonicotinoid at-planting, it will be important to monitor the crop to detect and then track the early season flush of aphids. If you can be patient, you can then follow the population and see if the early flush dies back quickly, thus allowing you to avoid insecticide application.
2. Confirm (or not) that your insecticide program is working. If a neonicotinoid is used at planting, it is likely to eventually lose effectiveness and aphids may start to build up. It is important to be in the crop to detect this change and track whether aphid numbers are building.
3. Keep an eye on predator populations. Aphids are sometimes referred to as the corn flakes of the insect world because so many insects like to eat them. It is definitely worthwhile to watch potato fields for the presence and abundance of the many common predators of aphids, some of which are shown in Figure 6. Watching predator numbers throughout the season allows you to have a sense of whether they will be able control any nascent aphid resurgence.

Figure 6. Common predators of aphids. Top row left to right: damsel bug (a.k.a. 'nabid'), two big-eyed bugs feeding on an aphid under the dry flower, a big-eyed bug (a.k.a. *Geocoris*), a lady beetle larva. Middle row left to right: three kinds of adult lady beetles (a.k.a. 'ladybugs'), a minute pirate bug (a.k.a. anthocorid). Bottom row left to right: larva of a brown lacewing, larva of a lady beetle, and pupa of a lady beetle.

How to look for aphids in a potato crop? There are strong opinions and two main camps: 1) leaf picking, and 2) beating sheet/tray/bucket methods. As an aphid specialist I have a definite preference: a 1 square foot plywood beating tray (Figure 7) combined with leaf picking. Why both methods, you might ask? I have learned from experience that beating trays like mine are good at detecting aphid populations on many kinds of plants. But, the best place to find aphids in potatoes is often the lower yellowing leaves inside the canopy, which are not easy to sample using a beating tray technique. Therefore, I recommend quick beating tray samples of the upper parts of the plants to detect recent colonists of all aphids plus established populations of potato aphid (potato aphid often prefers the upper stems, as in Figure 8a), and leaf picking deep inside the canopy to detect established populations of green peach aphid (Figure 8b).

Figure 7. My plywood beating tray, paint stirring stick for tapping on the plants, plus a hand lens and reading glasses for seeing the insects.

Summarizing:

- Aphids have unique biology that helps them be resilient, ubiquitous pests.
- PLRV and tuber net necrosis it causes can be controlled using insecticides aimed at aphids.
- PVY is transmitted mostly by transient, non-colonizing aphids, and insecticides are only a minor player in PVY control. For commercial growers, the best approach is to by seed with low PVY content.
- Neonicotinoids have apparently solved the PLRV/net necrosis problem by allowing production of virus-free seed.
- Avoid pyrethroids (IRAC Group 3), which can lead to aphid population buildup.
- It is important to scout for aphids and their predators. Bear in mind that sometimes aphid populations will drop off to near-zero naturally.

B

A

Figure 8. Photo A is a group of potato aphids on the upper foliage of potato. This is the red color form of potato aphid, which is more often green. Photo B is the kind of slightly yellow leaf to focus on when picking leaves for green peach aphids; this leaf has many aphids that would commonly be caused by over-use of pyrethroid insecticides early in the season.

References

Bradley, R.H.E., C.A. Moore and D.D. Pond. 1966. Spread of Potato Virus Y curtailed by Oil. *Nature* 209: 1370–1371.

Thomas, P. E., Pike, K. S., and Reed, G. L. 1997. Role of green peach aphid flights in the epidemiology of potato leaf roll disease in the Columbia Basin. *Plant Disease* 81: 1311-1316.