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Using Protector Plants to Guard Crops from Aphid-borne Non-persistent Viruses

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Aphids and plant viruses

Aphids are among the most serious agricultural insect pests. These soft-bodied insects can cause major economic losses to crops, both directly through cell destruction from their feeding and indirectly by transmitting plant diseases such as viruses. Aphids and other insects that carry and transmit plant viruses are known as vectors. Aphids' role as carriers and transmitters of plant viruses is often of greater economic concern than the damage they cause from feeding on plants. Although many invertebrate animals are capable of transmitting viruses from plant to plant, aphids are the most important group of virus vectors.

What are the groups of viruses transmitted by aphids?

Aphid caused plant viruses are divided into three groups. These include persistent, non-persistent and semi-persistent viruses. Non-persistent viruses are transmitted non-specifically by a large number of aphid species after making very brief probes into a plant with their mouthparts (seconds to minutes), are lost readily after probing into a healthy plant, and have a short retention time in the aphid (minutes). Conversely, persistent viruses are transmitted more specifically by a few aphid species that feed and colonize the crop, are retained in the aphid body for days to weeks, and can only be transmitted to a plant during long feeding periods (optimum 24–48 hours). Semi-persistent transmission shares some of the characteristics of non-persistently and persistently transmitted viruses, but typically the virus can be acquired and transmitted to a plant within minutes to hours during feeding and is retained in the body of the aphid for hours.

Facts about aphid vectors of non-persistent viruses

About half of the approximately 600 viruses spread by invertebrate organisms are transmitted by aphids, and most of the roughly 290 known aphid-vectored viruses are non-persistent viruses (NPVs). Aphid-borne, non-persistently transmitted virus diseases are of greatest economic importance in several annual cropping systems throughout the world. Aphids that transmit NPVs often do not remain or reproduce on the plant to which they transmit the virus. In many instances, these crops are not suitable for their reproduction or survival.

Why insecticides may not help control aphid-transmitted NPVs

Pesticides are regularly used to control aphids. However, insecticides are mostly ineffective in managing NPVs and may contribute to virus spread by causing greater aphid movement within the field. Because of the very short time needed to transmit a virus, aphids are capable of transmitting NPVs prior to being killed by an insecticide. In some instances, insecticides may increase virus transmission by killing off natural enemies that may keep aphid populations down. Only insecticides that reduce the probing activity of aphids can contribute to the management of NPVs. However, continual visits to the crop by migrating winged aphids also means that insecticides need to remain active for a lengthy period of time or be regularly applied, which could lead to the development of insecticide resistance among aphid and other insect pest populations. In addition, high-priced pesticides may be too expensive for use by resource-poor farmers, and they are often incompatible with organic farming.

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Resource-challenged farmers require safe, effective, and inexpensive methods for managing aphid-borne viruses. These limitations on pesticide use suggest the need for more sustainable strategies for managing NPVs.

What are protector/barrier plants?

Secondary plants grown within or bordering a primary cash crop for the purpose of protecting it from disease outbreak are often referred to as protector plants or barrier crops. This approach belongs to a wide array of habitat manipulation strategies that aims at making crops less favorable for pests and more attractive to beneficial insects. Using protector plants or barrier cropping is a cultural technique that perfectly fits under the philosophy of sustainable agriculture. Any form of plant diversification (e.g., mixed cropping, cover crops, border plants, intercrops, trap crops, flower strips, organic mulch, etc.) used to protect a primary cash crop from insect-transmitted viral diseases may be referred to as barrier cropping.

Why are aphid vectors manageable by barrier cropping?

There are several aspects of aphid behavior that makes them manageable by the barrier cropping strategy, much of which behavior centers around their flight activity while searching for a suitable plant for colonization, feeding, and reproduction.

(1) During flight, aphids respond strongly to visual stimuli and locate host plants by contrasting the soil background with the green color of plant foliage. Therefore, the greater the percentage of plant coverage in a crop field, the lower the probability an aphid will land in that field.

(2) Plant infection with NPVs usually starts at the crop edges, because aphids entering a field tend to land on the field perimeter first. Thus, if protector plants are grown around the perimeter of a cash crop, aphids may initially probe the protector plants instead of the cash crop and clean the virus off their mouthpart while probing the protector plants.

(3) Aphids cannot distinguish hosts from non-host plants until after landing on a leaf surface and examining it with their mouthparts. Their initial behavior after landing on a plant is to walk over the surface of the leaf while testing it. During the test phase, aphids make brief, shallow exploratory probes with their mouthparts. Thus any virus particle on their mouthparts can be released into a protector plant.

(4) This behavior, whereby aphids probe and/or feed on non-host plants, has important implications in designing disease management strategies. During host-seeking, aphids may spend a significant amount of time and energy assessing unacceptable host plants in habitats of plant mixtures, and they would therefore allocate less energy to colonizing and feeding on the host crop.

Thus, several behavioral aspects of aphids suggest that they may be managed by using protector plants.

Mechanisms whereby barrier plants may help reduce virus incidence

The exact mechanisms that reduce the number of virus-infected plants in crops with protector plants are not well understood. It has been suggested that insects flying over areas with several plant species will have several inappropriate landings on the wrong host plants. The tendency is then to leave the general area completely. Likewise it has been reported that during their host-recognition phase, if aphids determine they have alighted on an unsuitable host, they immediately resume flight. This flight may take an aphid out of the vicinity of a crop field. Further, because their ability to transmit NPVs is lost soon after acquiring a virus, aphids may lose the ability to transmit a virus while searching for suitable host plants.

As illustrated in Figure 1, the virus-sink hypothesis proposes that protector plants may act as a sink for NPVs. With most non-persistent viruses, aphids begin to lose their ability to infect immediately after acquiring the virus and will become non-infective within minutes while feeding. Furthermore, when aphids search for a host plant, they commonly lose their ability to transmit a virus after making a few brief probes on a healthy or non-susceptible protector plant. If aphids then alight and feed on a susceptible cash crop, there will be no opportunity for virus transmission, because the virus particles will have been removed from their mouthpart while probing the protector plant.

Others contend that protector plants act as physical barriers and reduce the total number of aphids entering the crop. In this situation, it is suggested that barrier plants reduce the number of potential infected aphids migrating into a crop field, rather than reducing the number of infected aphids. This suggests that if the protector plant is to be effective in reducing aphid colonization by acting as a physical barrier, a tall-growing protector plant such as sorghum, or a species that is tall relative to the

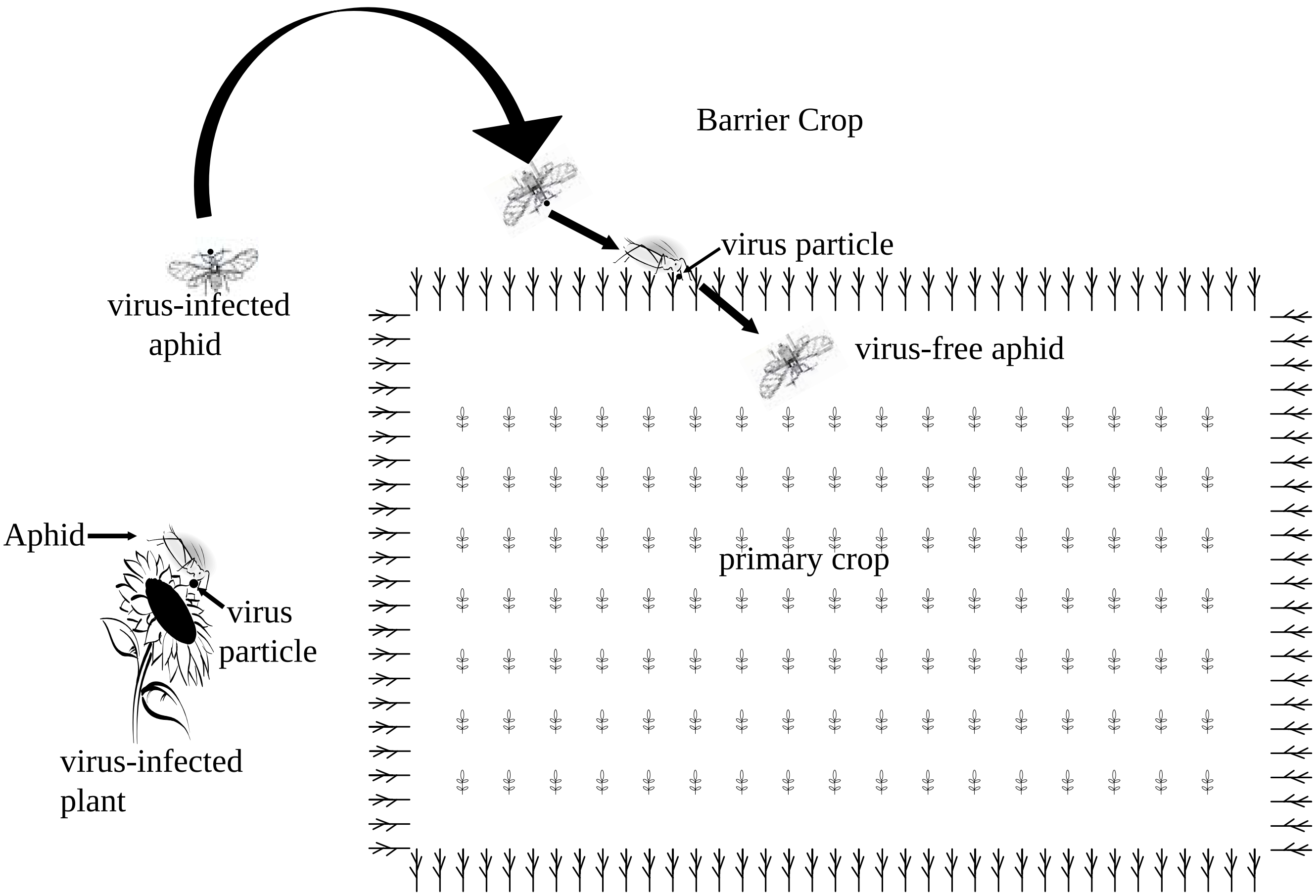

Figure 1. Demonstration of the virus-sink hypothesis.

An aphid acquires a non-persistent virus (NPV) by probing an infected plant. The virus-infected, winged aphid searching for a host plant lands on a protector plant in a barrier crop surrounding the primary crop. After probing the protector plant, the aphid loses the virus particles from its mouthpart. The virus-free aphid now enters the area of the primary cash crop, and because it no longer carries any virus particles, it is not capable of transmitting the NPV to the crop.

cash crop, should be used. The ability of protector plants to effectively impede or delay aphid movement into a crop will, among other factors, depend on the height of the protector plant at the time of strong virus pressure. In some circumstances, height may be less important than the percentage of soil covered by vegetation. It has been suggested that the number of aphids entering in a field should be lowest in fields consisting of high vegetative cover. Protector plants may also protect primary crops from NPVs by camouflaging them from aphids instead of providing a physical barrier.

Trap cropping has not been specifically acknowledged as a potential mechanism by which protector plants reduce the incidences of NPVs. Trap crops are plants that are grown to protect primary cash crops by attracting pest organisms that would normally colonize the primary crop. The principle of trap cropping is based on the fact that all pest organisms show a distinct preference for certain plant species, stage, or cultivar. It has been suggested that while flying, aphids use color vision primarily to distinguish plants on the soil surface. It is possible that when aphids land on a protector plant, it is not accidental but happens because aphids are more attracted to the protector plant than the cash crop. Therefore, protector plants may act as a "decoy" by attracting aphids away from the primary crop. Hence, selecting a protector plant that is more attractive to aphid landing than the primary crop may result in further protection from the spread of NPVs.

Five hypotheses explaining how barrier crops may reduce aphid vectors of NPVs

The following five hypotheses may explain how protector crops can affect aphid ability to transmit NPVs:

- appropriate vs. inappropriate landing
- virus sink
- physical barrier
- trap crop
- biological control.

The mechanisms by which protector plants act to protect crops from NPVs are likely not mutually exclusive, and all or a mixture of these five hypothetical mechanisms may operate concurrently. However, it can be acknowledged with certainty that diversifying the plant fauna within a crop field interferes with the normal host-plant-finding capabilities of insect pests. In the case of aphids that transmit plant viruses, this disruption in searching behavior should help protect crops from aphid-borne NPVs.

Limitations of using protector plants

Findings from several studies reported in Table 1 indicate that protector plants can be successfully used to reduce yield loss caused by non-persistently transmitted aphid-borne viruses. Still, there may be limitations to using this strategy. For example, perennial crops or crops grown year-round may have continually strong virus pressure from year to year, and protector plants may not be very effective under these conditions. However, under this circumstance selecting a barrier plant species that is attractive to natural enemies of aphids may be helpful, especially if the main aphid infecting the crop colonizes it.

In many cropping systems, viruses may not be the sole cause of yield loss. Under multi-pest circumstances, the positive impact of protector plants on virus incidence may be negated by other pest organisms unaffected by the presence of protector plants.

Another potential challenge in using protector plants is choosing an effective plant species to guard the cash crop. Once the protector plant is chosen, the next objective is to determine how best to incorporate it into the cropping system so that it effectively protects the targeted crop without negating any positive benefits of disease suppression. Competition between the protector plant and cash crop may be considered the "Achilles heel" of using protector plants. If the strategy is to reduce aphid numbers entering a crop field by inter-planting, it is important to pick protector plants that will achieve complete ground coverage as soon as possible. Determining the acreage to be devoted to the protector plant, the time to plant the protector plant in relation to the cash crop, and the planting density to use to avoid yield loss due to competition may be especially challenging decisions. However, competition may be less of a concern if other protector-cropping tactics are used. For example, if the approach is to use the protector plants as a physical barrier that prevent aphids from entering the field, planting tall barrier plants along the perimeter of the crop will remove competition or limit it to border row areas.

Deciding which barrier tactic to deploy can be an arduous task because a sufficient amount of information is essential to making a sound judgment. For example, perimeter non-host barrier plants may not be effective for large-acreage plantings, because it may only protect a limited number of border rows. In this instance, intercropping the protector plant with the cash crop may be a more viable choice. In addition, perimeter non-host barrier plants may not be practical if the only significant virus source is coming from seed-infected plants. Even if the choice of protector plant and tactic is solved, the logistics of managing two plant species concurrently within the same field can be challenging in some commercial operations.

Another critical issue associated with the adoption of an ecologically based pest management strategy includes the cost differences to farmers. There may be increased production costs associated with adding protector plants to the primary crop field, especially if the protector plant is row-intercropped. Therefore, from an economic viewpoint, any increase in marketable yield due to barrier cropping must compensate for additional expenditures associated with the protector plant. Use of control measures that involve major disruption to normal production practices may be costly and unfeasible unless there is a high return from protecting the crop.

Incorporating barrier cropping with other disease-management strategies

This publication has focused on one management tool (i.e., barrier cropping) for preventing yield reductions caused by aphid carriers of NPVs. However, the opportunity to successfully reduce disease spread in a cropping system may be greatly enhanced if multiple pest-management tactics are used concurrently. In many instances, barrier cropping may not significantly reduce the severity of disease caused by aphids when used as a single treatment. However, when integrated with other management tactics (e.g., cross protection, mineral oils, insecticides, resistant cultivars, sanitation, and cultural management), disease incidence may be reduced more significantly. Although we suggest that barrier cropping should be integrated with other management tactics, before increasing the complexity of disease management practices it is important that aphid reactions to individual tactics be understood.

Using protector plants for a variety of on-farm benefits

We have mainly spotlighted the use of protector plants for preventing yield reductions caused by aphid carriers of NPVs. However, protector crops can be used to help suppress other pests and pathogens impacting cropping systems. For example, cover crops, which are non-cash crops typically grown during the off-season for their indirect beneficial effects such as reducing soil erosion, have been successfully used as protector plants to reduce the occurrence of aphid-borne NPVs. However, cover crops and other protector plants may also help prevent yield reductions caused by other insect pests, as well as plant pathogens, weeds, and plant-parasitic nematodes. Cover crops may also be used to improve soil structure or nutrient status, and when incorporated into the soil they may help increase soil organic matter content. Thus, protector plants when appropriately used can potentially provide several valuable benefits to a cropping system.

Currently, researchers in Hawaii, Florida, and California are evaluating sunn hemp, marigold, and cowpea for their ability to reduce the occurrences of aphid-borne NPVs and suppress weed, insect, and nematode pests directly through modification of the cropping environment and enhancement of beneficial organisms. We believe that to optimize their use in integrated pest management programs, protector plants should not be used solely to mitigate problems caused by non-persistent viruses but concurrently used to help suppress multiple pest organisms and provide other potential benefits to a farming operation.

Concluding remarks

Several studies have shown that barrier cropping is a promising tool for reducing yield losses caused by aphid-borne NPVs. Although barrier cropping with protector plants is not a well recognized management tool, we hope that we have provided the agricultural community with information that can be used to help them protect their crops from aphid-transmitted non-persistent viruses and other potential yield-reducing factors.

References and further reading

Fereres, A. 2000. Barrier crops as a cultural control measure of nonpersistently transmitted aphid-borne viruses. Virus Research 71: 221–231.

Hooks, C.R.R., and A. Fereres. 2006. Protecting crops from non-persistently aphid-transmitted viruses: A review on the use of barrier plants as a management tool. Virus Research. 120: 1–16.

Hooks, C.R.R., K.-H. Wang, and D. Fallon. 2006. An ally in the war against nematode pests: Using sunn hemp as a cover crop to suppress root-knot nematodes. University of Hawaii at Manoa, College of Tropical Agriculture and Human Resources, Plant Disease publication PD-32. www.ctahr.hawaii.edu/oc/freepubs/pdf/PD-32.pdf

Ngouajio, M., M.E. McGiffen Jr., and C.M. Hutchinson. 2003. Effect of cover crop and management system on weed populations in lettuce. Crop Protection 22: 57–64.

Wang, K.-H., and R. McSorley. 2004. Management of nematodes and soil fertility with sunn hemp cover crop. University of Florida, Institute of Food and Agricultural Sciences Extension, EDIS publication NG043. http://edis.ifas.ufl.edu/NG043

Wang, K.-H., B.S. Sipes, and D.P. Schmitt. 2002. Crotalaria as a cover crop for nematode management: A review. Nematropica 32: 35–57.

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Table 1
Effects of barrier plants on aphid transmitted non-persistent plant viruses and crop yield

Crop protected	Virus targeted	Barrier plant	Response	Factors involved	Country	Reference
Family Cucurbitaceae						
Muskmelons	WMV-1, WMV-2	wheat, swiss chard	Radish and Swiss chard were too competitive. Cantaloupe in wheat protected plots had equal or better quality than check.	delay frequency and reduced virus severity	USA	Toba et al., 1977
Zucchini	PRV-W	buckwheat, weeds, yellow mustard	Increased marketable yields during one of two years	delay virus onset no. of winged aphid reduced	USA, Hawaii	Hooks et al., 1998
Family Solanaceae						
Chilli	CMV	sunflower, sorghum sesame, pearl-millet	All barrier crops reduced the disease incidence and increased yield. Fields with pearl-millet gave the highest yields during the spring season.	No explanation suggested	India	Deol and Rataul 1978
Chilli	CVMV	maize, brinjal	Yields were higher when interplanted with maize or brinjal but maize a better protector crop	more winged aphids, disease higher and spread faster in monocrop	Malaysia	Hussein and Samad 1993
Chilli	CMV	maize, sorghum, sunflower	All barrier crops reduced disease incidence and increased yield compared to the control. Maize was the most effective barrier plant. Insecticidal sprays applied to the barrier plants further suppressed disease spread.	barrier crops acted as “spread breakers” by preventing direct aphid colonization on the chilli plants	India	Anandam and Doraiswamy 2002

Table 1
continued

Crop protected	Virus targeted	Barrier plant	Response	Factors involved	Country	Reference
Pepper	CMV, PVY	sorghum	A sorghum barrier contributed to a significant reduction of CMV spread and delayed PVY spread.	Sorghum plants acted as a sink for both viruses	Spain	Avilla et al., 1996
Pepper	CMV, PVY	maize, vetch, Sorghum	Reduction in virus spread and yield increase in two of the four years	barriers acted as a virus sink, but did not reduce aphid landing in crop	Spain	Fereres 2000
Pepper	PVY	sunflowers	reduced virus spread	blocked winged aphid landing rates	USA	Simons, 1957
Potato	PLRV	wheat, mustard	Potato yield greater in barrier plots, highest yields in wheat	Protector plants acted as a mechanical aphid barrier. wheat believed to attract less aphids than mustard	Bangladesh	Mannan 2003
Potato	PVY	sorghum, potato, soybean, wheat	Aphid landing rates similar in all plots, virus incidence was reduced along the field edge of protected potato	barriers acted as a sink (e.g., aphid vectors lost virus prior to landing on seed potato	USA	Difonzo et al., 1996
Potato	PVY	wheat straw mulch	Straw mulch reduced PVY incidence but had no significant impact on yield	reduced optical contrast between plant and soil	Germany	Saucke and DÖring 2004
			Family Fabaceae			
Cowpea	CpMV	pearl millet	Number of infected plants were significantly reduced in plots screened by pearl millet. Yields were further increased by using a systemic insecticide on the millet	Aphid population was greater near the barrier and the insecticide help eliminate the aphids at the barrier	USA	Gay et al., 1973