Introduction and Significance

A general and rapid plant decline was a major problem for strawberry growers from 2001 to 2004 until the causal agents and vectors were identified and appropriate control measures could be taken. A virus complex was identified in the declining strawberries that consisted of two whitefly transmitted viruses and at least one aphid transmitted virus. There was not a specific combination of viruses that caused the decline symptoms, but in all cases there was a virus complex involved with at least three and up to six viruses present. The aphid transmitted viruses all have limited host ranges and need to be able to move from strawberry to strawberry to persist at a location. The whitefly transmitted virus, Beet pseudo yellows, has a broad host range and could persist in weeds or native vegetation near strawberry fields. At this time it appears that the whitefly transmitted virus, Strawberry pallidosis, has a narrow host range and likely persists primarily in strawberry. The presence of viruses in nurseries would allow for distribution to fruit production fields where transmission could lead to mixed infections and subsequent decline.

Symptoms and diagnostic features

Strawberry decline requires infection of plants with multiple viruses and in California this is usually a combination of whitefly and aphid transmitted viruses, thus it also requires the presence of multiple vectors. The disease is the result of a virus complex that includes one or more of the whitefly transmitted viruses (Beet pseudo yellows virus, Strawberry pallidosis associated virus, and recently we found a third crinivirus) with at least one of the aphid-transmitted viruses. Symptoms of this decline are often mistaken for physiological or nutritional disorders, pesticide phytotoxicity, cyclamen mite, foliar nematode or other diseases. Older leaves of affected plants often develop a red color, and newer leaves show a distortion (Figure 1) and some cultivars develop red colored lesions on the major veins and petioles (Figure, 3) and produce small leaves (Figure 1 and 2). Roots become stunted followed by failure of the plant to continue to produce healthy leaves and fruit. Infection with any one of the viruses does not cause the decline symptoms and as far as we know, infection with several of the whitefly transmitted viruses does not cause decline.

Figure 1. Plants of ‘Ventana’ infected with Strawberry pallidosis, Beet pseudo yellows and Strawberry mild yellow edge virus.

Figure 2. Plants of ‘Camarosa’ in a fruit production field showing severe decline, these plants were infected with Strawberry pallidosis, Beet pseudo yellows, Strawberry mild yellow edge virus.
In production fields, vector control is more difficult since there is a food crop being harvested. Beet pseudo yellows virus has a large host range among crop and weed species, infecting plants in at least 12 different taxonomic families. Strawberry pallidosis associated virus has a narrow host range, and thus, starting with virus-free material will have more of an impact with this virus. No sources of resistance have been identified for either virus. Growers should focus on utilizing an integrated approach to management, targeting both vector and virus. Control of whitefly or aphid vectored viruses in the nursery or fruiting fields in organic or conventional agriculture is most effective when virus inoculum can be eliminated. Thus, the importance of using certified virus-indexed planting stock. If one has a problem with virus induced strawberry decline, care should be taken to ensure that all strawberry plant material is eliminated from the field and perimeter before replanting. Vector control for the strawberry aphid and the aphid transmitted viruses is easier than controlling whiteflies since the major aphid vector and the primary viruses have very limited host ranges. Strawberry is the primary host for the viruses and the aphid. Avoiding planting near second year fields that have a problem with decline as this would be an important inoculum source for the viruses and probably the vectors. Maintaining second year fields will increase the risk of the aphid-transmitted viruses as is seen in the Pacific Northwest where strawberry plantings are kept for 2-4 years. In this area, the aphid-transmitted viruses are much more common than in the California production system. In greenhouse studies, plants infected only with Beet pseudo yellows and Strawberry pallidosis associated virus did not show any visual symptoms. In some cultivars there is a reduction in runner production and root growth with the whitefly transmitted viruses but not the severe decline observed in some production fields from 2000 to 2004.

References
Wintermantel, W.M. 2004. Emergence of greenhouse Whitefly (Trialeurodes vaporariorum) transmitted Criniviruses as threats to vegetable and fruit production in North America. APSnet feature article June 2004 (www.apsnet.org/online/feature/whitefly/).
Causal agents
The aphid-borne viruses (Strawberry mottle, Strawberry crinkle, Strawberry mild yellow edge and Strawberry vein-banding) all have very limited host ranges and will not persist at a site in the absence of strawberry (Fragaria spp.) to serve as a host. With the exception of Strawberry mottle virus, these viruses only are transmitted efficiently by the strawberry aphid. The strawberry aphid has very limited host range and also needs a Fragaria host for its survival at a location. Strawberry chlorotic fleck associated virus and Strawberry mottle virus are potentially transmitted by the cotton aphid (Aphis gossypii) and these viruses could be a problem in the absence of the strawberry aphid provided there were sources of the virus in nearby fields and the cotton aphid was established in the field. The whitefly (Fig. 4) transmitted viruses are Strawberry pallidosis associated virus and Beet pseudo yellows virus and a third crinivirus, yet unnamed, recently identified in strawberry.

Management of virus decline
Best management will include an integrated approach focused on maintenance and use of virus-indexed nursery material, testing of plant material exhibiting suspicious symptoms, elimination of weed and crop sources of virus to the extent possible near strawberry fields, and reducing vector populations through biological or insecticidal methods.

Identification of the cause of the decline symptom is a necessary first step in addressing the problem since there are a number of potential causes. Knowing that the decline is caused by a combination of whitefly and aphid transmitted viruses helps in developing management strategies for the problem. The first and most important strategy is to start with certified planting material. Prior to 2003 there were no reports of whitefly transmitted viruses in strawberry. Thus, controlling whiteflies in production fields and nurseries was not considered important unless the numbers were high enough to damage the plants. With the discovery that several whitefly transmitted viruses infect strawberry and that these viruses are important components of strawberry decline, the threshold for whiteflies needed to be reconsidered. In nurseries the threshold should be as close to zero as is feasible. The same is true for aphid management in nurseries. The importance of virus-free nursery stock can not be over emphasized. As the knowledge base on which viruses are present and their vectors increases, the importance of managing multiple vectors becomes obvious. The whitefly vectored viruses in strawberry in recent years is an excellent example of this. Since 2004, the nurseries have been very active in controlling whiteflies as well as aphids and the incidence of virus infections have decreased dramatically.

In production fields, vector control is more difficult since there is a food crop being harvested. Beet pseudo yellows virus has a large host range among crop and weed species, infecting plants in at least 12 different taxonomic families. Strawberry pallidosis associated virus has a narrow host range, and thus, starting with virus-free material will have more of an impact with this virus. No sources of resistance have been identified for either virus. Growers should focus on utilizing an integrated approach to management, targeting both vector and virus. Control of whitefly or aphid vectored viruses in the nursery or fruiting fields in organic or conventional agriculture is most effective when virus inoculum can be eliminated. Thus, the importance of using certified virus-indexed planting stock. If one has a problem with virus induced strawberry decline, care should be taken to ensure that all strawberry plant material is eliminated from the field and perimeter before replanting. Vector control for the strawberry aphid and the aphid transmitted viruses is easier than controlling whiteflies since the major aphid vector and the primary viruses have very limited host ranges. Strawberry is the primary host for the viruses and the aphid. Avoiding planting near second year fields that have a problem with decline as this would be an important inoculum source for the viruses and probably the vectors. Maintaining second year fields will increase the risk of the aphid-transmitted viruses as is seen in the Pacific Northwest where strawberry plantings are kept for 2-4 years. In this area, the aphid-transmitted viruses are much more common than in the California production system. In greenhouse studies, plants infected only with Beet pseudo yellows and Strawberry pallidosis associated virus did not show any visual symptoms. In some cultivars there is a reduction in runner production and root growth with the whitefly transmitted viruses but not the severe decline observed in some production fields from 2000 to 2004.

References
Wintermantel, W.M. 2004. Emergence of greenhouse Whitefly (Trialeurodes vaporariorum) transmitted Criniviruses as threats to vegetable and fruit production in North America. APSnet feature article June 2004 (www.apsnet.org/online/ feature/whitefly/).
Introduction and Significance

A general and rapid plant decline was a major problem for strawberry growers from 2001 to 2004 until the causal agents and vectors were identified and appropriate control measures could be taken. A virus complex was identified in the declining strawberries that consisted of two whitefly transmitted viruses and at least one aphid transmitted virus. There was not a specific combination of viruses that caused the decline symptoms, but in all cases there was a virus complex involved with at least three and up to six viruses present. The aphid transmitted viruses all have limited host ranges and need to be able to move from strawberry to strawberry to persist at a location. The whitefly transmitted virus, Beet pseudo yellows, has a broad host range and could persist in weeds or native vegetation near strawberry fields. At this time it appears that the whitefly transmitted virus, Strawberry pallidosis, has a narrow host range and likely persists primarily in strawberry. The presence of viruses in nurseries would allow for distribution to fruit production fields where transmission could lead to mixed infections and subsequent decline.

Symptoms and diagnostic features

Strawberry decline requires infection of plants with multiple viruses and in California this is usually a combination of whitefly and aphid transmitted viruses, thus it also requires the presence of multiple vectors. The disease is the result of a virus complex that includes one or more of the whitefly transmitted viruses (Beet pseudo yellows virus, Strawberry pallidosis associated virus, and recently we found a third crinivirus) with at least one of the aphid transmitted viruses. Symptoms of this decline are often mistaken for physiological or nutritional disorders, pesticide phytotoxicity, cyclamen mite, foliar nematode or other diseases. Older leaves of affected plants often develop a red color, and newer leaves show a distortion (Figure 1) and some cultivars develop red colored lesions on the major veins and petioles (Figure 3) and produce small leaves (Figure 1 and 2). Roots become stunted followed by failure of the plant to continue to produce healthy leaves and fruit. Infection with any one of the viruses does not cause the decline symptoms and as far as we know, infection with several of the whitefly transmitted viruses does not cause decline.