Improved management of thrips and *Tomato spotted wilt virus* (TSWV) in California lettuce fields (2013-2014)

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The immediate objectives of our ongoing project were: 1) continue to survey selected spring- and fall-harvested lettuce fields for a second year in Huron to gain better insight into when and from where thrips and TSWV enters into commercial fields, 2) assess the potential role of soil as an early season source of thrips and TSWV infection for spring-planted lettuce, 3) complete the thrips-transmission experiments to assess suitability of lettuce as a TSWV inoculum source for tomatoes and, 4) provide preliminary recommendations for thrips/TSWV management in lettuce based on year 2 data.

We identified and monitored 8 fall- and 3 spring-harvested lettuce (will be referred as fall-lettuce and spring-lettuce, respectively) fields with yellow sticky cards in the greater Huron area in 2013 and 2014, respectively. The average thrips populations in September in fall-lettuce fields were considered to be moderate levels (~300 thrips/card/2-week), and these decreased to very low levels (44 thrips/card/2-week) by early-October and then remained very low until harvest in November (Fig. 1). Consistent with this trend, thrips populations remained in very low levels (<100 thrips/card/2-week) in spring-lettuce fields during the winter (January-February) until March (Fig. 2). Thus, thrips populations that were associated with fall- and spring-lettuce fields in the greater Huron area were very low. All thrips from lettuce were identified as Western flower thrips (*Frankliniella occidentalis*).

TSWV was eventually detected in all monitored fall-lettuce fields but was sporadic and remained at very low levels (<1-3%) up to the harvest in November. In spring-lettuce fields, TSWV was also detected in all monitored fields, but at very low levels (<2%) up to harvest in March. The low TSWV incidences in fall-lettuce in 2013 can be attributed to the relatively low incidences of TSWV in the 2013 processing tomato crop. In 2013, the predominant virus in tomato was the leafhopper-transmitted *Beet curly top virus*, which does not infect lettuce. We also believe that the very low levels of TSWV and thrips populations in spring-lettuce in 2014 can also attributed to the very low levels of TSWV and thrips populations in fall-lettuce fields in 2013. Furthermore, because of the very low levels of TSWV in lettuce, we did not see any evidence that TSWV carried over from fall- to spring-lettuce and then to tomatoes in 2014. Consistent with this observation, TSWV infections early-planted tomato crops in the Huron area were very low in the greater Huron area. Together, these results indicated that, in 2014, lettuce was not an important TSWV and/or thrips inoculum source for nearby or subsequent crops (i.e., tomato and pepper).

To assess the potential role of soil as an early season source of thrips and TSWV infection for spring-lettuce and, subsequently, for processing tomatoes, we collected soil samples from 2 fall-lettuce and 2 spring-lettuce fields after the harvest. In addition, soil was sampled from one processing tomato field that had processing tomatoes in 2013 in March 2014. Sterile soil was used as a control. Soil samples were placed in closed containers with a fine screen window for air flow and kept in greenhouse maintained at 19-26 °C, a temperature that would stimulate adult thrips emergence. Adult thrips emerged from all soil samples whether they had been planted in lettuce or tomato (Table 1). Thrips did not emerge from the sterile soil sample, indicating that the thrips trapped in this study came from the soil rather than from outside. The number of thrips that were captured on yellow sticky cards placed with soil samples from lettuce fields were considerably higher than those that from soil from field that had processing tomato (Table 1). Thrips numbers were slightly higher on yellow sticky cards that were placed with soil from spring-lettuce fields (freshly harvested) compared with those that placed with soil from fall-lettuce fields that were idle since the harvest in November (Table 1). Together, these results indicated that soil can be an inoculum source of thrips for spring-lettuce and later for subsequent other crops after spring-lettuce harvest. These findings are important because after spring-lettuce harvest soil, especially those that left fallow, can be an important thrips inoculum sources.

Although emerging thrips were captured from all of these soil samples, none of them were found to be carrying TSWV, as they all tested negative for TSWV by the RT-PCR test (Table 1). In contrast, known lab-reared viruliferous thrips (positive control) all tested positive for the virus. These results may not be surprising because, even though most of these soil samples were taken from spots in lettuce fields that where TSWV infections were detected, TSWV levels were still very low (<3%). Furthermore, fava bean indicators planted in these soil samples as well as other emerging volunteer crops and weed plants, did not develop TSWV symptoms throughout the duration of these experiments. Consistent with these results, selected fava beans and volunteer/weed plants also tested negative for TSWV with immunostrips and/or RT-PCR tests (Table 1).

The results of lab experiments that were conducted to assess whether lettuce is a good TSWV source revealed that lettuce is indeed a good source of TSWV and can be potential inoculum source for viruliferous thrips that can go to other TSWV-susceptible crops. In these experiments, TSWV-infected lettuce was collected from Huron and used as an inoculum source for sap-transmission of TSWV to healthy iceberg and romaine lettuce plants. Following rub-inoculation, this inoculum source was able to infect both lettuce varieties as well as Datura plants. These inoculated plants developed TSWV symptoms and these plants and TSWV-infected Datura plants were then used as acquisition hosts for first instar larvae of nonviruliferous thrips to acquire TSWV. In thrips-transmission experiments, individual adult male and female thrips that had developed from these first instar larvae were used to feed on healthy lettuce leaves and transmission efficiency rate was determined via ELISA. Results of these experiments showed that thrips that were fed on TSWV-infected lettuce and Datura plants had overall similar transmission efficiency rates to lettuce of 54% and 51%, respectively (Table 2). Moreover, male adult thrips transmitted the virus slightly higher rates compared with female thrips, (58% vs. 50% with lettuce as an acquisition host, and 53% vs. 50% with Datura as an acquisition host). Together, these results indicate that lettuce can be as good of a TSWV acquisition host as Datura, a well-known good TSWV host.

Thrips phenology model: timing generation peaks

We extended the existing thrips phenology model which is used for guiding spray timing for controlling TSWV in processing tomato. The phenology model uses hourly temperature data, collected by standard weather stations, to calculate thermal time accumulation for Western Flower Thrips. Based on an analysis of several published thrips development studies, we know that thrips development does not occur below 45F, and we know both the temperature-dependent development rate and the total thermal time required for each complete life-cycle from egg to adult. Only adult thrips can spread TSWV, so the dates when adults take flight in each generation are the key to efficient use of insecticide. We selected 5 weather stations in the Huron area (Figure 3) to generate projections of adult thrips peak generation times. For the 2013 data the projected dates coincided well with the observed peaks in the counts of adult thrips shown in Figure 1 indicating that the development model does accurately project the dates when adult thrips will be active.

Figure 4 shows the projected adult peak times for the five weather stations for fall 2014.

Recommendations for thrips and TSWV control in lettuce

Based on our results thus far, we recommend lettuce growers following control measures for controlling thrips and TSWV in lettuce fields.

Before planting

- evaluate planting location and time to avoid high TSWV inoculum sources
- implement weed management
- be aware of level of TSWV in tomato, pepper or other crops in area

During the season

- monitor fields for thrips
- manage thrips when populations reach high densities (i.e., >500 thrips per yellow sticky card)
- rotate insecticides
- monitor fields for TSWV and, if possible, remove infected plants
- implement weed management

After harvest

- promptly remove and destroy plants by plowing after harvest
- control weeds/volunteers

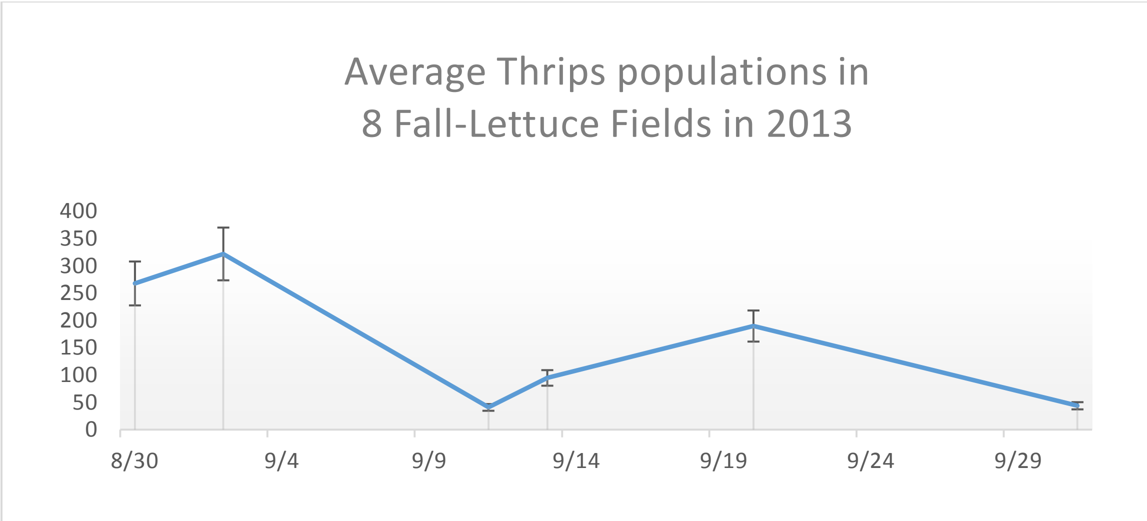

Figure 1. Average thrips populations determined from yellow sticky cards in fall-lettuce in 2013.

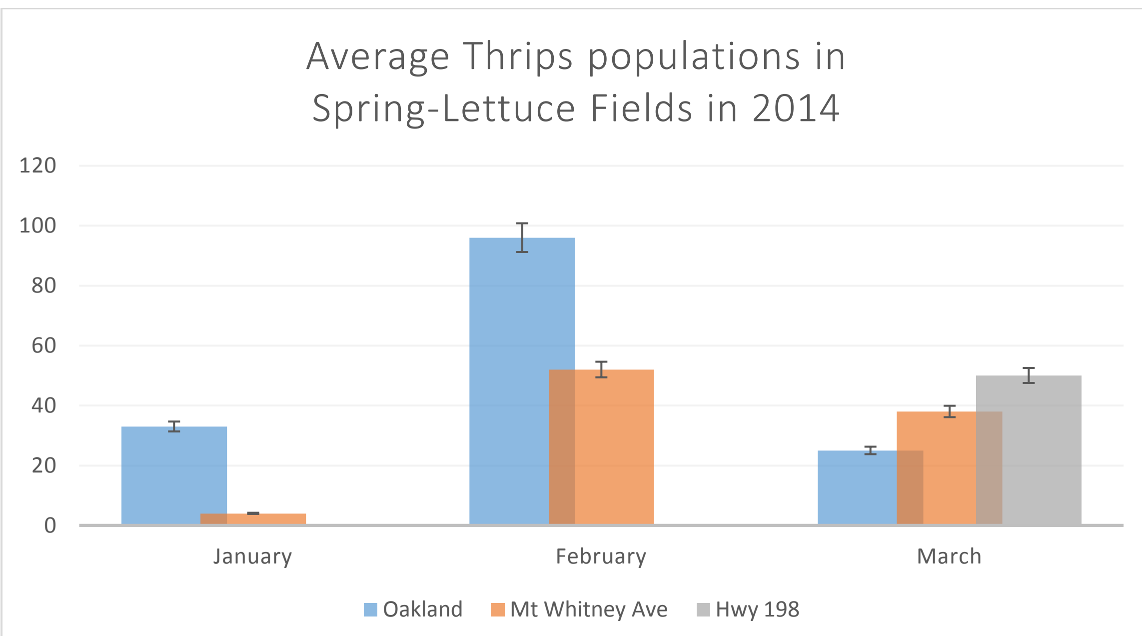

Figure 2. Average thrips populations determined from yellow sticky cards in spring-lettuce in 2014.

Table 1. Number of adult thrips emerging from soil collected from lettuce and tomato fields and detection of TSWV in the collected thrips.

Sample #	Source of the soil samples	Collection Date	Previous/Current Crop Type	Number of captured thrips	RT-PCR tests of thrips	RT-PCR tests of plants [a]	Soils Discarded
1	W Oakland Ave	19-Mar	Fall-Lettuce	**14**	Negative	Negative	20-Jun
2	W Mt Whitney Ave	19-Mar	Fall-Lettuce	**21**	Negative	Negative	20-Jun
3	S Butte Ave	19-Mar	Spring-Lettuce	**38**	Negative	Negative	20-Jun
4	W Mt Whitney Ave	19-Mar	Spring-Lettuce	**35**	Negative	Negative	20-Jun
5	W Gale Ave	19-Mar	Processing Tomato	**2**	Negative	Negative	20-Jun
6	UC Davis Greenhouse	19-Mar	Sterile soil; Negative Control	**0**	N/A	Negative	20-Jun

[a] Fava bean indicator and/or volunteer or weed plants

Table 2. Comparison of TSWV-thrips transmission rates from two acquisition hosts: lettuce and Datura.

Acquisition Host	**Lettuce**		**Datura**	
Inoculation Host	**Lettuce**		**Lettuce**	
Thrips	**Male**	**Female**	**Male**	**Female**
Exp. I	7/10 [a]	5/10	5/10	5/10
	5/10	8/10	6/10	5/10
Exp. II	4/10	2/10	7/10	6/10
	7/10	5/10	3/10	4/10
Subtotal	23/40	20/40	21/40	20/40
	58%	**50%**	**53%**	**50%**
Total	43/80		41/80	
	54%		**51%**	

[a] Number of plants infected/total inoculated as determined by a ELISA test.

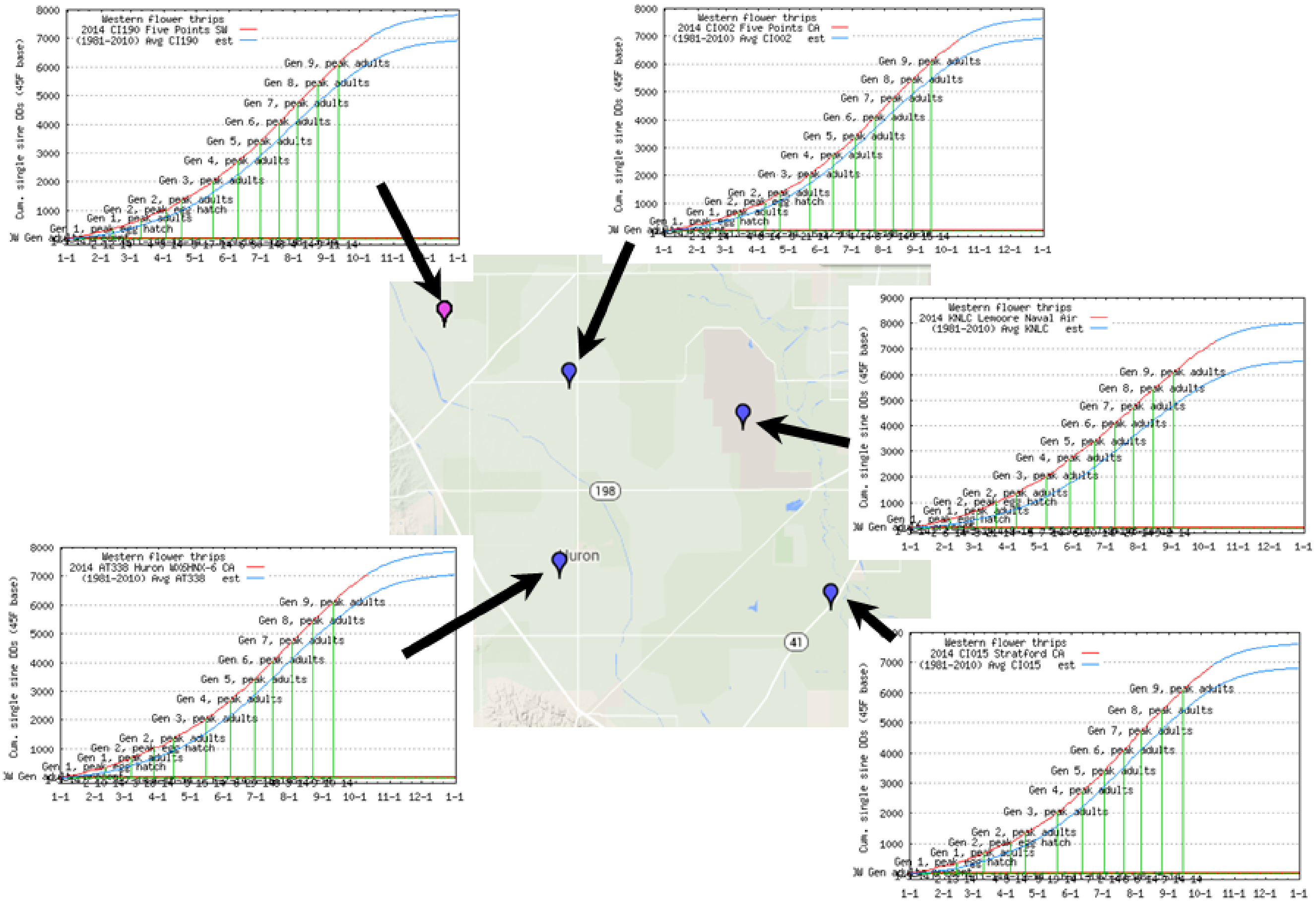

Figure 4. Locations of weather stations used for fall thrips projections in the Huron area. Thrips generation times are shown