Project Title:

Toward the Development and Application of Degree Day Model and Risk Index to Predict Development of Thrips and *Tomato Spotted Wilt Virus* (TSWV) and Implement an IPM Strategy in California Processing Tomato Fields (2012)

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Summary:

The goal of this ongoing project is improved understanding of thrips population dynamics and *Tomato spotted wilt virus* (TSWV) incidence in processing tomatoes in Central California and application of this knowledge to the development of an effective IPM strategy. In 2012, monitoring of representative tomato fields in Fresno, Kings, Merced and northern (Yolo, Solano, Colusa and Sutter) Counties revealed the build-up of thrips populations in April-May, somewhat later than previous years. Interestingly, a drop in thrips populations was detected from mid-June to early July, and this was associated with implementation of thrips management during this period. Consistent with these results, the first detection of TSWV in tomato plants was in Fresno County in mid-April, and in early May in other counties. TSWV was eventually detected in most monitored fields, and a number of fields in the northern production areas had relatively high incidences by early June. However, the overall incidence was relatively low in 2012 (0-14%), even in the northern fields that had high early incidences. As in the last 2-3 years, fall crops (lettuce and radicchio) were monitored during fall/winter seasons. In general, these potential TSWV bridge crops had low thrips populations and TSWV incidence, although some fall-planted lettuce fields and a radicchio field in Fresno had high incidences of TSWV infection. As in previous seasons, winter and spring weed surveys revealed very low levels of TSWV infection (~0.2%). RT-PCR testing of thrips revealed that most thrips were not carrying the virus throughout the season, although thrips collected from infected tomato plants were positive for TSWV. Thrips-transmission efficiency experiments were completed and revealed that male adult thrips transmit TSWV more efficiently than female adult thrips. The overall transmission efficiencies of colonies from Fresno and Yolo were different, with thrips from the Fresno colony having a higher transmission rate (44%) than thrips from the Yolo colony (33%). In addition, the origin of the virus isolate also played a role in thrips transmission efficacy, because the TSWV-Fresno isolate was more readily transmitted by thrips than the TSWV-Yolo isolate.

Results of our greenhouse experiments for the assessment of the role of the soil-emerging adult thrips as an inoculum source for early season tomatoes confirmed that adult thrips emerge from soil, but no TSWV was detected in these thrips. Laboratory experiments revealed that thrips can stay dormant in soil for up to 7 weeks, and that some emerging adults retained the virus and were able to infect plants after emerging from soil. This strongly suggests that adult thrips emerging from soil can be an inoculum source, and is a possible explanation for how single TSWV-infected plant may be observed within fields early in the season. In 2012 insecticide trials, materials that reduced thrips numbers included Radiant and possibly two newer materials (Grandevo + organo-silicone and Torac with Agri-Mek and Dynamic). Results of the 2012 trial generally supported results of earlier trials in that Radiant is among the top performing materials, and that Beleaf either alone or tank-mixed with a pyrethroid can provide some control. In 2011, we developed a TSWV Risk Index (TRI), for predicting the potential for losses due to TSWV in Central Valley processing tomato fields. Based on information for each field monitored in 2012, the TRI was moderate for most fields in 2012. However, with some of the additional data added to the TRI this year we identified a number of low and high risk fields in 2012, and the TSWV incidences in these fields correlated with the TRI. Our phenology or degree day model for thrips population development in the Central Valley accurately predicted the timing of adult thrips generations. Thus, we are now feeling that this model can be used as a reliable predictor of when thrips populations increase, and when it is best to apply thrips management strategies. We now believe that the IPM strategy generated for thrips and TSWV is effective at reducing disease incidence. Key aspects includes proper timing of thrips management strategies and being able to identify high risk fields where IPM practices should be implemented. We now hope to continue to validate the thrips model and risk index to make these more grower-friendly and facilitate use of IPM strategy.

Objectives:
The objectives of this project in 2012 were 1) conduct surveys of selected tomato fields to gain insight into when and from where thrips and TSWV enter into commercial processing tomato fields and assess the capability of our degree day model to predict the appearance of thrips populations in 2012, 2) to gain insight into potential sources of thrips and TSWV for tomatoes in the Central Valley, 3) to assess the role of TSWV resistant (*Sw-5*) tomato varieties for selection of 'resistance breaking' TSWV-isolates in California, 4) to assess the role of soil emerging thrips in TSWV epidemiology, 5) to evaluate transmission efficiency of TSWV for thrips populations from different geographic origins, 6) to utilize a PCR method for detecting TSWV in thrips and develop improved diagnostics for other tomato-infecting viruses, 7) to assess various thrips control methods, 8) to continue to develop and validate a phenology model and a risk assessment system for thrips and tomato spotted wilt disease, respectively, and 9) to continue to develop and assess an integrated pest management (IPM) strategy for TSWV in the Central Valley.

Information on Materials and Methods can be found in our CTRI proposal for 2012 and available upon request.

Results:

Field Monitoring: Monitoring efforts for thrips and/or TSWV were initiated in selected fall crops (wheat, onion, radicchio, lettuce and in some weedy orchards) in fall 2011 and in processing tomato fields at the beginning of tomato growing season for 2012. In 2012, all monitored fields were established with transplants. Table 1 lists the 24 fields that were monitored in 2012 and indicates final TSWV incidence in each field.

Yellow sticky cards: In 2012, the build-up of thrips populations started in late April in Fresno and Kings Counties, and was not detected in most monitored fields until mid-May in Merced and northern (Yolo, Solano, Colusa and Sutter Counties). Populations reached high levels by June (>3000 thrips/card), but shortly dropped to moderate levels (<1500 thrips/card) during July. A second peak was detected in August (up to 9,000 thrips/card) in most monitored fields. High thrips populations persisted into September and gradually declined in October (Fig. 1). The apparent population drop in June-July (in all counties) was striking because it had not been seen in previous years and it was not predicted based on our degree-day model (there was no evidence of a noticeable delay in thrips generation period differences in weather temperatures in July compared with previous years). Thus, it is possible that these decrease in thrips population during June-July reflected the widespread implementation of thrips management in early June.

Flower sampling: Thrips populations in flowers were detected soon after flower emergence, and thrips continued to be detected in flowers for the rest of the season. In 2012, similar to other years, most of the monitored fields had populations of 2-5 thrips per flower throughout the blooming stage. Overall, it continues to appear that the populations determined by yellow sticky cards are more informative than populations determined from flowers.

TSWV incidence: In 2012, the first detection of TSWV in processing tomato was in Fresno County in 14 April in a field established near a spring lettuce field with TSWV-infected plants. TSWV was first detected in Merced and northern counties early May, whereas it was not detected in Kings County until late May. In 2012, the overall incidence of TSWV in processing tomato fields in Fresno and Kings Counties were, with a few exceptions, low to moderate (0-14%, Table 1). In 2012, the overall incidence of TSWV in processing tomato fields in Merced County was very low (0-2%). In 2012, TSWV was widespread and present at higher incidences in northern counties (up to 90% only in a few fields). Although the overall incidence of TSWV in monitored fields was relatively low (0-12%) and did not cause economic losses, some fields had high incidences and may have experienced economic loss.

Thus, in 2012, the overall incidence of TSWV in monitored fields in Fresno, Kings and Merced Counties was lowest since the beginning of our project in 2007. The overall pattern of disease development was similar in all of these years: low TSWV incidence in early-planted fields and higher incidences in late-planted fields. However, potential for TSWV outbreaks was shown in fields in northern counties as well as some fresh market tomato fields in the I-5 corridor, in the Dos Palos/Firebaugh area, where high TSWV incidences (>35% in some parts of the field) were observed.

Survey of potential hosts for TSWV and thrips: We continued our efforts to identify reservoir hosts of TSWV and thrips before, during and after the processing tomato season in 2012. We again surveyed spring- and fall-planted lettuce in Fresno, spring- and fall-planted radicchio in Merced, and numerous weeds collected in the winter and spring.

Lettuce: TSWV was not found in most spring lettuce fields; however, very low levels of TSWV (<1%) were observed in a few fields. Overall, spring lettuce was considered clean and not to be a major inoculum source for processing tomatoes in 2012. Interestingly, high levels of TSWV in fall lettuce did not carry over to the spring lettuce.

Radicchio: In the winter of 2012, a radicchio field in Fresno had very high levels of TSWV (up to 60%). In contrast, all monitored radicchio fields in Merced were free of TSWV and had low thrips populations. In spring 2012, TSWV was detected in low incidences in some monitored radicchio fields in Merced and Fresno, but the incidence was sporadic (<1%) and did not cause economic losses in this crop. In general, radicchio growers in Merced are effectively managing TSWV and thrips and minimizing its role as a source of TSWV.

Fava bean: Early in 2012, we monitored two fava bean fields in one location in Yolo County, and surveys revealed that despite of very low thrips populations there were TSWV infections (<3%) in these fields. In 2012, the first TSWV outbreak in tomato in Yolo County was detected in a field that was ~1.5 mile from these fava bean fields.

Weeds: In 2012, weeds were collected from areas with TSWV outbreaks, and tested for the virus (Table 2). Most symptomless weeds collected before and during 2012 tomato growing season were negative for TSWV. A few weeds with symptoms (necrosis and thrips-feeding damage) were found and these were infected with TSWV. In addition, TSWV-infected weeds (sowthistle, prickly lettuce and black nightshade) were collected from spring lettuce fields and weedy orchards. However, the overall incidence of TSWV infection in weeds was very low (a total of 10 TSWV-infected weeds detected/602 samples tested; overall incidence 0.2%) and this is similar to results from previous years. To date, we have not found evidence of any weed that is extensively infected by TSWV in the Central Valley of California.

Additionally, before the growing season in 2012, four wheat and two onion fields were monitored for thrips and thrips from these fields were counted and tested for TSWV with the RT-PCR assay. Thrips population densities on wheat were low through April. In onions, thrips population densities were also low until in early April, but populations rapidly increased in late April. To date, TSWV has not been detected in thrips collected from wheat and onions, which are non-hosts of the virus.

Assessment the role of TSWV resistant (*Sw-5*) tomato varieties for selection of 'resistance breaking' TSWV-isolates in California:

In the Central Valley, more fields being planted with tomato varieties carrying the TSWV resistance gene (*Sw-5*), especially in fields with a history of TSWV or in late planted. In 2012, our survey results indicated that resistant tomato plants with *Sw-5* in the Central Valley generally did not show symptoms of TSWV infection. However, in a couple fields, symptoms were observed in *Sw-5* tomatoes and infection with TSWV was confirmed with RT-PCR tests.

Furthermore, to assess whether these *Sw-5*-infecting viruses were 'resistant-breaking' TSWV, a molecular analysis of two genes was performed. Virus isolates from these plants, as well as from susceptible tomatoes, were examined and the results did not show any difference in the sequences of genes. These results indicated that the isolates from *Sw-5* tomatoes were not resistance-breaking strains.

Interestingly, when some of these TSWV-infected *Sw-5* plants were used for rub-inoculation experiments to assess if the virus isolates were able to infect *Sw-5* and/or susceptible tomato plants, TSWV symptoms did not appear on *Sw-5* or susceptible plants. However, different virus symptoms appeared on all inoculated plants and these were determined to be caused by *Tomato mosaic virus* (ToMV). Results of RT-PCR assays confirmed that plants were infected with both TSWV and ToMV. Furthermore, when we tested 30 more *Sw-5* tomato plants with or without fruit symptoms for TSWV, 29/30 of the plants were found to be infected with TSWV and ToMV. One plant had characteristic TSWV symptoms (bronzing, necrosis and ring spots) on leaf and fruits and was negative for ToMV. Later, this plant and all other plants were tested by PCR to assure they were true *Sw-5* variety and, not surprisingly, all plants but one tested positive for presence of *Sw-5* gene. This one plant was found to have segregated for the *Sw-5* gene, which is why it had characteristic TSWV symptoms. This unexpected finding of mixed infection of *Sw-5* varieties with TSWV and ToMV is very interesting and more studies are needed to address whether these mixed infections allow TSWV isolates to infect *Sw-5* varieties in California.

Assessment of the potential role of the soil-emerging adult thrips as inoculum sources of TSWV for early planted tomatoes:

Soil samples collected from fields: In 2012, we again collected soil samples from various fields to assess for whether adult thrips emerged from soil. Similar to 2011, we found that adult thrips emerged from some of the soil samples, and we recovered more thrips from the 2012 soils than from the 2011 soils. Similar to 2011, most of the emerging thrips were captured in first or second week of the experiment. Thrips populations on these yellow sticky cards were variable (1-174 thrips/card), and highest populations were from soil samples collected from a plowed processing tomato field. Higher populations also came from soils from fall crops and weedy orchards (Table 3). None of the thrips from these soils tested positive for TSWV by the RT-PCR assay. Interestingly, in most containers, many weeds and volunteer crops germinated and started to grow during the experiment. These plants, as well as the fava bean indicators, did not develop symptoms of TSWV infection, consistent with the RT-PCR results indicating that the thrips were not carrying TSWV. To further test whether these volunteer tomatoes or weeds were infected with the TSWV, leaf samples from these plants as well as the fava beans indicator plants that were placed in each container were analyzed with RT-PCR. All of these plants were tested negative for TSWV.

Soil maintained under laboratory conditions: Initially, we tested rates of adult emergence from pupae of nonviruliferous thrips from various types of soil and for different periods of time at different temperatures (e.g., at 4, 15 and 25ºC). We found that 60-70% of adult thrips emerged from soil after pupae were incubated at 15ºC for 4 weeks or 4ºC for a week. Rates of emergence of nonviruliferous thrips were then tested by incubating pupae at 4ºC for 0 to 8 weeks.

The results showed that the emerging rates declined over time to 10%, 6% and 0% for 6, 7 and 8 weeks of storage at 4ºC, respectively (Fig. 4A). We also found that viruliferous thrips had similar rates of emergence following 1, 2 and 3 weeks at 4ºC (Fig. 4B). Furthermore, we confirmed that after 3 weeks at 4ºC treatment, emerging adult thrips were able to transmit TSWV to healthy Datura seedlings. Thus, our results indicated that thrips pupae can survive and provide adult thrips from soil after 4ºC treatment for up to 7 weeks, and that emerged viruliferous adult thrips were able to transmit TSWV after at least 3 weeks of 4ºC treatment.

Together, these results indicated that thrips pupae can stay dormant in the soil up to seven weeks and that some adults emerging from these pupae may well retain TSWV (at least three weeks) and transmit the virus after emerging from soil. It appears that viruliferous adult thrips emerging from soil can be a potential inoculum source for early-planted tomatoes as well as other susceptible plants (weeds or bridge hosts), in which the virus can be amplified.

Detection of TSWV in thrips and studies of thrips biology: Periodic RT-PCR tests performed with thrips collected from flowers and yellow sticky cards revealed that none of the insects were positive for TSWV in 2012, whereas lab-reared viruliferous thrips controls and some of the thrips collected directly from TSWV-infected tomatoes were positive. These results indicated that most of the adult thrips present in processing tomato fields throughout the season were not carrying the virus. Overall, RT-PCR tests of thrips for TSWV does not appear to be an effective tool for predicting when TSWV will appear in the field because the number of thrips carrying the virus is so low.

Comparison of thrips transmission efficiency for thrips colonies from Fresno and Yolo: We completed our studies comparing the TSWV-transmission efficiency of thrips populations originating from Fresno and Yolo to transmit TSWV-Fresno and -Yolo isolates (TSWV-F and TSWV-Y). Consistently, our results showed that transmission rate of Fresno thrips with TSWV-F was greater (43.8%) than Yolo thrips with TSWV-Y (22%). Male thrips from both populations transmitted TSWV more efficiently than female thrips (Table 5). Interestingly, transmission rates increased to 37% for Fresno thrips with TSWV-Y, confirming that the Fresno thrips population had a greater transmission efficiency. Furthermore, transmission rates of the Yolo thrips population were also elevated (32.9%) when TSWV-F was used for transmission, suggesting that the TSWV-F isolate was more readily transmitted by both populations. Based on our findings, the Fresno thrips population showed higher transmission efficiency for both TSWV isolates compared with the Yolo thrips population. This was consistent with our finding that thrips populations are often higher in tomato fields in Yolo County, but the incidences of TSWV are typically higher in Fresno County. Furthermore, regardless of the geographic origin, male adult thrips transmitted TSWV more efficiently than female adult thrips, and this is in agreement with previous results of other researchers.

Development a phenology model and a risk assessment system for thrips and tomato spotted wilt disease in processing tomato fields in Central Valley of California: In 2011, we developed a predictive tool to assist growers to determine when thrips populations begin to increase. This phenology model is a “degree day’ model that utilizes the robust relationship between temperature and thrips development rates to project the timing of appearance of successive thrips generations.

In 2012, this model was modified and validated, and compared with real-time thrips populations in monitored fields. The model predicted at least eight thrips generations during the tomato growing season. In most instances, the model was accurate in predicting the timing of these generations. We assume that thrips numbers will increase with the appearance of each generation, allowing the model to be validated by comparison with field data. Again, in 2012, after each successive prediction of thrips generation, an increase in cumulative thrips populations as determined on yellow sticky cards provided evidence of more thrips being generated (Figs. 2 and 3).

As the predictions made by the model became available during the growing season, the information was regularly updated on the model web page and provided to growers through the monthly CTRI update. The model projections were provided in a window of up to 10 days in advance so that growers could implement thrips management in a timely manner. We believe that, in 2012, the drop in thrips populations in June-July was due, in part to timely implementation of thrips control based on the results of the model's forecasts and backed up by field monitoring. We will continue to modify and validate the model for the 2013 growing season and improve the accessibility of model's web page to growers and PCAs so that timely insecticide implementation can be made. The model's web page on thrips population projections can be found on the following website (https://sites.google.com/site/cubelabsite/current-research/tomato-spotted-wilt-virus/thrips-population-projections).One possible new development will be to replicate the model-based projections on a dedicated Facebook page.

In 2011, we developed the TSWV risk index (TRI) for California processing tomatoes as a tool to help growers predict the relative level of risk for TSWV development in a given field based upon a variety of factors known to influence disease development. In 2012, evaluations of TRI revealed certain factors that were consistently more important than others, allowing us to modify the TRI to be more accurate (Table 6). In 2012, the proximity of TSWV-infected crops/weeds to fields appeared to be a very important factor and, thus, the point value for this factor was increased. Another important factor was the planting density, as it was apparent that TSWV impact in fields with single rows was more pronounced than those with double rows; thus, the point value for single row plantings was increased. The planting of a *Sw-5* tomato variety dramatically reduces TSWV incidence; thus, the point value for this factor was changed to a credit (negative -35).

In 2012, using the current version of TRI, fields identified as high risk were consistently found to have higher TSWV incidences (e.g. monitored BF, YL and EG fields in Yolo with 7, 7 and 12% TSWV; and monitored North, Oakland and Ness fields in Fresno with 7, 12, and 14% TSWV) compared with other monitored fields (e.g. RO, PR and AO fields in Yolo and Harris, Mt. Whitney and Tranquility in Fresno with <2% TSWV). The risk index for the majority of monitored fields in 2012 was moderate, but some low risk fields were also identified. We hope to continue to evaluate and modify the TRI, as we believe this tool will be beneficial for decision making and will reduce risk of TSWV associated losses.

Insecticide Trial: Two experiments were conducted at UC West Side Research and Extension Center in Fresno County to compare activity of insecticides against thrips on tomatoes and to assess the impact of these programs on TSWV in 2012. Processing tomato transplants (cv. H8004) were transplanted on 2 May, sprinkled for two weeks, and irrigated with buried drip for the remainder of the season. The 2012 evaluation of insecticide programs was conducted with treatments that were similar but not identical to those treatments that were tested in 2009 and 2010. In 2012, several materials reduced the levels of thrips when compared with the untreated control (Table 7). Results of the 2012 trial generally supported results of earlier work in that Radiant has consistently been among the top performing materials, and Beleaf either alone or tank-mixed with a pyrethroid has provided a level of control. Other treatments that resulted in lower levels of thrips were the new materials Grandevo with organo-silicone, and Torac with Agri-Mek and Dynamic. However, unlike 2007 and 2008 results, but similar to 2010 results, Venom also reduced thrips population densities. Although efficacy on thrips counts are still in progress and will be available through CTRI, in 2012, there were clearly differences among the foliar treatments in terms of yield (Table 8) and in incidence of TSWV symptoms on plants (Table 9). In 2010, there were extremely high levels of virus in the vicinity of the field station and it was present at intermediate levels in 2009, 2011 and 2012. Therefore, it is possible that the impact of insecticides is largely dependent upon whether the majority of the virus is due to spread within the field or with virus-carrying thrips from outside of the field. Regardless of the year, we have never seen a reduction in disease associated with the drip applied materials, but we saw an increase in yield this year in the treatment. No phytotoxicity symptoms were detected. Together, these results indicate that some materials continued to reduce thrips populations to some extent and reduce TSWV incidences, but that growers can not rely on insecticide application for efficient control.

Integrated pest management (IPM) for TSWV in Central California:
Our accumulated research findings on thrips population densities and TSWV development on processing tomatoes in Central Valley of California are presented in Figure 4. Based on this understanding, the following IPM approach for managing TSWV in processing tomatoes has been developed. This approach has been presented to growers through many presentations, reports and a UCIPM flyer. The flyer is available for interested parties upon request. The IPM program is outlined below and continues to be modified and validated. The management strategies are segmented into **preplan**t, **in-season** and **post-harvest** crop periods.

A) Preplant
i) planting location/time of planting-this will involve determining if proximity to the foothills or other alternate crop hosts (e.g., lettuce or peppers) favors infection and/or if early or late-planted fields have higher incidences of TSWV. If either of these scenarios is found, then this may indicate possible management strategies.
ii) resistant cultivars-these are available, but may not be necessary **if other practices are followed**. Resistant cultivars should be used in **hot-spot areas or in late planted fields**, especially in near those fields in which TSWV infections have already been identified.
iii) weed management-maintain weed control in and around tomato fields and especially in fallow fields and orchards, as weeds are potential TSWV hosts. Indeed, our results here indicated that if weeds are allowed to grow in fallow fields, they can amplify thrips and TSWV and serve as inoculum sources for processing tomatoes.

B) In-season
i) monitoring for thrips/TSWV-monitoring thrips populations and TSWV incidence can indicate when to apply insecticides for thrips control, thereby reducing TSWV spread. All evidence indicates that thrips management should be initiated early (e.g., April/May) to reduce the development of virus-carrying adult thrips that can spread the virus within and between fields. This may even need to be done before disease symptoms are observed. More accurate timing of such treatments may be come from using the TRI and phenology model.
ii) roguing – roguing of infected tomatoes before fruit set can be an efficient way of reducing TSWV inoculum in field especially early in the season.
iii) weed management-maintain effective weed control in and around tomato fields.

C) Post-harvest
i) sanitation-immediately plow under crop residue following harvest.
ii) cover crops-if you plant cover crops, consider use of non-host cover crops (e.g., triticale and ryegrass) to reduce volunteers and weeds that can harbor TSWV and thrips vector (note that thrips can stay in soil long period of times).
iii) bridge crops- **1)** avoid planting radicchio, lettuce and fava beans, **2)** establish fall crops of these plants away from late-planted tomatoes, **3)** monitor for thrips and TSWV, **4)** implement thrips management if necessary and, finally, **5)** immediately plow under crop residue following harvest.

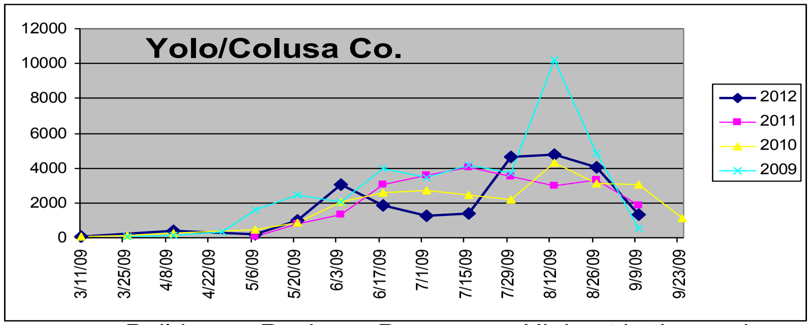
Current situation of thrips and TSWV in California:

- Western flower thrips and tospoviruses have emerged as major pests in California crops and are likely to continue to be a problem in crops such as lettuce, pepper, radicchio and tomato.
- It is difficult to predict when and where TSWV outbreaks will occur.
- Not all aspects of thrips and TSWV biology fully understood.
- **No** single approach is adequate for management of thrips or TSWV.
- Evidence that the IPM approach is effective:
  -Losses due to TSWV in monitored fields have been minimal
  -Growers using some or all of the IPM practices have not experienced significant losses due to TSWV
- Progress in managing thrips and TSWV in radicchio has been reduced TSWV in Merced
- Economic losses due to TSWV in 2012 were minimal to none, although some fields did have high TSWV incidences (~14%)
- The phenology (degree day) model can predict when thrips populations begin to increase and subsequent generations.
- A risk index for tomato fields has been developed that can help growers predict the chances of developing TSWV in their field, thereby allowing for decision to be made regarding management practices.

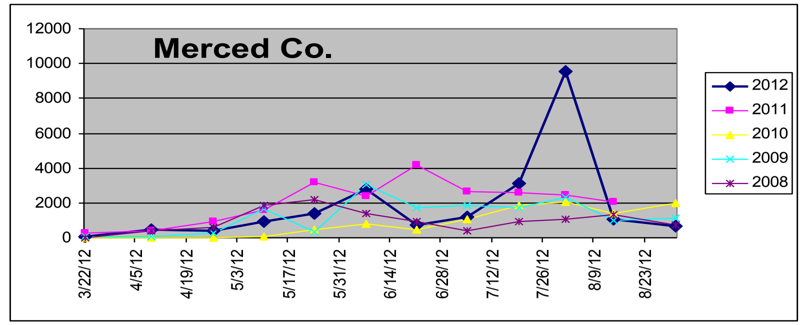
Table 1. List of monitored processing tomato fields: their locations and TSWV incidence in 2012.

	Monitored Fields 2012	
	Northern Counties	**TSWV %**
RO	Winters, Yolo	0
BF	County Line, Colusa	7
AO	County Line, Colusa	0
PR	Dixon, Solano	2
EG	Robin,Sutter	12
YL	Yolo Town,Yolo	7
	Merced County	
PT	Rogers Rd, Paterson	2
GC	Gun Club Rd, Gustine	1
FM	Fentem Rd, Gustine	2
BC	Bert Crane Rd, Merced	0
DF	Dickenson Ferry Rd, Merced	0
LG	Le Grand Rd, Merced (Fresh Market)	0.5
BH	Buchanan Hallow Rd, Merced (Fresh Market)	0.5
	Fresno County	
North	Firebough area	7
Oakland	Five Points area	12
Mt.Whitney	Five Points area	0
Tranquility	Tranquility area	2
Nees	Firebough area	14
Harris	Five Points area	0.5
	Kings County	
Tomato #1	Lassen Ave between Phelps and Jayne	2
Tomato #2	Laurel Ave at Avenal Cutoff	0.3
Tomato #3	Nevada Ave & Kent	2
Tomato #4	El Dorado Ave near Dorris	5
Tomato #5	Lassen Ave & Tornado	7

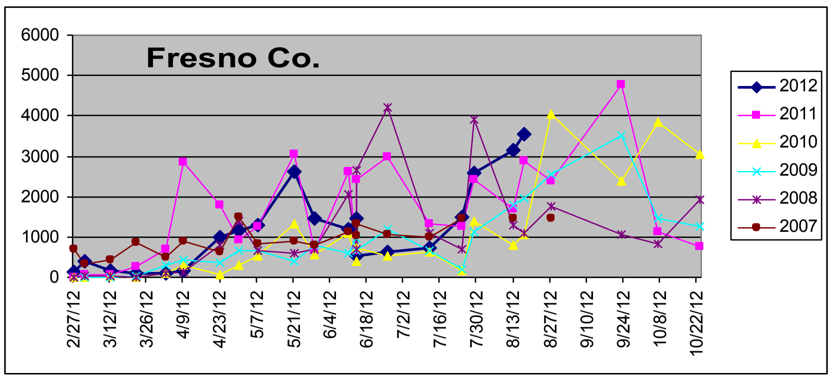
Average Thrips Populations per Yellow Sticky Card



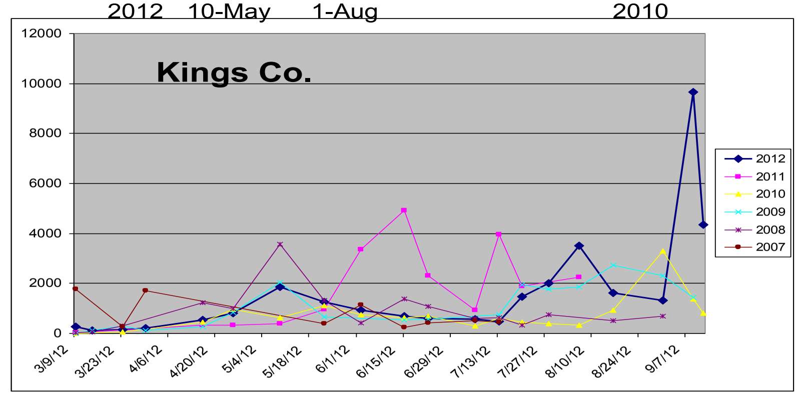
	Build up	Peak	Drop	Highest in the peak
2009	8-May	14-Aug	11-Sep	2009
2010	21-May	13-Aug	23-Oct	2012
2011	26-May	14-Jul	24-Sep	2010
2012	17-May	13-Jun	6-Sep	2011



	Build up	Peak	Drop	Highest in the peak
2008	4-Apr	16-May	10-Oct	2012
2009	6-Apr	15-May	2-Oct	2011
2010	14-May	23-Jul	5-Oct	2009
2011	12-May	21-Jul	15-Oct	2008
2012	10-May	1-Aug		2010



	Build up	Peak	Drop	Highest in the peak
2007	6-Apr	25-May		2011
2008	9-Apr	29-May	20-Oct	2008
2009	19-Mar	22-Jul	11-Aug	2010
2010	3-May	21-Jul	21-Oct	2012
2011	11-Apr	18-Aug	23-Sep	2009
2012	23-Apr	17-Aug		2007



	Build up	Peak	Drop	Highest in the peak
2007	31-Mar	29-Jun	August	2012
2008	3-Apr	1-May	October	2011
2009	14-Apr	11-Aug	October	2008
2010	23-Apr	26-Aug	November	2010
2011	12-May	16-Jun	November	2009
2012	25-Apr	9-Sep		2007

Fig. 1. Average thrips counts per yellow sticky card in monitored fields in Fresno and Kings Counties in 2007-2012, in Merced County in 2008-2012 and Yolo and Colusa Counties in 2009-2012. Note the thrips population build up, peak and drop dates are indicated below graphs. Highest thrips populations during peaks are ranked (high to low) from top to bottom.

Table 2. Weed survey results for TSWV incidence during 2012.

Weed [a]	Tested (+)	Weed [a]	Tested (+)
Black nightshade	10 **(1)**	Curlydock	22 (0)
Bindweed	58 (0)	Malva	68 (0)
Flaree	30 (0)	Datura	10 (0)
Pineapple weed	24 (0)	Monocots	18 (0)
Sowthistle	134 **(7)**	Shepherd's purse	3 (0)
Prickly lettuce	85 **(2)**	Fiddler neck	5 (0)
Russian thistle	16 (0)	Pigweed	8 (0)
Buckhorn Plantain	8 (0)	Turkey mullein	15 (0)
Wild radish and Mustard	30 (0)	Other common weeds	38 (0)

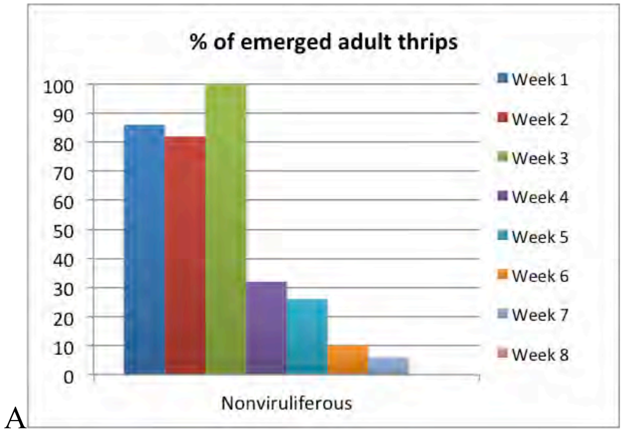
(+) number of plants tested positive for TSWV by immunostrips and RT-PCR.
[a], Total weed samples from all counties

Table 3. Summary of the assessment of the potential role of the soil-emerging thrips (soils from fields)

Sample #	Source of the soil samples	Collection Date	Previous/Current Crop Type	Number of captured	RT-PCR tests of thrips	RT-PCR tests of plants	Soils Discarded
	Yolo & Colusa Counties						
1	HWY 113	1-Mar	Weedy Prunus	**129**	Negative	Negative	27-Apr
2	Sutter County	1-Mar	Proc. Tomato	**12**	Negative	Negative	27-Apr
3	Yolo/Colusa County Line	1-Mar	Proc. Tomato	**26**	Negative	Negative	27-Apr
4	Yolo Rd 29	1-Mar	Fava Beans	**40**	Negative	Negative	27-Apr
	Merced County						
5	SM Sandy Mush - Merced	29-Feb	Fall Radicchio	**14**	Negative	Negative	27-Apr
6	LG La Grand Rd. -Merced	29-Feb	Late Fresh Mark. To	**2**	Negative	Negative	27-Apr
7	HT Hunt Rd. -Gustine	29-Feb	Late Fresh Mark. To	**1**	Negative	Negative	27-Apr
8	PT Paterson/Wastley	29-Feb	Weedy Almond	**9**	Negative	Negative	27-Apr
	Fresno County						
9	Gale & Butte	28-Feb	Onion	**37**	Negative	Negative	27-Apr
10	Woolf Creek	28-Feb	Proc. Tomato	**4**	Negative	Negative	27-Apr
11	North -Fairbaugh	28-Feb	Proc. Tomato	**174**	Negative	Negative	27-Apr
12	Farming D -Five Point	28-Feb	Spring lettuce	**10**	Negative	Negative	27-Apr
13	North -Fairbaugh	28-Feb	Almond	**4**	Negative	Negative	27-Apr
	Kings County						
14	John Farms	28-Feb	Proc. Tomato	**3**	Negative	Negative	27-Apr
15	Huron	28-Feb	Fall Radicchio	**149**	Negative	Negative	27-Apr
16	Plymouth	28-Feb	Weedy Almond	**13**	Negative	Negative	27-Apr
17	UC Davis Greenhouse	28-Feb	Sterile soil; (-) control	**0**	N/A	N/A	27-Apr

Table 4. Summary of the assessment of the potential role of the soil-emerging thrips (laboratory conditions)

A



B

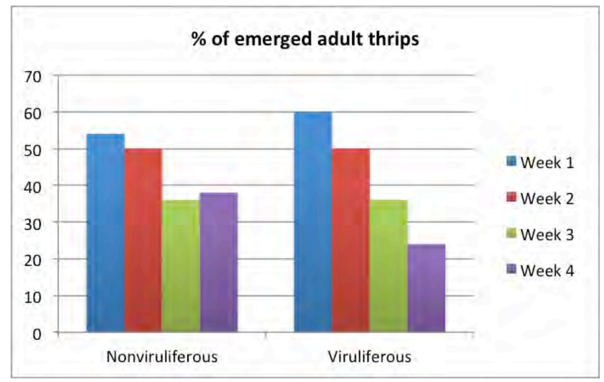


Table 5. Summary of assessment and comparison studies in transmission efficiency of thrips and TSWV isolates collected from Fresno and Yolo Counties.

TSWV-Fresno isolate				TSWV-Yolo isolate			
Fresno Thrips		Yolo Thrips		Fresno Thrips		Yolo Thrips	
Male	Female	Male	Female	Male	Female	Male	Female
45% (8)[a]	42.5% (8)	40% (7)	25.7% (7)	42% (5)	32% (5)	26% (5)	18% (5)
43.8%		**32.9%**		**37%**		**22%**	

[a] **Numbers in parentheses represent replicates of independent experiments**

Table 6. Tomato spotted wilt virus Risk Index (TRI) for Processing Tomatoes in the Central Valley of California (2012 index)

Tomato Variety[1]	Examples	Risk Index Points
a,b,c	stunted plt w less fruit, very severe, dead like	50
d,e,f	Res. size plt w less fruit, severe symptoms	40
g,h,i	Nor. size plt w many fruits severe symptoms	30
j,k,l	Nor. plt w many fruits some symptoms	20
m,n,o	Vigor.Plt w many fruits almost no symptom	10
p,q,r	with SW5	-35
Planting Date[2]		
Prior to February 1	First planted fields in any given region	10
February 1-29	week or two later than first planted fields	15
March 1-15	week earlier than recommended period	10
March 16- April 31	Recommended period (Majority of fields)	5
May 1-20	week or two later than majority of fields	15
May 21- June 5	tree week or more later planted from major	25
After June 5	latest planted fields in a given region	35
Plant Population[3]		
Less than 1 plant per foot	single row (7000 per acre)	35
2 to 3 plants per foot	double row (9000 per acre)	15
More than 3 plants per foot	double row but more dens (>9000 per acre)	5
Planting Method		
Direct seeded		10
Transplanted		5
Proximity to Known Bridge Crops		
adjacent	radicchio, lettuce, fava, weed/fallow field, pepper or tomato	25
less than 1 mile radius distance	(if TSWV confirmed add 20 more points)	15
1-2 mile radius distance	(if TSWV confirmed add 10 more points)	10
greater than 2 mile or None	(if TSWV confirmed add 5 more points)	5
Proximity to Thrips Source		
adjacent	wheat, pea, alfalfa or weedy patches etc.	20
less than 1 mile radius distance		15
1-2 mile radius distance		10
None		5
At-Plant Insecticide		
None		15
for other pests (+ thrips)		10
specifically for thrips		5
Weed situation/Herbicide use		
w/out herbicide but weedy	In-field ONLY weed population	15
w/out herbicide but not so weedy		10
w/out pre emergence herbicide or NO weed		5
Total Points (0-225)	**Risk of Losses Due to TSWV**	
Less than or equal to 95	**Low**	
Greater than 100 or equal to 150	**Moderate**	
Greater than 150	**High**	

[1] Additional varieties will be included as data to support the assignment of an index value are available.
[2] In those years when the normal date of planting for the first tomato in an area is delayed due to inclement weather, these date ranges should be moved later by an equal amount. In most years, these date ranges will also vary slightly with latitude. Dates can be shifted 5 days earlier in the extreme southern counties and 5 days later in the extreme northern counties.

Note that point values in the index are not final and shown here as an example.

Table 7. Insecticide efficacy against Western flower thrips in processing tomatoes in 2012.

Treatment	4 Aug	
	Nymphs	Adults
Grandevo 3.0 lbs + organo-silicone 0.25%	**1.3**	**30.7**
Torac 15EC (tolfenpyrad) 21 fl oz	0.0	62.7
Venom 70SG 0.895 lb	0.3	70.0
Radiant 7.0 fl oz	**0.7**	**45.7**
HWG 86 10SE (cyazypyr) 20.5 fl oz	1.0	72.7
Agri-Mek SC 3.0 fl oz	2.3	57.7
Torac 15EC (tolfenpyrad) 21 fl oz + Agri-Mek SC 3.0 fl oz + Dynamic 0.25%	**0.0**	**38.7**
Entrust SC 7 floz/acre + MSO 0.5%	0.0	51.7
Untreated control	1.3	76.7
$LSD_{0.05}$	1.9	36.1
CV (%)	143.0	36.9

[z] **Treated 10, 18 and 26 Jul with Co_2-pressurized back pack sprayer at 40 gal/acre. Unless otherwise specified, all materials were applied with Dynamic at 0.25%.**
[y] **Collected 25 samples per plot in 70% Et-OH and counted nymph and adults under dissecting scope.**

Table 8. Influence of insecticide programs for controlling: thrips, TSWV incidence, yield and other quality parameters.

Treatment[z]: Injections into drip irrigation system buried to 10 in	Yield (tons/ acre)[w]	Fruit quality (% by weight)[y]: red	grn	rot	sun brn	TSWV	PTAB[x]: color	solids	pH
Platinum75SG 3.7 oz (7 Jun), Venom 6.0 oz (27 Jun)	29.5	57.1	5.2	28.4	3.6	**5.7**	21.9	5.34	4.48
Platinum75SG 3.7 oz (7 Jun), cyazypyr 13.5 oz (27 Jun)	26.7	48.3	4.8	33.8	2.2	**10.9**	22.1	5.30	4.45
Untreated	24.3	47.6	5.9	35.2	3.2	**8.1**	22.3	5.41	4.45
Drip injection, probability[v]	2.46	NS	NS	NS	NS	**NS**	NS	NS	NS

Foliar applications: Trans. drench	12 Jun	22 Jun	29 Jun	9 Jul	18 Jul	Yield (tons/ acre)	Fruit quality (% by weight): red	grn	rot	Sun brn	TSWV	PTAB: color	solids	pH
cyazypyr	Radiant 10 fl oz	Dimth 4EL 1pt.	Radiant 10 fl oz	Dimth 4EL 1pt.	Radiant 10 fl oz	29.0	54.9	5.9	31.5	2.3	**5.3**	22.3	5.38	4.45
	Radiant 10 fl oz	Dimth 4EL 1pt.	Radiant 10 fl oz	Dimth 4EL 1pt.	Radiant 10 fl oz	28.3	54.7	5.8	27.9	3.4	**8.2**	21.8	5.26	4.44
	Radiant 10 fl oz	Dimth 4EL 1pt.				26.6	51.1	4.3	33.0	2.8	**8.6**	21.8	5.43	4.47
Untreated						23.0	43.1	5.2	37.5	3.4	**10.9**	22.6	5.34	4.48
$LSD_{0.05}$[v]						3.07	NS	NS	NS	NS	**NS**	NS	NS	NS
AB						0.03	NS	NS	NS	NS	**NS**	NS	NS	NS
CV (%)						13.7	22.7	40.6	28.3	58.9	**52.7**	4.8	6.43	1.30

[z]Experimental area was transplanted on 17 May with cv. H8004 processing tomato plants at UC West Side Research and Extension Center. Foliar applications were made with a backpack sprayer at 30 gpa.

[y] Twenty to 25 lbs samples were taken from a mechanical harvester, and hand sorted. Fruit in each category were weighed and percentage by weight was calculated.

[x] A sample of 50 red fruit from each plot were tested for color solids and pH by Processing Tomato Advisory Board laboratory in Helm, CA.

[w] Yields per acre were calculated based on machine-harvests on 9 Sep.

[v] Least significant difference at probability of 0.05. NS signifies that there is no significant difference.

Table 9. Influence of insecticide programs for control of thrips and TSWV incidence.

Treatment[z]: Injections into drip irrigation system buried to 10 in	TSWV %[y]: 6 Jun	20 Jun	18 Jul	23 Aug
Platinum75SG 3.7 oz (7 Jun), Venom 6.0 oz (27 Jun)	**0.1**	**5.4**	**28.7**	**19.8**
Platinum75SG 3.7 oz (7 Jun) cyazypyr 13.5 oz (27 Jun)	**0.1**	**5.8**	**14.1**	**17.9**
Untreated	**0.2**	**4.3**	**21.7**	**21.2**
Probability	NS	NS	NS	NS

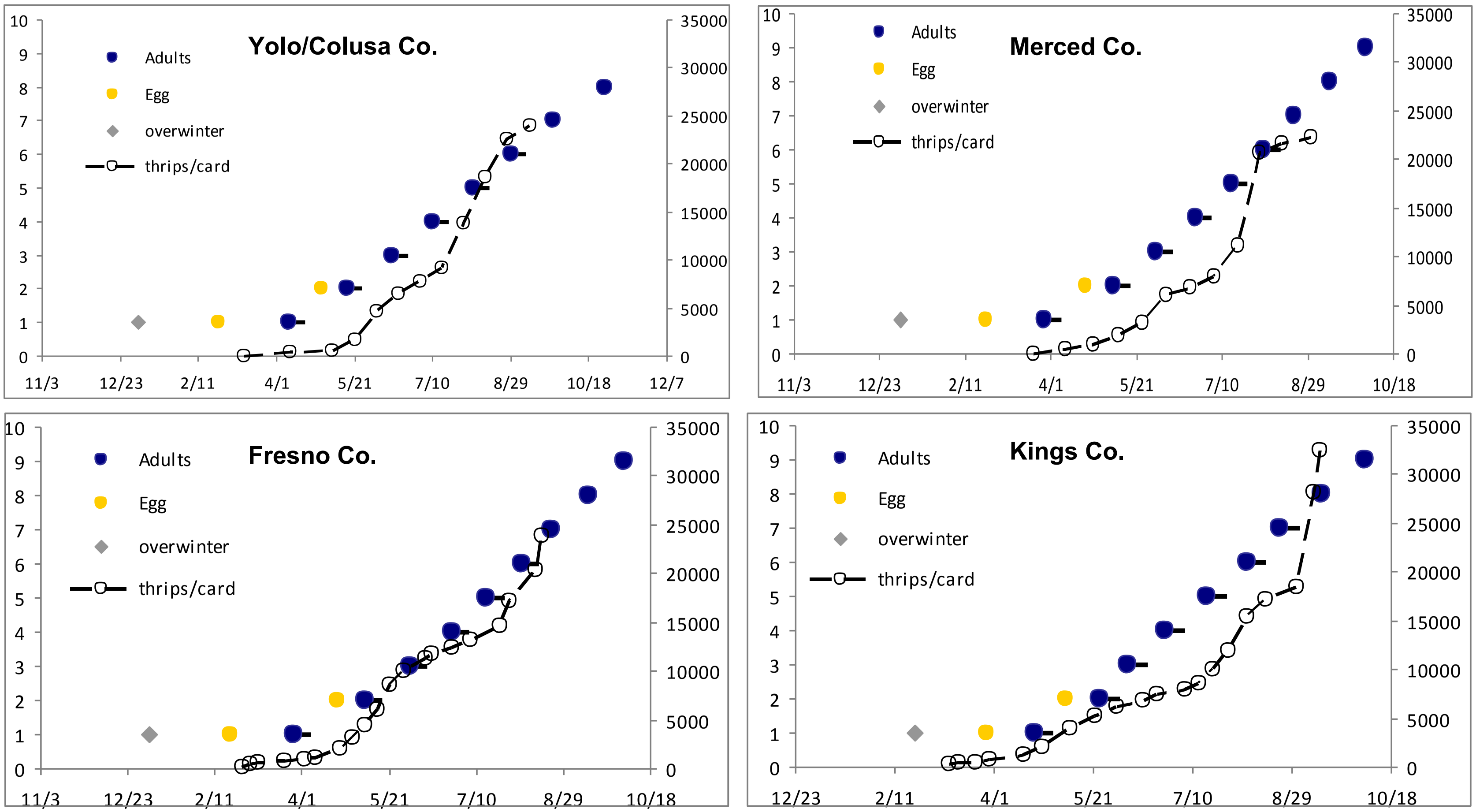
Foliar applications: Trans. drench	12 Jun	22 Jun	29 Jun	9 Jul	18 Jul	TSWV %: 6 Jun	20 Jun	18 Jul	23 Aug
cyazypyr	Radiant 10 fl oz	Dimth 4EL 1pt.	Radiant 10 fl oz	Dimth 4EL 1pt.	Radiant 10 fl oz	**0.3**	**4.3**	**13.7**	**13.2**
	Radiant 10 fl oz	Dimth 4EL 1pt.	Radiant 10 fl oz	Dimth 4EL 1pt.	Radiant 10 fl oz	**0.0**	**5.2**	**31.9**	**13.2**
	Radiant 10 fl oz	Dimth 4EL 1pt.				**0.3**	**4.5**	**16.8**	**18.6**
Untreated						**0.0**	**6.6**	**23.7**	**33.5**
$LSD_{0.05}$						NS	NS	NS	
AB						NS	NS	NS	NS
CV (%)						317.1	67.38	108.6	36.87

[z] Experimental area was transplanted on 17 May with cv. H8004 processing tomato plants at UC West Side Research and Extension Center. Foliar applications were made with a backpack sprayer at 30 gpa.

[y] Percentage of plants exhibiting Tomato spotted wilt virus symptoms per plot (n=55 to 65)

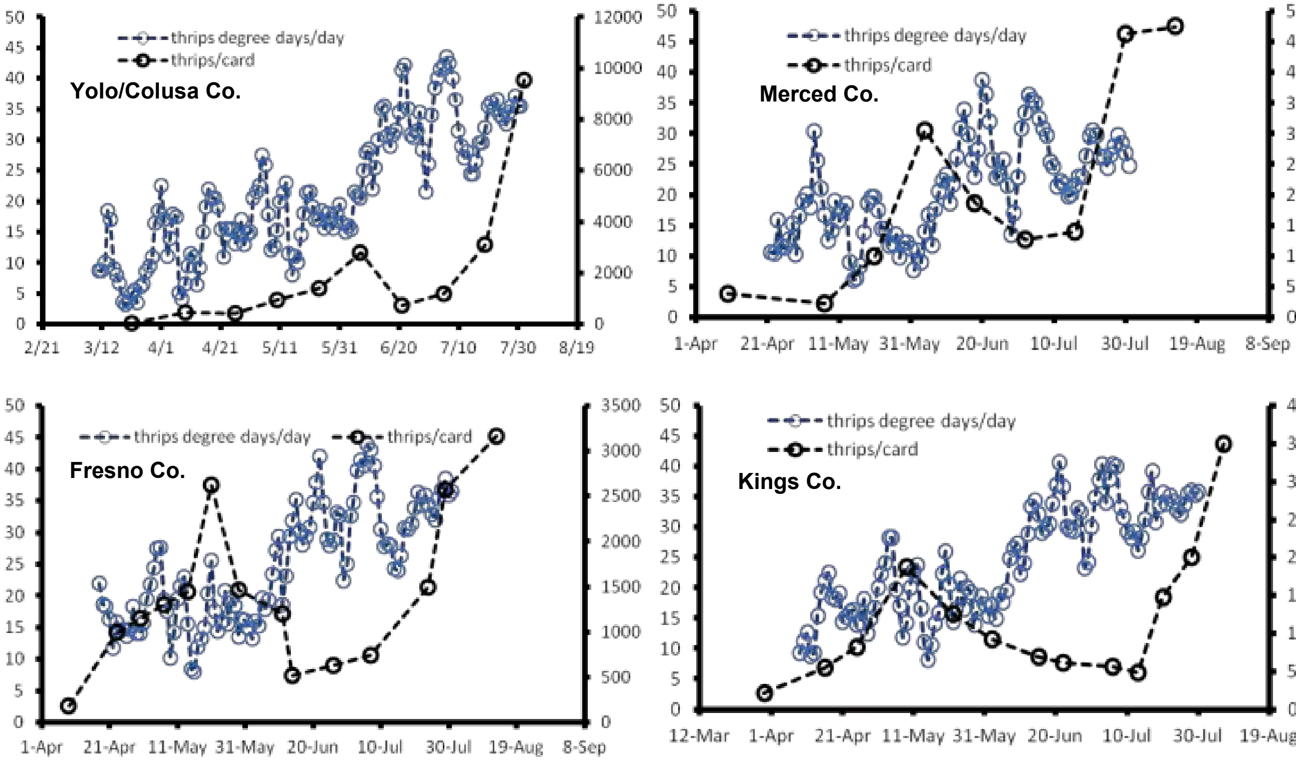
[xv] Least significant difference at probability of 0.05. NS signifies that there is no significant difference.

Fig 2. The phenology model predictions for thrips generations in monitored fields and their comparison with actual thrips dynamics (cumulative data) recorded in 2012.



Note that left axis are thrips generation numbers, right axis are cumulative thrips numbers per card and horizontal short lines projected from adults indicate insecticide implementation windows for growers to assure regional thrips control.

Fig 3. The phenology model predictions for thrips generations in monitored fields and their comparison with actual thrips dynamics (thrips/card data) recorded in 2012.



Note the period from May/June until early July, thrips numbers went down while degree days ramped up. One explanation is that early spraying in May/June, targeting generations 2 or 3 knocked the thrips back in July.

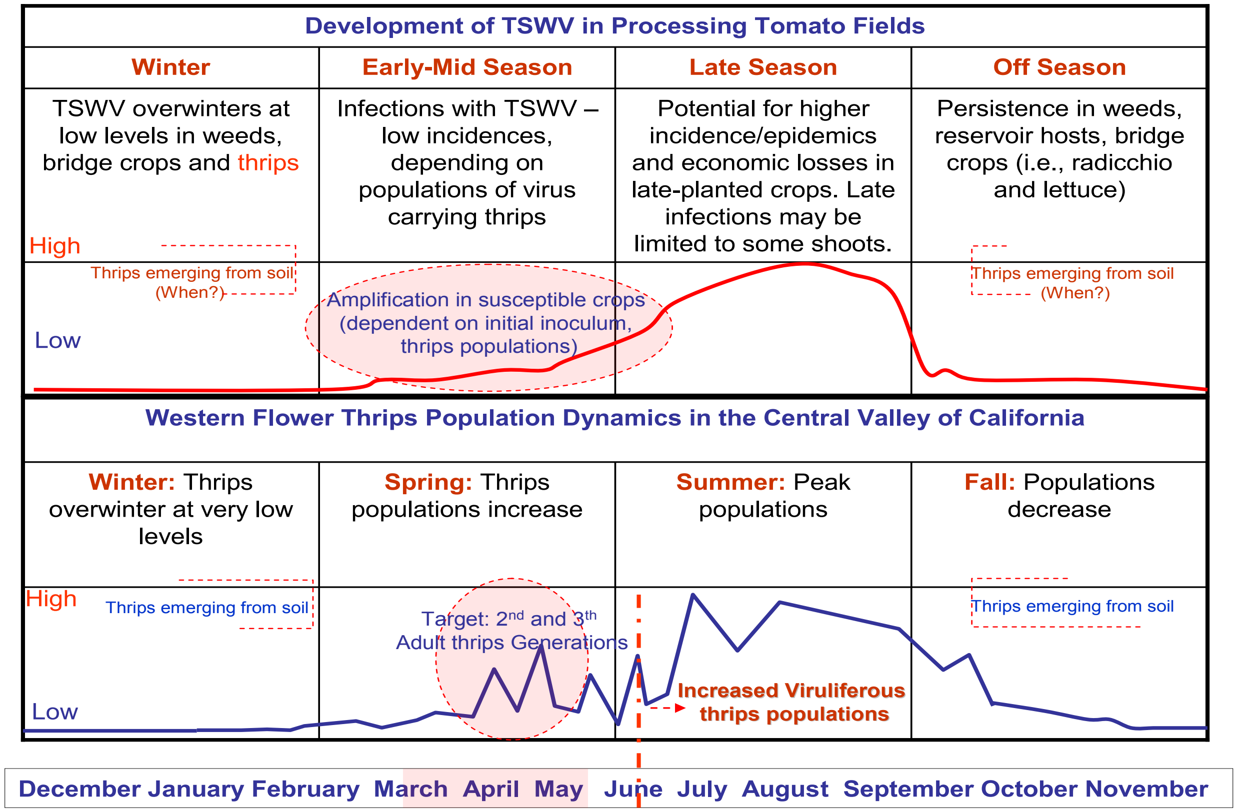


Fig. 4. Schematic presentation of thrips population dynamics and development of tomato spotted wilt diseases in processing tomatoes in the Central Valley of California. The recommended thrips management period is highlighted with dashed loop.