Project title: Western Flower Thrips Abundance and Incidence of Tomato Spotted Wilt in Processing Tomato Fields in the Central Valley of California (2009)

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Abstract

The goal of this project is improved understanding of thrips population dynamics and *Tomato spotted wilt virus* (TSWV) incidence in processing tomatoes in Central California, and development an IPM strategy for TSWV. Population densities of western flower thrips (WFT; *Frankliniella occidentalis*) and TSWV incidence were monitored in processing tomato transplant-producing greenhouses and associated fields in the Central Valley of California for a third year in 2009. Thrips were monitored with yellow sticky cards and in tomato flowers, whereas as TSWV incidence was assessed visually or with sensitive indicator plants. Similar to 2007 and 2008 results, tomato transplants had low thrips populations and no detectable TSWV infection. Monitoring of representative direct-seeded and transplanted tomato fields (including those established with monitored transplants) in Fresno, Kings and Merced Counties revealed that thrips populations in 2009 were similar to those detected in 2008, which were higher than populations detected in 2007. For all three years, thrips populations began to increase in April, peaked in May and gradually declined with low thrips populations detected in September. However, this trend was different in Yolo and Colusa Counties. Thrips populations were up to four fold higher compared with populations in other counties, and these high populations were detected throughout the growing season, with a peak populations detected in August. TSWV was first detected in mid-March in Yolo and Colusa, early April in Merced whereas in Fresno and Kings Counties, it did not appear until late April to early May. Eventually, TSWV was detected in most monitored fields, but at relatively low incidences (0-8%) up through harvest. For example, TSWV incidences in monitored tomato fields were 0-7% in Fresno and Kings Counties, 0-8% in Yolo and Colusa Counties and 0-4% in Merced County. Based on discussions with our farm advisor cooperators and growers, we believe that TSWV did not cause economic losses in any of the monitored fields. Inoculum sources for thrips/TSWV vary depending on the county

and agricultural production area. Thus, there is no single main source of the virus throughout the state. Almond orchards had low thrips populations, and winter and spring weed surveys revealed very low TSWV infection (<0.1%). However, weeds can be significant inoculum sources if allowed to multiply in fallow fields. For example, in Fresno, high TSWV in sowthistle and prickly lettuce (up %7 infection) was correlated with TSWV outbreaks in nearby tomato fields. In Fresno, lettuce fields had low thrips populations and low TSWV infection. In Merced, radicchio can be an important source of thrips and TSWV. However, the implementation of effective management practices was seamed to minimize the inoculum source. In Yolo County, thrips and TSWV were detected associated with winter planted fava beans and early TSWV outbreaks in tomato were associated with fava bean. Thus, fava bean may be an important inoculum source in the area. TSWV was infrequently detected in thrips collected out of the monitored fields. In insecticide trials, materials that significantly reduced thrips numbers included Radiant (spinosad), dimethoate, Beleaf, Hero and HGW86+ Brigade. However, the effect of these materials was only for ~7 days. Thus, our results in 2009 were consistent with our proposed model of TSWV infection of processing tomatoes in California: low levels of initial TSWV inoculum are increased in early-planted crops, with highest levels of infection in later-planted fields, especially those with high thrips populations. Based upon these findings, an integrated pest management strategy for TSWV in processing tomatoes in California is proposed.

Objectives

The objectives of this study were 1) to determine thrips populations and TSWV incidence associated with greenhouse-produced tomato transplants, 2) to determine whether any linkage exists between thrips and TSWV and greenhouse-produced transplants and outbreaks of TSWV in the field, 3) to gain insight into potential sources of TSWV for tomato in the Central Valley, 4) to assess various thrips control methods and 5) to develop an integrated pest management strategy for TSWV in the Central Valley.

Materials and Methods

Thrips monitoring in transplant greenhouses. Four transplant greenhouses (California Transplant in Newman, Mezzei Transplant in Fresno, Westside Transplant in Huron and Speedling in Watsonville) were monitored for thrips and TSWV incidence in 2009. These greenhouses produce tomato transplants for planting in southern Fresno, Kings, Merced, Yolo and Colusa Counties. Yellow sticky cards were again used to monitor thrips. At each site, six to ten yellow sticky cards were placed among tomato transplants in a greenhouse, and four sticky cards were placed around the periphery of the property. Cards were changed weekly or biweekly from March to June at all sites. At California Transplant, continuous monitoring around the periphery has been ongoing since March 2007. Population densities were estimated by counting thrips on yellow sticky cards in the laboratory with a dissecting microscope at 40x magnification. Thrips were counted and identified to species and gender.

Thrips monitoring in representative fields. Table 1 lists the 44 fields and their locations that were monitored in 2009. A total 24 tomato fields, and 20 fields planted with other crops in association with processing tomato production were monitored for thrips and/or TSWV. Yellow sticky cards were placed in each of the four corners of a field just above the canopy. Cards were changed weekly or biweekly beginning in February and up to harvest (July-October). Thrips were counted as described above. Population densities of thrips were also estimated weekly or biweekly by randomly collecting flowers, placing these into vials with 70% ethanol and returning vials to the laboratory for counting. Flower samples were collected from the same sites where yellow sticky cards were placed (four sites per field and 10 flowers per site). Total numbers of thrips adults and larvae were counted and identified to species.

Indicator plants. In order to detect TSWV early in the growing season (i.e., before tomatoes start showing obvious symptoms) fava beans, a sensitive TSWV indicator, were placed near each yellow sticky card placed in greenhouses and fields. Indicator plants were seeded and grown in an insect-free greenhouse at UC Davis. The potted 10-day-old indicator plants were changed weekly along with the yellow sticky cards. Indicator plants were brought to the laboratory at UC Davis, kept for 10 days, and then symptom development and thrips populations assessed.

TSWV incidence and detection. Percent TSWV incidence in tomato, lettuce and radicchio fields was determined by visually examining plants at the four locations in each field. At each location, all plants in 10 yards (meters) of each of 5 randomly selected rows (each separated by 5 rows) were examined. An overall incidence of tomato spotted wilt at each site of the field (four per field) was calculated (presented as number of infected plants per 100 row feet and % incidence). Disease incidence was assessed weekly and selected plants tested with ImmunoStrips (AgDia) and RT-PCR by using *N* gene-specific primers.

Isolate collection and genetic diversity of TSWV. Symptomatic plants were also randomly collected from different locations in 2009. In order to assess the genetic diversity of TSWV isolates from the Central Valley, the fragment of RNA encoding the *N* gene was amplified by PCR and the sequence of the *N* gene determined and compared among isolates that previously collected from different times and locations.

Comparison of insecticides for control of thrips on tomato. The study was conducted at the University of California West Side Research and Extension Center at Five Points, California. Processing tomato plants (variety H8004) were transplanted on 6 May. The field was sprinkler irrigated until 18 May and was irrigated with buried drip for the remainder of the season. The selection of materials tested was based on promise in previous thrips insecticide trials, and communication with Pest Control Advisors and chemical company representatives. The experimental design was a four replication randomized complete block and plot size was on 66 inch bed by 50 ft. Materials were applied in the equivalent of 30 gallons of water per acre with surfactant Induce 0.25% on 21 July. On 25 July, ten 12 inch shoots per plot were collected and shaken onto a white material. Thrips that were moving were counted separately from those that were apparently dead.

Table 1. List of monitored fields and their locations in 2009.

Fresno & Kings Counties	Locations	Merced County	Locations	Yolo/Colusa Counties	Locations
5 Star DS Proc	Five Points	GT2 TP-Processing	Gillette / Burchell	Rominger Org. TP Proc	Winters
5 Star TP Proc	Five Points	PL-1 TP Fresh Mark	Planada/La Grand Rd	Bradford TP Proc	Yolo County Ln
Ness TP Proc	Firebaugh	CD-1 TP Fresh Mark	Childs Ave	T&P 1 TP Proc	Williams
Silaxo TP Proc	Five Points	LG-8 TP-Processing	Fancher Ranch	Vann TP Proc	Williams
Woolf Creek TP Proc	W Huron	AT-4 Org TP-Proc	Athlone / S Mush Rd	T&P 2 TP Proc	S. Wilson Bend Rd
Woolf Lassen TP Proc	S Huron	MN-3 TP-Processing	Minturn / B. Hollow	Dettling TP Proc	Dunnigan
Woolf Gale DS Proc	W Huron	BU-1 TP L.Fresh Mark	Burchell/ La Grand Rd	Aoki TP Proc	Yolo County Ln
5 Star Wheat	Five Points	AT1 Rad-Fall Rad 08	Athlone / S Mush Rd	Hot TP Proc	Tyndall Landing
5 Star Peas	Five Points	LG3 Rad-Spring Rad	Fancher Ranch	Grimes TP Proc	Grimes
5 Star Spinach	Five Points	LG2 Rad-Fall Rad 08	Fancher Ranch		
Anderson Lettuce	Five Points	LG4 Rad-Spring Rad	Fancher Ranch		
Britz Lettuce	Five Points	AT2 Rad-Spring Rad	Athlone / S Mush Rd		
T&A Lettuce	Five Points	AT-5 Fall Rad 09	Athlone / S Mush Rd		
Wheat Creek	W Huron	LG-7 Fall Rad 09	Fancher Ranch		
Wheat Lassen	S Huron	CW-2 Fall Rad 09	Chowchilla		
Huron Rad 1 & 2	S Huron				
Harris Almond	Coalinga				
Ness Almond	Firebaugh				
Almond Orchards 1, 2 &3	S Huron				

TP, transplanted; **Proc**, processing tomato; **DS**, direct seeded; **Rad**, radicchio; **L**, late planted ; **Mark**, market; **Org**, organic

Results

Transplant Monitoring

Thrips and TSWV monitoring was initiated in mid-February 2009 in transplant houses. Thrips populations were detected in transplant greenhouses; however, in general, populations were relatively low (1-280 thrips/card). Highest populations were identified in late May, and were lower and two weeks later compared with 2008 populations (up to 850 thrips/card). The peak thrips populations in transplant houses correspond the time when thrips populations are peaking in the fields (May-June). Consistent with this finding, cards outside greenhouses had up to 850-1,500 thrips/card in May and June, respectively (Figs. 1 and Appendix A1). Population densities also varied among greenhouses. For example, at California (CA) Transplant, the average total thrips count per card was ~10-60, with a peak population detected (850 thrips/card) in late May. At Westside transplants the average total thrips count per card was ~10-30, with a peak populations detected (280 thrips/card) in late April.

Thrips populations detected outside of the greenhouses peaked from mid-May (~300-500 thrips/card) through June (~1500 thrips/card) with numbers decreasing by early July (Figs. 1 and A1). Average thrips counts per card for outside of Westside Transplant (WSTP) and Mezzei transplants were similar to those for CA Transplants in 2009. However, populations outside of Speedling greenhouses (Watsonville) were lower per card was low compared with CA (10-30 thrips/card) (Figs. 1 and A1). Thrips captured from all these greenhouses were identified as western flower thrips, and the numbers of females were three-fold higher than males.

In general, thrips populations associated with transplants were relatively low in 2007, 2008 and 2009. No obvious thrips damage was observed on transplants, nor were symptoms of TSWV observed on transplants that were grown in any of the monitored greenhouses. Consistent with this, no TSWV symptoms were observed on the fava bean indicators in greenhouses. Together, these results indicate that transplants are not an important inoculum source for thrips or TSWV in the field.

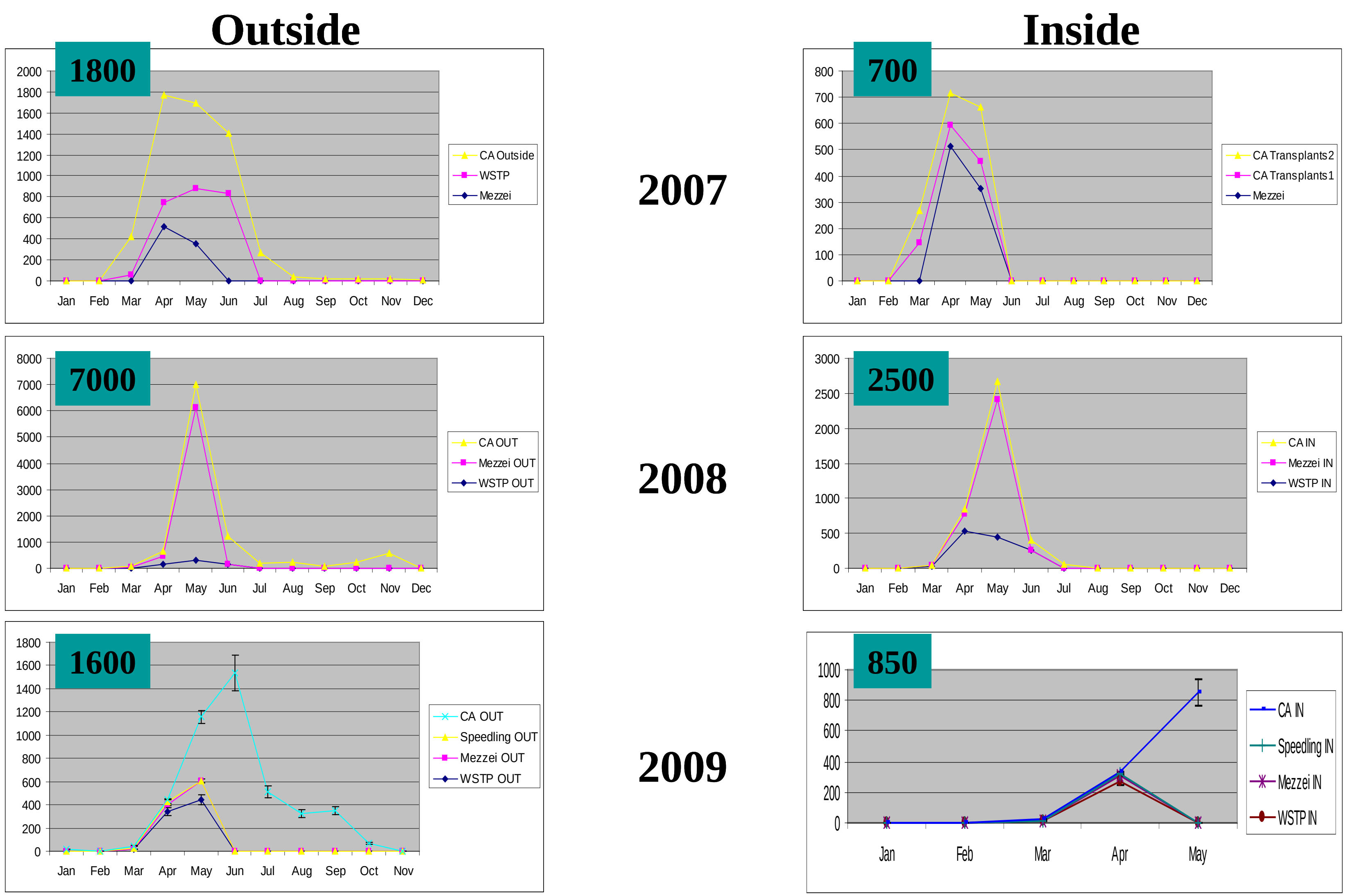

Fig.1. Average thrips counts on yellow sticky cards in and out side of tomato transplant houses. Boxed numbers show average thrips populations on yellow sticky cards during the peak.

Field Monitoring

Field monitoring for thrips and TSWV was initiated in transplanted and direct-seeded fields in early March 2009. In 2009, most of the fields that were monitored were transplanted because there were relatively few direct-seeded fields, especially in Merced, Yolo and Colusa Counties. In 2009, thrips populations were similar for direct-seeded fields and transplanted fields in Fresno and Kings Counties (Figs. 2 and A3-6).

In 2009, the average thrips populations in Fresno and Kings Counties were slightly higher than those detected in 2007, but still considerably lower those detected in 2008 (e.g., maximum populations were 2000 and 3500 in 2007 and 2009, respectively, compared with 7000 in 2008). However, in 2009, populations remained high for a longer period of time (through September), which was more similar to 2008 (Figs. 2 and A3). In Fresno and Kings County locations, thrips populations peaked in mid-May (3,000-3,500/card), remained at moderate levels (1,500/card) through August and then slightly increased during late August (when thrips migrated from harvested tomato fields). Populations dropped significantly during September.

In Merced, thrips populations increased in May, but then gradually decreased through September (Figs. 2 and A4). Population densities detected in 2009 were similar to those detected in 2008 (average 1000-2500 thrips per card in 2008 and 2009). However, the trend of thrips build-up in Merced was slightly different in 2009 compared with 2008. In 2008, populations started increasing in April and May but peaked in July and August before decreasing in September. In 2009, thrips populations started increasing in April, peaked in May and slowly decreased through September (Fig. A4).

Yolo and Colusa Counties processing tomatoes were monitored for thrips populations and TSWV incidence in 2009. Overall thrips populations were substantially higher than in the other counties throughout the growing season. Thrips populations started to build-up in May, and increased through August, when populations peaked (Fig. A5). During May, while thrips populations were peaking in other counties locations (3,000-5000 thrips per card), in Yolo and Colusa thrips populations were ~4,000 thrips per card, which was only the beginning of the thrips build-up. Populations then increased substantially through August, reaching up to 12,000 thrips per card in some late-planted tomato fields (Fig. A5). Also, populations remained very high (4,000-8,000 thrips per card) compared to fields in other counties. Because all our monitored fields were harvested by the end of August, we monitored another filed in Grimes, CA in September. In this field, thrips populations were found to be very low during September (~500 thrips per card) (Fig. A5), suggesting that populations were declining in the area by September. All thrips captured in the monitored fields in 2009 were identified as western flower thrips, and female thrips populations were three-fold higher than male populations.

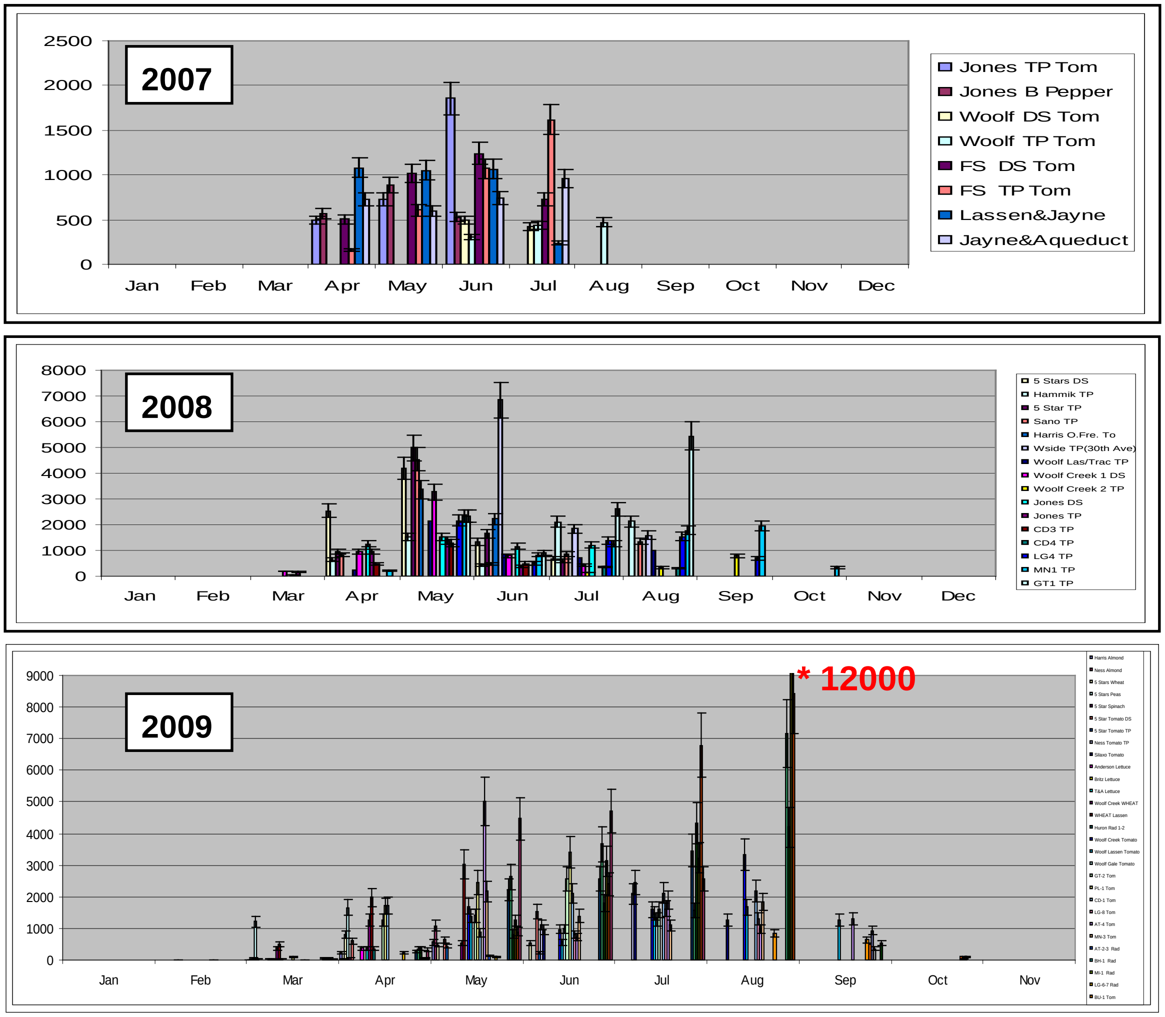

Fig. 2. Average thrips counts per yellow sticky card in monitored fields in all counties. Figure shows snap view of average thrips populations in 2007, 2008 and 2009 for comparison. More detailed figure for average thrips populations in 2009 for each county is presented separately in the Appendix (A3-A6).

Flower sampling was initiated at bloom stage of development. Average thrips numbers in flowers in 2009 were four-fold higher compared with 2007, but similar to 2008 (0.5-2/flower in 2007 and 2-9/flower in 2008 and 2009). Thrips populations persisted in flowers throughout the growing season (Figs. 4 and A2). In 2009, thrips larvae were commonly found in flowers, similar to 2007 and 2008. This indicates that thrips are reproducing on tomatoes, and may indicate the potential for secondary spread of TSWV. Evidence of this came from the finding of late season TSWV infections in which only one shoot on a plant developed TSW-like symptoms. This was also observed in 2008.

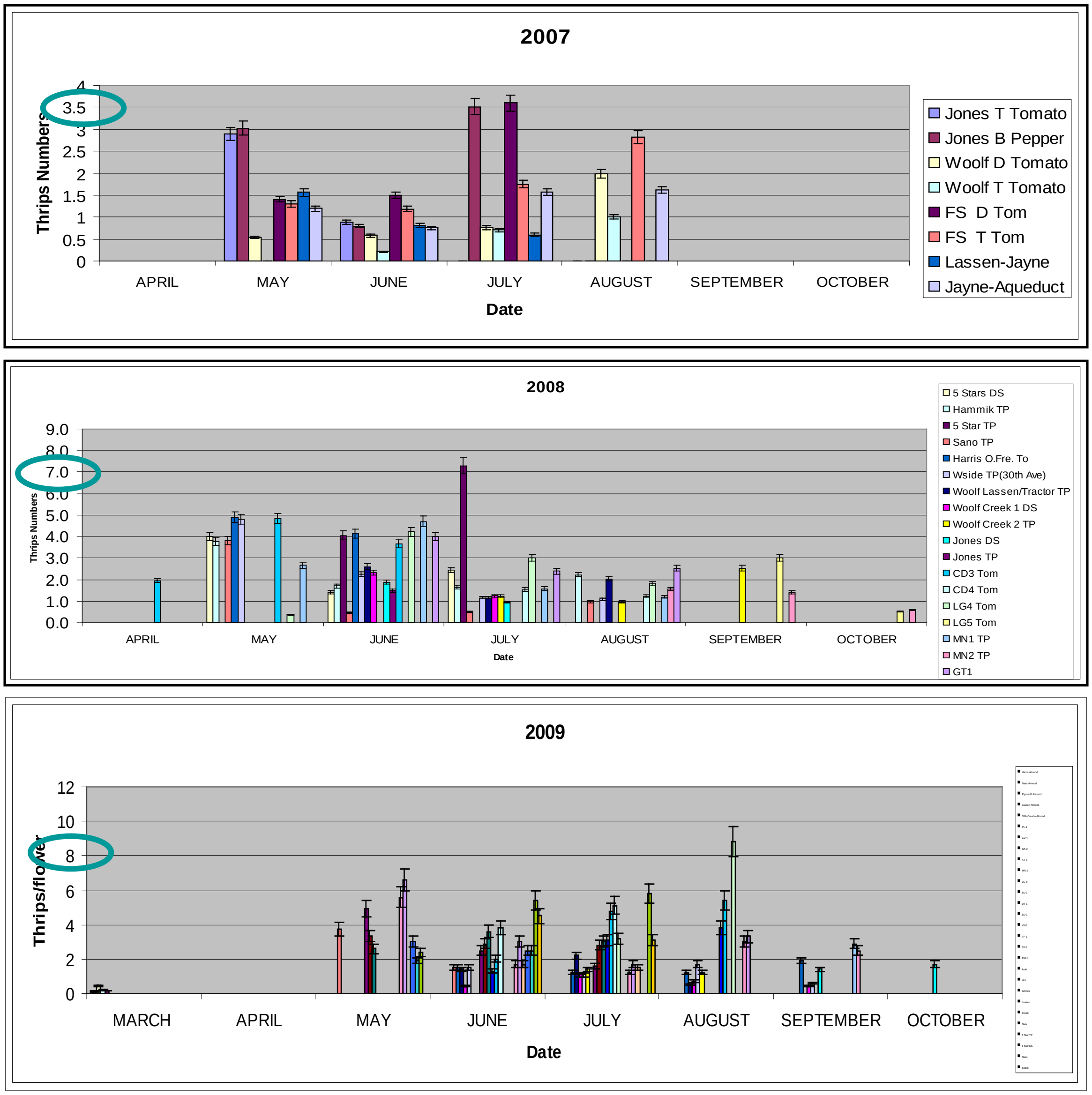

Figure 4. Average thrips counts per flower in monitored fields in all counties in 2007, 2008 and 2009. Highest thrips number per flower during each year's peak time circled on scale. Figure shows snap view of average thrips populations in 2007, 2008 and 2009 for comparison. More detailed figure for average thrips populations in 2009 is presented separately in the Appendix (A2).

The first detection of TSWV in tomato plants was in Yolo county on 18 March in two transplanted processing tomato fields in Dunnigan (Dettling and Bradford). TSWV was detected in Merced about two weeks later (early April). In Fresno and Kings Counties, TSWV was not detected until the last week of April or first week of May. TSWV was subsequently detected in tomatoes and peppers in the areas surrounding Kettleman City, Coalinga, south west of Firebaugh and north east of Huron. In Fresno and Kings Counties, TSWV was first detected on 24 April and first week of May in 2007 and 2008, respectively. Thus, detection of TSWV in Fresno and Kings Counties was a month later than Yolo County. However, overall incidence of TSWV in processing tomato fields remained low throughout 2009, i.e., 0-4%, 0-8% and 0-7% in monitored fields in Merced, Yolo/Colusa and Fresno/Kings Counties, respectively (Figs. 5 and A7). TSWV appeared in all monitored fields, but infection levels did not increase in September or October and incidence remained less than 5% in most of the monitored fields. The highest incidence of TSWV was in late-planted fields that had high thrips populations.

The overall incidence of TSWV in 2009 (0-8%) was slightly higher than in 2007 and similar to the incidence in 2008. The overall pattern of disease development was similar in all these years. Furthermore, significant economic losses due thrips/TSWV were not reported for the monitored fields in 2007, 2008 or 2009.

In 2009, the incidences of curly top disease and *Alfalfa mosaic virus* (AMV) were greater than TSWV in some of the monitored fields. This complicated disease diagnosis as early symptoms of these viruses are similar. For example, in the AT-4 field, an organic processing tomato field in Merced, the incidence of AMV was 50% and the incidence of curly top was 4%, whereas the incidence of TSWV was sporadic. The AT-4 field was planted next to an old alfalfa field and was relatively isolated from rest of the tomato production areas in Merced. When this alfalfa field was disked, aphids presumably carrying AMV moved into the field. Consequently, plants in this field were infected with AMV. In 2007 and 2008, during the course of testing many symptomatic plants, we found infection by either TSWV, curly top virus or AMV, but never a mixed infection of any of those. Interestingly, in 2009, we found a few mixed infections of TSWV and curly top virus, TSWV and AMV or curly top and AMV.

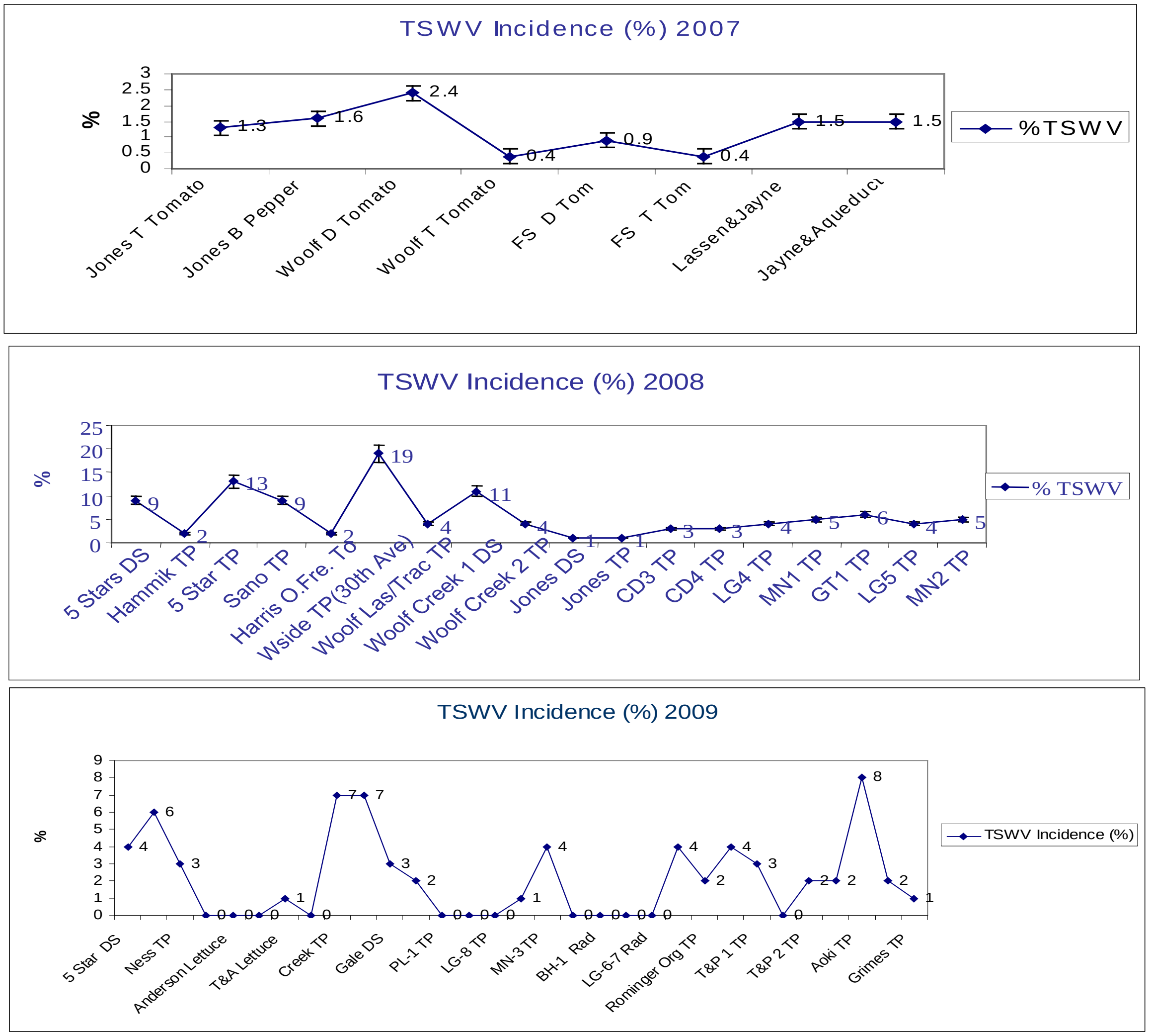

Figure 5. Percent of TSWV incidences in monitored fields in 2007, 2008 and 2009. More detailed figure for TSWV incidence in 2009 is presented in the Appendix (A7).

Survey of potential hosts for TSWV and thrips

To search for potential hosts for TSWV and thrips before, during and after the processing tomato season, we again monitored representative almond orchards, spring-planted lettuce in Fresno, and spring- and fall-planted radicchio in Merced and Huron, and numerous weeds collected in the winter and spring.

Almond flowers were collected and thrips from these flowers were counted and tested for TSWV with RT-PCR. Thrips population densities were low on yellow sticky cards placed in the almond orchards and in flowers (Figs. 2, 4, A2 and A3). Consistent with these results, indicator plants placed in these orchards remained free of TSW-symptoms. To date, TSWV has not been detected in thrips from almond orchards or in almond trees. These results are consistent with almonds not playing a major role in TSWV epidemiology.

Thrips populations in monitored lettuce fields were low and TSWV was detected sporadically in all monitored lettuce fields in Fresno in 2009. Overall, spring lettuce fields in Fresno had very low incidences of TSWV (0-1%) and do not appear to be inoculum sources for tomato (Figs. 5 and A7).

Radicchio fields in Fresno and Merced, which were initially under plastic, did not have TSWV and thrips populations were minimal during the winter (Figs. 5 and A4). In 2009, TSWV appeared in all of the monitored radicchio fields, but incidence remained sporadic and did not reach to the levels to cause economic losses in this crop or be an inoculum source for tomatoes. Furthermore, effective sanitation of harvested crops has reduced the role of radicchio as a TSWV bridge crop in Merced County and this has been reflected by the low incidence of TSWV in tomato in 2008 and 2009. Thus we believe the importance of radicchio as a TSWV inoculum source for tomato has been reduced.

Another potential source of the virus is thrips emerging from pupae in the soil. However, our monitoring results indicated very low numbers of emerging thrips from soil, and those that were tested were not viruliferous. Thus, we continue to believe that TSWV overwinters at low levels in weeds or winter bridge crops (e.g., fava bean, lettuce or radicchio; Fig. A8) and is then amplified in susceptible crop hosts during the growing season. All collected thrips were identified as western flower thrips.

In areas with recent outbreaks of TSWV, weeds and plants other than tomato were collected and tested for the virus (Table 2). Most samples tested were negative for TSWV, although lettuce, pepper, spinach, London rocket, cardone, malva, prickly lettuce, groundsel, black nightshade, ground cherry, bindweed (morning glory) and sowthistle tested positive for the virus. However, the incidence of TSWV infection in all these plants was very low (<0.1%). To date, we have not found evidence of any weed that is extensively infected by TSWV. Interestingly, this year some of the bindweed samples, a perennial weed known as TSWV/thrips host, were infected with TSWV and show symptoms of virus infection. Thus, we will be following bindweed in areas having outbreaks to determine whether these weeds are potential inoculum sources for next season's tomatoes.

Because of water shortages in Fresno County, some old lettuce fields were left in fallow and had high populations of prickly lettuce and sowthistle, weeds known as TSWV hosts. In two such fields, 100 prickly lettuce and 100 sowthistle plants were examined for tospovirus-like symptoms, and weeds with symptoms was tested for *Impatiens necrotic spot virus* (INSV) and TSWV. On 25 March, 6% of the sowthistle plants were infected with TSWV as determined by immunostrips and one was infected with INSV. Flowers from the sowthistle plants were examined, and both larval and adult thrips were present. On April 22, weeds in another fallowed field in the Five Points area were evaluated. Here, weeds showed symptoms of infection and 2% of the sowthistle and 7% of the prickly lettuce plants tested positive for TSWV, whereas all plants tested negative for INSV. Tomatoes in fields closest to those fallow fields showed earliest development of tomato spotted wilt symptoms, indicating that these weeds were sources of inoculum. Growers were alerted and prompt control of those weeds was implemented. Thus, weeds in fallow fields represent a new potentially important inoculum where both thrips and TSWV can be amplified and then serve as a source for early colonization/infection of nearby processing tomato fields.

In 2009, surveys were conducted in Yolo and Colusa counties in (January-February) in order to try to identify inoculum sources of thrips and TSWV for processing tomato fields. We found that fava beans were grown in some locations as a cover crop, especially in established orchards. Our initial surveys of these fava beans revealed presence of high thrips populations and TSWV infections. Immunostrip and RT-PCR tests were used to confirm TSWV infection. This finding is very important because fava beans are very good host for both thrips and TSWV (note that we use fava beans as indicator plants in our TSWV monitoring). Thus, fava bean represents a possible bridge crop and/or reservoir for TSWV and thrips for processing tomato fields in Yolo and Colusa counties.

Furthermore, because various seed production fields are established around our monitored tomato fields in Yolo and Colusa counties, we regularly visited such plots to look for tospovirus-like symptoms in various crops. A report from Georgia indicated that Vidalia onions were found to be mixed infected of TSWV and *Iris yellow spot virus* (IYSV), another *Tospovirus*. This report alerted us to look for possible Tospovirus infections especially in onions. However, we did not find any evidence of TSWV/IYSV infections in our onion scouting during 2008 and 2009.

Genetic diversity of TSWV Isolates from the Central Valley

Selected tomatoes as well as other crops such as pepper, radicchio and lettuce, and weeds showing virus-like symptoms were collected and tested again for TSWV in 2009 by RT-PCR. The amplified *N* gene DNA fragment from selected TSWV isolates was cloned and sequenced to determine the genetic diversity of the TSWV in the Central Valley of California. Sequence analysis of TSWV *N* genes revealed a very closely related group of isolates, as no major differences were found, irrespective of the host, location and year of isolation. Similar results were obtained with TSWV sequences amplified from thrips. These results indicate that in Central California, the TSWV population is fairly homogeneous, and likely represents a geographically isolated population.

Table 2. Weed survey results for TSWV incidence during 2008-09.

Weed	Tested (+)	Weed	Tested (+)
Barnyard grass	27 (0)	Lambs quarters	64 (0)
Black nightshade [ab]	**36 (2)**	**Malva [a]**	**114 (1)**
Bindweed [abc]	**37 (3)**	Mustard	62 (0)
Bur clover	25 (0)	Nettle	25 (0)
Common sunflower	28 (0)	Pigweed	27 (0)
Dodder	25 (0)	**Prickly lettuce [abc]**	**96 (3)**
Fiddle neck	26 (0)	Purslane	25 (0)
Ground cherry [a]	**25 (1)**	Russian thistle	35 (0)
Groundsel [a]	**40 (1)**	**Sowthistle [abc]**	**74 (4)**
Jimsonweed	25 (0)	Tree tobacco	25 (0)

(+) number of plants tested positive for TSWV by Immunostrips and RT-PCR. [abc]**,** Merced, Yolo/Colusa, and Fresno/Kings Counties, respectively

Detection of TSWV in thrips and studies of thrips biology

Thrips from flower samples that were collected from each monitored fields were pooled in a way to represent the biweekly population from each field, and tested by RT-PCR throughout the season. In RT-PCR tests performed with randomly collected thrips, most of the insects were negative, whereas lab-reared viruliferous thrips control and some of the thrips samples that were collected from infected tomatoes were positive. These results indicate that most of the thrips in the processing tomato fields were not carrying the virus. This is also consistent with the relatively low levels of TSWV in tomato in 2009, despite the high thrips populations in many of the fields. If more of these thrips were carrying the virus, it is likely that the incidence of TSWV would have been much higher. Thus, there was no correlation between thrips populations and TSW disease incidence.

In 2009, we found that thrips populations were relatively high in Yolo County processing tomato fields, but TSWV incidence was not any higher than that in other monitored counties (compare Figs. A3, A4 and A5). These results suggested that thrips populations in different areas may have different virus transmission efficacy, as was previously reported for different parts of the world. To test this idea and to study thrips biology more deeply, we started rearing thrips colonies in our laboratory from different counties and we are currently testing their TSWV transmission efficiency on tomato, onion and alfalfa. Results of this study will provide better understanding on when to apply insecticide for thrips management. Presently we can only provide recommendations for thrips management based on their population densities as determined with yellow sticky cards and flower sampling.

Insecticide Trial

Based on counts of live western flower thrips from the shoots in comparison to the untreated control, the materials that showed efficacy against thrips included Radiant 6.0 fl oz, HGW86 10SE 13.5 fl oz + Brigade 6.4 fl oz, Beleaf 50SG 2.8 oz, Hero EW 11.2 fl oz, Surround 25 lbs and Dimethoate 4EL 1.0 pt (Table 3). Radiant 6.0 fl oz and Dimethoate 4EL 1.0 pt have shown promise in two similar trials conducted at UC WSREC in 2007 and 2008. Surround showed promise in the 2008 trial, and Beleaf 50SG + Mustang had reduced thrips counts in this trial in 2007 and 2008, while the Mustang alone was not effective either year. There is evidence from the result of trials at this site that Radiant, Beleaf 50SG, Surround and Dimethoate 4EL have activity under conditions present at this site. Two treatments, HGW86 10SE 13.5 fl oz + Brigade 6.4 fl oz and Hero EW 11.2 fl oz, showed promise in the 2009 insecticide efficacy trial and should be included in future work to evaluate their potential fit into a thrips management program.

Table 3. Comparison of insecticides for control of thrips on tomato.

Treatment (concentration/acre)	live	dead
Radiant 6.0 fl oz	0.8	24.8
HGW86 10SE 13.5 fl oz + Brigade 6.4 fl oz	2.3	19.3
Beleaf 50SG 2.8 oz	4.0	34.0
Hero EW 11.2 fl oz	3.5	25.8
Surround 25 lbs	4.0	21.5
Dimethoate 4EL 1.0 pt	6.0	32.3
Requiem 2.0 qts	7.5	33.0
Leverage 5.1 fl oz/a	8.5	45.0
Requiem 3.0 qts	10.0	34.3
Untreated control	11.0	23.8
LSD 0.05	4.7	18.1
CV (%)	56.40	42.44

Efficacy thrips counts from ten 18 inch long shoots in 7/21/09 (materials applied on 17 July)

Integrated pest management for TSWV in Central California

Based upon our accumulated research findings on thrips population densities and TSWV development on processing tomatoes in Central Valley of California, the following IPM approach for managing TSWV is proposed:

A) Preplant

- **i) planting location/time of planting**-avoid hot spots known to have had high TSWV the previous year and avoid planting near and winter fields of potential bridge crops (e.g., radicchio).
- **ii) resistant cultivars**-these are available, but may not be necessary if other practices are followed.
- **iii) weed management**-maintain weed control in and around tomato fields and in nearby fallow fields as weeds are potential TSWV hosts. Our results in 2009 indicate that if weeds are allowed to grow in fallow fields that they can amplify thrips and TSWV and serve as inoculum sources for processing tomatoes.

B) Production

- **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 adults thrips that can spread the virus within and between fields. This may even need to be done before disease symptoms are observed.
- **ii) weed management** -maintain effective weed control in and around tomato fields.

C) After harvest

- **i) sanitation**-immediately plow under crop residue following harvest.
- **ii) bridge crops**-minimize the planting of bridge crops that will maintain thrips/TSWV in the absence of tomato and or provide inoculum for spring-planted tomatoes. If this is not possible (e.g., lettuce in Fresno and radicchio in Merced), thrips management should be practiced if necessary (note that our results indicate that thrips populations are low in the winter) and prompt sanitation (plowing under old crops and residues) should be practiced.

Appendix

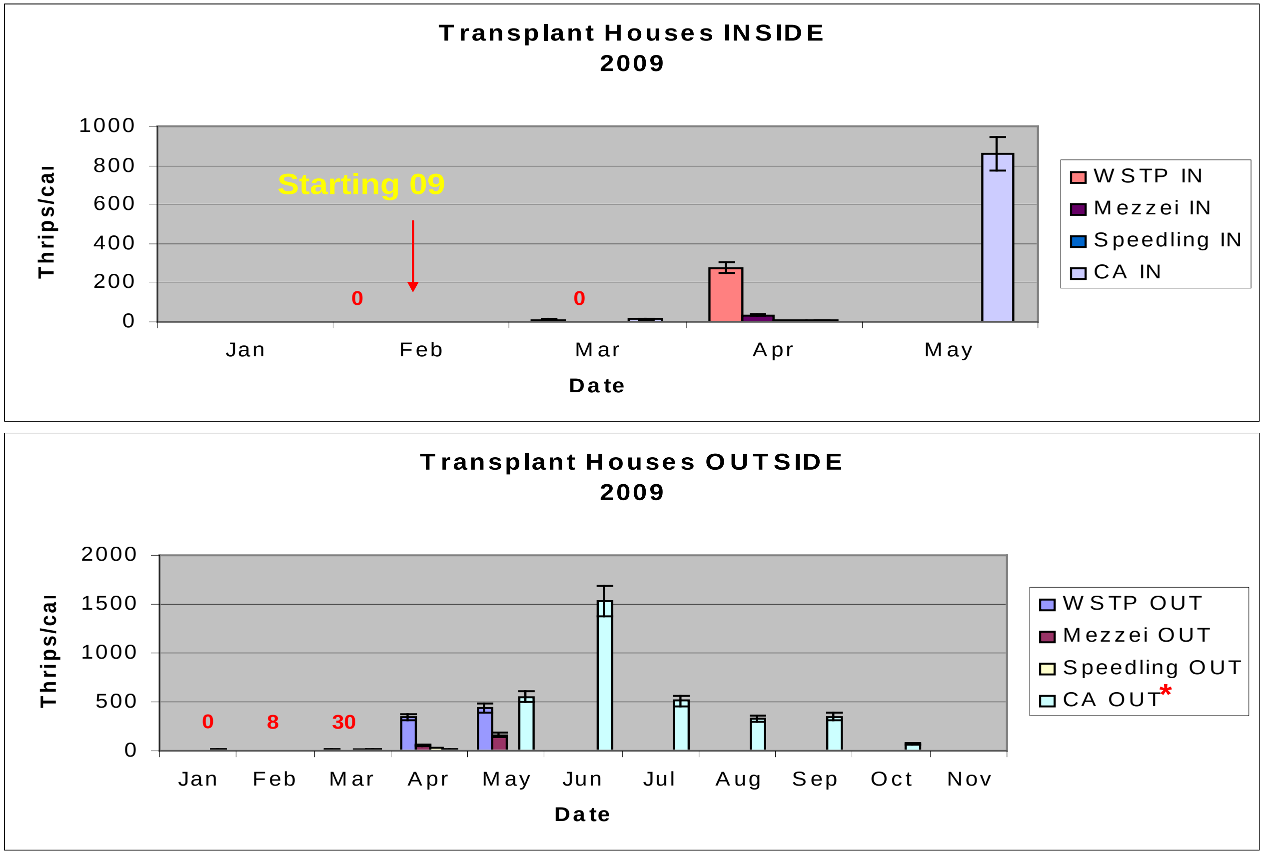

Figure A1. Average thrips counts on yellow sticky cards in and out side of tomato transplant houses in 2009. Beginning of monitoring shown with red arrow and red numbers represent average thrips population at indicated dates. **WSTP,** Westside Transplants-Huron; **Mezzie,** Firebaugh; **Speedling,** Watsonville, **CA,** California Transplants- Newman; * California Transplant perimeters are monitored continuously since February 2007.

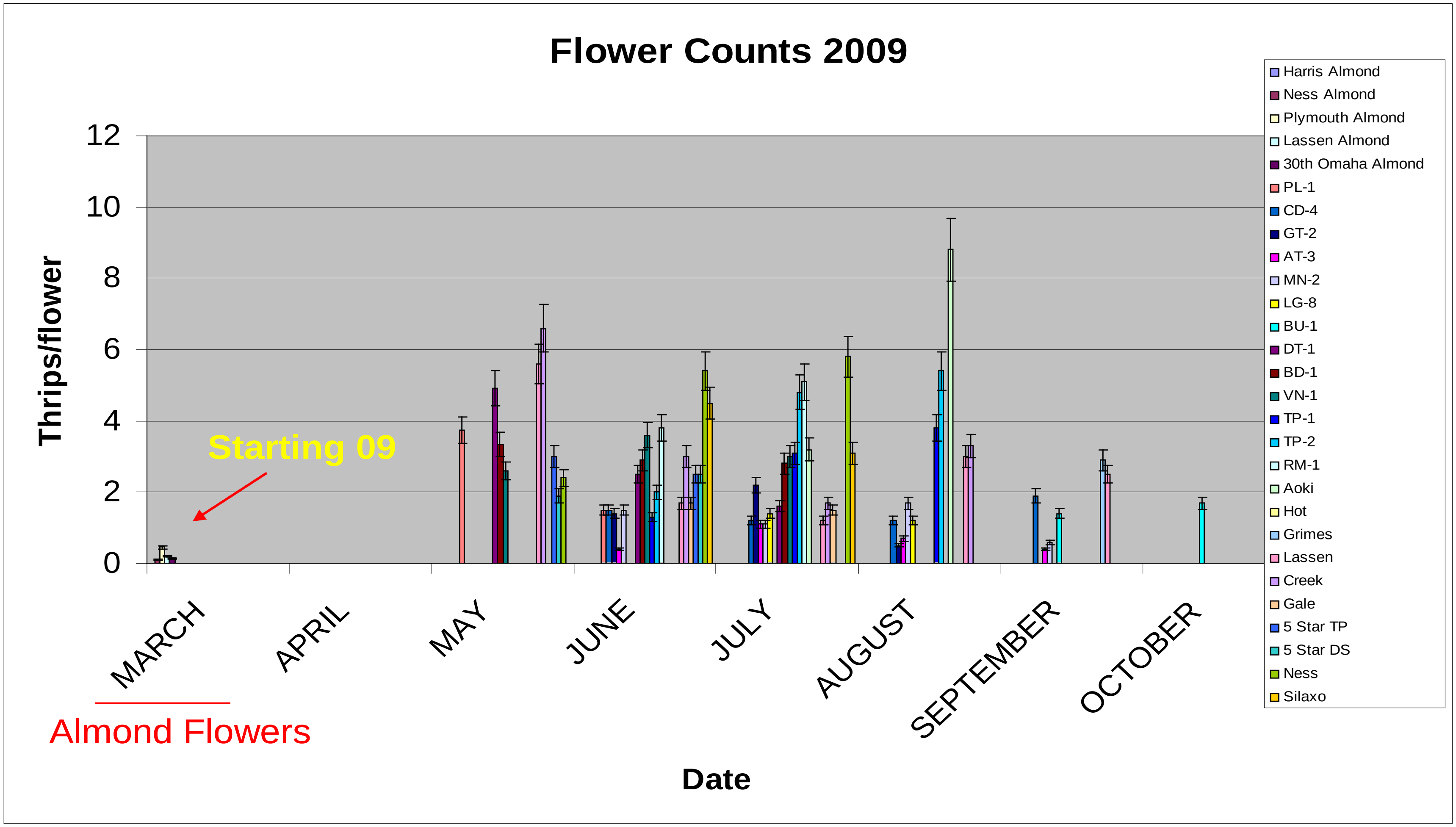

Figure A2. Average thrips counts per flower in monitored fields in 2009. Red arrow indicates beginning of monitoring and represents thrips populations in almond flowers during winter and spring.

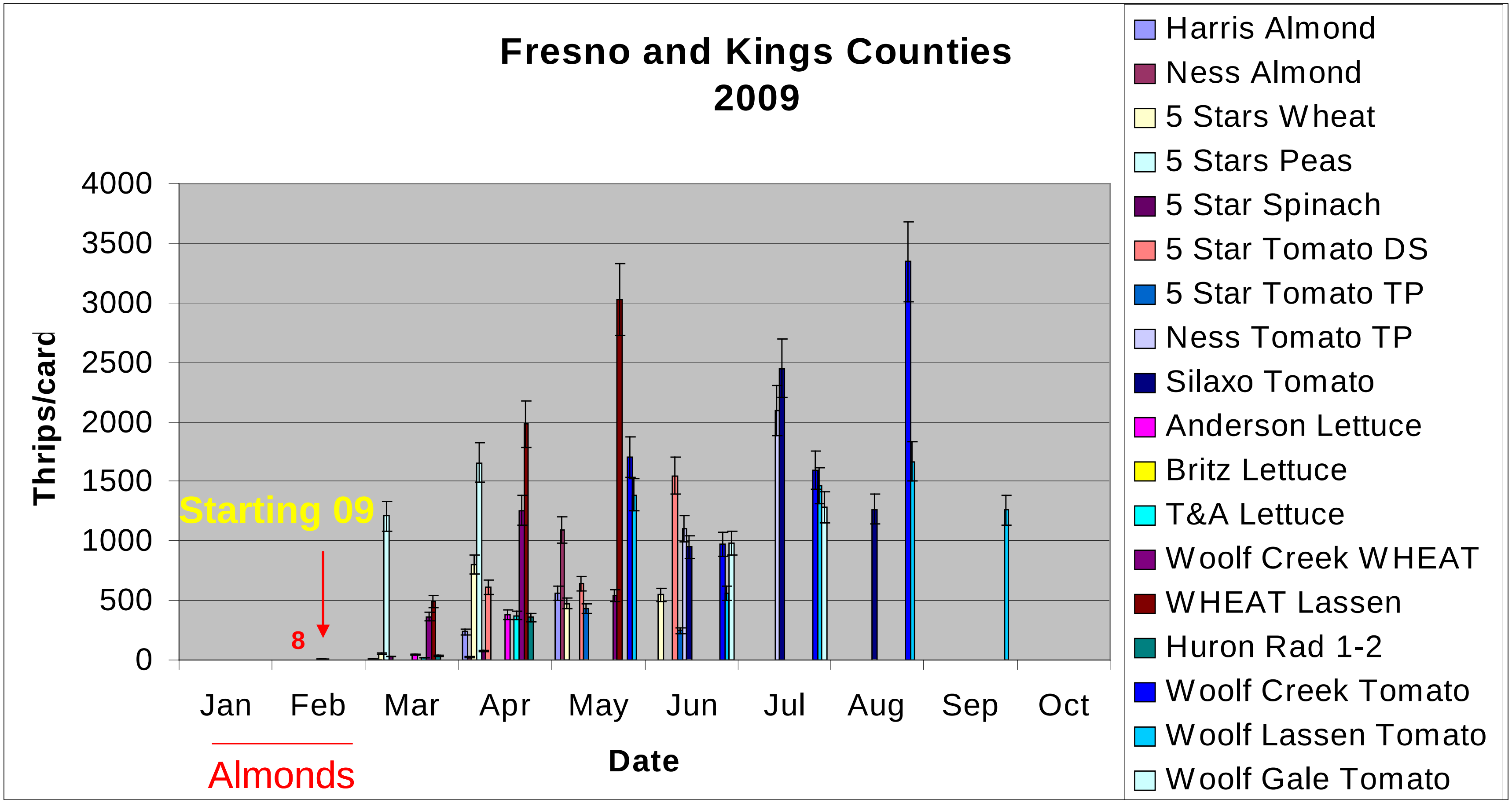

Figure A3. Average thrips counts on yellow sticky cards in Fresno and Kings Counties in 2009. Beginning of monitoring shown with red arrow and red number represent average thrips population at indicated date.

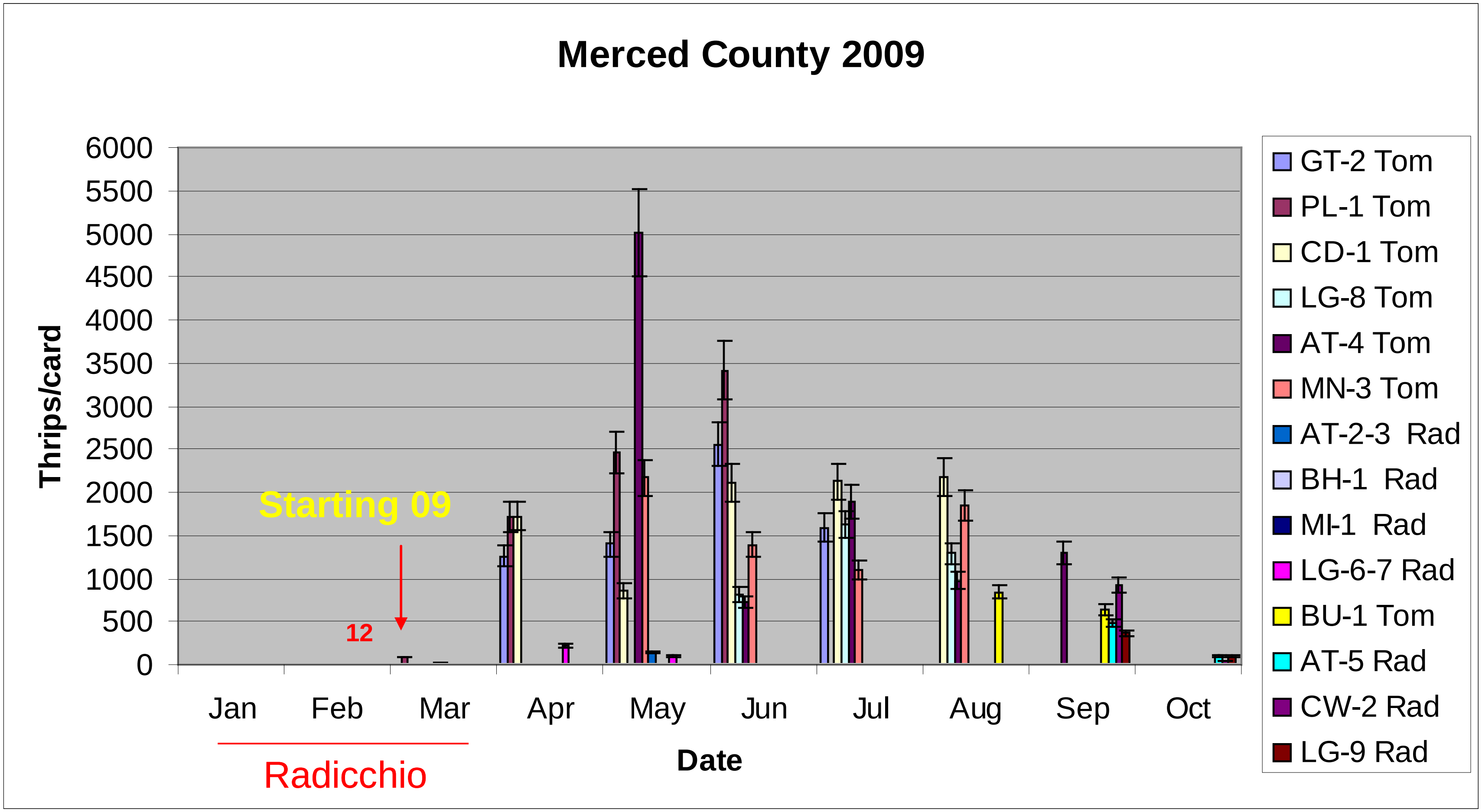

Figure A4. Average thrips counts on yellow sticky cards in Merced County in 2009. Beginning of monitoring shown with red arrow and red number represent average thrips population at indicated date.

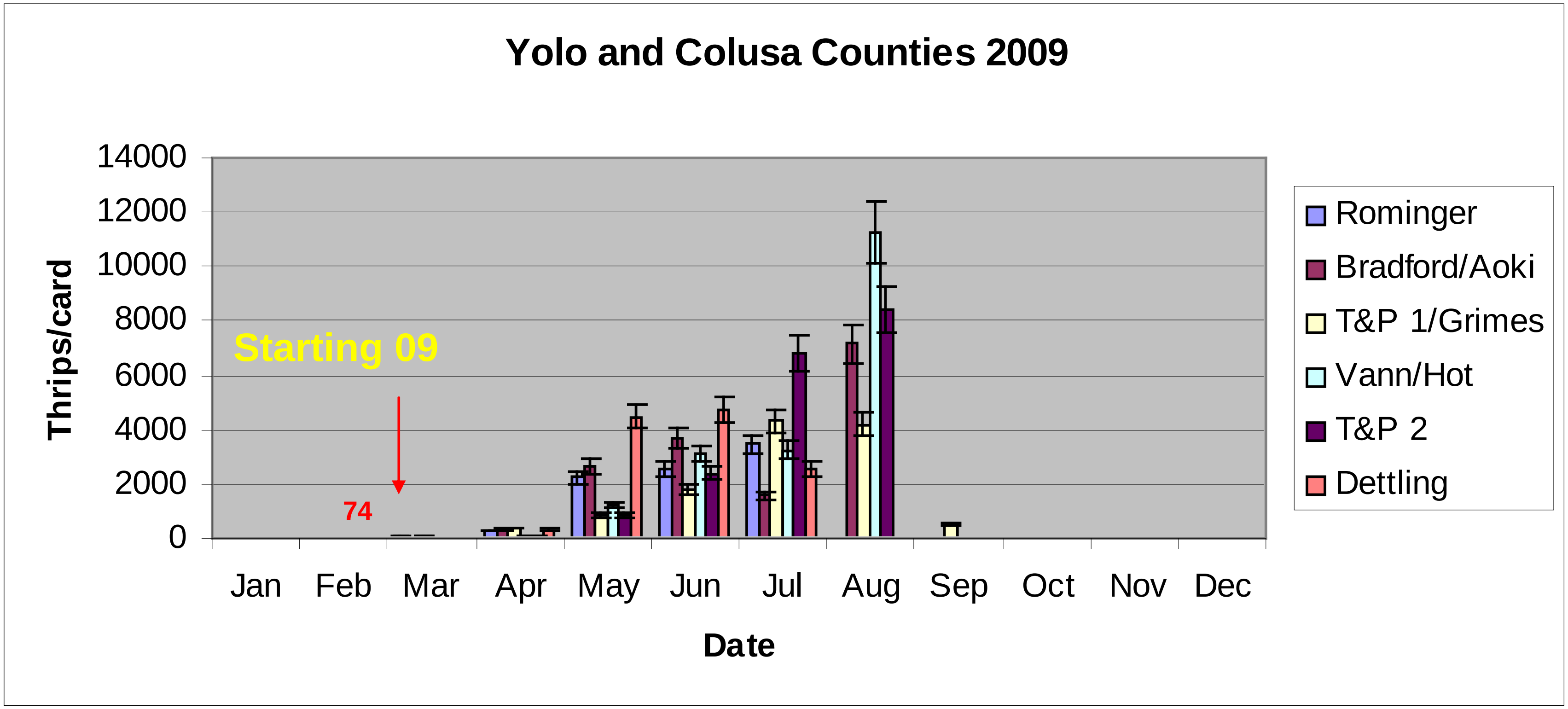

Figure A5. Average thrips counts on yellow sticky cards in Yolo and Colusa Counties in 2009. Beginning of monitoring shown with red arrow and red number represent average thrips population at indicated date.

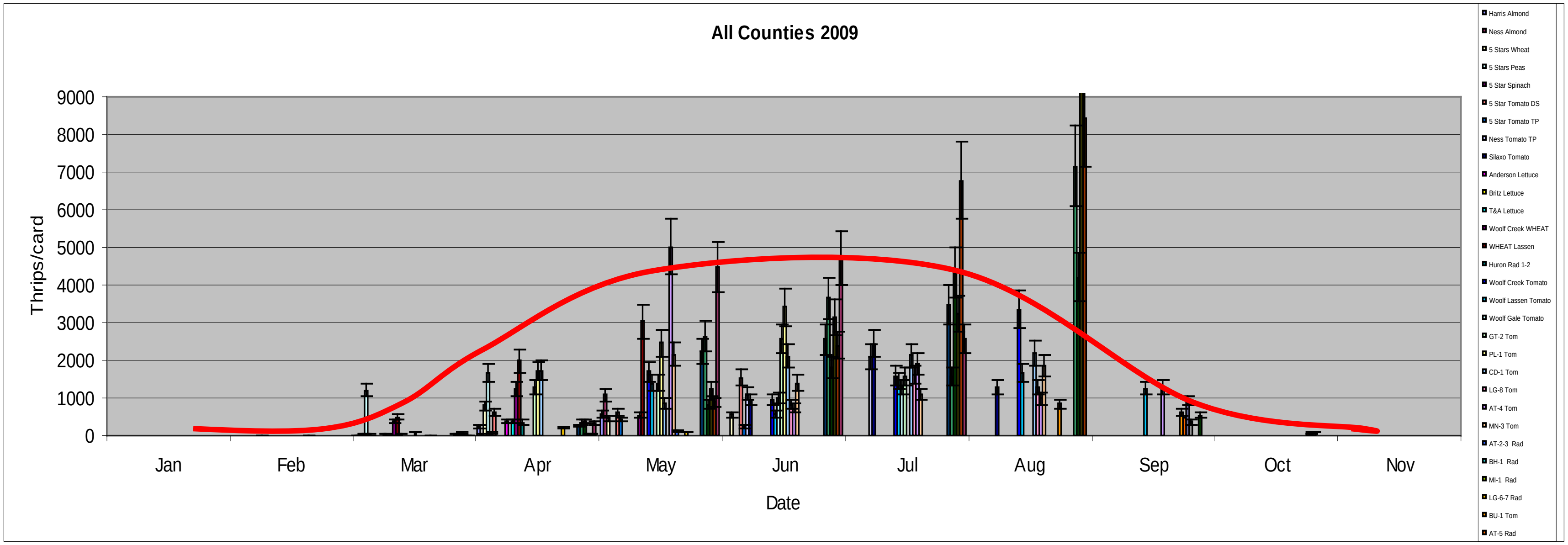

Figure A6. Average thrips counts on yellow sticky cards in all monitored fields in 2009. Red line depicts general thrips population dynamics in Central Valley of California. Thrips population starts to increase during March, peaks in May-June and stays high until August and then slowly decreases through October.

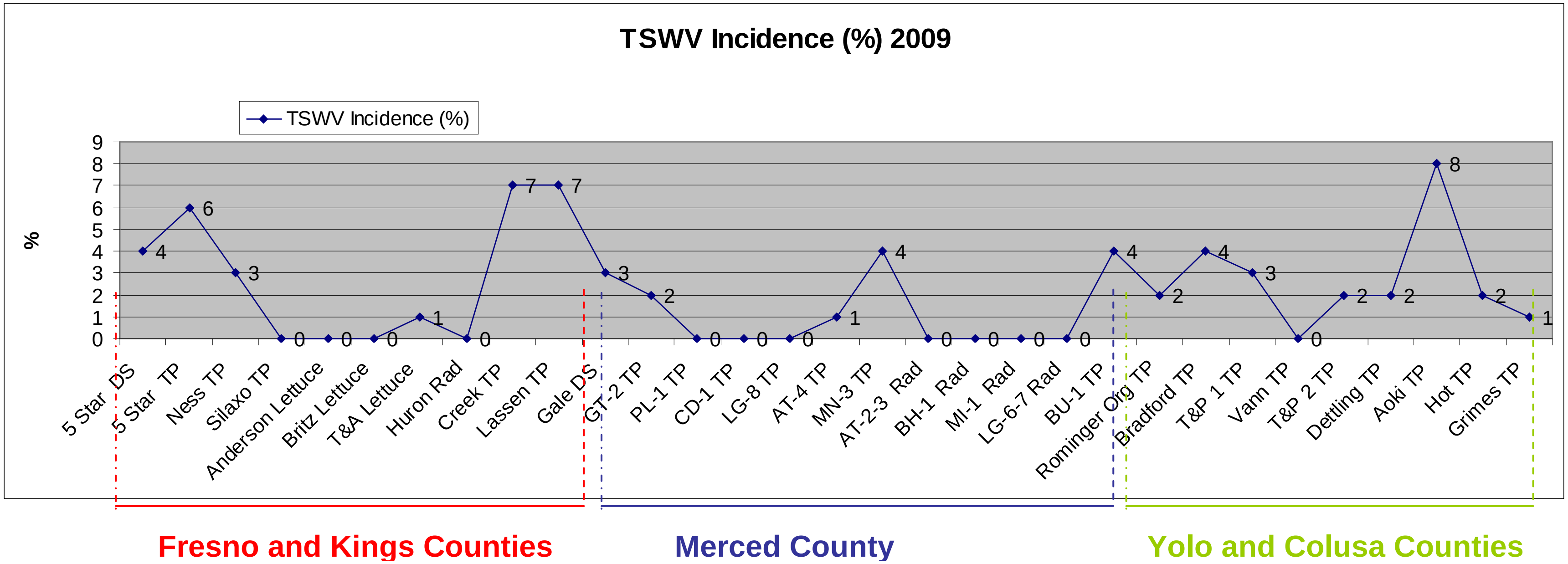

Figure A7. Percent of TSWV incidences in monitored fields in 2009.

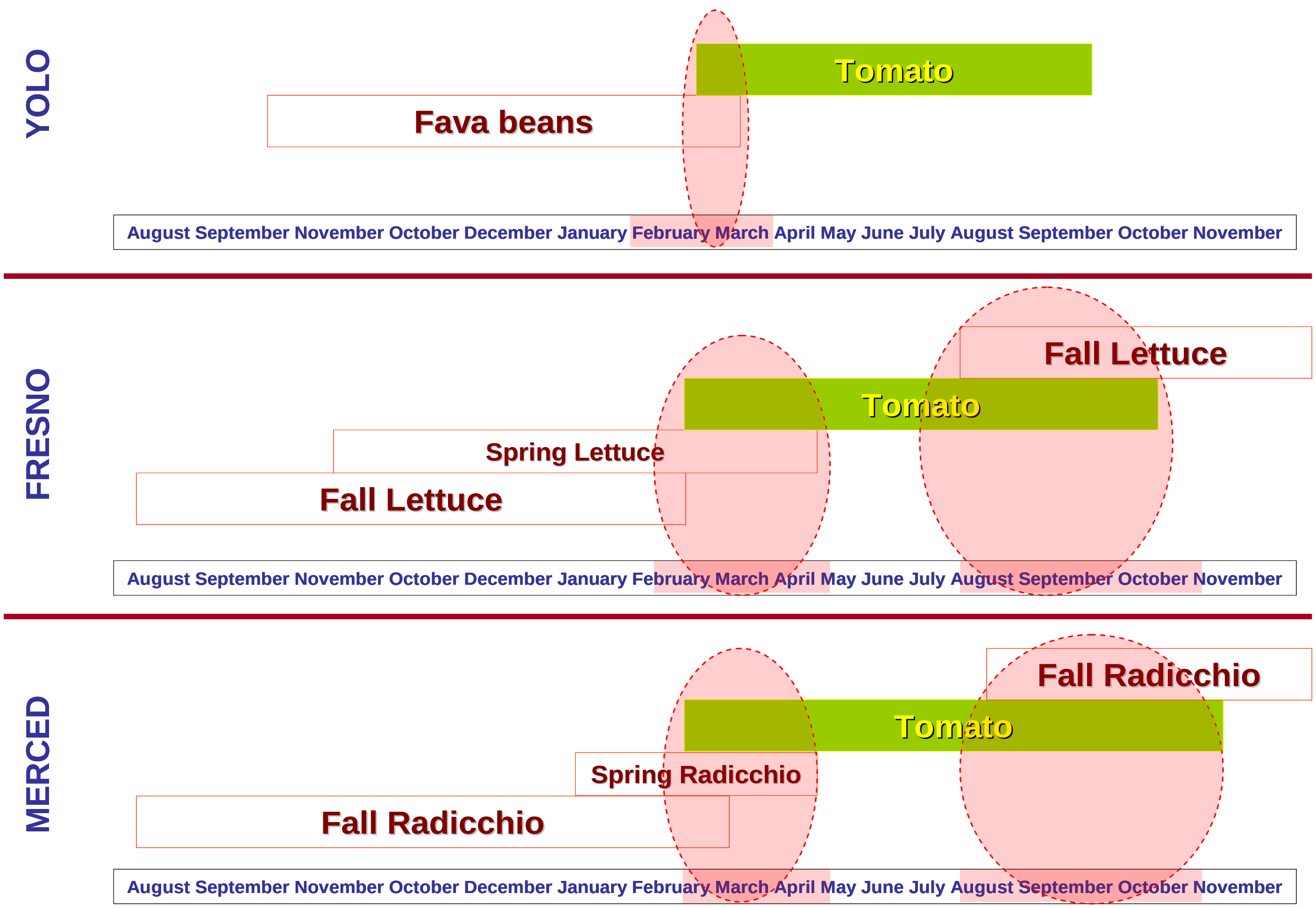

Figure A8. A diagram depicting dominant cropping pattern of potential "bridge crops" for TSWV and the thrips vector in processing tomato production areas in Central Valley. The diagram shows crop's planting and harvesting times and their overlapping periods with tomato production periods (shaded months and circles) in Yolo/Colusa, Fresno/Kings and Merced counties.