Population Fluctuations of Thrips (Thysanoptera) and Their Relationship to the Phenology of Vegetable Crops in the Central Region of Mexico

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Source: Florida Entomologist, 98(2) : 430-438

Published By: Florida Entomological Society

URL: https://doi.org/10.1653/024.098.0206

Population fluctuations of thrips (Thysanoptera) and their relationship to the phenology of vegetable crops in the central region of Mexico

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Abstract

The presence of thrips in vegetable crops has become an important phytosanitary issue in Mexico. Their direct injuries to plants are the result of the feeding by their immature and adult stages, whereas their indirect injuries are caused by the transmission of various viruses. The objective of this study was to identify the species of thrips associated with 6 vegetable crops in order to determine their population fluctuations and to ascertain the effects of temperature and rainfall on their populations. Samples were collected from zucchini, onion, pepper, cucumber, tomato, and tomatillo in Puebla and Morelos from Feb 2010 to Feb 2011. Three species were identified: *Frankliniella occidentalis* (Pergande) (Thysanoptera: Thripidae) on all vegetables, *Frankliniella fortissima* (Priesner) on zucchini and cucumber, and *Thrips tabaci* (Lindeman) (Thysanoptera: Thripidae) on onion and pepper. The highest population level for thrips coincided with the presence of flowers on the crops, except in the case of onion. In general, 2 to 6 generations of thrips were present in each crop cycle, and the levels of populations decreased when the plants were near senescence. The main suppressive effect of weather on thrips populations was caused by rainfall.

Key Words: *Frankliniella fortissimo*; *Frankliniella occidentalis*; *Thrips tabaci*; flowering; rainfall

Resumen

La presencia de trips en cultivos hortícolas es un importante tema fitosanitario en México. Sus daños directos hacia plantas son el resultado de la alimentación de los estados inmaduros y adultos, mientras que sus daños indirectos son causados por la transmisión de varios virus. El objetivo de este estudio fue identificar las especies de trips asociadas con 6 cultivos hortícolas a fin de conocer su fluctuación poblacional y comprobar los efectos de la temperatura y precipitación en sus poblaciones. Las muestras fueron colectadas en calabacitas, cebolla, pimiento, pepino, tomate y tomate de cáscara en Puebla y Morelos, de Feb 2010 a Feb 2011. Se identificaron tres especies: *Frankliniella occidentalis* (Pergande) (Thysanoptera: Thripidae) en todos los cultivos, *Frankliniella fortissima* (Priesner) en calabacita y pepino, y *Thrips tabaci* (Lindeman) (Thysanoptera: Thripidae) en cebolla y pimiento. El nivel poblacional más alto para los trips coincidió con la presencia de flores en los cultivos, excepto en cebolla. En general de 2– 6 generaciones de trips se presentaron en cada ciclo de cultivo y los niveles poblacionales disminuyeron en plantas cercanas a la senescencia. La precipitación fue el principal efecto climático supresivo de la población de trips.

Palabras Clave: *Frankliniella fortissima*; *Frankliniella occidentalis*; *Thrips tabaci*; floración; precipitación

Tomato (*Lycopersicon esculentum* L.; Solanales: Solanaceae), tomatillo (*Physalis ixocarpa* Brotero; Solanales: Solanaceae), pepper (*Capsicum annum* L.; Solanales: Solanaceae), zucchini (*Cucurbita pepo* L.; Cucurbitales: Cucurbitaceae), cucumber (*Cucumis sativus* L.; Cucurbitales: Cucurbitaceae), muskmelon (*Cucumis melo* L.; Cucurbitales: Cucurbitaceae), watermelon (*Citrillus lunatus* Tunberg; Cucurbitales: Cucurbitaceae), broccoli (*Brassica oleracea* L. 'Italica'; Brassicales: Brassicaceae), and onion (*Allium cepa* L.; Aspargales: Amaryllidaceae) are the main vegetable crops in Mexico. Their importance lies in their production value and the surface area cultivated. This group of crops generates 55% of the total value of the horticultural production of Mexico (SIAP-SAGARPA 2012). They are considered as a source of income and employment in the agricultural sector and as being important to society because of the impact that they have on the nutrition of the population (Delgadillo 2000).

Vegetable crops are attacked by a number of pest organisms with whiteflies, mites, and thrips being the most important. Thrips are very small, cosmopolitan insects, measuring 0.1 to 15 mm in length. They have long slender bodies ranging from pale white to dark brown in color with 2 pairs of thin cilia-fringed wings that have bristles on the veins. Thrips have a singular buccal apparatus of which only the right mandible is fully developed (Mound et al.

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Supplementary material for this article in Florida Entomologist 98(2) (June 2015) is online at http://purl.fcla.edu/fcla/entomologist/browse

1993; Johansen & Mojica 1997; Mound 2005; Garcia et al. 2011). There are around 6,000 thrips species worldwide, of which 1% are identified as agriculturally important pests, and most of these belong to the Thripidae (Ananthakrishnan 1979; Mound & Marullo 1996; Mound 1997; Mound 2002; Soto et al. 2009).

According to Lewis et al. (1997), *Frankliniella occidentalis* (Pergande) (Thysanoptera: Thripidae), *Thrips palmi* (Karny) (Thysanoptera: Thripidae), and *Thrips tabaci* (Lindeman) (Thysanoptera: Thripidae) are considered the main pests in cucumber, pepper, tomato, onion, and zucchini, causing direct and indirect damage. Direct damage is caused by nymphs and adults feeding on plant cell contents with the consequent decrease of photosynthetic capability (Shipp et al. 2000). Indirect damage comes from the transmission of viruses like the "tomato spotted wilt virus" (TSWV) and the "impatiens necrotic spot virus" (INSV) (Daughtery et al. 1997; Shipp et al. 2000).

McPherson & Douce (1992) estimated an annual decrease of over USD 20 million in tomato, pepper, onion, and watermelon crops as a result of attack from thrips. Fournier et al. (1995) reported losses from 34 to 43% on onion caused by *T. tabaci*, and Shipp et al. (2000) asserted that *F. occidentalis* decreased cucumber production under greenhouse conditions by 4.7 to 27%. *Thrips tabaci* is the most harmful and frequent species on onion crops. Adults and nymphs cause destruction to the tissue and silver spotting on the surface of the leaves. According to Ramírez et al. (2010), when populations are numerous, they can cause wilting and premature senescence. Plants suffering from water stress are more susceptible to attack by *T. tabaci*.

In Mexico, studies of thrips in relationship to vegetable crops are rare and limited to their identification. Johansen & Mojica (1993) recognized *T. tabaci* as an economically important pest of onion. Meanwhile, Cih Dzul et al. (2011) reported *F. occidentalis* on tomato; González & García (2012) mentioned it affecting cucumber crops; and Valenzuela et al. (2010) identified and described the population fluctuation of *F. occidentalis*, *Franklinothrips vespiformis* (Crawford) (Thysanoptera: Aeolothripidae), *Scolothrips sexmaculatus* (Pergande) (Thysanoptera: Thripidae), *Franklinothrips orizabensis* (Johansen) (Thysanoptera: Aeolothripidae), and the genera *Bregmatothrips* sp. (Thysanoptera: Thripidae), *Microcephalothrips* sp. (Thysanoptera: Thripidae), and *Haplothrips* sp. (Thysanoptera: Phlaeothripidae) on zucchini (*Cucurbita moschata*; Cucurbitales: Cucurbitaceae).

The proper identification of insect pests is fundamental to their effective control. The relevance of thrips, given that they are cosmopolitans and that they transmit phytopathogenic viruses, makes it necessary to identify the species associated with vegetable crops, as well as to describe their population fluctuations. The present research was done to determine the species of thrips (Thysanoptera) present on 6 vegetable crop species, as well as their relationship with the phenology of these crops and with environmental conditions.

Materials and Methods

Two study zones were established in several places. Firstly in the state of Puebla, crops were located in the municipalities of Tilapa (18°33'12"N, 98°36'42"W; 1,192 m asl), Izucar de Matamoros (18°30'0"N, 99°0'0"W; 1,322 m asl), Chiahutla (18°17'48"N, 98°38'10"W; 982 m asl), and Tepeojuma (18°42'15"N, 98°30'06"W; 1,385 m asl). Secondly in the state of Morelos, the crops were located in the northern region in the municipalities of Atlatlahucan (18°55'10"N, 98°53'62"W; 1,652 m asl) and Tlayacapan (18°57'15"N, 98°54'45"W; 1,576 m asl), and in the southeast region in the municipalities of Axochiapan (18°31'01"N, 98°44'18"W; 1,385 m asl) and Tepalcingo (18°24'09"N, 98°18'16"W; 1,385 m asl) .

Samples were taken from Feb 2010 to Feb 2011, so that the spring–summer and fall–winter production cycles were covered. In the study zones in Puebla and Morelos, sampling sites were established in tomato, pepper, tomatillo, onion, zucchini, and cucumber crops. The sampling sites were located preferably in young crops. Sampling was done at 15 d intervals until harvest or until the crop was discarded.

Each sampling site was 1 ha in surface, where compound sampling was done in the 4 corners and center; each of the 5 points was 25 m^2, where 5 randomly selected plants were examined. Twenty-five plants per ha were examined. This type of sampling captures the greatest variability in the study site and is recommended to detect sources of infestation coming from all 4 directions (Flores 2010).

The sampling unit (SU) was represented by a single plant in every case; however, the way the sample was obtained differed for each crop, depending on the vegetative structures where thrips are commonly found. In onion, the base of the leaves was checked as well as the shoot; in tomato, tomatillo, and pepper, a 10 × 10 cm white checkered sheet was placed under each plant and the top 2 thirds of the plant was vigorously shaken to capture and count the specimens; on cucumber, 2 flowers, or flower capsules, and 3 young leaves were taken from each plant; and in zucchini, 2 female flowers and 3 young leaves were taken per plant.

The total number of thrips in their nymphal and adult stages was counted. The total number of samplings per site varied, due to crop cycles ending on different dates. To analyze population fluctuation, a total of 24 visits were carried out in the study zones. We established 28 sampling sites: 2 for tomato with 10 sampling dates; 3 for pepper with 17 samplings; 4 for tomatillo with 15 samplings; 3 for zucchini with 13 samplings; 8 for onion with 49 samplings; 8 for cucumber with 33 samplings; for a total of 137 samplings (Table 1).

The environmental variables studied were rainfall and temperature. The data were obtained from meteorological stations corresponding to each study site. They were analyzed together with the population densities obtained during the sampling dates. With information regarding temperature conditions in each sampling site, the heat units (HU) were calculated based on the method described by Allen (1976). Based on the temperature requirements of the thrips species under study, the number of complete generations through HU accumulation was estimated in order to identify the sites with more favorable temperature conditions for the development of the pest. The temperature requirements for *F. occidentalis* are 195 HU with the lower threshold temperature being 9.5 °C (Ramírez et al. 2009). The temperature requirements for *T. tabaci* are 180 HU with the lower threshold temperature being 11.5 °C (Ramírez et al. 2010).

Thrips samples were collected in labeled glass jars containing 70% ethanol. The materials were taken to the Entomology Laboratory of Colegio de Postgraduados, where they were processed. Permanent mounts were prepared with the Canada balsam technique proposed by Johansen & Mojica (1997). To identify specimens to the species level, we used the Stannard (1968), Mound & Marullo (1996), and Soto & Retana (2003) keys. To confirm species identity, the mounted specimens were sent to Thysanoptera specialist Dr. Roberto M. Johansen Naime, Biology Institute, UNAM (Universidad Nacional Autónoma de México). To determine the species, 160 samples were obtained, of which 12 were from tomato, 30 from zucchini, 46 from onion, 19 from pepper, 38 from cucumber, and 16 from tomatillo. It is worth mentioning that the samplings were carried out in the target crops, so surrounding weeds were not examined.

Table 1. Samples of Thysanoptera collected on vegetable crops in Mexican states of Puebla and Morelos showing the crops, locations, dates, and number of thrips samplings in 2010–2011.

Crop	Location	Date	No. of samplings
Tomato	Tlayacapan, Mor.	10 Apr to 06 Jun, 2010	5
	Atlatlahucan, Mor.	01 Aug to 09 Oct, 2010	5
Chili pepper	Izucar de Matamoros, Pue.	08 May to 01 Aug, 2010	7
	Tlayacapan, Mor.	22 May to 01 Aug, 2010	6
	Tepeohuma, Pue.	02 Jul to 21 Aug, 2010	4
Tomatillo	Tlayacapan, Mor.	19 Jun to 19 Jul, 2010	3
	Tepeohuma, Pue.	23 Oct to 18 Dec, 2010	4
	Tlayacapan, Mor.	18 Dec, 2010 to 11 Feb, 2011	4
	Tlayacapan, Mor.	18 Dec, 2010 to 11 Feb, 2011	4
Zucchini	Tlayacapan, Mor.	11 Sep to 06 Nov, 2010	5
	Tepalcingo, Mor	09 Oct to 27 Nov, 2010	4
	Tlayacapan, Mor.	18 Dec, 2010 to 11 Feb, 2011	4
Cucumber	Tepeohuma, Pue.	27 Mar to 08 May, 2010	3
	Tlayacapan, Mor.	10 Apr to 22 May, 2010	4
	Tepeohuma, Pue.	24 Apr to 22 May, 2010	3
	Tlayacapan, Mor.	22 May to 19 Jul, 2010	5
	Tepeohuma, Pue.	19 Jul to 24 Sep, 2010	5
	Atlatlahucan, Mor.	01 Aug to 09 Oct, 2010	5
	Tlayacapan, Mor.	24 Sep to 27 Nov, 2010	5
	Tepalcingo, Mor.	23 Oct to 27 Nov, 2010	3
Onion	Axochiapan, Mor.	08 May to 01 Aug, 2010	6
	Tilapa, Pue.	08 May to 01 Aug, 2010	7
	Tepeohuma, Pue.	21 Aug to 09 Oct, 2010	4
	Tepeohuma, Pue.	09 Oct, 2010 to 08 Jan, 2011	6
	Tepalcingo, Mor	09 Oct, 2010 to 08 Jan, 2011	6
	Tepalcingo, Mor	09 Oct, 2010 to 08 Jan, 2011	6
	Axochiapan, Mor.	23 Oct, 2010 to 11 Feb, 2011	7
	Axochiapan, Mor.	23 Oct, 2010 to 11 Feb, 2011	7

STATISTICAL ANALYSIS

The calculation of HU (Allen 1976) as well as the comparative population fluctuation graphs were made using Microsoft Excel 2010.

Results

A colored version of each of the figures in this report can be seen online in Florida Entomologist 98(2) (June 2015) at http://purl.fcla.edu/fcla/entomologist/browse.

Three thrips species were determined, all of them belonging to the Thripidae family, *Frankliniella fortissima* (Priesner), *F. occidentalis*, and *T. tabaci*. The species that was most frequently found in the crops was *F. occidentalis*, which was present in all 6 vegetable crops. This proved its cosmopolitan behavior and its polyphagia, which agrees with Stuart (2009). In tomato, 100% of the collected insects corresponded to this species; in pepper, 98.94%; in tomatillo, 99.06%; in cucumber, 98.68%; in zucchini, 96.16%; and in onion, 2.60%. Additionally, *T. tabaci* was present in onion, where it was the most abundant at 97.39%; in pepper, 1.05%; in tomatillo, 0.93%; and in cucumber, 0.84%. These results show the preference of *T. tabaci* for crops in the Liliaceae, which agrees with Torres-Villa et al. (1994), who reported it as the dominant species with over 95% frequency on plant species belonging to the Liliaceae. *Frankliniella fortissima* was found at very low densities on zucchini (3.83%) and on cucumber (0.47%). In the 160 collected samples, we found that *F. occidentalis* was present in 69%, *T. tabaci* in 28%, and *F. fortissima* in 3%.

With respect to the thrips species per crop, we observed that on tomato, only *F. occidentalis* was present in all 12 samples. On pepper, *F. occidentalis* was identified in all 19 samples, in one of which we found the combination *F. occidentalis + T. tabaci* with the latter species at a very low density. *Frankliniella occidentalis* was present in all 38 cucum-

Table 2. Frequencies of thrips species identified in the samplings of 6 vegetable crops in Puebla and Morelos, 2010–2011.

Species	Tomato	Chili pepper	Green tomato	Cucumber	Zucchini	Onion
F. occidentalis	12	18	15	36	26	0
F. fortissima	0	0	0	0	4	0
T. tabaci	0	0	0	0	0	42
F. occidentalis + T. tabaci	0	1	1	1	0	4
F. occidentalis + T. tabaci + F. fortissima	0	0	0	1	0	0
Total of samples	12	19	16	38	30	46

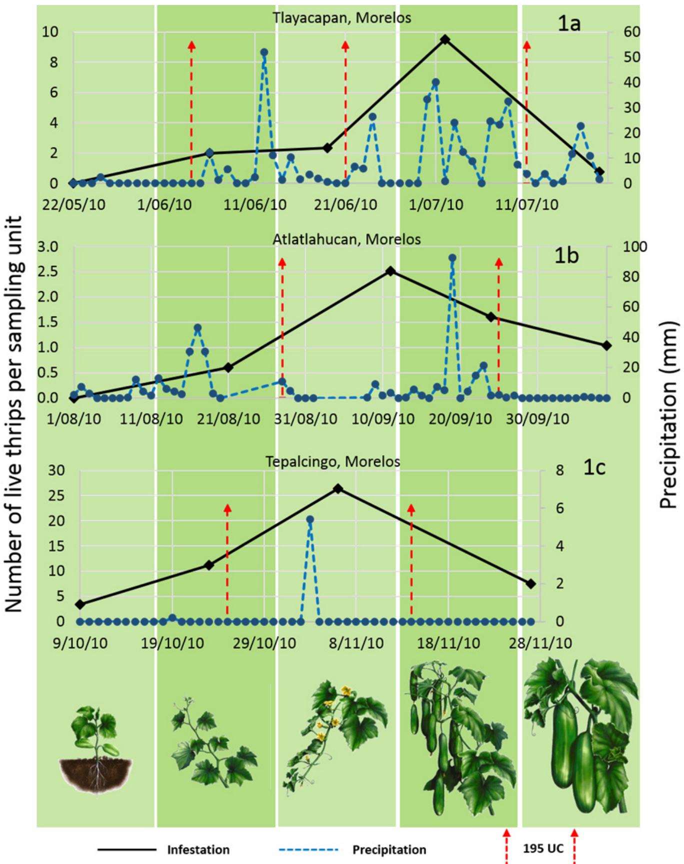

Fig. 1. Population fluctuation of *Frankliniella occidentalis* in the cucumber crops at Atlatlahucan and Tepalcingo, Morelos, Mexico, 2010–2011. Sufficient thermal units (195 degree days) occurred to support 1 life cycle of *F. occidentalis* from transplantation until the 1st vertical arrow and subsequently between consecutive arrows.

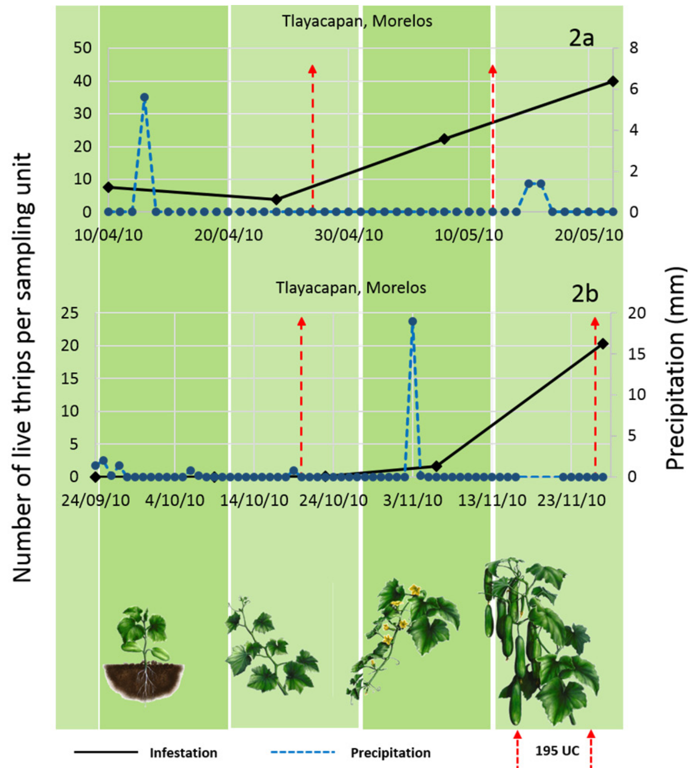

Fig. 2. Population fluctuation of *Frankliniella occidentalis* in the cucumber crops at Tlayacapan, Morelos, Mexico, 2010–2011. Sufficient thermal units (195 degree days) occurred to support 1 life cycle of *F. occidentalis* from transplantation until the 1st vertical arrow and subsequently between consecutive arrows.

ber samples, and in 1 of these *T. tabaci* was present, and in another *F. fortissima* and *T. tabaci* were present albeit at very low population densities. On tomatillo, *F. occidentalis* was identified in all 16 samples, and in 1 one of these samples *T. tabaci* was also present. On onion, *T. tabaci* was present in all 46 samples, and in 4 of them *F. occidentalis* was present albeit at very low densities. Finally, on zucchini, *F. occidentalis* was found in 26 of the 30 samples, whereas *F. fortissima* was registered in the remaining 4 (Table 2).

Frankliniella occidentalis was present on the cucumber crops throughout the whole study period (Figs. 1, 2, and 3), and the timing of its population fluctuations differed among the various sampling sites; however, most of the population spikes were registered during the flowering stage. Thus, *F. occidentalis* reached its highest levels at 30 to 40 d after transplanting. At all locations, there were enough HUs to allow at least 2 generations to complete their development. At Tepeojuma (Fig. 3a), from Apr to May, the temperature allowed the development of 4 generations in only 50 d. The maximum population (38.5 thrips per sampling unit) occurred at the end of the sampling period. Contrastingly, at Tlayacapan (Fig. 2b), 60 d were required to complete enough HU for 2 generations and this happened during Sep to Nov. The maximum population (20 thrips per sampling unit) was registered at the end of the sampling period. Rainfall varied among the sampling sites, but the *F. occidentalis* population fluctuations were not determined by rainfall (Figs. 2b and 3a).

At 2 of the experimental sites with zucchini crops, intense rains were registered (> 40 mm). This kept the *F. occidentalis* population density low, with no more than 1.5 individuals per sampling unit, and the population remained at these levels until the end of the crop cycle (Figs. 4a and 4c). Additionally, at Tepalcingo (Fig. 4b), the population peaked during the flowering and fruiting periods (9 thrips per sampling unit). At Tepalcingo, enough HUs were accumulated to allow 4 generations to develop.

At the sampling sites for pepper crops, the frequency of *F. occidentalis* exceeded 98%. The samplings indicated that the maximum infestation values occurred during flowering and at the beginning of fruit development. At Izucar de Matamoros (Fig. 5a), the temperature conditions (HU) were sufficient to allow 6 generations to complete development. Toward the end of the study period, population densities tended to decrease, and this coincided with crop senescence and/or frequent rainfall (> 20 mm). Concurrent with these population studies at Izucar de Matamoros, similar studies were conducted at Tlayacapan (Fig. 5b). At Tlayacapan, the density of the thrips infestation was related to rainfall. At this site, 20 mm rainfall more per day occurred during 11 d. Consequently, the smallest population levels on pepper occurred at Tlayacapan, i.e., fewer than 5 thrips per sampling unit.

In tomato crops, the highest population density occurred during flowering with more than 50 specimens per sampling unit at Tlayacapan (Fig. 6a), whereas at Atlatlahucan, a maximum of 18 thrips per sampling unit were registered (Fig. 6b). At both sites, no clear relationship was found between temperature, rainfall, and population density of *F. occidentalis*, but at both sites the pest population declined as the crop went into senescence.

In tomatillo, the most dense *F. occidentalis* population occurred at Tlayacapan (Fig. 7b) with a maximum spike of 147 individuals per sampling unit, followed by another site in the same municipality (Fig. 7c), where a maximum population of 64 specimens per sampling unit was

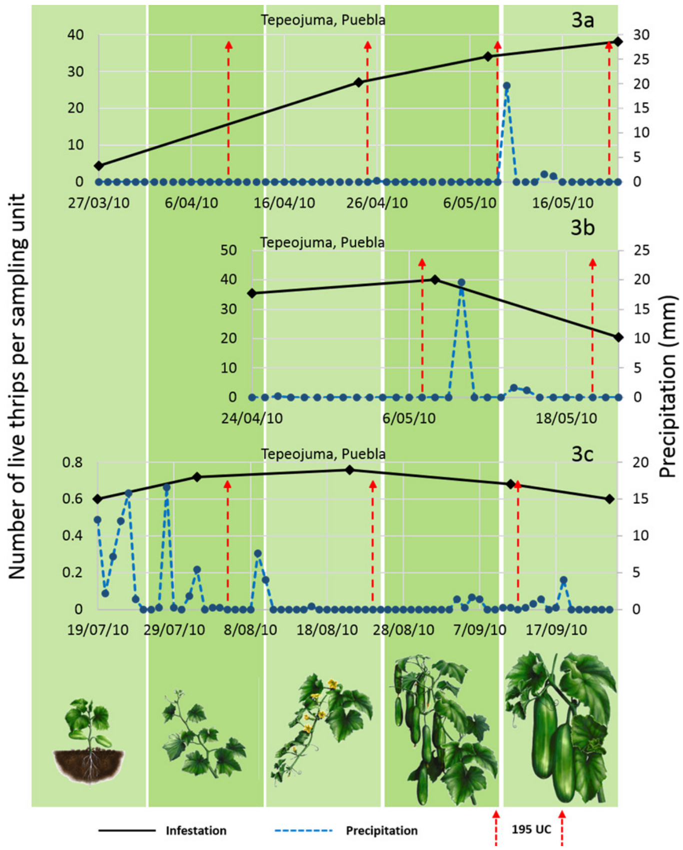

Fig. 3. Population fluctuation of *Frankliniella occidentalis* in the cucumber crops at Tepeohuma, Puebla, Mexico, 2010–2011. Sufficient thermal units (195 degree days) occurred to support 1 life cycle of *F. occidentalis* from transplantation until the 1st red vertical arrow and between consecutive red arrows.

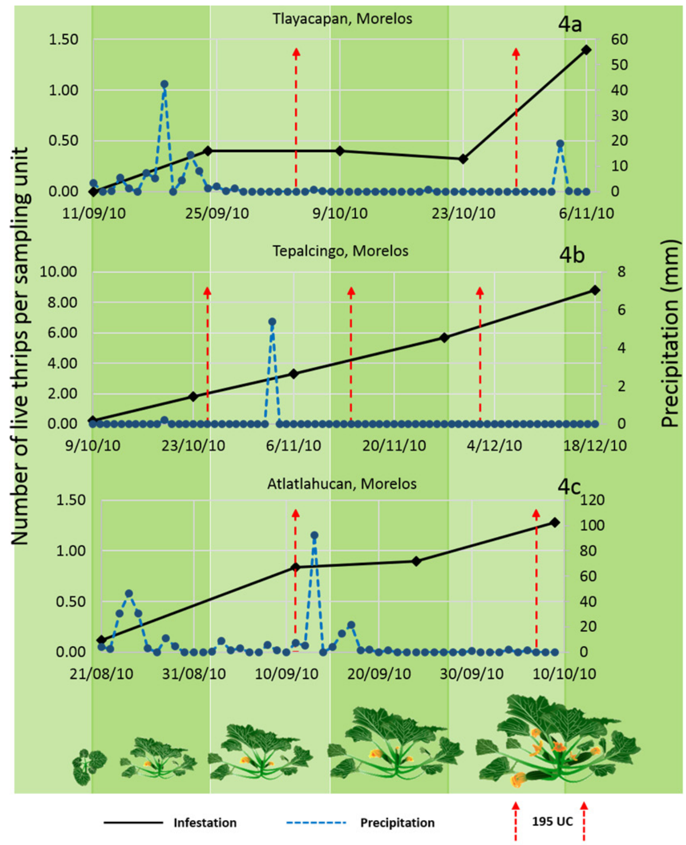

Fig. 4. Population fluctuation of *Frankliniella occidentalis* in the zucchini crops at Tlayacapan, Tepalcingo and Atlatlahucan, Morelos, Mexico, 2010–2011. Sufficient thermal units (195 degree days) occurred to support 1 life cycle of *F. occidentalis* from transplantation until the 1st red vertical arrow and between consecutive red arrows.

registered. Tomatillo develops during the coldest season of the year, thus requiring more than 30 d to accumulate enough HUs for one *F. occidentalis* generation to develop. After this date (01 Jan 2011), the population increased to more than 60 individuals per month per sampling unit. The *F. occidentalis* populations at Tlayacapan (Fig. 7a) and Tepeojuma (Fig. 7b) showed similar behaviors with maximum population spikes during flowering. Additionally, no relationship was found between temperature, rainfall, and population density of the thrips populations at these sites. At both sites, the pest population declined as the crop went into senescence.

Of the 3 thrips species studied, *T. tabaci* was the most important one for onion crops. *Trips tabaci* specimens constituted more than 97% of thrips individuals in the samples. Figures 8, 9, and 10 show that the *T. tabaci* thrips populations began to increase 25 d after transplanting. Rainfall and temperature conditions had no evident effect on infestation levels. Thus the levels of infestations were clearly related to the phenology of the onion crops. Thrips counts indicated that the highest *T. tabaci* population spike in the field occurred about 100 d after transplanting. In most cases, maximum population densities of 60 – 80 specimens per sampling unit were registered.

Discussion

Frankliniella occidentalis was overwhelmingly the most prevalent thrips pest species in zucchini, pepper, tomato, cucumber, and tomatillo crops. This species maintained high population levels, possibly because of the wide variety of crops and weeds that serve as its hosts, and because of its well-known great reproductive capacity (Soto et al. 2009). Our general results for zucchini, pepper, tomato, cucumber, and tomatillo partially agree with those obtained by Ascensión-Betanzos et al. (1999), who mentioned that the highest thrips populations occurred during flowering periods and in the warmer periods. In the present study, high populations were present during prolonged periods of high temperatures, as in the case of pepper crops in Tepeojuma; however, high populations were also registered during the coldest period (Dec–Jan), as in the case of tomatillo crops in Tlayacapan. These results agree with those of Urías-López et al. (2007), who stated that the most important factor that affects thrips population levels is the phenological stage of the plant. Indeed, this is so because many thrips species strongly prefer flowers and young buds. The other important species in this study was *T. tabaci*, which was dominant on onion but rare on the other vegetable crops in this study. The narrow structure and serosity of the leaves of this crop provide a microenvironment favorable for the sustained reproduction of this pest, which has a great capacity to reproduce in part through parthenogenesis. According to the temperature requirements of *T. tabaci* indicated by Ramírez et al. (2009), at least 2 generations were completed during the sampling period. An increase in population density was observed in the 2nd generation.

Cucumber strongly facilitated the population growth of *F. occidentalis* (Fig. 2), which was particularly rapid starting with the beginning of flowering. Temperature conditions were more favorable for *F. occidentalis* during Apr and May, when 2 generations were completed in a 35 d period. In contrast, Fig. 2b shows that in the cool temperatures of Oct and Nov approximately 60 d were necessary to accumulate enough HU for 2 generations.

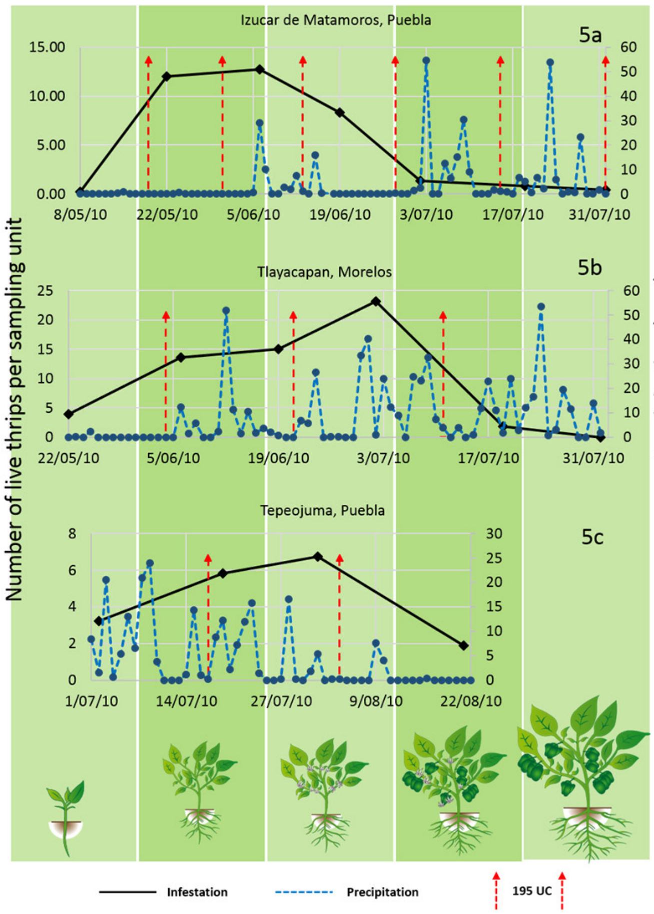

Fig. 5. Population fluctuation of *Frankliniella occidentalis* in the pepper crops at Izucar de Matamoros and Tepeojuma, Puebla, and Tlayacapan, Morelos, Mexico, 2010–2011. Sufficient thermal units (195 degree days) occurred to support 1 life cycle of *F. occidentalis* from transplantation until the 1st vertical arrow and subsequently between consecutive arrows.

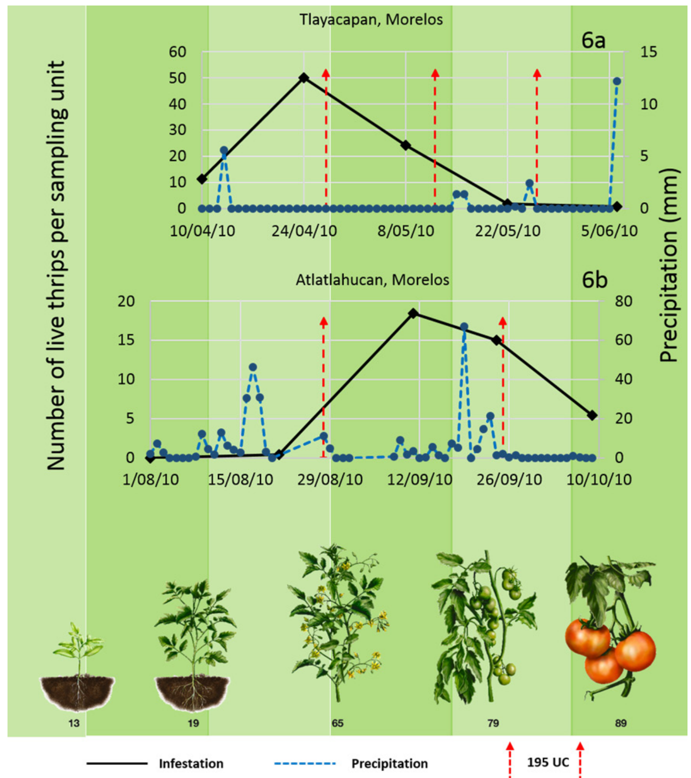

Fig. 6. Population fluctuation of *Frankliniella occidentalis* related with tomato crops at Tlayacapan and Atlatlahucan, Morelos, Mexico, 2010–2011. Sufficient thermal units (195 degree days) occurred to support 1 life cycle of *F. occidentalis* from transplantation until the 1st vertical arrow and subsequently between consecutive arrows.

In Puebla, 2 distinct types of handling were found. Figure 3a shows the population fluctuation of *F. occidentalis* in a ground-level growing crop (cucumber). The temperature conditions and plant structures offered conditions that allowed sustained population increase, so that 4 generations were registered in the study period. Regarding the crop in Fig. 3b, the samplings began during the flowering stage. Because of this, the initial population was dense, i.e., 35 individuals per sampling unit. In this case, strong rainfall, at least 20 mm, was registered on May 10th, which could have caused the population to decrease. Additionally, the crop began to senesce about 1 mo after sampling began. Data pertaining to crop with proper agricultural handling with leads and plastic mulching is shown in Fig. 3c. Although the temperature conditions were favorable for the development of 3 *F. occidentalis* generations, populations were always sparse. In general, at every sampling, less than 1 individual per sampling unit was registered.

During the study, we observed that zucchini began to develop without any thrips, and that the thrips population density increased with the formation of flowers. Moreover, the temperature conditions did not favor the optimum development of *F. occidentalis*, so at least 20 d were needed to complete the HU requirements for 1 generation of thrips. Figure 4b pertains to a zucchini crop established in Tepalcingo, Morelos, in which the *F. occidentalis* population was higher and the temperature conditions favored the development of 3 biological cycles of the pest.

Data on pepper in Figs. 5a and 5b show the effect that rainfall of around 20 mm had in causing the *F. occidentalis* population to decrease. Towards the end of the sampling period, frequent rainfall was registered, which kept the population levels low, less than 2 individuals per sampling unit. In the case of Fig. 5c, a drastic *F. occidentalis* population decline was observed because the pepper crop senesced very quickly. This sharp decline occurred even though optimum temperature conditions prevailed that allowed 2 generations to be completed in 35 d. Frequent rainfall events helped to keep the population at low levels. As had been reported by Soto et al. (2009), in some cases we, too, observed an adverse effect of rainfall on populations of thrips. It is possible that the structure of pepper crops provided no refuge that allowed the pest to be protected from rain, and intense and frequent rains were registered in the study period.

The relationship between a commercial tomato crop and *F. occidentalis* thrips can be seen in Figs. 6a and 6b. The decrease in the thrips population (Fig. 6a) cannot be attributed to weather conditions, because the rainfall registered was not of a magnitude that could affect the population. The sudden decrease in population density of this insect is attributed to chemical control. As a result of the high commercial value of the tomato crop, growers make at least 6 insecticide applications in the study zone. Figure 6b shows that rainfall kept the *F. occidentalis* population levels low during the early phenological stages of tomato, but once the intensity of rainfall became minor, the populations increased to a maximum level of 18 individuals per sampling unit, which coincided with the flowering and fruiting stages. On September 19th, an intense 60 mm rainfall was registered, which caused population decrease. This last population decrease coincided with the end of flowering and the harvest time.

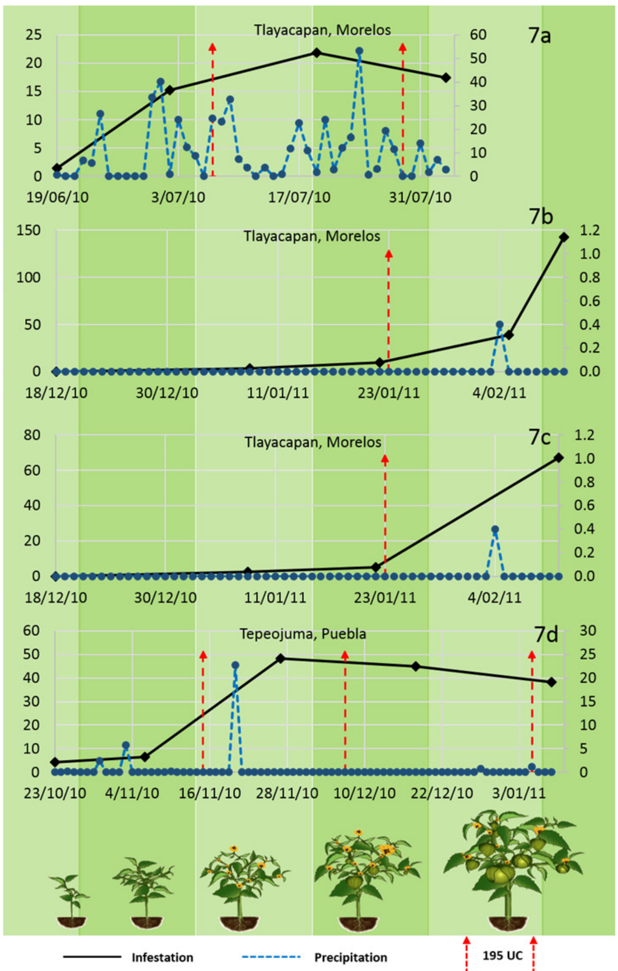

Fig. 7. Population fluctuation of *Frankliniella occidentalis* in the tomatillo crops at Tlayacapan, Morelos, and Tepeojuma, Puebla, Mexico, 2010–2011. Sufficient thermal units (195 degree days) occurred to support 1 life cycle of *F. occidentalis* from transplantation until the 1st vertical arrow and subsequently between consecutive arrows.

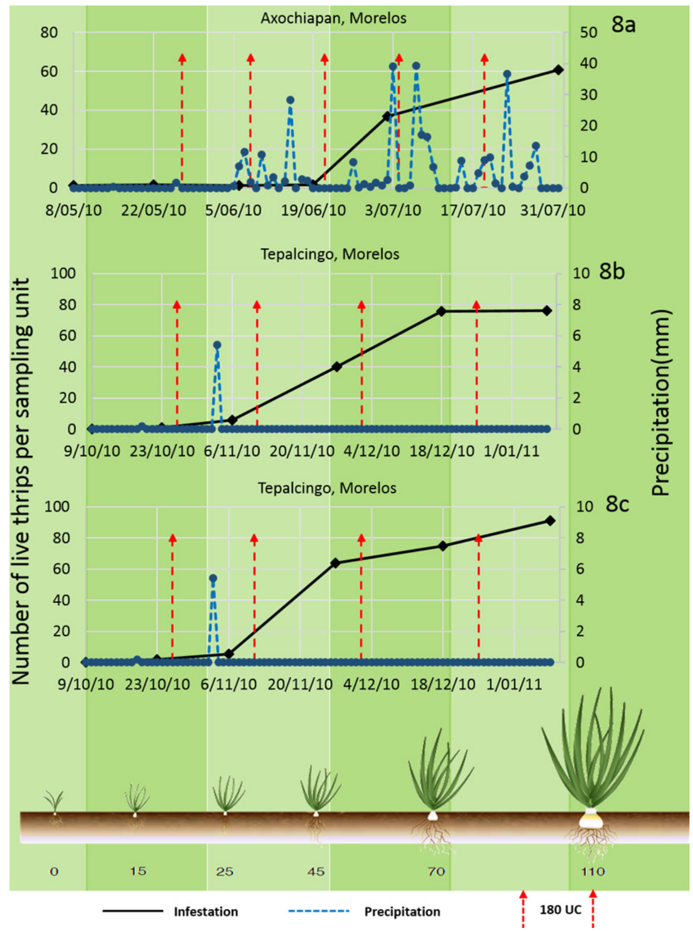

Fig. 8. Population fluctuation of *Thrips tabaci* in the onion crops at Axochiapan and Tepalcingo, Morelos, Mexico, 2010–2011. Sufficient thermal units (180 degree days) occurred to support 1 life cycle of *T tabaci* from transplantation until the 1st vertical arrow and subsequently between consecutive arrows.

In tomatillo crops in Tlayacapan, no clear effect of rainfall on the *F. occidentalis* population was observed (Fig. 7a). This could have been because the crop was covered in weeds, which could have offered more safe refuges for the pest. Johansen & Mojica (1997) point out the high polyphagy of *F. occidentalis*. Concurrent with the previous results, the highest population density was registered during the tomatillo flowering stage, and it began to decrease during the fruiting stage (Fig. 7d). Figures 7b and 7c reflect the fact that at the time that the samples were taken, the temperatures were not favorable for the development of the pest, because 35 d were needed to complete its HU requirements. It is worth mentioning that during the initial phenological stages of the plants, up to 23 d after transplanting, the crop was protected by an agribon-type fabric cover that delayed the arrival of thrips. The sudden increase in population density could be because the fabric cover was removed and the crop lost its protection. Therefore, we concluded that the population increased from thrips invasion coming from neighboring crops like pepper and zucchini; however, the highest number of individuals was found in tomatillo.

In general, the narrow architecture of onion plants and the serosity of the leaves decrease the effect of rainfall on the population of *T. tabaci*, which find refuge in the leaves. Figure 8a shows that the population increased from 30 d after transplanting, despite there being frequent rainfall, sometimes over 30 mm per event. Additionally, it is important to note that starting a few days after transplanting, the temperature conditions were favorable to allow the development of at least 2 *T. tabaci* generations. Figures 8b and 8c show similar population growth with a constant population increase from 25 d after transplanting onward. In both cases, temperatures were adequate to allow the development of at least 4 generations, so that the population level was largely determined by the phenological stages of the plants.

Figure 9 shows the development of *T. tabaci* populations on 2 onion crops at Axochiapan, Morelos, where an initial population of about 5 thrips per plant was observed 25 d after transplanting. By mid-cycle, approximately 60 d after transplanting, an average 20 thrips per sampling unit was registered. Later, the population increased until it reached 55 thrips per sampling unit at 90 d. Subsequently, a decreasing tendency of the population was confirmed, it being the result of the crop undergoing senescence. During the evaluation period, the temperature conditions were favorable for the development of at least 4 generations; however, the level of infestation by the pest was largely determined by the phenology of the onion crop.

At Tilapa, Puebla, frequent rainfall events (Fig. 10a) appeared to delay the establishment of the *T. tabaci* until 55 d after transplanting. At this site, temperature conditions were ideal for the development of 6 generations during the crop cycle, and the level of infestation was definitely governed by the phenology of the onion crop. At Tepeojuma, Puebla, isolated rains of considerable magnitude (> 20 mm) occurred (Figs. 10b and 10c), but they had no discernible effect on the develop-

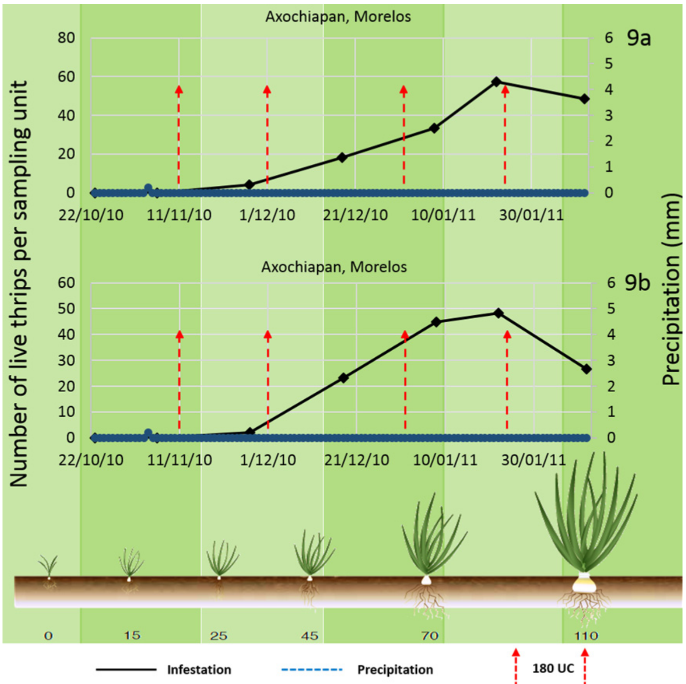

Fig. 9. Population fluctuation of *Thrips tabaci* in the onion crops at Axochiapan, Morelos, Mexico, 2010–2011. Sufficient thermal units (180 degree days) occurred to support 1 life cycle of *T. tabaci* from transplantation until the 1st vertical arrow and subsequently between consecutive arrows.

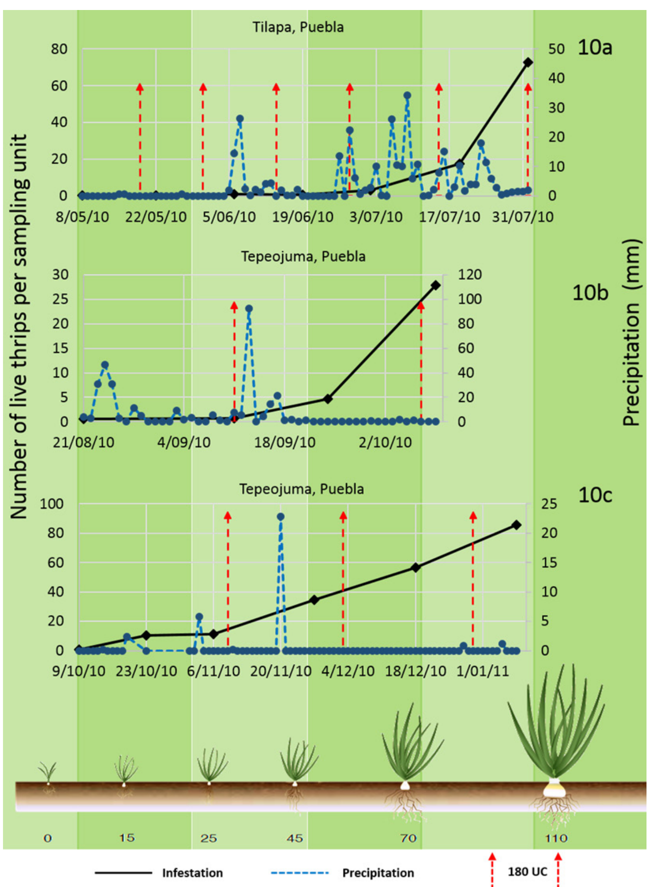

Fig. 10. Population fluctuation of *Thrips tabaci* in the onion crops at Tilapa and Tepeojuma, Puebla, Mexico, 2010–2011. Sufficient thermal units (180 degree days) occurred to support 1 life cycle of *T. tabaci* from transplantation until the 1st vertical arrow and subsequently between consecutive arrows.

ment of the population. In these cases, after 45 d, constant increases in population density were registered with maximum spikes at 70 d after transplanting.

Our results partially agree with Porras et al. (2007), who stated that the population fluctuation of *T. tabaci* was determined by crop phenology with some effect of relative humidity and populations present in previous periods. The predominant thrips species on vegetable crops in the central region of Mexico are *F. occidentalis* and *T. tabaci*, with *F. fortissimo* occurring to a much lesser extent. *Frankliniella occidentalis* and *T. tabaci* can be found on the same crop, with *F. occidentalis* predominant on tomato, pepper, tomatillo, zucchini, and cucumber; and *T. tabaci* predominant on onion. *Frankliniella fortissima* was found on zucchini and cucumber at a population density of 1 individual per plant, and it appears to prefer to feed on Cucurbitaceae. *Frankliniella occidentalis* and *F. fortissima* were not found together in a single sample. *Thrips tabaci* can be present at very low levels on pepper, tomatillo, and cucumber. The thrips populations in this study reached maximum levels during the flowering stage. In the case of *T. tabaci* on onion, maximum population levels were reached at 50 to 60 d after transplanting. Frequent rainfall (> 20 mm/rainfall event) can affect the normal development of the *F. occidentalis* populations but not those of *T. tabaci* on onion. The greatest number of thrips generations occur during May to Jul when *F. occidentalis* on pepper and *T. tabaci* on onion can reach up to 6 generations per crop cycle.

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