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Authors: Hall, David G., and Simms, Michael K.

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DAMAGE BY INFESTATIONS OF TEXAS CITRUS MITE (ACARI: TETRANYCHIDAE) AND ITS EFFECT ON THE LIFE OF 'VALENCIA' LEAVES IN AN IRRIGATED CITRUS GROVE

DAVID G. HALL AND MICHAEL K. SIMMS

Research Department, United States Sugar Corporation, P.O. 1207, Clewiston, Florida 33440

ABSTRACT

Studies were conducted during 1996-1999 to evaluate damage to citrus leaves by the Texas citrus mite, *Eutetranychus banksi* (McGregor), and its impact on leaf longevity in irrigated citrus. Natural mite infestations were followed in a citrus orchard ('Rhode Red Valencia') under irrigation management, and damage to leaves and leaf abscission were assessed periodically. The number of feeding stipples per cm² on the upper leaf surface was used as an index of feeding damage. A variable 'mite-days' [average number of mites per leaf multiplied by the number of days of infestation] was used to characterize infestation densities over time. Increases in average numbers of stipples per cm² per leaf (Y) across different mite-day values (X) were described by the equation $Y = 44.08 + 0.59X$ ($r^2 = 0.57$). A model including temperature was marginally better. The final mean density of feeding stipples on infested leaves for the 1996, 1998 and 1999 evaluation periods averaged 327, 134 and 873 per cm², respectively, with an overall mean of 470. Leaf life from the date of full expansion until abscission averaged 443, 387 and 380 days for the respective periods, with an overall average of 399 days. The observed life of the leaves was typical to what has been observed in Florida citrus. Overall, no significant negative relationship was found between leaf life and mite damage. The study indicated that damage by Texas citrus mites to 'Valencia' citrus leaves promoted little or no premature leaf abscission in irrigated trees.

Key Words: Citrus red mite, *Panonychus citri*, leaf abscission, damage assessment, Florida citrus

RESUMEN

Estos estudios fueron conducidos durante 1996-1999 para evaluar el daño en las hojas de cítricos causado por el ácaro téjano de cítricos, *Eutetranychus banksi* (McGregor), y su impacto sobre la longevidad de las hojas de cítricos en huertos irrigados. Las infestaciones naturales de los ácaros fueron observadas en un huerto de cítricos de la variedad 'Rhode Red Valencia' bajo el sistema de irrigación, y se evaluaron periódicamente el daño y la desprendimiento de las hojas. El número de picaduras por cm² sobre la superficie superior de la hoja fue usado como un índice del daño causado por la alimentación. Una variable 'días-de ácaros' [el promedio del número de ácaros por hoja multiplicado por el número de días de infestación] fue usada para caracterizar la densidad de la infestación sobre el tiempo. El aumento en el número promedio de las picaduras por cm² por hoja (Y) a través de diferentes valores de "días-de ácaros" (X) fue descrito por la ecuación $Y = 44.08 + 0.59X$ ($r^2 = 0.57$). Un modelo incluyendo la temperatura fue ligeramente mejor. El promedio final de la densidad de las picaduras en las hojas infestadas en los años 1996, 1997 y 1999 fue 327, 134 y 873 por cm², respectivamente, con un promedio total de 470. La vida de la hoja desde la expansión completa hasta el desprendimiento duró un promedio de 443, 387 y 380 días para los períodos respectivos, con un promedio total de 399 días. La longevidad de las hojas observadas fue típica de lo que fue observado en los cítricos de Florida. Sobre todo, no se encontró una relación negativa significativa entre la longevidad de la hoja y el daño hecho por los ácaros. El estudio indicó que el daño causado por el ácaro téjano de cítricos a las hojas de cítricos 'Valencia' promovió poco o nada el desprendimiento prematura de las hojas en arboles irrigados.

Of the four spider mite species (Acari: Tetranychidae) reported to infest Florida citrus, the Texas citrus mite (*Eutetranychus banksi* (McGregor)) and the citrus red mite (*Panonychus citri* (McGregor)) are the most prevalent and important spider mite pests (Childers 1994). The Texas citrus mite lives and (presumably) feeds almost exclusively on the upper leaf surface (Childers et al. 1991) while the citrus red mite

may live and (presumably) feed on either leaf surface (Muma 1961, Jones & Parrella 1984). Feeding by these spider mites on the upper leaf surface results in small, whitish or light-colored stipples within the palisade leaf layer where cytoplasmic contents including chlorophyll are removed (Albrigo et al. 1981). When leaves are heavily damaged by spider mites, mesophyll collapse may occur and leaves may abscise prema-

turely, particularly during dry, windy conditions (Browning et al. 1995, Hare & Youngman 1987). Whether mite damage and/or premature leaf abscission promotes economic losses in Florida citrus has never been documented but considered probable.

The stipple damage associated with spider mite injury to the upper surface of leaves serves as an index of the intensity of mite damage. Individual stipples are small, ranging from around 0.04 to 0.52mm in diameter (mean 0.172mm, SEM 0.025; 'Valencia' leaves; damage by *E. banksi* and/or *P. citri*) (Hall, unpublished). Variation in the size of individual stipples may be a function of how long a mite feeds and the developmental stage of a mite as well as other factors including leaf age and leaf tissue characteristics. Whether or not each individual stipple is always the result of a single feeding wound is not known. Individual stipples sometimes are so close to each other that they coalesce, and as the density of stipples increases, incidences of coalescence increase. Spider mite damage to a leaf may not be apparent to the naked eye until stipple densities exceed densities of 100 to 150 stipples per cm². In rating damage by the naked eye, visual damage ratings of faint, light, moderate and heavy damage may generally be associated with stipple densities of around 200, 400, 1,000 and 1,800 stipples per cm², respectively.

Little is known regarding the quantitative relationship between Texas citrus mite or citrus red mite infestation densities over time and resulting amount of leaf stippling damage to Florida citrus, information which could be helpful in establishing management guidelines. Economic thresholds for the citrus red mite in California during the 1980s (2 to 4 adult female mites per leaf depending on the time of year and density of predatory mites) were based largely on preventing excessive stipple damage in the absence of more appropriate information on the relationship between damage and economic losses (Pehrson et al. 1984, Hare & Youngman 1987, Hare et al. 1990). Whether these thresholds are appropriate for preventing excessive damage by infestations of Texas citrus mites or citrus red mites in Florida citrus is not known. Although premature leaf abscission may be a major concern with damage by these mites, particularly if trees with damaged leaves are subjected to adverse environmental conditions (e.g., drought and hot windy weather), quantitative data are lacking on the relationship between mite damage and premature leaf abscission in Florida citrus.

Presented here are the results of quantitative assessments of (1) the relationship between Texas citrus mite infestations over time and resulting damage to 'Valencia' citrus leaves and (2) the influence of Texas citrus mite damage on leaf abscission in 'Valencia' in irrigated citrus.

MATERIALS AND METHODS

Four cohorts of 100 flush citrus leaves ('Rhode Red Valencia') were studied during 1996-1999 at a well-managed, irrigated orange grove on a flatwoods (sandy spodosol) soil in Hendry County, Florida. The full-expansion dates for leaves of the four cohorts were approximately 1 September 1996 (trees 4.3 years old); 1 October 1997 (trees 5.4 years old); 1 October 1998 (trees 6.0 years old); and 1 March 1999 (trees 6.5 years old). The trees were planted on two-row beds with a tree spacing of 3.7m and row spacing of 7.6m. For each cohort, 50 newly-expanded flush leaves were tagged along the bed side of one row of trees and 50 were tagged along the bed side of the adjacent row along the same bed (one or two tagged leaves per tree; in cases where two were tagged per tree, these were 0.6 to 0.9m apart). All tagged leaves were 0.6 to 1.8m above the ground and near the outside of the canopy. Leaves of the 1999 cohort were tagged along a bed next to the bed where the 1998 cohort of leaves was tagged. The length of each leaf from the base (excluding the petiole) to the tip and the width at the widest point of each leaf were measured (cm). Leaf area (one surface) in cm² (Y) was estimated from leaf length (χ_1) and width (χ_2) using the following equation: $Y = 1.88 + 0.195(\chi_1)^2 + 0.487(\chi_2)^2$, $r^2 = 0.94$, $n = 100$ (Hall, unpublished).

Leaves were examined weekly to identify spider mites present on the upper leaf surface. For each species present, the number of spider mites (excluding eggs) was counted. Within each cohort of leaves, mite damage to 20 leaves was limited by periodically wiping mites off with a soft damp cloth or by misting them with either a 5% petroleum oil (FC-435-66) in water solution or a fenbutatin-oxide 50W treatment (0.6 g per 500ml water). For each cohort of leaves, numbers of mites per leaf were studied for 3 to 4 months, after which weekly mite counts were discontinued and all leaves were individually treated with the fenbutatin-oxide treatment to eliminate mites. Thereafter until abscission, each leaf was periodically treated with either the oil or fenbutatin-oxide treatment to prevent further mite infestations.

In addition to counting mites on the upper surface of leaves, damage by mites to the upper leaf surface was quantified weekly on 52, 40 and 50 infested leaves for the 1997, 1998 and 1999 cohorts. Early during the development of mite infestations on the leaves of each cohort, few infested leaves were available for damage evaluations. When numbers of infested leaves increased to more than 20, we split the leaves into two groups and evaluated them biweekly, one group evaluated one week and the second group the following week. When the number of infested leaves exceeded 40, we split the leaves into three groups and evalu-

ated damage to each group every three weeks, one group per week. The average density of stipples per cm² across the upper leaf surface was used as the measure of mite damage. Damage by mites to individual leaves was assessed beginning on the first day mites were observed on the leaves and continued until all leaves of a cohort were treated to eliminate mites. After all leaves had been treated with fenbutatin-oxide to eliminate mites, a final estimate of the average stipple density was made for every leaf within each cohort. For the 1996 cohort of leaves, the average density of stipples on each leaf was estimated only after appreciable damage had occurred to leaves and mites had been controlled. For all cohorts, estimates of average stipple densities per leaf were made by counting the number of stipples per cm² at each of 10 sites uniformly spaced across the upper surface of each leaf. To count stipples, an Edmond Scientific comparator (12X transparent base magnifier with 27mm contact reticule adapter ring, Kellner-type/AR coated lens, reticule with 1-cm² grid of 100 squares, Edmond Optics, Barrington, NJ USA) was placed against or just above the leaf surface. The leaf and magnifier were held so that as much light as possible illuminated the leaf surface being examined. All stipples within the grid were counted when there were less than approximately 100 stipples within the grid; however, when there were more than approximately 100 stipples within the grid, the number of stipples within a sub-sample of ten squares of the grid was counted and multiplied by ten to estimate the total number per cm². At high stipple densities per cm² (e.g., 1,500 or more), stipples sometimes coalesced, making it difficult to estimate the actual number present. In this case, the number of individual stipples constituting an area of coalesced stipples had to be estimated based on the average diameter of surrounding or nearby individual stipples. Leaves with dust or sooty mold were gently cleaned using a soft cloth dampened with water before counting stipples (the entire surface when no mites were present or 10 spots each approximately 1-cm² in size if mites were present). For final stipple counts, the entire upper surface of each leaf was gently cleaned with water, after which the magnifier was placed against the wet leaf surface.

Records were maintained for each leaf of each cohort on the incidence of injury by citrus leaf-miner (*Phyllocnistis citrella* Stainton) and citrus rust mites (*Pyllocoptruta oleivora* (Ashmead) and *Aculops pelekassi* (Keifer)), infection by greasy spot (*Mycosphaerella citri* Whiteside), nutritional disorders, mesophyll collapse, freeze damage and hail injury. The percentage surface area infected by greasy spot was estimated for 1998 leaves on 28 May 1999 and for 1999 leaves on 17 February 2000. Air temperature, rainfall, evaporation and wind data during the study period were obtained

from the Corp of Engineer's Moore Haven Lock 1 weather station about 4.8 km north of the study sites. Exceptional environmental events during the study were noted.

Relationship Between Mite Density and Damage

The quantitative relationship between spider mite densities per leaf (upper surface) and resulting damage to the upper surface of leaves was investigated by comparing the average mite density on a leaf over a period of time to the increase in average stipple density over the same period of time (data from cohorts 1997, 1998 and 1999). For each infestation period on each leaf, the average number of mites per leaf was calculated by averaging the numbers of mites observed on different observation dates during the infestation period. The duration of mite infestation (days) was determined by the number of days between the first and last observation dates during the infestation period. An infestation density/duration variable 'mite days' (see Allen 1976, Yang et al. 1995) was calculated for each infestation on each leaf: 'mite days' = (average number of mites per leaf) * (number of days). The resulting damage caused by mites feeding during each infestation period on each leaf was estimated by subtracting the mean number of stipples per cm² present at the beginning of the period from the mean number present at the end of the period. A linear regression analysis was conducted between the increase in mean stipple densities per cm² per leaf and 'mite days' for leaves of each cohort and over all three cohorts. Correlation analyses were conducted between the following variables: increases in stipple densities; 'mite days'; leaf area; mean, maximum and minimum daily air temperatures; daily rainfall; daily evaporation; and daily wind. Stepwise regression analyses were then conducted using variables significantly correlated ($P \leq 0.05$) with increases in damage to select a multiple regression model for predicting damage.

Relationship Between Mite Damage and Leaf Abscission

The leaves of three cohorts (1996, 1998 and 1999) were examined every 2 to 5 weeks (mean 20.7 days, SEM 2.1 days) after mite infestations were controlled to determine when the leaves abscised. The abscission date was estimated using the mid date between the date abscission was discovered and the date a leaf was last observed on a tree. 'Leaf life' was approximated as the period of time from the date of full expansion until the abscission date. 'Life after attack' by mites was approximated as the period of time between a leaf's mean infestation date (weighted on infestation densities across successive infestation dates) and its abscission date.

To determine if spider mite damage promoted premature abscission, linear regression analyses were conducted between 'leaf life' and damage (average number of stipples per cm²); and between 'life after attack' and damage (average number of stipples per cm²). Analyses on 'life after attack' were restricted to leaves on which mites were observed on at least three successive sample dates. Leaves with disorders such as damage by other arthropod pests, nutritional problems, freeze damage and hail injury were excluded from all analyses. Correlation analyses were conducted to investigate the relationship between 'leaf life' and each of the following variables: average number of stipples per cm²; mean surface area with greasy spot infection; mean, maximum and minimum daily air temperature; daily wind; daily rainfall; daily evaporation; and interaction effects between mite damage and each of the other independent variables. For each date on which leaf abscissions were discovered (i.e., an abscission event had occurred), the percentage of abscised leaves within each cohort was calculated. Correlation analyses were then conducted to investigate the relationship between percentage leaf drop and the aforementioned variables. For all correlation analyses, air temperature, wind, rain and evaporation data were averaged over a period of within 40 days prior to discovering leaf abscission. For variables which were significantly correlated ($Pr > |r| \leq 0.05$) with 'leaf life' and 'life after attack', stepwise regression analyses were conducted to select regression models for predicting the life of leaves damaged by spider mites.

RESULTS AND DISCUSSION

Both Texas citrus mites and citrus red mites were observed on leaves during this study, with Texas citrus mites being the predominant species (Table 1). Spider mites densities were greater on the 1996 and 1999 leaf cohorts (e.g., means of 18.8 and 21.9 Texas citrus mites per leaf, respectively) than on the 1997 and 1998 cohorts (e.g., means of 5.1 and 4.0 Texas citrus mites per leaf, respectively) (Table 1). Among the three fall flush cohorts, mite densities on leaves during the first several months after leaf expansion were greater during 1996 than either 1997 or 1998 and, based on correlation analyses (not presented), these infestation density differences were attributed to less rainfall during these months in 1996 based on rainfall at the weather station. This is consistent with Pratt & Thompson (1953), who previously reported a negative relationship between rainfall and citrus spider mite levels. During each of the four flushes investigated in this study, spider mite infestations generally began to develop within 1 to 3 months after leaves had fully expanded (Fig. 1). Leaves of the 1998 cohort, which were present on trees and being monitored when

TABLE 1. POPULATION DENSITIES OF TEXAS CITRUS AND CITRUS RED MITES OBSERVED DURING THE STUDY.

Cohort	Number of leaves	Sample period	Total number of leaf samples	Spider mite species observed	Number of leaf samples mites observed	Mean (SEM) number mites per leaf sample	Maximum number mites per leaf sample
Sep 1996	100	Sep '96-Jan '97	933	Texas mites	363	18.8(1.4)	241
				Red mites	22	1.4(0.2)	4
				Both mites	55	20.7(3.4)	122
Oct 1997	100	Oct '97-Mar'98	2088	Texas mites	88	5.1(0.8)	41
				Red mites	30	1.6(0.2)	4
				Both mites	7	8.6(2.4)	18
Oct 1998	100	Oct '98-Jan '99	1779	Texas mites	177	4.0(0.4)	43
				Red mites	51	1.7(0.2)	9
				Both mites	38	7.4(1.3)	43
Mar 1999	100	Mar '99-Apr '99	786	Texas mites	335	21.9(1.7)	236
				Red mites	26	4.2(2.0)	52
				Both mites	73	24.2(4.3)	237

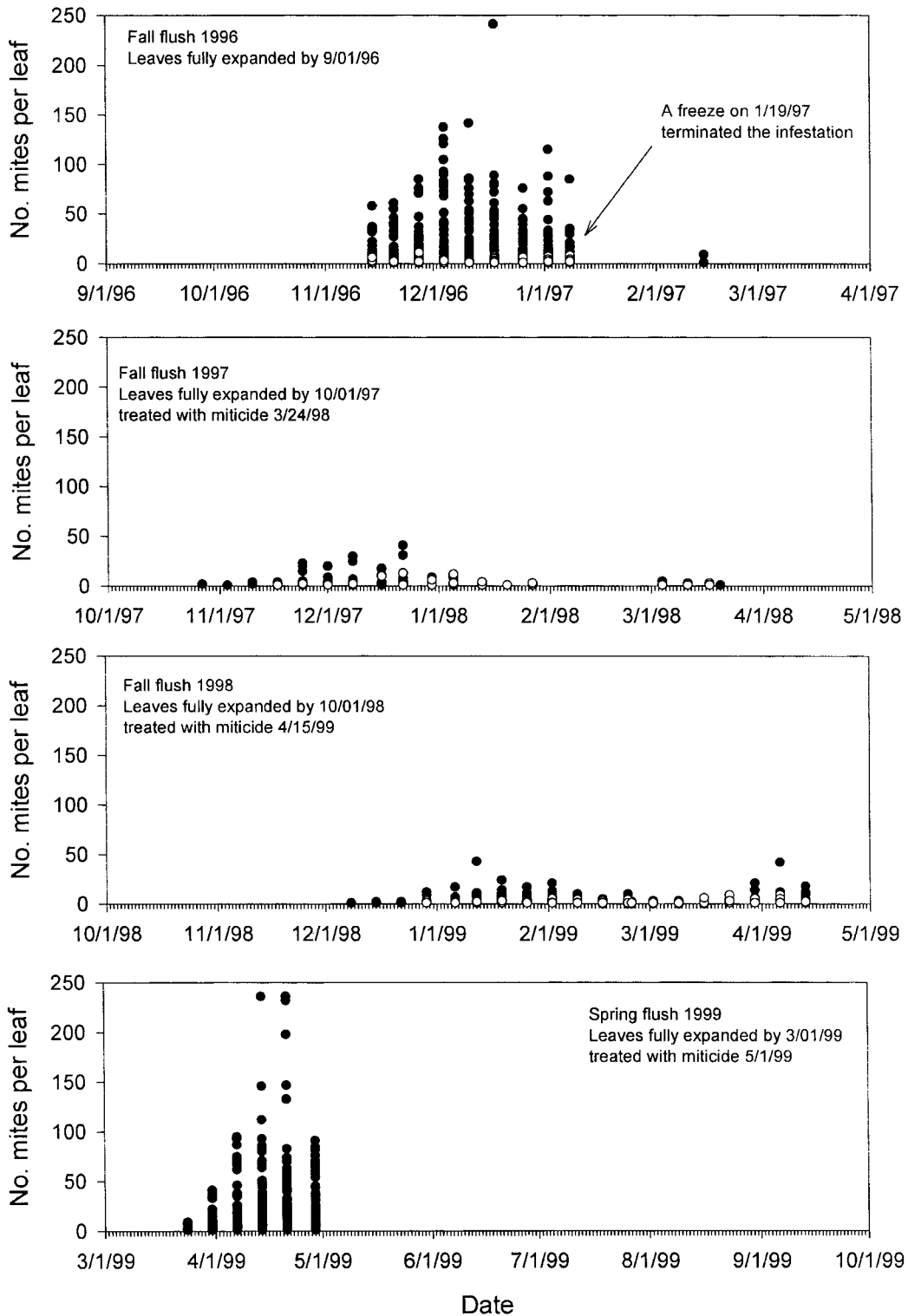


Fig. 1. Spider mite infestations (densities per leaf and dates) observed during the study (Texas citrus mite densities solid data points, citrus red mite densities open data points).

research was initiated on the 1999 cohort, were infested by lower densities of spider mites than the leaves of the 1999 cohort during March and April 1999. The reason mites were more abundant on the younger leaves was not known but could have been related to factors such as microclimate, leaf nutrition or biological control.

Relationship Between Mite Density and Damage

Since only a few citrus red mites were observed during this study, analyses on the quantitative relationship between mite infestations and resulting damage were restricted to leaves known to be infested solely by Texas citrus mites. Data for a total of 131 individual leaf infestations of Texas citrus mites were subjected to analyses comparing leaf infestation densities/durations to resulting damage, with data for 58, 34 and 39 individual infestations from the 1997, 1998 and 1999 cohorts, respectively. Overall, these infestations averaged 21.9 days in duration (SEM 0.5 days) at a mean density of 7.8 Texas citrus mites per leaf (SEM 1.3 mites).

A statistically significant relationship was found between infestations ('mite days') of Texas citrus mites and resulting increases in densities of stipples per cm^2 for each of the 1997, 1998 and 1999 cohorts. Over all 3 cohorts, increases in the mean density of stipples per cm^2 per leaf (Y) were related to 'mite days' (X) by the equation $Y = 44.08 + 0.59X$ ($r^2 = 0.57$, $F = 168.8$, $\text{Pr} > F = 0.0001$, $\text{df} 130$, slope SEM = 0.045) (Fig. 2). The intercept parameter 44.08 (significantly greater than zero, $t = 2.7$, $\text{Pr} > t 0.008$) reflected the presence of stipples which could not be attributed directly to mites observed on leaves. This may have been a result of mites moving from leaf to leaf or being subjected to mortality factors prior to leaf observations.

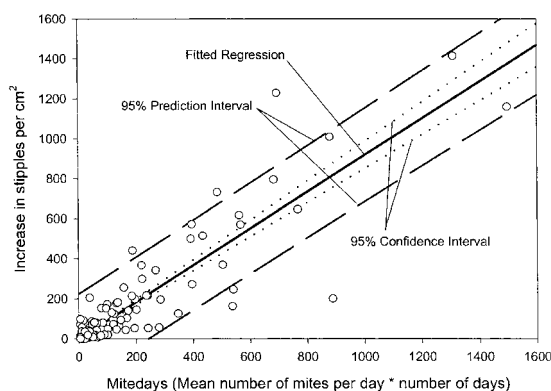


Fig. 2. Relationship between increases in feeding damage (mean stipple density per cm^2 per leaf) and mite days (mean number mites per leaf times the number of days of infestation) on leaves infested by Texas citrus mites, data from 1997-1999 combined.

Stepwise regressions indicated that increases in the mean density of stipples per cm^2 per leaf (Y) were best described by a multiple regression model based on 'mite days' (X_1) and maximum daily air temperatures at the weather station (X_2): $Y = -414.6 + 0.516X_1 + 17.9X_2$, $r^2 = 0.60$, $F = 94.4$, $\text{Pr} > F = 0.0001$, $\text{df} 130$. Texas citrus mites therefore caused more damage as temperature increased. The correlations between observed and estimated increases in damage were similar with respect to the multiple regression model ($R = 0.77$, $\text{Pr} > |R| = 0.0001$) and the simple model based only on 'mite days' ($r = 0.75$, $\text{Pr} > |r| = 0.0001$). A strong statistical relationship existed between estimates from the simple model (Y) and the multiple regression model (X): $Y = 6.89 + 0.95X$, $r^2 = 0.95$, $F = 2,512.8$, $\text{Pr} > F = 0.0001$, $\text{df} 130$. Based on the slope 0.95, the inclusion of maximum daily temperatures only marginally improve estimates across the temperatures observed during our study. Over all three cohorts, leaf area and increases in mite damage were negatively correlated, but regression analyses indicated leaf area was not a significant variable in predicting damage. The leaves studied were fairly uniform in size, with leaf area averaging 40.5 cm^2 (SEM = 1.2, $n = 127$). It remained probable that a given density of mites would cause more damage over a given period of time to small leaves than to large leaves.

Relationship Between Mite Damage and Leaf Abscission

Leaf disorders observed during the study included damage by citrus rust mites (species not identified), leaf miners and some other leaf-feeding insects, greasy spot disease, freeze damage, and hail injury. Although little damage by rust mites occurred during the study, two leaves of the 1996 cohort and one leaf of the 1999 cohort were dropped from leaf life assessments due to rust mite injury. Two leaves of the 1998 cohort were dropped from life assessments due to nutritional problems (yellowing), and 15 leaves of this cohort were dropped from life assessments due to damage by leaf-feeding insects. Among leaves within the 1996 cohort, 62 were damaged by a freeze on 19 January 1997 (temperatures as low as around -5°C for several hours at the weather station, probably colder at the study site); 48 of these leaves abscised within several days following the freeze and 14 others were rendered unfit for further research, leaving 36 leaves for life assessments. Among these 36 leaves, 13 had suffered considerable spider mite damage (e.g., averages in excess of 1,000 stipples per cm^2) before the freeze, suggesting that a freeze will not necessarily promote immediate abscission of leaves with mite damage. Among leaves of the 1998 and 1999 cohorts, 37 and 20 leaves, respectively, were ren-

dered unfit for leaf life assessments due to hail damage suffered on 28 May 1999. Twelve leaves of the 1999 cohort abscised or were hedged off before a final estimate of spider mite damage was made and were thus not available for leaf life assessments. Fifty-one of the 67 remaining leaves of the 1999 cohort were selected for leaf life assessment studies. None of the leaves studied developed any signs of mesophyll collapse. In spite of two standard summer treatments of copper and petroleum oil used for greasy spot control each summer, low infection levels of greasy spot developed on at least some leaves in each cohort. Usually, only one to several small infection sites could be found on any leaf with greasy spot. All leaves with greasy spot were therefore retained for leaf life assessments.

Data on spider mite infestations and damage, greasy spot infections, and leaf longevity are presented in Table 2. The life of all leaves studied, from full expansion to the abscission date, is depicted in Fig. 3. A total of only four leaves studied were known to have been infested solely by citrus red mites (Table 2). Among 45 leaves known to have been infested by both Texas citrus and citrus red mites, averages of 5.7 (SEM = 1.2) Texas citrus mites and 0.9 (SEM = 0.3) citrus red mites per leaf were observed. Data from leaves with citrus red mites were retained for all analyses, however, since so few citrus red mites were observed, conclusions from the data regarding the influence of mite damage on leaf abscission may only be applicable to Texas citrus mites.

An average leaf life of 399 days was estimated across all leaves ($n = 133$), with averages of 443, 387 and 380 days for the 1996, 1998 and 1999 cohorts, respectively (Table 2). The maximum life expectancy of the leaves appeared to be 18 to 20 months (Fig. 3). An average density of 470 stipples per cm^2 per leaf was estimated across all leaves studied, with averages of 327, 134, and 873 stipples per cm^2 per leaf for the 1996, 1998 and 1999 cohorts, respectively. Within the 1996 cohort, leaf life (Y) decreased as mite damage (X) increased ($Y = 489.7 - 0.144X$; $F = 9.47$, $Pr > F = 0.0041$; $df = 35$), but the relationship between leaf life and damage was statistically weak (e.g., $r^2 = 0.22$) (Fig. 4). No negative relationship was found between leaf life and spider mite damage among leaves of either the 1998 or 1999 cohorts (Fig. 4). Statistical analyses on the combined data from the three cohorts indicated no significant relationship between leaf life and mite damage. The 1996 cohort of leaves was subjected to a hard freeze during January 1997 and, although the leaves followed until abscission did not exhibit any signs of freeze damage, this adverse temperature event may have contributed to the shortened life of leaves with mite damage. Other unknown factors may have contributed to the reduced life of these leaves with mite damage. Al-

though the life of leaves within the 1996 cohort tended to shorten as mite damage increased, the average life of these leaves was longer than the life of leaves of the other two cohorts.

In addition to being subjected to a hard freeze on January 19, 1997, the 1996 cohort of leaves was subjected to near-freezing (1 to 4°C at the weather station) air temperatures for a short period of time one day during April 1997 (no leaf drop occurred during this month), on one day during December 1997 (20% of this cohorts leaves dropped during December), and on several days during January, February and March 1998 (some leaves of this cohort dropped during January and February of 1998, and 25% dropped during March 1998). The 1998 cohort of leaves was subjected to near-freezes on several days during December 1998, February 1999, March 1999, and January 2000 (none of the Fall 1998 cohort leaves dropped during any of these 4 months). The 1999 cohort of leaves was subjected to near-freezes on several days during March 1999 and January 2000 (none of this cohort's leaves dropped during March 1999 and few dropped during January 2000). Overall, near-freezing temperatures for short periods of time did not appear to promote premature abscission of leaves whether they were damaged by mites or not.

The 1998 and 1999 cohorts of leaves were subjected to two notable wind events, the first event during October 1999 associated with Hurricane Irene on 15 -16 October (23.7 and 25.5 mph average daily wind speeds, respectively, at the weather station) and the second event on one day during January 2000 (16.7 mph average daily wind speed at the station). These wind events did not result in an immediate drop of any leaves.

A total of 40 leaf abscission events (21, 11 and 8 for the 1996, 1998 and 1999 cohorts, respectively) were subjected to correlation analyses between leaf life (days after fully expanded to the abscission date), damage (stipple density per leaf) and environmental variables. Only 5 events could be subjected to correlation analyses with greasy spot infections for 1999 data because three leaves of this cohort abscised before greasy spot ratings were made. Analyses over all data indicated that leaf longevity was not correlated with the amount of mite damage to a leaf (Table 3). A significant negative correlation (i.e., $Pr > |r| \leq 0.05$) was found between leaf life and mite damage for the 1996 cohort of leaves ($r = -0.59$, $Pr > |r| = 0.01$) but not for either the 1998 or 1999 cohorts nor over all 3 cohorts combined. A significant negative correlation was found between leaf life and incidence of greasy spot. No significant correlations were found between leaf longevity and any of the environmental variables. Analyses on 'leaf life after attack' indicated that, for the 1996 cohort, life after damage decreased as mite damage increased (Fig. 5). However, the relationship be-

TABLE 2. SPIDER MITE DAMAGE AND GREASY-SPOT INFECTIONS ON LEAVES MONITORED UNTIL ABSCISSION.

Cohort	Mite species observed on leaves	Number of leaves	Mean number (SEM) mites per leaf ^a	Mean (SEM) no. stipples per cm ²	Percent leaves with greasy-spot	Mean (SEM) pct leaf area infected by greasy-spot	Mean (SEM) leaf life (days)
Sep 1996	Texas mites	19	11.0(3.5)	421.7(129.9)	26.3	— ^b	414.4(34.8)
	Citrus red mites	2	0.3(0.1)	8.2(5.6)	50.0	— ^b	445.0(9.0)
	Both mites	11	8.7(3.1) ^c	326.7(85.5)	27.3	— ^b	457.1(45.0)
	Neither mite	4	—	35.6(24.9)	50.0	— ^b	535.5(24.1)
	Over all	36	8.5(2.2)	326.8(76.1)	30.6	— ^b	442.6(23.5)
Oct 1998	Texas mites	11	0.7(0.3)	139.5(46.2)	90.0	1.2 (0.7)	352.6(34.6)
	Citrus red mites	2	0.1(0.04)	116.0(35.5)	50.0	0.3 (0.2)	259.0(0.0)
	Both mites	15	1.0(0.4) ^d	214.6(50.6)	92.9	0.9 (0.4)	392.7(31.2)
	Neither mite	18	—	66.4(22.9)	100.0	2.7 (0.7)	416.2(25.0)
	Over all	46	0.5(.02)	134.4(23.2)	93.2	1.6 (0.4)	386.5(16.8)
Mar 1999	Texas mites	31	12.2(2.0)	869.8(136.9)	4.2	0.1 (0.1)	373.3(7.3)
	Citrus red mites	0	—	—	—	—	—
	Both mites	19	9.9(2.0) ^e	922.8(155.7)	16.4	0.4(0.3)	391.9(12.3)
	Neither mite	1	—	4.1 (-)	0.0	—	336.0(-)
	Over all	51	11.1(1.5)	872.6(102.0)	9.5	0.2 (0.1)	379.5(6.5)
Overall	Texas mites	61	9.7(1.6)	598.6(88.4)	28.3	0.4 (0.2)	382.3(13.1)
	Citrus red mites	4	0.2(0.1)	62.1(28.1)	50.0	0.3 (0.3)	352.0(53.8)
	Both mites	45	6.7(1.3) ^f	541.0(87.6)	44.2	0.7 (0.2)	408.1(16.1)
	Neither mite	23	—	58.3(18.6)	90.0	2.7 (0.4)	433.4(22.4)
	Over all	133	6.7(0.9)	469.5(52.9)	45.9	1.1 (0.2)	399.0(9.2)

^aMean number per leaf over all dates mites were observed on a leaf.
^bGreasy spot infection area on leaves was not estimated, but percentage surface area infected was low.
^cAverages of 12.2 and 0.6 Texas and citrus red mites, respectively, observed per leaf.
^dAverages of 0.7 and 0.4 Texas and citrus red mites, respectively, observed per leaf.
^eAverages of 8.3 and 1.6 Texas and citrus red mites, respectively, observed per leaf.
^fAverages of 5.7 and 0.9 Texas and citrus red mites, respectively, observed per leaf.

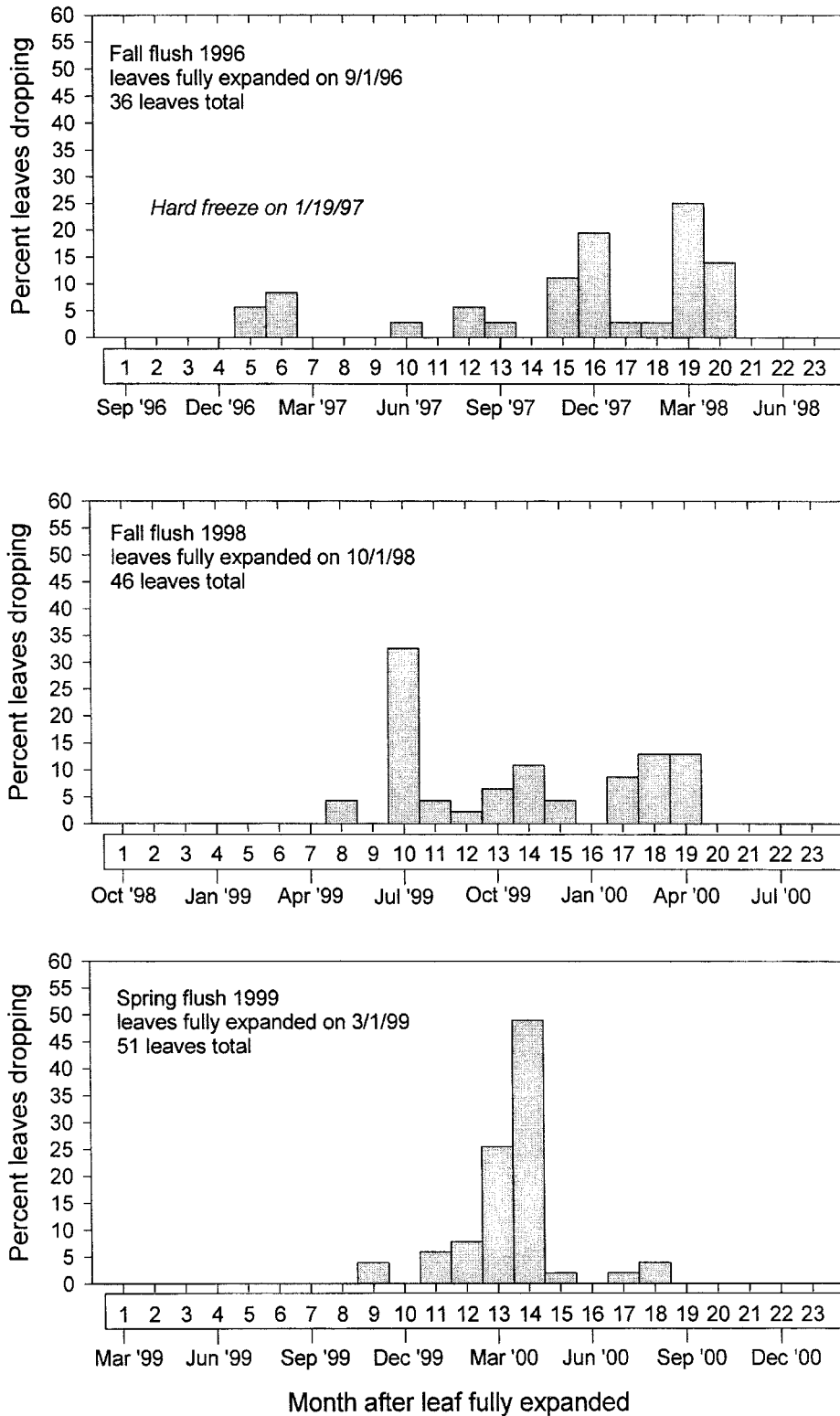


Fig. 3. Percentage abscission of citrus leaves over time.

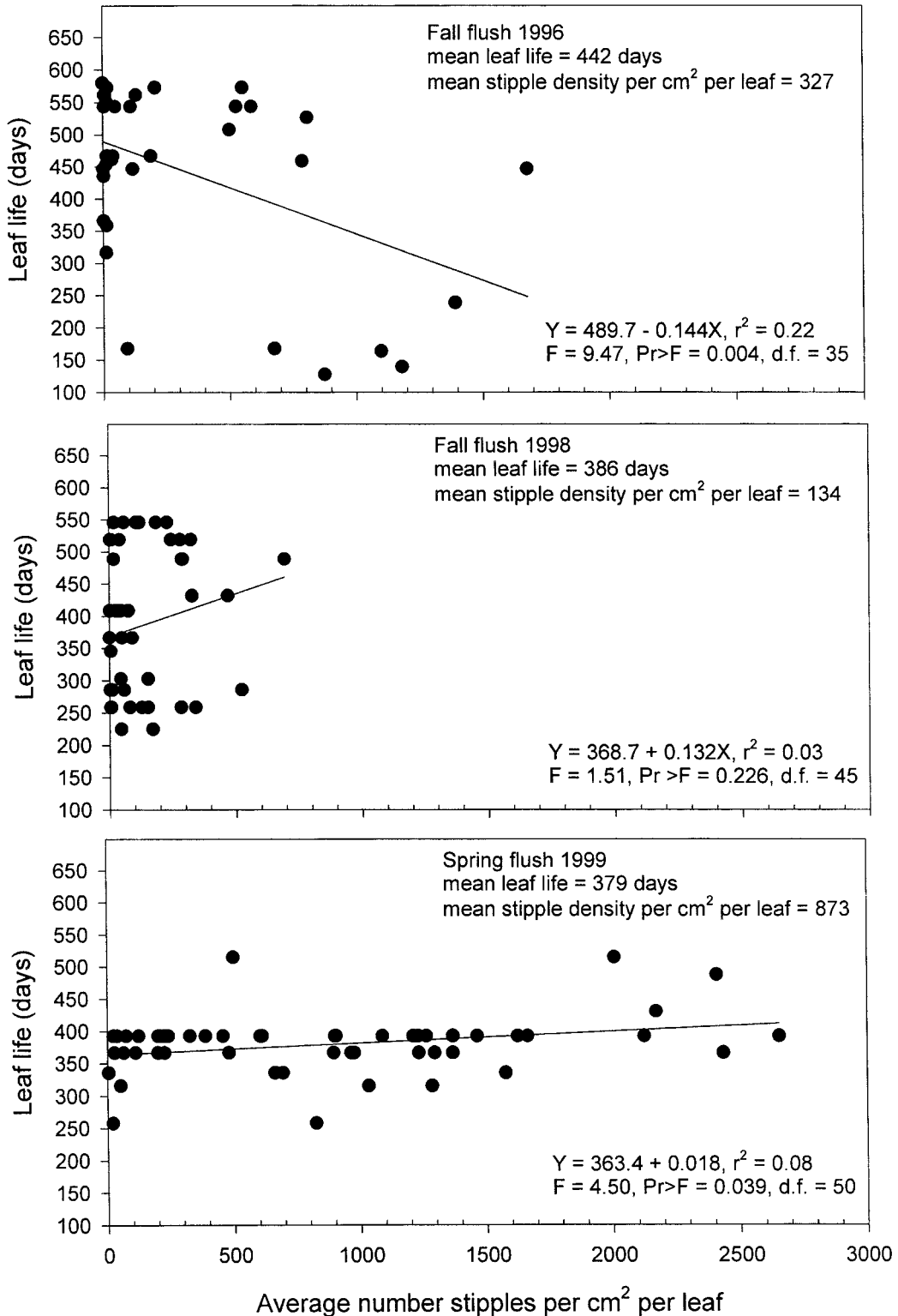


Fig. 4. Relationship between leaf life (days from full flush expansion until abscission) and spider mite damage (mean number of stipples per cm²).

TABLE 3. PEARSON CORRELATION COEFFICIENTS FOR THE RELATIONSHIP BETWEEN LEAF LIFE (DAYS FROM FULL EXPANSION TO DROP) AND SPIDER MITE DAMAGE TO LEAVES (MEAN NUMBER OF STIPPLES PER CM²), INCIDENCE OF GREASY SPOT, AIR TEMPERATURE AND WIND. FOR ENVIRONMENTAL VARIABLES, DATA FROM WITHIN 40 DAYS PRIOR TO DISCOVERING LEAF DROP WERE AVERAGED FOR THE CORRELATION ANALYSES.

Variable	Correlation between leaf life and the indicated variable	
	r	Pr > r
Mean number (#) stipples per cm ²	-0.13 ^a	0.42
Mean percent surface area per leaf with greasy spot	-0.58 ^b	0.02
Mean daily air temperature (°C)	-0.15 ^a	0.37
Mean minimum daily air temperature (°C)	-0.08 ^a	0.63
Mean maximum daily air temperature (°C)	-0.22 ^a	0.17
Mean daily wind (k)	0.21 ^a	0.19
Mean daily evaporation (cm)	0.03 ^a	0.88
Mean daily rainfall (cm)	0.07 ^a	0.66
Mean # stipples per cm ² X mean pct area per leaf with greasy spot	-0.34 ^b	0.20
Mean # stipples per cm ² X mean daily air temperature (°C)	-0.06 ^a	0.71
Mean # stipples per cm ² X mean minimum daily air temperature (°C)	-0.02 ^a	0.91
Mean # stipples per cm ² X mean maximum daily air temperature (°C)	-0.08 ^a	0.61
Mean # stipples per cm ² X mean daily wind (k)	0.04 ^a	0.81
Mean # stipples per cm ² X mean daily evaporation (cm)	-0.02 ^a	0.92
Mean # stipples per cm ² X mean daily rainfall (cm)	0.10 ^a	0.56

^an = 40.

^bn = 16.

tween damage and 'life after attack' for the 1996 leaves was weak ($r^2 = 0.16$), and no significant negative relationship between these variables was found among leaves of either the 1998 or 1999 cohorts. Further, leaves of the 1996 cohort stayed on trees longer after being damaged by mites than did leaves of the other two cohorts.

The longevity of leaves damaged by infestations of the Texas citrus mite, or by infestations of Texas citrus mites in combination with low levels of citrus red mites, was similar regardless of the amount of damage by mites (Fig. 6). The research indicated that, over all leaves evaluated in this study, Texas citrus mite damage promoted little or no premature abscission of citrus leaves. Also, damage resulting from low levels of citrus red mites in combination with infestations of Texas citrus mites did not decrease the longevity of citrus leaves during this study. No conclusions could be made from this study about the effect of extensive citrus red mite injury on leaf longevity. Thompson et al. (1954) observed mesophyll collapse in June following large outbreaks of the citrus red mite in April and May and reported that heavy leaf drop by citrus trees during late winter may sometimes be promoted in Florida by citrus red mite infestations (no data presented). Some scions may be more sensitive to damage by Texas citrus mites than 'Valencia' (e.g., 'Sunburst' mandarin, see Albrigo et al. 1987), and premature leaf abscission associated with mite injury may be more likely to occur in these scions even in an irrigated orchard.

Infestations of Texas citrus mites occur primarily on the upper surface of leaves and, consequently, feeding injury by these mites may occur primarily on this leaf surface. The Texas citrus mite could be a more important pest if it fed on the lower leaf surface. McCoy (1976) found that injury by citrus rust mites (species not indicated) to the lower surface of leaves promoted more mesophyll collapse and leaf drop than damage by the mite to the upper leaf surface. For this same reason, the citrus red mite may be a more important pest than the Texas citrus mite, as this mite infests both the upper and lower leaf surfaces (Jones & Parrella 1984). Rust mite damage to the upper leaf surface may promote less water loss from a leaf than damage to the lower leaf surface because the upper surface lacks stomates, has a highly developed waxy layer, and has a compact palisade parenchyma layer of cells beneath the epidermis that contribute to the prevention of water loss (McCoy 1976). Therefore, the effect on water loss of damage by Texas citrus mites to the upper leaf surface may also be less. Based on research by McCoy (1976), the ultimate cause of premature defoliation of citrus leaves is water loss. Although injury by mites may promote water loss, a good water supply for trees may help prevent premature abscission of leaves damaged by mites. Working in trees with an overhead watering system rarely used during the winter, McCoy (1976) speculated that scant rainfall (0.5 cm per week) promoted premature abscission of leaves

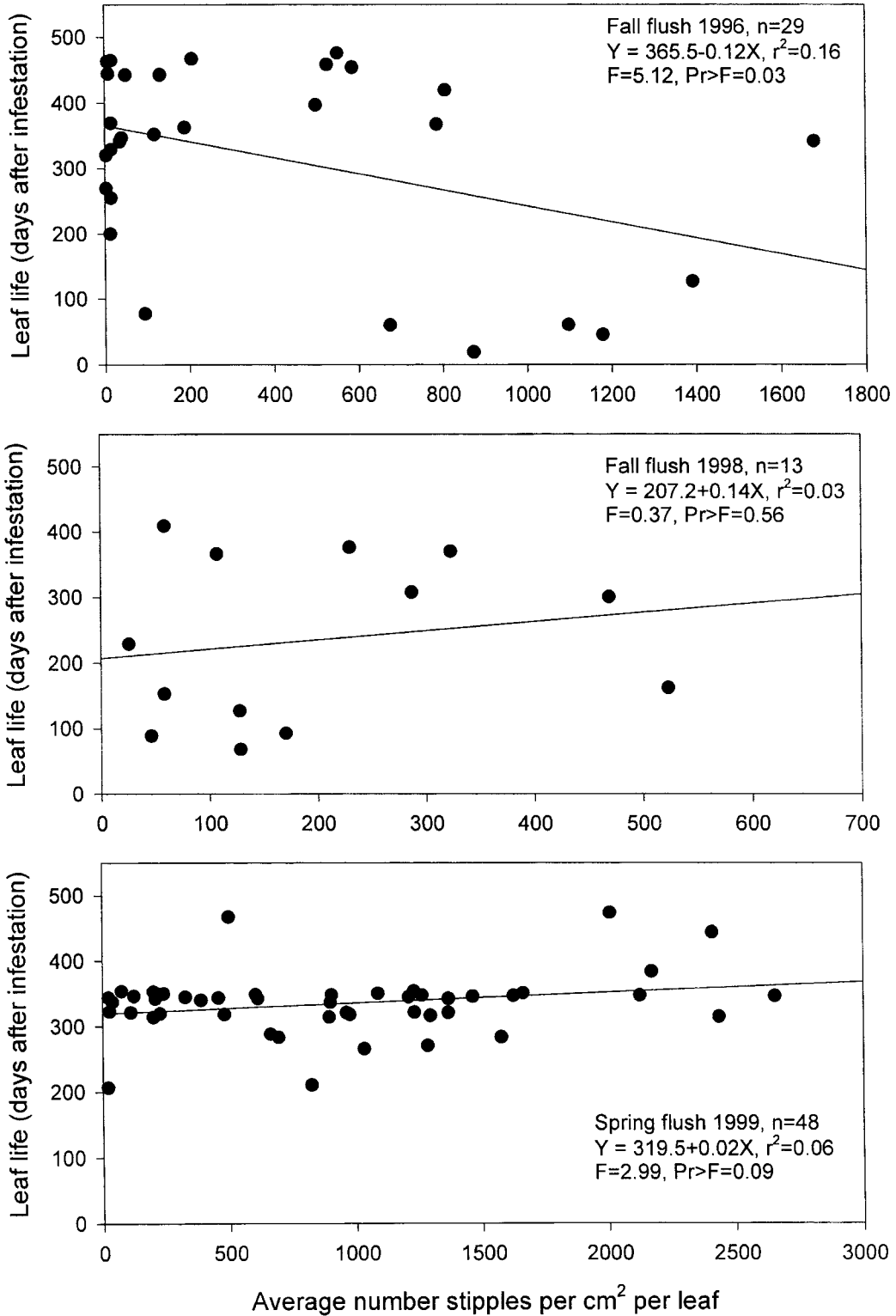


Fig. 5. Relationship between leaf life after mites damaged leaves (days from damage until abscission) and spider mite damage (mean number of stipules per cm²).

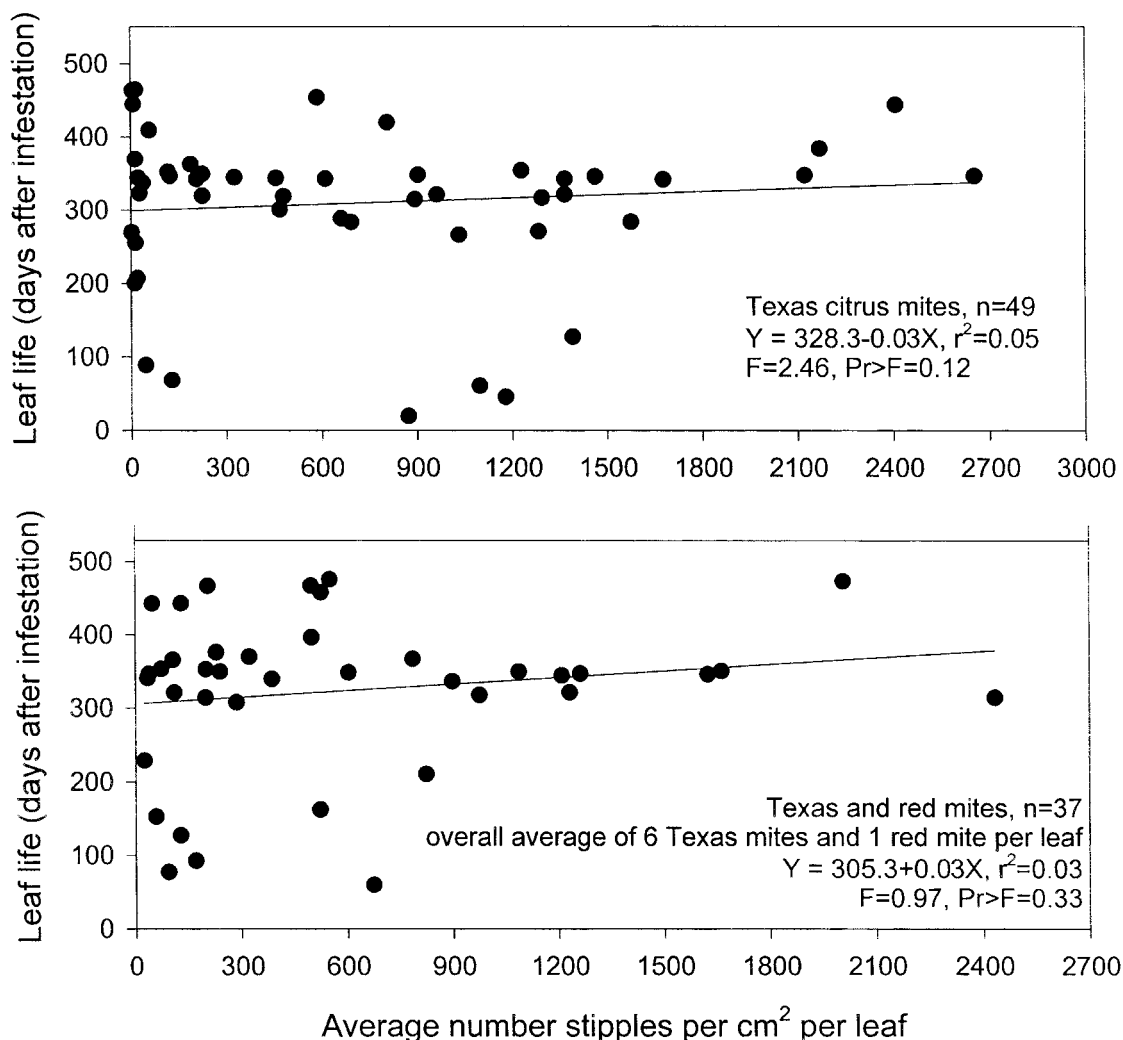


Fig. 6. Leaf life (days) after attack by mites and damage, leaves infested by Texas citrus mites or both Texas citrus and citrus red mites.

damaged by rust mites and that increased water loss from leaves through mite feeding damage to the lower leaf surface may be enough during dry periods to cause leaf abscission. The equivalent of an average of 2.4, 2.5 and 1.2 cm of daily rain in the general vicinity of our study site was associated with periods of time we observed leaf drop among the 1996, 1998 and 1999 cohorts, respectively, considerably more than 0.5 cm per week. But for each cohort, there were one or two 40-day periods during which weekly rainfall at the weather station averaged less than 0.5 cm, and for the 1999 cohort there was one 40-day period during which no rainfall was recorded. Increases in leaf abscission at the study site were not observed during these dry periods. Irrigation during dry periods may have helped prevent premature abscissions of citrus leaves with mite damage

and, therefore, the results of our study may only pertain to irrigated trees.

Healthy citrus leaves can remain on a tree for 2 to 3 years or longer (Kelley & Cummins 1920, Davies & Albrigo 1994). Disease and pest pressures as well as low light levels can significantly reduce leaf longevity (Davies and Albrigo 1994). In a California study, the majority of orange leaves abscised by 17 months and almost all by 24 months (Wallace et al. 1954). Whiteside (1982) speculated that, in the absence of freezes and greasy spot disease, the expected life of citrus leaves in Florida may be 1 to 2 years, similar to what was observed in our study. This supports the conclusion that damage by Texas citrus mites had little influence on leaf longevity under our study conditions. A study of mature 'Valencia' trees indicated that leaf abscission may occur all year long,

with higher abscission rates during late September-November and mid-April to May (Erickson & Brannaman 1960). The greatest abscission rate in citrus normally occurs during the spring flowering period (Erickson 1968). Whiteside (1982) reported that the major seasonal leaf drop from Florida citrus trees begins after the spring growth flush has emerged (usually in March) and may extend until late-May. During our study, abscission of leaves of the spring 1999 cohort generally followed Whiteside's seasonal leaf drop profile while abscission of leaves of the fall 1996 and 1998 cohorts generally did not (Fig. 3).

Based on the study, the amount of physical damage to citrus leaves resulting from an infestation of Texas citrus mites can be projected based on duration of mite densities. If the economic importance of damage by the mite was known, such projections could be useful in making mite control decisions. Whether or not feeding injury by Texas citrus mites to leaves results in economic losses remains to be determined. Although premature leaf abscission could be an important economic problem associated with damage by some pests, our study indicated it was not important with respect to Texas citrus mites in an irrigated citrus orchard.

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