TABLE 3. Within-plant distribution of *Tetranychus cinnabarinus* on cotton, Imperial Valley, 1983

Date	Total no. nodes	Mean no. females	Mainstem node*															
			1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Jun 6	9.53	0.06				X	X	X	X	X	X	X						
Jun 13	11.95	0.01					X	X			X		X	X				
Jun 20	14.07	0.00											X		X			
Jun 27	17.50	0.01	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Jul 4	18.39	0.02	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Jul 11	19.81	0.01	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Jul 18	22.24	0.01				X	X	X			X	X				X		X
Jul 25	23.67	0.04	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Aug 1	25.24	0.03	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Aug 8	25.77	0.05		X	X	X	X	X	X	X	X	X	X		X	X		X
Aug 15	27.39	0.11			X	X	X	X	X	X	X	X	X	X	X	X	X	X
Aug 22	30.30	0.23			X	X	X	X	X		X	X		X	X	X	X	X
Aug 29	30.13	0.37			X	X	X					X	X	X			X	X
Sep 5	32.26	0.57					X	X	X	X			X		X	X		
Sep 12	36.32	1.04				X	X	X	X	X							X	X
Sep 19	38.51	1.94				X	X	X										
Sep 26	38.84	1.21				X	X											
Oct 3	40.64	2.84				X	X											

*X = Node with highest mean mite population and nodes with mean mite populations not significantly different from highest (Duncan's New Multiple Range Test $P < 0.05$).

conditions.

During the 1983 season, mite populations were lower (table 3). The early-season population peak seen in 1982 did not occur in 1983. In late 1983, populations increased to an average of 2.8 per leaf, which was considerably lower than the intensity recorded in 1982.

Because previous analysis showed no effect on within-plant distribution due to chemical treatment, analysis for each date was based on data pooled among treatments (tables 2 and 3). When individual dates were considered, a large range of mainstem node leaves did not significantly differ ($P<0.05$) from the most heavily infested node leaf.

In 1982, sampling in the range of nodes 3 to 5, and in most cases 6, would have always given an accurate indication of mite infestation; this range however, did not occur in 1983. Possibly because of low mite populations in 1983, only node 5 was consistent as the best place to sample for mite infestations. Therefore, throughout both seasons, node 5 was consistent in not significantly differing from the most heavily infested node.

In 1983, early-season mite populations were at times so low that, of the 1,536 leaves sampled weekly, even one mite on one leaf would make that node the most infested, or not significantly different from the most infested nodes; this occurred on June 13, June 20, and July 18. In such cases, leaves at node 5 were sometimes significantly different from the mainstem node leaves with the highest mean mite population. However, when sampling populations to determine the need for chemical control, this situation would not lead to an unacceptable decision, inasmuch as the conclusion not to treat would be reached by sampling node 5 leaves. Therefore, node 5 provides the most reliable choice of sampling unit for detecting damaging levels of *T. cinnabarinus*. Furthermore, this sampling unit is independent of chemical treatment.

The sampling scheme

Using data collected from node 5 leaves, a method for sampling field populations of *T. cinnabarinus* was developed.

A person sampling mites in cotton would use the graph (p. 28) by plotting Tn and n after each sample unit is counted. When the plot falls above the line of the desired precision level, sampling is stopped and the mean density is calculated as $m = Tn/n$. The precision of this estimate will be approximately that of the line on the graph. As the precision level (D_0) increases, the accuracy of the estimate of population intensity decreases and less sampling is required to reach the stop line.

Conclusion

Although binomial and sequential sampling plans for spider mites have been developed for cotton grown in the San Joaquin Valley, the necessary economic thresholds for *T. cinnabarinus* on cotton had not been established, mainly because accurate less time-consuming sampling methods were not available. Using our sampling scheme, researchers can now determine the economic thresholds required to develop a sequential sampling program for spider mites in Imperial Valley cotton. This technique will ultimately generate treatment decisions by cotton growers and pest control advisors

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The citrus red mite, *Panonychus citri*, is the most important mite pest of citrus in California. It attacks leaves and fruit of lemon, orange, and grapefruit. Heavy infestations during times of plant water stress can cause leaf and fruit drop, twig dieback, and even death of large branches. In 1977, the last year for which data are available, estimated loss statewide due to the citrus red mite totaled $15.9 million.

Despite the importance of this mite, little progress has been made in two aspects important to instituting a pest management program: (1) development of sampling plans that allow rapid assessment of population levels and (2) establishment of the relationship between citrus red mite feeding damage and yield reductions. Lack of statistically adequate sampling plans has hindered attempts of pest control advisors to direct control measures on the basis of population levels, because of the time and effort needed to take a census of mite populations. This has also handicapped researchers attempting to quantify the relationship between mite feeding and yield reductions.

We have devised a sampling plan to enable rapid estimation of within-tree mite population levels based on the presence or absence of adult female citrus red mites. This plan is effective in conjunction with a sequential sampling plan to estimate the number of trees necessary to provide an accurate estimate of the areawide population level. Together, the plans will enable researchers and pest control advisors to obtain the maximum amount of information on citrus red mite populations with a minimum outlay of time and effort.

Infested-leaf index

Because citrus trees can have more than 100,000 leaves per tree, an accurate estimate of the mite population within a tree must be determined before an areawide mean can be calculated. Previous work by Dr. J. A. McMurtry, University of California, Riverside, has shown that a greater proportion of the citrus red mite population is found on leaves at the tree's outer periphery. With this in mind, we randomly selected 30 leaves from the tree's outer canopy between 2 and 6 feet from the ground. They were placed in a large wire basket and both leaf surfaces were immediately sprayed with hairspray to stop all mite movement.

The samples were taken to the laboratory, and the number of adult females, adult males, and active (nonquiescent)

Presence-absence sampling of citrus red mite on lemons

Citrus groves suffering water stress induced by Santa Ana winds can be severely damaged by citrus red mite. (Photo courtesy Dr. Robert Brown)

immature stages on each leaf surface was recorded. The values for each tree were collated into total active stages, and the following indices of population density were calculated: proportion of leaves infested with at least one female on the top surface of the leaf, proportion of leaves infested with at least one female on the bottom surface of the leaf, and proportion of leaves infested on either side with at least one adult female. The adult female was chosen because of its relatively large size and lower density, compared with the other stages.

Linear regression was used to determine which of the infestation indices was best related to the total population. The regression was forced through the origin because, if there are no mites, the percentage infestation must also be 0.

Sampling strategies

Sampling, as described here, was conducted on five plots at the following location and times: Two plots of 15-year-old 'Lisbon' lemons at the UC Citrus Research Center (CRC) in Riverside were studied (30 trees sampled in early summer 1982, and 20 trees in late winter 1983). Three plots of 13-year-old 'Eureka' lemons in the Fallbrook area of San Diego County were sampled in summer 1982 (25 trees), early fall 1982 (29 trees), and late fall 1982 (21 trees). Several groves and times were chosen to incorporate grove and seasonal effects on population structure.

To determine the number of trees necessary for sampling, the relationship between the mean number of mites per tree and the variation in the number of mites between trees must be known. To establish this relationship, we used "Taylor's power law," developed by Dr. L. R. Taylor at the Rothamsted Experimental Station in England. We used data from four plots each consisting of 48 trees; each plot was sampled weekly for seven consecutive weeks in southern California between spring 1981 and summer 1982. One plot was at CRC, Riverside, and two were in Ventura County's Saticoy area (all Lisbon lemons); the fourth plot was in San Diego County's Oceanside area (Eureka lemons). Trees were sampled, as described, except that the hairspray was eliminated. A mite-brushing machine was used to count the mean number of mites per leaf for each tree.

Results

The best relationship was found between the total active stages per leaf and the proportion of leaves whose lower

TABLE 1. Constant precision sequential sampling chart for citrus red mite on lemons

No. trees sampled	No. leaves infested	Mean no. of mites per leaf	Cumulative no. of mites/leaf*	Sampling stops if cumulative no. mites/leaf is ≧ †
1	7	1.13	1.13	403.7
2	12	3.33	4.46	73.9
3	10	2.31	6.77	27.4
4	3	0.21	6.98	13.6
5	14	4.53	11.51 ------------→	7.8
6				5.0
7				3.4
8				2.5
9				1.9
10				1.4

$$\text{Mean} = \frac{11.51}{5} = 2.3 \text{ mites/leaf}$$

* To calculate the areawide mean, divide the cumulative number of mites per leaf by the number of trees sampled.
† Fixed level of precision = 0.25.

TABLE 2. Presence-absence intra-tree sampling plan for citrus red mite on lemons

No. leaves infested per 30-leaf sample	Tree mean no. mites/leaf
1	.02
2	.09
3	.21
4	.31
5	.58
6	.83
7	1.13
8	1.48
9	1.87
10	2.31
11	2.80
12	3.33
13	3.90
14	4.53
15	5.20
16	5.91
17	6.68
18	7.48
19	8.34
20	9.24
21	10.19
22	11.18
23	12.22
24	13.31
25	14.44
26	15.62

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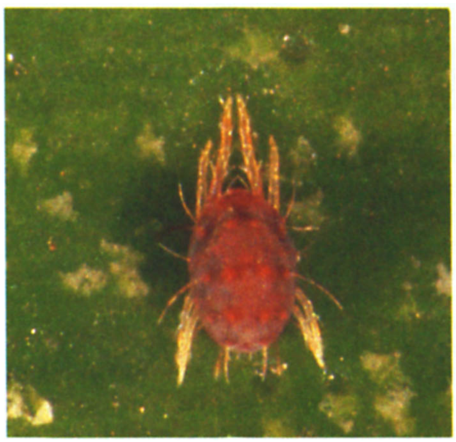
surface was infested with at least one adult female. The equation accounts for 97 percent of the variation in the data: $\hat{Y} = 4.56X$ (Y = square root total number of active stages per leaf, X = proportion of the 30-leaf sample with the lower surface infested with at least one adult female). Use of this relationship enables rapid estimation of the mite population on a per-leaf basis from the proportion of leaves infested. There were no significant differences among plots, indicating that this method can be used throughout the year in different lemon-growing areas and on different lemon varieties.

Analysis of mite populations between trees showed that Taylor's power law accurately predicts the relationship between the mean and variance and accounts for 87 percent of the variation in the data. Again, this relationship held true for all plots, suggesting that the sampling plan was not affected by season, grove, variety, or differences in predator populations. With knowledge of the relationship between the mean and variance provided by Taylor's power law, a constant precision sequential sample can be derived. The constant precision sequential sample, based on the repeatability of an estimate, was used instead of the more common sequential sample that relies on attainment of a predetermined threshold. This was done because the relationship between citrus red mite feeding and yield reductions has not been quantified. This way, the researcher and pest control advisor can determine accurately the mean number of mites per leaf on a particular tree or areawide and decide whether the population level warrants treatment.



The citrus red mite is the most important mite pest of lemon, orange, and grapefruit in California, causing leaf and fruit drop and twig dieback.

The size of the area sampled should be based on the minimum-size area to which a grower would apply treatment. Trees within this area should be randomly selected and a 30-leaf sample should be taken. The leaves sampled should all be fully expanded and collected randomly from the outer periphery of the tree between 2 and 6 feet above the ground. There should be no bias towards sampling trees (or leaves on a tree) with either obviously high or low populations. If there are known "hot spots," they should be monitored separately and not included in the sampling plan.

The sampling table provided works in the following manner. The number of leaves in a 30-leaf sample, with at least one adult female on the lower surface, is placed next to the tree number sampled. In our example (table 1), 7, 12, 10, 3, and 14 leaves were infested on the five separate trees. The mean number of mites per leaf is found in table 2 and entered in column 3 of table 1. The values of the tree means are then added in the fourth column. When the value in the fourth column is greater than or equal to the number in the fifth column, sampling stops and the areawide mean is determined by dividing the value in column 4 by the number of trees sampled as shown in the table.

The time savings possible with the sequential sample is demonstrated by examining four plots consisting of 30 trees each. Using the sequential sample, an average of 7 trees out of a possible 30 trees had to be sampled to estimate accurately the areawide mean. The means obtained in this fashion were all within ± 1 standard error of the mean calculated by sampling all 30 trees in each plot. In addition, because only the presence or absence of adult females on the lower surface must be assessed, time savings over counting each female makes use of these plans even more attractive.

This sampling plan provides a rapid estimate of citrus red mite population levels with minimal effort. However, because it relies on the location of adult females on the leaf, use of this method immediately after application of certain pesticides (such as Morestan), which have been shown to repel citrus red mite, may yield erratic results. The goal of future research will be to determine whether the relationships presented here can be used on orange and grapefruit.

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