Day-degree requirements for development of life stages of San Jose scale*

Stage	Day-degrees Male	Day-degrees Female
Embryo (egg) development	405	421
First instar (crawlers, white caps, black caps)	318	331
Second instar	213	220
Pupal stages — males	95	
Tight cap — females		58
Pre-mating adults	19	20
Average D°/generation	1050	1050

*Lower threshold = 51° F; upper threshold = 90° F. The lower threshold is the temperature below which the insect's development stops; the upper threshold the temperature above which the development rate begins to decrease. The amount of heat between the two thresholds that is needed for the insect to develop from one stage to the next is calculated in day-degrees — the degrees of temperature above a threshold for each day.

alternative to laborious inspection of fruit wood or the even less desirable method of finding infested fruit. After the pheromone trapping system for San Jose scale was introduced, research cooperators in Utah and Michigan produced a phenology model for scale, using a large amount of California data. Early-season (first-flight) trapping data used in conjunction with the model should lead to improved timing of treatments for San Jose scale, particularly against crawlers in late April or early May. Using lower and upper threshold values of 51° and 90° F, respectively, the day-degree requirements as used in the model are given in the table.

The model accommodates three hypothetical types of growth curves for San Jose scale. In the first cycle or generation curve that we might expect to see for San Jose scale, only overwintered black caps (late first-stage scale) would be producing new crawlers in the spring. This is the so-called early curve. Calculations show that, on the average, 225 D° were required for scale development from January 1 to the point at which first males were observed in pheromone traps, with an early population curve. However, the model projects that 274 D° are required, on the average. Similarly, development from first male flight in the spring until first crawlers were observed required approximately 323 D°. The model projects a day-degree requirement of 372°. Therefore, in the hypothetical early curve we see a rather wide divergence between observed events (first male, first crawler) and what the model predicts for these same events.

When we evaluated a so-called mid-curve, in which all stages (black caps, mature mated, and unmated females) of San Jose scale would be expected to survive the winter and produce individuals in the spring generation, we found a much closer correlation between observed events and what the model projected should happen. This was true for both time periods: from January 1 until first males were trapped, and from first males trapped until first crawlers were observed.

When the third hypothetical generation or growth curve was evaluated, in which only overwintered mature females would be expected to survive, we again found considerable variation between observed events in the field and those the model projected, particularly in the D° accumulations from first males until first crawlers appeared in the field. From a practical standpoint for California, the early or mid-curves would be the most realistic with regard to scale development.

In considering how the San Jose scale model can be used in pest management programs, application of chemical controls for scale crawlers in May would be one of the most critical areas to evaluate. Based on model projections, we would anticipate crawler emergence approximately 400 D° after the first males in any given generation have been collected in pheromone traps. As in the case with oriental fruit moth egg hatch, however, we suspect that spray timings at the very beginning of crawler emergence probably would not be optimum, but instead should be delayed for several days. This means that we could add approximately 100 to 150 D° to the crawler emergence curve beyond first crawler and spray at that point.

This approach to spray timing for San Jose scale needs to be verified with field plot work. However, as in the case with the oriental fruit moth model, we still feel that the model is sufficiently accurate to begin using it under a variety of pest control advisor and grower applications to challenge its validity and detect the weak points that undoubtedly exist.

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Field data indicate that natural populations of the two-spotted spider mite, *Tetranychus urticae* Koch, can decrease strawberry yields by 10 to 15 percent at various harvest periods during the season. Since 1964, entomologists at University of California, Riverside, have been conducting research to develop a practical program for managing the mite on summer- and winter-planted strawberries in southern California, studying the efficacy of predatory mites and selective miticides, as well as the injury caused by spider mite feeding. Effective control measures are being sought for incorporation into integrated programs in commercial strawberry plantings.

Photosynthesis and productivity

In California, commercial strawberry varieties produce fruit continuously throughout the winter and spring. Fruit filling and enlargement occurs when plant canopies are established and after the plant's initial storage reserves have been utilized. Carbohydrates and other materials migrating into developing berries originate predominantly in chlorophyllous tissues, and the relative quantity of nutrients available primarily depends on the rate of photosynthesis, in which sugars (photosynthates) are produced by the binding of carbon and water molecules into carbon-based chains. Photosynthesis occurs within the chloroplasts of leaf cells and is powered by solar energy absorbed by the pigment chlorophyll. The required water is brought up from the roots through the process of translocation. The second component, carbon dioxide, enters the leaf tissue through the stomata — small closable apertures in the epidermis. While stomata facilitate movement of carbon dioxide into the leaf, they also allow large quantities of water to be lost by evaporation to the atmosphere — a process known as transpiration. When transpiration rates exceed the rate of water uptake by the roots, the plant wilts.

Photosynthates are required for respiration and growth of vegetative structures (leaves, stems and roots) as well as for fruit production. By continuously producing new foliage, the plant replaces leaves that may die within several weeks after development.

Feeding by two-spotted spider mite causes plant stress, which detrimentally affects photosynthesis, transpiration, fruit production, and vegetative growth. Reductions in photosynthesis rates from mite-caused stress decrease berry production (fig. 1). The amount of stress and time of the season when stress occurs largely determine the extent of injury to the strawberry plant. Ideally,

Spider mites can reduce strawberry yields

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Strawberry plants are particularly susceptible to rapid spider mite buildup early in the season. The resulting stress reduces quantity and quality of harvestable fruit.

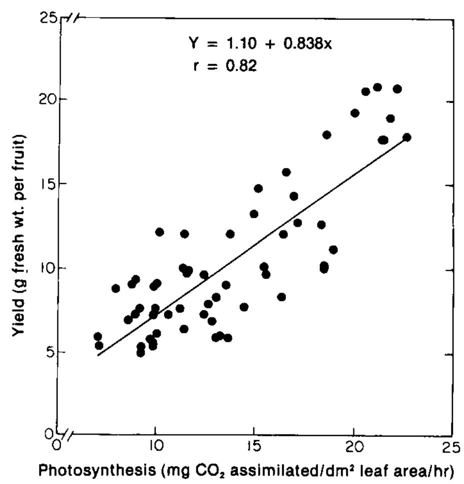

Fig. 1. Strawberry yield as related to photosynthesis rates of mite-stressed plants.

growers on a sound pest management program, using an economic threshold, would permit some reduction in photosynthesis, but would begin control measures before fruit production is affected if spider mite populations continue to increase.

Summer- and winter-planted berries

Studies conducted at the University of California's South Coast Field Station, Santa Ana, have shown that the intensity of strawberry plant responses to spider mite feeding stress varies, depending on crop maturity and planting time. Small-plot experiments on summer-planted berries revealed that high spider mite populations late in the season significantly reduced photosynthesis and transpiration rates from infested plants (fig. 2). Photosynthesis and transpiration rates of plants artificially inoculated with high early-season mite infestations decreased four weeks earlier than those of plants with high late-season populations.

Injury caused by high early-season populations was more apparent both physiologically and visually in the field. Distorted, stunted plant growth was evident, and many mature leaves appeared bronzed and dry on their lower surfaces.

Reduced physiological activity persists in plants with high spider mite populations unless mite densities decline. After mite-caused stress decreases, new foliage is rapidly initiated. Although such leaves may be small and chlorotic, their photosynthesis rates are comparable to those in older leaves from plants on which mite populations have been suppressed. This host recovery phenomenon does not occur on plants with low, suppressed mite populations where new foliage is produced uniformly throughout the season.

Stress-inducing mite population levels significantly influence the number and size of fruit produced per plant (see table). Decreases in fruit number were greatest in plants with high early-season populations. Early-season mite populations caused earlier and

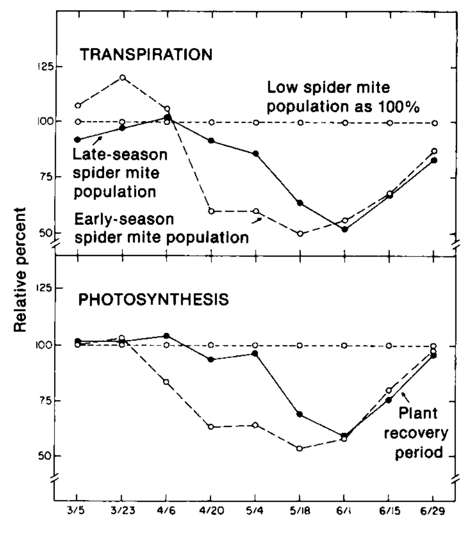

Fig. 2. Seasonal transpiration and photosynthesis trends of summer-planted strawberries stressed by two-spotted spider mites. Data are plant means, expressed as percentage of rates obtained from nonstressed plants, Irvine, California, 1979.

Summary of monthly yields in strawberry plantings subjected to low, high early-season,* and high late-season populations of two-spotted spider mite, Orange County, California, 1979

Harvest period†	Number of fruit per plant			Fruit size§			Total yield per plant		
	Low	Early	Late	Low	Early	Late	Low	Early	Late
				g	g	g	g	g	g
April Mean/week	7.7	8.8	8.5	17.0	17.3	17.1	122.6	127.3	132.2
May Mean/week	10.7a	9.5b	10.5ab	10.7a	9.6b	10.4a	119.4a	96.3b	114.1a
June Mean/week	5.7a	4.1c	4.9b	7.1a	6.7b	6.4ab	40.1a	27.9b	32.5ab
Season totals	107.2	92.3	106.2	11.7	11.1	10.9	1,212.8a	1,102.6b	1,229.9a

*Plants inoculated March 1, 1979, with 20 gravid female *Tetranychus urticae* Koch per plant.
†Mean of four replicate plots of 30 plants. Means in horizontal rows without letters or followed by the same letter are not significantly different, Duncan's multiple range test, P = <0.05.
§Mean fresh weight (grams) per fruit.

more pronounced effects on berry size than naturally occurring, later season populations.

Fruit number and size determine total yield, and changes in either component can influence the overall yield per plant. Plants naturally infested with high mite populations showed a reduction in total yield beginning in mid-May. Those stressed by early-season spider mite populations showed significant reductions in total yield one week earlier. Once they began, total yield reductions persisted throughout the remaining season. Before reductions, all stressed plants exhibited increases in total yield weight because of the increase in fruit number harvested early in the season.

In small-plot experiments, responses of winter-planted berries to spider mite stress were similar to those of summer-planted berries. Photosynthesis and transpiration rates were as much as 50 percent lower in plants wth high late-season populations than in plants where mites were suppressed (fig. 3a). Photosynthesis and transpiration reductions in stressed plants were accompanied by decreases in fruit weight, number, and size, in that order (fig. 3b). Reductions in photosynthesis caused by spider mite feeding also affected the production of flowers and new leaves (fig. 3c).

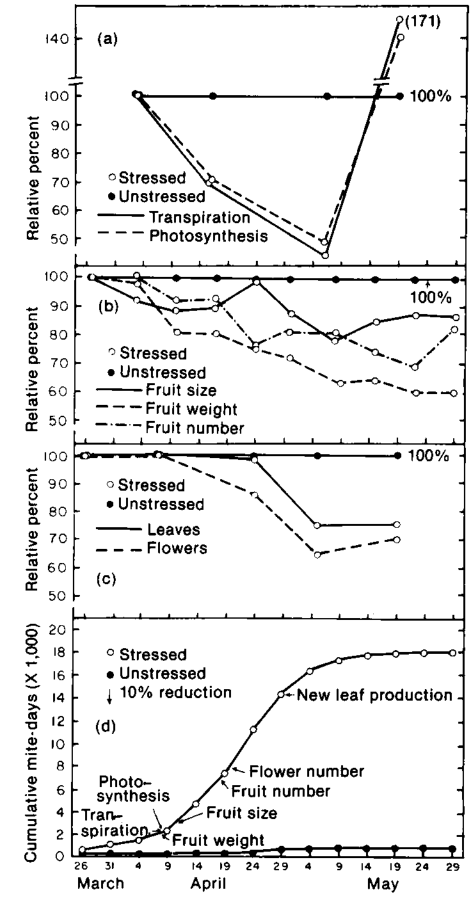

Fig. 3. Plant responses to mite-caused stress (a, b, c), and cumulative mite-days from stressed and unstressed plants with 10 percent reductions in physiological and growth processes chronologically indicated. (d).

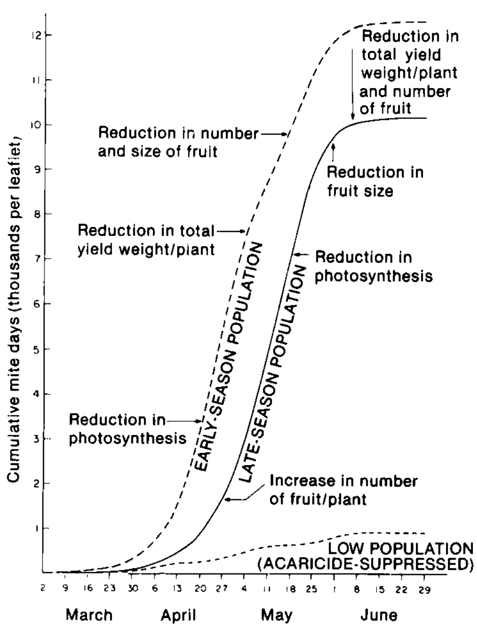

Fig. 4. Sequenced mite-day model of early- and late-season spider mite buildups and responses of summer-planted strawberries.

Sequenced mite-day models

Converting weekly spider mite densities to accumulated mite-days (one mite-day is equivalent to one mite feeding for one day) makes it possible to express both density and duration of a spider mite infestation as one value. The sequenced mite-day model based on data from summer-planted berries (fig. 4) includes only statistically significant events occurring at pertinent points on the population curves. High early-season populations of the two-spotted spider mite significantly reduced photosynthesis at 3,200 mite-days per leaflet, total yield per plant at 7,600 mite-days per leaflet, and each yield component at 9,900 mite-days per leaflet.

Although small increases in number of fruit were recorded before the reduction in photosynthesis in early-season-stressed plants, this trend was significant at 1,700 mite-days on plants subjected to a more gradual mite-day accumulation. Photosynthesis in plants exposed to high mite-day levels later in the season significantly declined only after 7,100 mite-days. Yield was subsequently reduced after 9,800 mite-days per leaflet.

A similar sequenced mite-day model based on data from winter-planted berries (fig. 3d) includes pertinent points on the population curves where physiological, yield, and growth parameters were each reduced 10 percent. First, photosynthesis, transpiration, and fruit weight from stressed plants decreased, followed by fruit size, fruit number, flower initiation, and new leaf development.

Summary

Photosynthesis was negatively correlated with accumulated mite-days/leaflet. Under the resulting high levels of stress, reductions in quantity and quality of harvestable fruit occurred. Further stress reduced the development of flowers and new leaves.

Impaired carbon dioxide uptake (indicated by reduced transpiration rates) and fixation (synthesis of carbon-based sugars) reduce the availability of simple sugars and other photosynthates required in the development of reproductive and vegetative plant structures. If mite-day accumulations are gradual, the plant compensates for a period of time before economic injury results. Conversely, when high levels of plant stress develop rapidly, photosynthesis and productivity are severely restricted.

Although plants may begin to produce new foliage during this time, the diminished supply of photosynthates from heavily infested leaves and the strong competition for these products by developing fruit may reduce the compensation capacity of plants damaged early in the season. Additionally, younger plants have less leaf area to withstand the injury and reduced photosynthates and productivity occur at much lower mite-day levels, when compared with plants that have gradually increasing infestations of spider mites occurring after maturation is more advanced. Plants that undergo a gradual mite-day buildup and late-season stress show more than twice the tolerance to the same mite-day levels that caused injury early in the season.

Because of plants' susceptibility to spider mite injury early in the season, the necessity of frequent sampling and pesticide use would be greatest during this time. Early-season control would allow for the production of maximum leaf area. A healthy, well-established plant canopy with large leaf area not only is more tolerant to spider mite stress, but also enables plants to yield higher quality fruit. When plants are mature, a tolerant approach to spider mite infestations is possible. The use of biological control agents (predatory mites) may be effective in mid- to late-season, when economic risk is minimal.

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