Effect of *Trialeurodes vaporariorum* (Homoptera: Aleyrodidae) on Yield of Fresh Market Tomatoes

M. W. JOHNSON, L. C. CAPRIO,[1] J. A. COUGHLIN,[2] B. E. TABASHNIK, J. A. ROSENHEIM,[3] AND S. C. WELTER[4]

Department of Entomology, University of Hawaii at Manoa,
Honolulu, HI 96822

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ABSTRACT Effect of the feeding of immature greenhouse whitefly, *Trialeurodes vaporariorum* (Westwood), and sooty mold contamination on tomato production was determined using small field plots. Total and grade-A fruit weights harvested were correlated negatively with cumulative immature greenhouse whitefly days (=pest-days). Effects of *T. vaporariorum* feeding on tomato yield were influenced by environmental factors. Percentages of fruit contaminated with sooty mold were correlated positively with cumulative immature greenhouse whitefly days. Cumulative immature greenhouse whitefly days were correlated positively with peak immature whitefly densities during the growth cycle of the plant. Results suggest that tomatoes grown in Hawaii may incur a 5% yield loss in grade-A fruit at about greenhouse whitefly levels as low as 70 cumulative greenhouse whitefly days per cm^2 tomato leaflet (=a peak density of 0.7 immature greenhouse whitefly per cm^2 tomato leaflet per day) due primarily to the consumption of plant assimilates by *T. vaporariorum*. Compared with direct greenhouse whitefly feeding, contamination of fruit with sooty mold was less important with respect to reducing overall crop yields. A 5% reduction in grade-A fruit due to sooty mold contamination was estimated at ≈300 cumulative greenhouse whitefly days per cm^2 tomato leaflet (=a peak density of 8.3 immature greenhouse whitefly per cm^2 tomato leaflet).

KEY WORDS Greenhouse whitefly, *Trialeurodes vaporariorum*, tomato

FRESH MARKET TOMATOES are one of Hawaii's most important vegetable crops; their value was ≈3 million dollars in 1989 based on production from 101 ha (Anonymous 1990). Like many of Hawaii's vegetable crops, tomatoes are infested by numerous pests (Mau 1983) that cause direct and indirect damage. Direct pests of the fruit include the tomato fruitworm, *Helicoverpa zea* (Boddie); tomato pinworm, *Keiferia lycopersicella* (Walsingham); beet armyworm, *Spodoptera exigua* (Hübner); melon fly, *Dacus cucurbitae* Coquillett; and southern green stinkbug, *Nezara viridula* (L.). Indirect pests include *Liriomyza* leafminers; western flower thrips, *Frankliniella occidentalis* (Pergande); sweetpotato whitefly, *Bemisia tabaci* (Gennadius); and greenhouse whitefly, *Trialeurodes vaporariorum* (Westwood). Of these indirect pests, greenhouse whitefly is probably of the greatest significance because of its frequent infestation of tomato and other vegetable crops across the state (M.W.J., unpublished data). Many growers routinely apply pesticides to suppress greenhouse whitefly populations. These applications can lead to population increases in greenhouse whitefly as well as the *Liriomyza* leafminers (M.W.J., unpublished data). Frequently, neighboring vegetable crops are inundated by dispersing greenhouse whitefly adults following the senescence or decline of an infested planting.

Injury to tomato plants by *T. vaporariorum* is caused by phloem feeding of immatures and adults on tomato foliage and the growth of sooty mold in honeydew produced during greenhouse whitefly feeding (Lloyd 1922, Hussey et al. 1969, Lindquist 1972, Byrne et al. 1990). Detailed studies quantifying the yield response of tomatoes to the direct effects of *T. vaporariorum* feeding are lacking (Byrne et al. 1990). Lindquist et al. (1972) reported reduced yields of greenhouse grown tomatoes due to greenhouse whitefly feeding but did not relate whitefly densities to losses in tomato yield. They suggested that *T. vaporariorum* populations be maintained at low levels throughout the crop production cycle to

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[1] Current address: Department of Entomological Sciences, University of California, Berkeley, CA 94720.

[2] Current address: Department of Environmental Biochemistry, University of Hawaii at Manoa, Honolulu, HI 96822.

[3] Current address: Department of Entomology, University of California, Davis, CA 95616.

[4] Department of Entomological Sciences, University of California, Berkeley, CA 94720.

produce maximum yields but did not quantify the greenhouse whitefly level. Based on Lloyd (1922) and Hussey et al. (1969), Byrne et al. (1990) concluded that economic losses resulting from growth of sooty mold on honeydew on vegetables was the greatest impact caused by *T. vaporariorum* on those crops. Low incidence of sooty mold can be tolerated, but must be washed off fruit before shipment to market. Fruit heavily covered with sooty mold are usually unacceptable for sale. Hussey et al. (1969) reported that a mean of ≈25 greenhouse whitefly nymphs per cm^2 of tomato apical leaflet resulted in ≈30% of the total fruit harvested contaminated with sooty mold growth. They suggested that greenhouse whitefly populations be limited to ≈7 nymphs per cm^2 of tomato apical leaflet to avoid economically significant sooty mold contamination on fruit. Physiological studies indicate that healthy, unstressed tomato plants produce more photosynthates than needed for growth and fruit production (Tanaka & Fujita 1974; Tanaka et al. 1974a,b). Thus, removal of plant assimilates by greenhouse whitefly feeding may not effect fruit weight or size significantly.

Densities at which indirect pests cause significant damage depend on several parameters, including the specific type of injury induced, the plant's response to the injury, the change in pest densities over time, and environmental conditions (Sances et al. 1982; Welter 1989; Welter et al. 1984, 1989, 1990; Rosenheim et al. 1990). Field-grown plantings may respond differently to pest injury than greenhouse crops. The impact of a pest is not necessarily correlated with the weekly densities or seasonal average density observed in a planting. Although pest density indicates a level of pest impact, it does not account for the length of time the pest density remains at a given level. Ruppel (1983) suggested the use of "insect-days" to better quantify this impact. One insect day (or pest day) is equivalent to one individual member of a given pest species feeding for 1 d.

Quantification of the response of fresh market tomatoes to injury caused by greenhouse whitefly would enable estimation of the maximum acceptable levels of *T. vaporariorum* infestation. Based on this information, economic injury levels and density treatment levels could be established along with consultant or grower-usable sampling programs. Additionally, the required effectiveness of biological or cultural controls could be expressed in terms of maximum allowable pest population levels. The objective of this study was to quantify the effect of immature greenhouse whitefly feeding and sooty mold contamination on production of field grown fresh market tomatoes in Hawaii.

Materials and Methods

Two field studies were conducted at the University of Hawaii Branch Experiment Station at Poamoho, Oahu, HI, during July–October 1987 and April–July 1988, respectively. For each study, 16 small field plots (36.1 m rows each) containing 60 tomato plants each (=2,352 plants per hectare) were established in a randomized complete-block design. Plants (Celebrity hybrid, Harris Moran Seed, Rochester, NY) were transplanted on 20 July 1987 and 28 March 1988. Plants were grown according to local practices (irrigation, fertilizer, staking, etc.), which included pruning field-grown plants in a manner similar to pruning of greenhouse-grown tomatoes. During the studies, daily high and low temperatures and daily total solar radiation (LI-COR LI-200S Pyranometer Sensor and LI-500 Integrator, LI-COR, Lincoln, NE) were recorded.

Each study included four experimental treatments comprising different levels of immature greenhouse whitefly: near zero, low, medium, and high densities. Whitefly densities were manipulated by the application of insecticides at various times during the crop cycle. The near-zero density treatment received weekly insecticide applications to maintain the lowest whitefly densities possible. The high-density treatment never received insecticide treatments directed at *T. vaporariorum*, so that pest numbers would not be suppressed. Low- and medium-density treatments received intermediate numbers of insecticide applications to establish low to moderate whitefly populations. To reduce the impact of foliage and fruit-feeding arthropods other than greenhouse whitefly on fruit production, these species were maintained at zero to low densities in all experimental plots by applications of selective insecticides.

In 1987, permethrin (Ambush 2 EC [emulsifiable concentrate], 0.224 kg (AI)/ha; ICI Americas, Wilmington, DE) and oxamyl (Vydate 2L [liquid], 1.12 kg (AI)/ha; E. I. DuPont de Nemours, Wilmington, DE) were applied to the near-zero treatment on 7, 14, 21, and 28 August; 4, 11, 17, and 24 September; and 2, 9, and 16 October to suppress greenhouse whitefly. Permethrin and oxamyl applications were made in the low-density plots on 28 August; 4 and 11 September; and 9 and 16 October and in the medium-density plots on 2 October. Avermectin (Avid 0.15 EC, 0.022 mg (AI)/ha; MSD AGVET, Rahway, NJ) was applied to all plots on 28 August and 4 September to reduce live *Liriomyza* larval densities to fewer than two per tomato leaflet. Malathion (5 EC, 1.4 kg AI/ha; Platte Chemical, Fremont, NE) was applied to all plots on 28 August and 4 September to suppress green peach aphid, *Myzus persicae* (Sulzer).

In 1988, permethrin was applied to the near-zero plots on 5, 15, 22, and 29 April; 5, 13, 20, and

27 May; 3, 10, 16; and 24 June; and 1 July to suppress greenhouse whitefly. Permethrin applications to low-density and medium-density plots were initiated on 13 and 20 May, respectively, and continued until study termination with application dates identical to those dates of application for the near-zero treatment. Avermectin was applied to all plots to suppress *Liriomyza* spp. and *F. occidentalis* populations on 8, 15, and 20 April; 10, 16, and 24 June; and 1 July. Methomyl (Lannate 1.8 L, 1 kg (AI)/ha; E. I. DuPont de Nemours) was applied to all plots weekly starting on 13 May to suppress lepidopterous pests. Pesticides were applied with a CO_2-charged boom sprayer (one to four nozzles on a vertical boom) that delivered water at 76–153 liters/ha at a pressure of 5.62 kg/cm^2 (=80 psi). Volume was increased to maintain thorough coverage as plants grew.

Thirty randomly selected mature leaflets were collected weekly from each plot beginning on 4 August 1987 and 18 April 1988, and continued until 26 October 1987 and 4 July 1988, respectively. Insect counts were made using a dissecting microscope. For each leaflet, numbers of *T. vaporariorum* nymphs and pupae found within four squares (1 cm^2 each) (randomly printed on an acetate film laid over the leaflet) were recorded and mean densities calculated. Live *Liriomyza* leafminers, immature and adult *Thrips* spp., and active spider mites found on the whole leaflets were recorded and mean densities calculated. Leaflets areas were recorded with a LI-COR portable leaf area meter (Model 3000, LI-COR, Lincoln, NE). Cumulative immature (nymphs & pupae) greenhouse whitefly days per cm^2 tomato leaflet were calculated for each small plot according to the methods of Ruppel (1983).

In each study, all small plots were harvested once weekly for 6 wk beginning with the initial harvest on 23 September 1987 and 1 June 1988, respectively. Fruit were picked when slightly pink to red in color. Fruit were categorized with respect to size: <5.1-cm diameter, nonmarketable; 5.1–6.3 cm diameter, "grade B"; and >6.3 cm diameter, "grade A." Fruit in each size category were weighed, counted and examined for insect and other types of damage (e.g., sooty mold and physiological abnormalities). Percentages of fruit contaminated with sooty mold were tabulated for each small plot. Numbers of plants per plot were recorded weekly during harvest. To account for the few plants lost (<5 plants per plot) in each plot to disease or other problems during the crop cycle, final harvest data per plot were based on mean fruit production per tomato plant adjusted to 60 plants per plot. Fruit weights per plot were expressed as kg/ha.

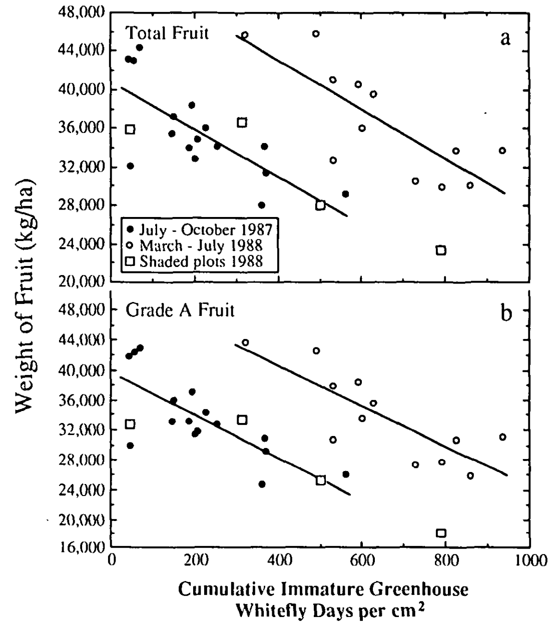

Fig. 1. Reductions in tomato yield weight associated with cumulative greenhouse whitefly days for (a) total fruit and (b) grade-A fruit in the 1987 and 1988 studies.

Statistical Analysis. Given variable rates of establishment of immigrating *T. vaporariorum* adults among experimental plots (edge effect), analysis of variance could not be used to determine differences among the treatments. Thus, impact of immature greenhouse whitefly on fruit yield was analyzed by regressing the weights of total fruit and grade-A fruit harvested per small plot against cumulative immature greenhouse whitefly days per plot (Statview 512+, Abacus Concepts, Berkeley, CA). Percentage of fruit contaminated with sooty mold was regressed against cumulative immature greenhouse whitefly days per plot. Regression analysis was also used to determine the relationship between cumulative immature greenhouse whitefly days and peak immature greenhouse whitefly densities recorded in small plots during the crop cycle. Mean daily high and low temperatures and daily total solar radiation recorded during the two studies were compared using a one-tailed *t*-test ($P < 0.001$). Analysis of covariance was performed (SAS Institute 1985) to evaluate jointly the effects of cumulative immature greenhouse whitefly days (covariate) and year (class variable), and percentage sooty mold contamination (covariate) and year (class variable). The year × greenhouse whitefly days interaction term and year × percentage sooty mold contamination interaction term were examined to test for homogeneity of slopes.

Results

Direct Impact of Greenhouse Whitefly. Fruit production in 1987 ranged from ≈28,000 to 44,400 kg/ha for total fruit (Fig. 1a) and from

≈24,600 to 43,000 kg/ha for grade-A fruit (Fig. 1b). A significant negative regression was found between cumulative immature greenhouse whitefly days and weight of total fruit ($y = 40{,}789 - 24.432x$; $r^2 = 0.530$; df = 14; $P < 0.01$) and grade A-fruit ($y = 39{,}784 - 28.710x$; $r^2 = 0.573$; df = 14; $P < 0.01$). Fruit production in 1988 ranged from ≈23,400 to 45,800 kg/ha for total fruit (Fig. 1a) and from ≈18,000 to 43,600 kg/ha for grade-A fruit (Fig. 1b). Yield data from four small plots were not used in the regression analyses for 1988 because a shadow cast by a windbreak adjacent to the field in 1988 dramatically reduced fruit production in those plots. Using 1988 data from the other 12 small plots, a significant negative correlation was found between yield and cumulative immature greenhouse whitefly days (total fruit: $y = 53{,}227 - 25.457x$; $r^2 = 0.616$; df = 10; $P < 0.01$; grade-A fruit: $y = 51{,}421 - 27.036x$; $r^2 = 0.658$; df = 10; $P < 0.01$).

Analysis of covariance (ANCOVA) showed no significant heterogeneity between years in slope (± SEM) of the yield response for total fruit (1987: −24.4 ± 6.1; 1988: − 25.4 ± 6.4; $P = 0.91$) or grade-A fruit (1987: −28.7 ± 6.6; 1988: −27.0 ± 6.2; $P = 0.85$). ANCOVA also showed that for a given value for cumulative immature greenhouse whitefly days, yield was significantly higher for 1988 than 1987 (total fruit: $F_{1,25} = 27.1$, $P < 0.0001$; grade-A fruit: $F_{1,25} = 27.0$, $P < 0.0001$). Intercepts for total and grade-A fruit in 1987 were 40,789 and 39,784 kg/ha, respectively, compared with total and grade-A fruit in 1988 of 53,227 and 51,421 kg/ha, respectively (Fig. 1). ANCOVA models which included effects of year and cumulative immature greenhouse whitefly days explained 58% of the variation in total fruit weight and 61% of the variation in grade-A fruit weight.

Reductions Caused by Sooty Mold. Data from both years were pooled because ANCOVA showed no significant heterogeneity between years in slope of the regression of cumulative immature greenhouse whitefly days per cm^2 with respect to sooty mold contamination for total fruit ($P = 0.25$) or grade-A fruit ($P = 0.79$) or the intercepts for total fruit ($P = 0.61$) or grade-A fruit ($P = 0.37$). For pooled data, significant regressions were found between cumulative immature greenhouse whitefly days per cm^2 and percentage sooty mold contaminated total fruit ($y = 0.01x - 0.98$; $r^2 = 0.71$; df = 26; $P < 0.0001$) (Fig. 2a) and grade A fruit ($y = 0.018x - 0.12$; $r^2 = 0.53$; df = 26; $P < 0.0001$) (Fig. 2b). Additionally, a significant regression (Fig. 3) was found between sooty mold on total fruit and sooty mold on grade-A fruit ($y = 1.33 + 1.92x$; $r^2 = 0.84$; df = 26; $P < 0.001$). The slope of the regression was significantly greater than 1.0 ($t = 11.5$, $P < 0.0001$), indicating that low percentages of total fruit contaminated with sooty mold actually translate into higher percentages of grade-A fruit with sooty mold. This may be caused by the proportionately larger surface area per individual grade-A fruit versus total fruit.

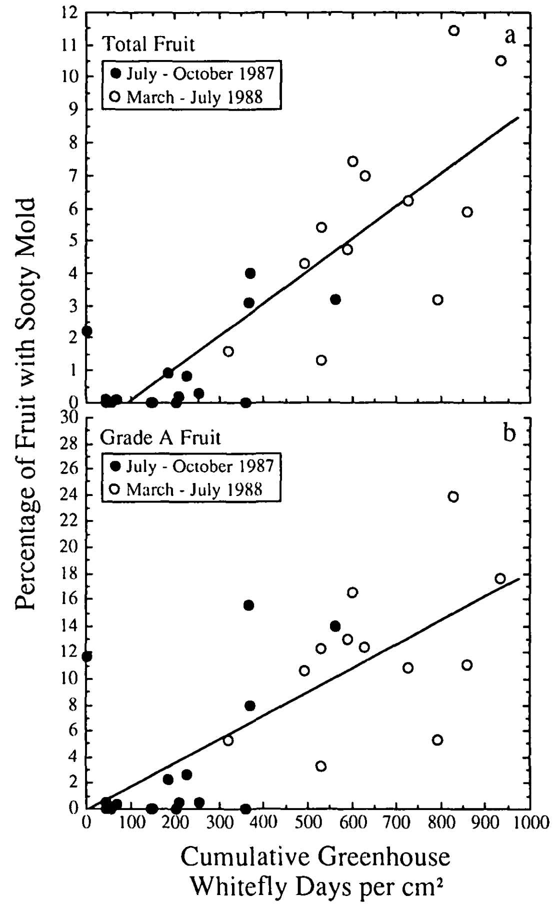

Fig. 2. Percentage sooty mold–contaminated tomato fruit associated with cumulative greenhouse whitefly days for (a) total fruit and (b) grade-A fruit in the 1987 and 1988 studies.

Greenhouse Whitefly Days Versus Greenhouse Whitefly Foliar Densities. From a practical viewpoint, a problem exists with the use of cumulative greenhouse whitefly days as a measure of whitefly feeding impact on fruit yields. It would be difficult for growers to determine numbers of whitefly days accumulated weekly without access to accurate whitefly counts and microcomputers. However, if a positive correlation exists between peak greenhouse whitefly density and the total cumulative whitefly days, it may be possible to express density treatment levels in conventional densities (Welter et al. 1989, Welter et al. 1990). Thus, peak immature whitefly densities recorded in the 1987 and 1988 yield-response studies were pooled and regressed against respective numbers of cumulative whitefly days. A significant positive regression was found between peak density and cumulative immature greenhouse whitefly days ($y = 48.8 +$

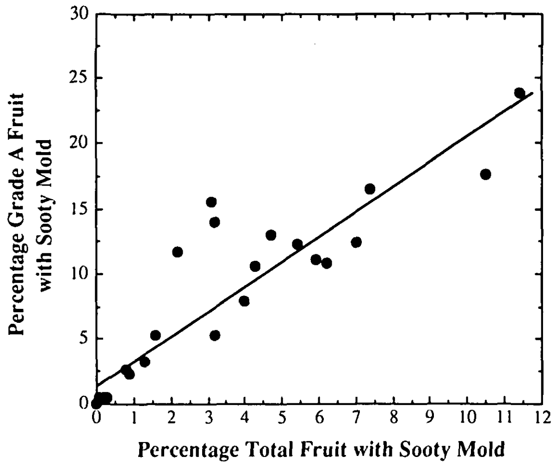

Fig. 3. Relationship between the percentages of total fruit and grade-A fruit contaminated with sooty mold for 1987 and 1988.

30.1x; r^2 = 0.94; df = 30; P = 0.0001) (Fig. 4). Using this relationship one can estimate the cumulative greenhouse whitefly days associated with a given peak density of greenhouse whitefly.

Discussion

Data collected in these studies indicate that the effects of *T. vaporariorum* feeding on tomato yield vary with cumulative immature greenhouse whitefly days. This relationship differed between years and may be influenced by environmental conditions. In contrast to the direct impact of greenhouse whitefly feeding on foliage, the accumulation of sooty mold on fruit as a function of cumulative immature greenhouse whitefly days did not differ between years. Thus, sooty mold contamination was influenced more consistently by the production of honeydew by the *T. vaporariorum* and may be affected less by environmental variation.

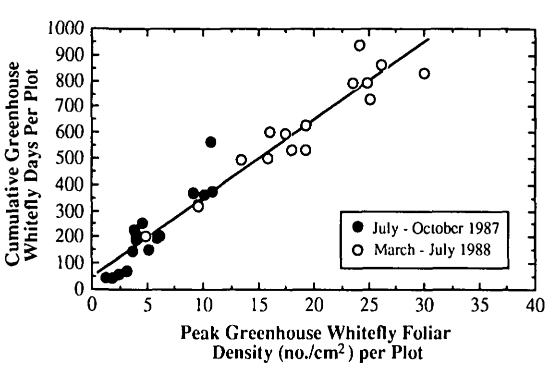

Fig. 4. Relationship between peak immature greenhouse whitefly foliar densities per crop cycle and estimated cumulative greenhouse whitefly days per crop cycle in small plots.

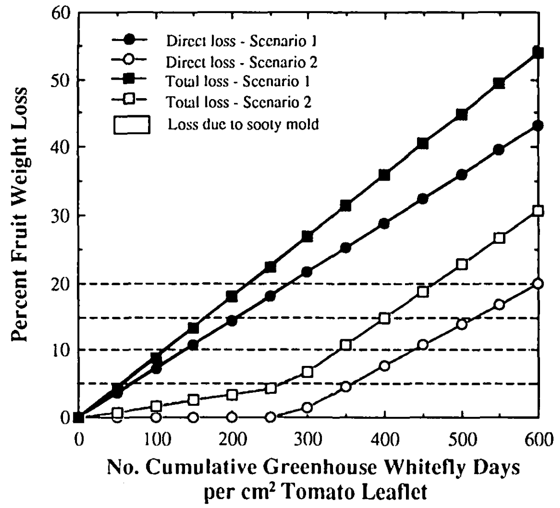

Fig. 5. Percentage yield loss in grade-A fruit associated with greenhouse whitefly feeding and greenhouse whitefly feeding plus sooty mold contamination as estimated for proposed scenarios 1 and 2 (see *Discussion*).

Because reliable yield data were lacking in 1988 for the levels of whitefly impact from near 0 to 300 cumulative immature greenhouse whitefly days (Fig. 1), two possible scenarios might be appropriate to interpret the overall impact of cumulative immature greenhouse whitefly days on fruit yield. In these scenarios, percentage fruit weight loss is estimated using a modified form of the regression equations generated for impact of cumulative whitefly days on tomato yields (Fig. 1) and for the relationship between cumulative whitefly days and percentage sooty mold–contaminated fruit (Fig. 2). In the first scenario (Fig. 5, scenario 1), one may assume that the regression lines for the total and grade-A fruit harvested in 1988 actually cross the Y axis at the predicted intercept. If true, and impact is expressed in terms of percentage reduction of grade-A fruit weight, the estimated impact of *T. vaporariorum* on overall percentage fruit loss (direct loss and sooty mold contamination) in 1987 was not significantly different from that impact estimated for 1988 (χ^2 = 8.4; df = 11; P = 0.68), and yield loss is highly predictable with respect to cumulative immature greenhouse whitefly days for 1987 and 1988. A 5% loss in grade-A tomato yield and little loss due to sooty mold contamination would be expected at 69 cumulative greenhouse whitefly days (0.7 immature greenhouse whitefly per cm^2 tomato leaflet) (Fig. 5). A 5% yield loss in grade-A fruit caused by sooty mold contamination alone would be reached at 298 cumulative greenhouse whitefly days (peak density = 8.3 immature greenhouse whitefly per cm^2 tomato leaflet). At that point, a total loss of 26% tomato yield would have occurred because of the combination of *T. vaporariorum* feeding and sooty mold contamination. Under this scenario, growers who time their control actions based on low levels (1–5%) of sooty mold contamination are losing significant yields because of greenhouse whitefly feeding alone.

However, a second possible scenario exists based on the assumption that maximum yields had been obtained each year and that there was no effect of greenhouse whitefly feeding in the 1988 study before the level of 300 cumulative immature greenhouse whitefly days was reached. Even though the Y intercepts differed in the regressions of yield on cumulative immature greenhouse whitefly days, the actual maximum fruit production (≈45,000 kg/ha) in each study was similar. Experimental yields were similar to mean tomato productivity in commercial operations on Oahu during 1987 (42,448 kg/ha) and 1988 (45,248 kg/ha), which were the highest for the state (Anonymous 1990). Additionally, given the relatively wide rows (2.28 m) necessary to accomodate the pesticide application equipment in our experimental plots, our yields (kg/ha) were probably much higher than those found in most Hawaiian commercial operations. When maximum yields from the research plots were converted to an estimate based on a 1.22-m row width (used commercially) with 0.3 m between plants along a row (used commercially and in our plots), the maximum yields were equivalent to 83,250 and 85,875 kg/ha in 1987 and 1988, respectively. This suggests that the maximum yields recorded in the 1987 and 1988 studies were near the upper limit for tomato production in Hawaii. Based on the regression (Fig. 1b) from March–July 1988 (Fig. 1b) and assuming that the maximum yield possible is 44,000 kg/ha and that no yield reductions occur because of direct whitefly feeding from 0 to 300 cumulative greenhouse whitefly days, ≈5% of the grade-A fruit would be contaminated with sooty mold before any yield losses occurred because of greenhouse whitefly feeding directly (Fig. 5: Scenario 2). When 5% yield losses occur due to greenhouse whitefly feeding (≈370 cumulative greenhouse whitefly days or 10.7 greenhouse whitefly immatures per cm^2 tomato leaflet), a yield loss of ≈6.5% will have occurred because of sooty mold contamination. This would equal a total loss of 11.5%. If this scenario is correct, this makes it difficult to define specific relationships between yearly *T. vaporariorum* infestations and potential yield losses. This may partially explain why most yield-impact studies on greenhouse whitefly populations in tomatoes have concluded that sooty mold accumulation definitely reduces marketable yields, but the effects of *T. vaporariorum* feeding on tomato productivity have been less apparent (Lloyd 1922, Hussey et al. 1969, Lindquist 1972).

If maximum tomato yields were reached in each study, then one may ask why the response lines were significantly different with respect to the numbers of cumulative greenhouse whitefly days required to cause yield reductions (Fig. 1). Given that both studies were completed in 101 d (transplant to final harvest) and the difference in actual time during which cumulative greenhouse whitefly days were recorded in each study was only 6 d, reasons for these differences are unclear.

Differences in yield may be related to seasonal differences between the studies (1987, July–October; 1988, March–July). Mean daily high and low temperatures were significantly less during the fruiting period in 1987 (high, 27.3 ± 0.19 °C; low, 20.2 ± 0.13 °C) than in 1988 (high, 28.9 ± 0.19 °C; low, 21.7 ± 0.12 °C) (high temperatures: $t = 7.12$, df = 156, $P < 0.0001$; low temperatures: $t = 8.21$, df = 156, $P < 0.0001$). However, photosynthesis rates among the studies probably differed little at these temperatures. Mean daily cumulative radiation recorded during the entire crop cycle (transplant to final harvest) in 1987 (15.3 ± 0.6 $MJ/d/m^2$) was significantly less (20.1%) than that recorded in 1988 (19.2 ± 0.5 $MJ/d/m^2$) ($t = 5.093$; df = 200; $P < 0.001$). Carbohydrate production in plants is influenced by photosynthesis which depends on light intensity and duration (Wardlaw 1968). According to Hobson (1988), light duration is the single most important factor limiting the production of carbohydrates in tomato leaves. Thus, during periods of longer daylight (e.g., summer), more assimilates are accessible from the plant, and greater numbers of cumulative immature greenhouse whitefly days may be necessary to reduce yields. Tomato yields recorded in the shaded plots in 1988 suggest that this may be true (Fig. 1). Although shaded plots received less light, ≈60–90 min in the mornings (≈0900–1030 hours), than unshaded plots, this was enough to effect the yields. The yield response in the 1988 shaded plots was similar to that recorded for the 1987 study where less solar radiation was recorded.

If light duration does account for these differences, then on the U.S. mainland, where summer day length exceeds that of Hawaii, the impact of *T. vaporariorum* on tomato yields may be expressed predominantly through sooty mold contamination with less effects of direct *T. vaporariorum* feeding. Under these conditions, the density treatment level of seven nymphs per cm^2, as suggested by Hussey et al. (1969), would be appropriate. However, for crops grown in Hawaii where day length varies only between 11 and 13.5 hrs over the entire year (Armstrong 1983), the impact of greenhouse whitefly feeding becomes more important as daily light periods shorten. This also would apply to greenhouse tomatoes produced on the U.S. mainland during the shorter days of winter.

An understanding of the impact of *T. vaporariorum* on tomato yield is necessary for the development of effective *T. vaporariorum* management strategies. Based on the results of this study, a conservative estimation suggests that a 5% yield loss in grade-A fruit can be expected at ≈70 cumulative greenhouse whitefly days per cm^2 tomato leaflet (=peak density of 0.7 immature greenhouse whitefly per cm^2 tomato leaflet) primarily because of the consumption of plant assimilates by the greenhouse whitefly. Varying impacts of equivalent levels of *T. vaporariorum* on tomato yields may be caused by seasonal changes in environmental conditions (i.e., light duration), but further studies are required to test this hypothesis.

Knowledge of the yield response of the crop to direct feeding and the relationship between sooty mold contamination and greenhouse whitefly infestations provides the first steps in the development of useful density treatment levels. Once these action levels are established, levels of necessary control either by chemical or biological means can be identified. Additionally, simple sampling methods such as binomial sampling can be developed to aid growers in routine monitoring of *T. vaporariorum.* Use of density treatment levels may not only increase tomato yields, but may also reduce unnecessary pesticide treatments which promote pesticide resistance and secondary pest upsets.

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