Growing Conditions Influence Mite Damage on Apple and Peach Leaves

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Additional index words. *Malus domestica*, *Prunus persica*, *Tetranychus urticae*, *Panonychus ulmi*, net photosynthesis, transpiration

Abstract. The effect of growing conditions on the physiological damage caused by mite feeding was evaluated. Control and twospotted spider mite (*Tetranychus urticae* Koch)-infested 'Imperial Delicious' apple (*Malus domestica* Borkh.) and 'Redhaven' peach [*Prunus persica* L. (Batsch.)] trees were grown under winter and summer greenhouse conditions. Mite feeding reduced net photosynthesis (Pn) of apple in both winter and summer, with equivalent regression models (Pn on mite days). Total chlorophyll content (TCHL) was decreased, and specific leaf weight (SLW) was increased by mite feeding in both winter and summer. In peach, Pn was also reduced by mite feeding, with equivalent regression models in winter and summer. SLW was unaffected, and TCHL was reduced by mite feeding in both seasons. Transpiration (Tr) of apple and peach was inconsistently affected by mites in winter and summer. In another experiment, control and European red mite (ERM) [*Panonychus ulmi* (Koch)]-infested 'Redchief Delicious' apple trees were grown in the summer under both greenhouse and field conditions. ERM feeding negatively affected Pn in both the greenhouse and the field, but reductions were less under field conditions. Mites reduced Tr 28% in the greenhouse and 12% in the field. TCHL, SLW, and leaf N content (LFN) were reduced by 16%, 24%, and 26%, respectively, in the greenhouse. In the field, TCHL was not significantly reduced, and SLW and LFN were reduced by 6% and 13%, respectively.

Tetranychid mites are an important pest in apple and peach orchards throughout the temperate zone. These mites reduce net photosynthesis (Avery, 1964; Avery and Briggs, 1968; Hall and Ferree, 1975), transpiration (Ferree and Hall, 1981), total chlorophyll content (Chapman et al., 1952; Zwick et al., 1976), and N content of leaves (Herbert and Butler, 1973; Klopfenstein and Holdsworth, 1978). Much of the research on mite feeding damage has been conducted in greenhouses, in both the winter and summer. To develop meaningful recommendations for mite control in the field, the relationship between growing condition and mite feeding must be assessed. The objectives of this study were to compare mite feeding damage on greenhouse-grown apple and peach trees in the winter and summer and on field vs. greenhouse-grown apple trees.

Winter (Expt. 1). Ten 1-year-old 'Imperial Delicious'/MM.111 apple trees and 10 'Red-

haven'/Halford' seedling peach trees in 3.7-liter containers were removed from cold storage and placed in a white-washed (50% shade) fan- and pad-cooled glasshouse on 27 Jan. 1988. Maximum temperature and photosynthetic photon flux (PPF) during the winter experiment were 32°C and 900 $\mu\text{mol}\cdot\text{s}^{-1}\cdot\text{m}^{-2}$, respectively. The medium consisted of equal parts, by volume, of peat, perlite, and vermiculite. All trees were pruned to ≈ 5 cm above the bud union. Trees were fertilized every 2 weeks with 200 mg N/liter from a Peters 20 N-8P-15K soluble fertilizer

(W.R. Grace and Co., Allentown, Pa.). Magnesium sulfate was applied foliarly at 12.4 g/liter¹ on 9 Mar. Endosulfan (Thiodan 50W) and methomyl (Lannate 50W) were applied as needed at 0.6 and 1.2 g a.i./liter, respectively, to control aphid and whitefly. Carbaryl (Sevin 50W) was applied at 1.2 g a.i./liter to eliminate mite predators.

A completely randomized design was used for each tree species, with five trees per mite treatment. One shoot per tree was allowed to develop, and a single leaf per tree was tagged at unfolding to serve as a test leaf. On 11 Mar., each test leaf was randomly assigned as either a control or mite leaf, and 50 adult twospotted spider mites (TSM) were placed on each mite leaf. Mites were allowed to develop naturally and were counted every 3 days. Mite population densities were calculated as mite days per leaf (MD) by averaging the number of mites counted on two consecutive dates and multiplying by the number of 24-hr periods elapsed between counts. MD quantifies both mite number and feeding duration, where one mite feeding for 10 days would be equivalent to 10 mites feeding for 1 day.

Net photosynthesis (Pn) was measured in the laboratory with an Anarad model Ar-600 infrared gas analyzer at 0, 4, 8, and 16 days after mite placement (DAMP) (Anarad, Santa Barbara, Calif.). The leaf chamber was a modification of the chamber described by Syvertsen and Smith (1983), without the heat exchanger. Lighting was provided with 500R/3FL lamps (Westinghouse), and PPF was 1050 $\mu\text{mol}\cdot\text{s}^{-1}\cdot\text{m}^{-2}$. The air flow rate into the chamber was 0.05 liters $\cdot\text{sec}^{-1}$. Air temperature in the chamber was maintained at $28 \pm 1^\circ\text{C}$ and dew point was $16 \pm 3^\circ\text{C}$. Transpiration (Tr) was measured simultaneously with Pn with a General Eastern model 1100 dew point hygrometer (General Eastern Instruments, Watertown, Mass.).

At the conclusion of the experiment (6 Apr.), leaves were harvested, weighed, and

Table 1. Influence of twospotted spider mite feeding on total chlorophyll content (TCHL) and specific leaf weight (SLW) of 'Imperial Delicious' apple and 'Redhaven' peach leaves grown under winter or summer greenhouse conditions (Expt. 1).

Apple						
	Control	Mite	Significance	Control	Mite	Significance
TCHL	1782	20	**	2170	22	**
SLW	0	25	NS	0	33	NS
Pn	1587	20	NS	2500	21	**
Tr	---	---	---	---	---	---
Peach						
	Control	Mite	Significance	Control	Mite	Significance
TCHL	0	25	NS	0	33	NS
SLW	1587	20	NS	2500	21	**
Pn	---	---	---	---	---	---
Tr	---	---	---	---	---	---

NS, **Nonsignificant or significant at $P = 0.01$, respectively ($n = 5$).

Received for publication 24 May 1989. The cost of publishing this paper was defrayed in part by the payment of page charges. Under postal regulations, this paper therefore must be hereby marked advertisement solely to indicate this fact.

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Fig. 1. Relationship between net photosynthesis (Pn) and mite days per leaf (MD) for apple and peach leaves grown under winter (X) and summer (□) greenhouse conditions (Expt. 1). Apple: X, $P_n = 95 - 0.029MD$, $R^2 = 0.70$; □, $P_n = 99 - 0.032MD$, $R^2 = 0.84$. Peach: X, $P_n = 98 - 0.020MD$, $R^2 = 0.70$; □, $P_n = 104 - 0.023MD$, $R^2 = 0.66$.

their areas measured with a LI-3000 portable leaf area meter (LI-COR, Lincoln, Neb.). Two leaf disks (1.2 cm² total area) were sampled from each side of the midrib, and total leaf chlorophyll content (TCHL) was determined by acetone extraction following the method of Arnon (1949), as modified by Marini (1986). Leaves were dried at 60°C and dry weights recorded. Specific leaf weight (SLW) was calculated by dividing dry weight by leaf area (corrected for disk removal).

Summer (Expt. 1). Ten 'Imperial Delicious'/MM.111 apple trees and 10 'Redhaven'/Halford seedling peach trees were removed from cold storage and placed in the same glasshouse on 15 Apr. 1988. The air maximum was 35°C and PPFD was 1000 $\mu\text{mol}\cdot\text{s}^{-1}\cdot\text{m}^{-2}$. The materials and methods were identical to those described for the winter experiment. The experiment was terminated on 24 Aug. 1988.

Greenhouse (Expt. 2). Eighteen 1-year-old 'Redchief Delicious'/MM.111 trees were planted as in Expt. 1 on 17 June 1987. The trees were pruned, fertilized, and maintained as previously described. The experimental design was completely randomized with nine trees per mite treatment.

On 29 July, one leaf per tree was randomly assigned as either a control or mite leaf, and 40 adult European red mites (ERM) were placed on each mite test leaf. Mites

were counted every 3 days and population densities were expressed as MD. Pn was measured with an ADC Model LCA-2 portable infrared gas analyzer (Analytical Development Corp., Hoddesdon, U. K.) at 0, 11, and 33 days after mite placement. Transpiration was measured with a LI-COR Model LI-1600 steady state porometer.

On 3 Sept., the leaves were harvested and fresh weight, TCHL, and dry weight were determined as previously described. Leaf N (LFN) was determined by a modified Kjeldahl analysis (Bremner and Breitenbeck, 1983).

Field Expt. 2). Forty 2-year-old 'Redchief Delicious'/MM.111 trees growing on the Virginia Tech Horticulture Farm, Blacksburg, Va., were selected. Trees were spaced 2 × 3 m. On 25 Feb. 1988, the trees were headed to ≈30 cm above the bud union. All but two uniform shoots were removed. On 15 May, one shoot leaf per tree was tagged at unfolding to serve as a test leaf.

Endosulfan (Thiodan 50W) was applied as needed at 0.6 g a.i./liter to control aphids. Carbaryl (Sevin 50W) was applied as needed at 1.2 g a.i./liter to control Japanese beetle and eliminate mite predators. On 23 May, cyhexatin (Plictran 50W) was applied at 225 mg a.i./liter to all trees to control mites until mite treatments commenced.

A completely randomized design was used,

consisting of a control and a mite treatment with 20 replications per treatment. On 3 July, 'Delicious' apple spurs infested with ERM were placed in the mite-treated trees. Control trees received cyhexatin applications every 2 weeks (beginning on 3 July) at 225 mg a.i./liter to control mites. Mite populations on the other trees were allowed to develop naturally. Mites (on infested leaves) were counted weekly, and mite populations were expressed as MD. Mites were killed with a cyhexatin application on 18 Aug. Pn and Tr were measured on sunny days (PPFD > 1000 $\mu\text{mol}\cdot\text{s}^{-1}\cdot\text{m}^{-2}$) with an ADC portable infrared gas analyzer and LI-COR steady state porometer. Pn and Tr were measured four times at weekly intervals beginning on 18 Aug. (after mite removal). Leaves were harvested on 16 Sept. and LFN, fresh and dry weight, TCHL, and SLW were determined.

Statistical analysis. Pn was regressed on MD for each experiment and species, and slopes and intercepts of the regression models were compared using indicator variables in multiple regression analysis (Montgomery and Peck, 1982). To account for day-to-day fluctuations in Pn during the experiment, Pn of each mite-treated leaf was expressed as a percentage of the mean Pn rate of the controls on each measurement date. TCHL, SLW, and LFN data for each experiment were analyzed by analysis of variance.

Experiment 1. Mite feeding reduced Pn of apple in both the winter and summer experiment, with statistically equivalent linear regression models (Fig. 1). Accumulation of 1200 MD reduced apple Pn by ≈40% for both winter- and summer-grown trees. Mite feeding also reduced Pn of peach in both the winter and summer experiment (equivalent models), but the slopes of these models differed significantly from the slopes for apple. Accumulation of 1200 MD reduced peach Pn by ≈25%. Mite feeding had an inconsistent effect on Tr of both apple and peach (data not presented).

Direct comparison of the apple and peach TCHL and SLW data between the winter and summer conditions is made with caution due to the discrepancy in accumulated MD (Table 1). Under winter conditions, TCHL of apple was reduced, and SLW increased with 1782 MD. In the summer experiment, TCHL was reduced, and SLW increased nonsignificantly with 2170 MD. Peach data under winter conditions were similar to that found with apple, although differences were not significant. Under summer conditions, TCHL was reduced, and SLW increased nonsignificantly following 2500 MD.

Experiment 2. In the greenhouse, a negative linear relationship was found between Pn of apple leaves (percent of control) and ERM MD ($P_n = 100 - 0.024 MD$, $R^2 = 0.82$). This model was statistically equivalent to the peach regression models with TSM, but not the apple regression models with TSM in Expt. 1. Pn was reduced 50% and Tr 28% following 2330 MD (Table 2). Since results were similar for all measurement dates from the field experiment, only data for the final measurement date are presented. In the field,

Table 2. Influence of European red mite feeding on net photosynthesis (Pn), transpiration (Tr), total chlorophyll (TCHL), specific leaf weight (SLW), and leaf N content (LFN) of 'Redchief Delicious' apple leaves grown under field and greenhouse conditions

Treatment	(no.)	(g/m ²)	(g/m ²)	(µg/cm ²)	(µg/cm ²)	(µg/cm ²)	(%)
Greenhouse							
Control	0	13.0	5.0	29	6.4	0.25	2.4
Mite	2330	6.5	3.6	22	5.4	0.19	2.2
Mite	3056	10.0	5.9	55	11.0	0.21	2.5
Significance	---	*	**	NS	***	*	***

NS,*,***Nonsignificant or significant at $P = 0.05$, 0.01 , or 0.001 , respectively (greenhouse, $n = 9$; field, $n = 20$).

3056 MD reduced Pn only 17% and Tr by 12%.

TCHL, SLW, and LFN were reduced by 16%, 24%, and 26%, respectively, following 2330 MD in the greenhouse (Table 2). In the field, there was a 6% and a 13% decrease in SLW and LFN, respectively, following 3056 MD. TCHL was not significantly affected by mite feeding in the field.

ERM is the most important mite pest in Virginia apple and peach orchards. However, it was necessary to use TSM in the first experiment due to the constraints of the ERM life cycle. ERM overwinter as eggs and rarely hatch before early April, even in a warm greenhouse. TSM have been used in many previous experiments on leaf physiological damage and they reproduce year-round in the greenhouse.

The reduced Pn of apple leaves due to mite feeding was similar to the results of previous studies. Hall and Ferree (1975) reported similar percentage decreases in Pn for 'Delicious' leaves with TSM. Ferree et al. (1986) measured no clear Tr effect following TSM feeding on winter-grown, 'Delicious' leaves. In a related study, Tr of 'Golden Delicious' leaves was reduced by 135 TSM MD, but not at greater populations (Ferree and Hall, 1981). Tr of apple was generally reduced in our study by ERM feeding, but the results with TSM on apple and peach were inconsistent.

Reductions in TCHL and LFN in apple leaves due to mite feeding are well documented (Chapman et al., 1952; Klopfenstein and Holdsworth, 1978), and, in our study, reductions were measured under greenhouse conditions in both winter and summer. Mites remove cellular contents when feeding (Avery and Briggs, 1968); therefore, decreases in SLW following ERM feeding in both the greenhouse- and field-grown leaves were not unexpected (Expt. 2). However, TSM feeding resulted in higher SLW (Expt. 1). This discrepancy may be partly due to differences in feeding patterns between the two mite species, but SLW of apple leaves increased upon ERM feeding in a previous greenhouse study (Campbell and Marini, 1990). Increased SLW may be due to a wound response by the leaf induced by mite feeding. The effect of mite feeding on SLW needs more study.

Our results support the indications that

peach leaves are more tolerant of mite feeding than apple. Peach and apple leaves generally responded similarly to mite feeding, but peach leaves were affected to a lesser extent by similar white densities. Mobley (1989) found that 900 TSM MD reduced apple Pn 45%, whereas 3000 MD were required for an equivalent reduction in peach Pn. Accumulations of 8900 ERM MD on 'Cresthaven' peach trees did not affect shoot growth, and 3600 MD did not influence fruit quality (color, flesh firmness, soluble solids concentration, or size) (McClernan and Marini, 1986). Bailey (1979) found that TSM populations of 40 to 50 mites/leaf had no effect on yield of 'Wright' peach, but lesser populations of ERM decreased 'Delicious' fruit weight and number (Klopfenstein and Holdsworth, 1978).

Youngman et al. (1986) found *Tetranychus* spp. (TSM) more damaging than *Panonychus* spp. (ERM) on almond leaves, and Mobley (1989) found similar results with apple. ERM feeding was generally less damaging to leaf physiology than TSM feeding in our studies. ERM densities were greater in the field than in the greenhouse. Physiological responses were significantly reduced in the field, but to a lesser extent than in the greenhouse. Morphological differences between the greenhouse and field leaves may explain these differences. Compared to greenhouse-grown leaves, field-grown leaves were thicker, with nearly twice the SLW and TCHL. Blair (1951) found that visible damage and nutrient depletion were less severe in ERM-infested leaves with a thick palisade parenchyma. Avery and Briggs (1968) found that mites generally penetrate less than one half of the thickness of the leaf during feeding. Therefore, due to the physical limitations of mite stylet penetration, thicker leaves should sustain less damage.

Our greenhouse results indicate that apple and peach trees respond similarly to mite feeding in winter or summer. However, there were large differences in the physiological response to mite feeding in greenhouse- and field-grown 'Delicious' leaves. These results suggest that the physiological function (gas-exchange, LFN, and TCHL) of greenhouse-grown leaves is more susceptible to mite feeding than that of field-grown leaves, leading to the adoption of conservative control levels for mites. In the development of ac-

tion thresholds, experimental conditions should be considered and, ideally, based on field experiments.

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