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Relationships Between Leaf : Fruit Ratio and Varying Levels of European Red Mite Stress on Fruit Size and Return Bloom of Apple

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Abstract. **Fruit size and return bloom of apple (*Malus domestica* Brokh.) were examined in 1982–84 under varying levels of crop load and stress caused by the European red mite [*Panonychus ulmi* (Koch)]. Trees of 'Rome Beauty'/MM.111 and 'Yorking' M.26 were subjected to two and three levels of mite stress, respectively, over a range of leaf : fruit ratios (LFRs). Regression models were used to explore the effect of LFR on fruit size and return bloom at the various mite injury levels. There was a curvilinear relationship between mean fruit weight and LFR for most of the check and mite-injured groups. The relationship between bloom density and LFR was linear over the range studied. Both experiments indicated reduced fruit size and return bloom with moderate to high mite damage, regardless of LFR.**

The relationship between fruit size or return bloom of apple and crop load has been investigated since the 1920s (see ref. 8 for review). These studies were concerned with optimization of the fruit size and number relationship while maintaining annual bearing, two important components of monetary return to the grower.

Haller and Magness (12) and Haller (11) were among the first to use leaf : fruit ratio (LFR) (the number of leaves per fruit) in an attempt to optimize crop load. They found a strong correlation between increase in fruit volume and leaf area supplying the fruit. They also noted that there is a LFR at which maximum fruit growth is obtained (30 to 40 for 'Grimes' and 'Ben Davis', and up to 75 for 'Delicious'). Similar results were obtained by Murneek (21) and Preston (23). Hansen (13) calculated the saturation leaf area per fruit (i.e., the point at which all available assimilates are fixed in the fruit) as ≈14–17 leaves per fruit ('Golden Delicious'), depending on the time of season. Hansen (14) found a positive curvilinear relationship between fruit growth/m^2 of leaf area and crop load. Forshey and Elfving (8) describe a linear relationship between mean fruit weight and number of fruit/cm^2 of trunk cross-sectional area (CSA). However, they note that "thinning can quickly reach the point of diminishing returns" and that excessive thinning will lead to a reduction in fruit numbers, hence total yield, that will not be compensated for by an increase in mean fruit size.

Similar results have been obtained with flower bud initiation and return bloom. Harley et al. (15) found that at 10 leaves per fruit, no flower bud initiation occurred, while, at 70 leaves per fruit, all spurs formed flower buds. Aldrich and Fletcher (1) also concluded that the number of leaves per fruit was related positively to percentage bloom and set the following season. Shen (25) found the same positive relationship, and noted that there is a limit of about 700–1400 cm^2 of leaf area per fruit beyond which flower bud differentiation is not increased.

European red mite (ERM) [*Panonychus ulmi* (Koch)] injury to leaves also can reduce fruit size and return bloom. ERM damages the tree by removing cell contents, including chlorophyll. Mite feeding may decrease net photosynthesis and transpiration (3, 5, 7, 10). Hoyt et al. (16) found mite injury affected cumulative fruit growth. Asquith (2) and Baker (4) reported that mite injury caused a reduction in fruit size. Klopfenstein (17), Zwick et al. (27), and Ames et al. (10), on the other hand, found no reduction in fruit size. Return bloom has been reported by some (2, 18, 19) to be reduced greatly by mite damage, while others (6, 20, 27) found no effect. Hoyt et al. (16) reported no effect when mite populations occurred mid-season on vigorous trees, but pointed out that the timing of damage may be a crucial factor.

The objective of this investigation was to determine the effects of damage caused by ERM on fruit size and return bloom under varying levels of crop load. If competition among fruits is a primary determinant of fruit size and return bloom, then the effects of ERM damage should increase as LFR decreases.

Materials and Methods

Conceptual model. A conceptual model for the relationship between fruit size and LFR under various levels of mite stress (Fig. 1) illustrates several hypotheses: a) fruit size increases in a curvilinear fashion with increasing LFR, up to a theoretical maximum, which is determined by genetic and environmental

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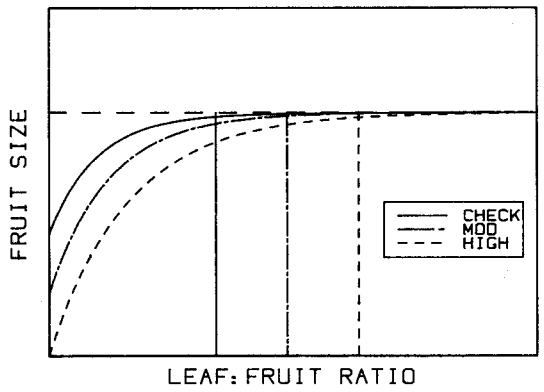

Fig. 1. Conceptual model of the relationship between fruit size and leaf : fruit ratio (LFR) with varying degrees of mite injury. Upper horizontal dashed line represents theoretical maximum fruit size. Curved lines represent fruit weight over a range of LFRs, and vertical lines mark the saturation LFRs at the different levels of mite injury (check or no mite injury, moderate, and high).

factors; b) the point at which the curve intersects with the theoretical maximum corresponds with the "saturation LFR," i.e., the point at which increases in LFR will not increase fruit size further [note that the term saturation is used in a different sense than by Hansen (13)]; c) mite injury decreases fruit size, but this decrease is proportionately greater at lower LFRs.

1982–83. The experiment was conducted in a 0.9-ha orchard near Arendtsville, Pa. The trees ('Rome Beauty'/MM.111) were planted in 1978 at a spacing of 3.7 × 10.2 m. Trees were lightly pruned in Winter 1981–82, but were not pruned during Winter 1982–83 to avoid interfering with the assessment of return bloom in May 1983. Trees received a fruit-thinning spray of 10 ppm 1-naphthaleneacetic acid (NAA) 20 days after full bloom (5 May), but no chemical thinning was done in 1983. Insecticide, fungicide, herbicide, and fertilizer applications conformed to recommended orchard practices (26).

The experimental design was a completely randomized 2 × 4 factorial treatment arrangement replicated six times, with two mite damage levels (check = 0 cumulative mite days and high = 1500 cumulative mite days) applied over four LFRs (20, 30, 50, and 70 leaves per fruit). Mite days are defined as one mite (per leaf) present for 1 day, and calculated as the mean of two successive counts (i.e., mean number of mites per leaf) multiplied by the number of intervening days. These weekly figures were summed over the season to give cumulative mite days (CMDs). It was assumed that actual mite injury increases as CMDs increased, and these terms are used interchangeably. The experimental units were individual scaffold limbs, 9–12 cm in circumference at the base. Two limbs per tree were used in the experiment, and both limbs were always in the same mite damage level. However, limbs were assumed to behave independently in terms of crop load, so limbs on the same tree were used as separate experimental units, and may have had different LFRs.

Mite day levels were obtained by infesting the experimental limbs with mites on 30 June 1982. Mites were counted in situ on 10 random leaves per limb at weekly intervals. The control trees were sprayed with tricyclohexylhydroxystannane (cyhexatin) on 23 July and 10 Aug. to keep them relatively mite-free, and then all trees received cyhexatin applications on 31 Aug. and 7 Sept. to prevent further mite damage.

LFRs were adjusted on 29 June (after June drop was complete) by counting the number of leaves on the limb, and then removing fruits to achieve the target level. Some large fruit dropped during July and August, so LFRs used in analyses were based on the number of fruit on the limb at harvest. Terminal growth was essentially complete by late June, so leaves were not recounted at harvest. An initial fruit diameter measurement was taken on 10 tagged apples on 30 June. Individual weights also were taken at harvest on the tagged apples, and total weight was taken on the rest of the apples (if any) on the limb and on the tree. The number of blossom clusters per limb was counted on 3 May 1983.

1983–84. The experiment was conducted in a 0.05-ha block of 4-year-old 'Yorking'/M.26 trees planted in 1980, at a spacing of 1.5 × 3 m. They had been defruited and received an application of 1800 ppm butanedioic acid mono(2,2-dimethylhydrazide)(daminozide) and 300 ppm (2-chloroethyl)phosphonic acid (ethephon) in 1982 to encourage heavy bloom in Spring 1983. A standard orchard fungicide and insecticide spray schedule was maintained throughout both growing seasons (26). A contact herbicide was applied at intervals to reduce weed competition.

The experimental design was a factorial treatment arrangement, with three target mite injury levels (check = 0 CMDs, moderate = 750 CMDs, and high = 1500 CMDs) applied over five LFR levels (45, 65, 85, 105, and 125 leaves per fruit). The experimental unit was an entire tree, with five replications per treatment. Because the canopies were beginning to overlap, the three mite treatments were applied to separate physically groups of trees and thereby minimize contamination of the check trees with mites. The LFR levels were assigned according to the fruit count taken after the completion of June drop, and the replicates were randomized within treatments. Full bloom occurred on 5 May.

A natural mite infestation was allowed to develop in early July in the moderate and high mite day groups. Counting of mites and calculation of CMDs were done in the same manner as the 'Rome Beauty' experiment, except that leaves were selected from the entire tree. Supplemental infestation was used to bolster mite populations that were falling short of target levels. CMDs were calculated immediately after each weekly mite count, and trees that were within ± 100 mite days of the target level were sprayed with a mixture of cyhexatin and *bis* 3,6-(2-chlorophenyl)-1,2,4,5-tetrazine (clofentezene) 1 and 8 days after the count. The check trees were sprayed with the same acaricides twice in July to keep them free of mites.

Leaf counts were made as in the 'Rome Beauty' experiment. The fruit were counted on 8 July, and excess fruit (if any) were removed to achieve the desired LFR. Severe thunderstorms occurred on 21 July and 1 Aug. 1983, which uprooted nine of the experimental trees and knocked off substantial numbers of fruit. Other trees in the block were substituted in the experiment immediately after the storms. LFR adjustments and mite counts were made on 22 July and 2 Aug. on the replacement trees. Mite days on replacement trees were estimated as the mean of the original (0) and the current number of mites per leaf, multiplied by the number of intervening days. LRFs used in analysis were based on number of apples on the tree at harvest.

Ten fruit per tree were chosen at random on 12 July, tagged, and the diameter measured; apples on replacement trees were measured at the time they were included in the experiment. All fruit on the trees were weighed and measured individually when the plots were harvested on 23 Sept. 1983. Blossom clusters per tree (return bloom) were counted 9 May 1984.

Statistical analysis. Although are designs were originally fac-

torial, with discrete levels of the LFRs, the difficulty in maintaining these levels led to continuous quantitative variables by the end of the experiments. This difficulty was true to a lesser extent for the mite day levels, but they were sufficiently distinct to use as qualitative variables. Thus, the response variables (fruit weight and blossom clusters per cm^2 of limb CSA) were fitted to regression models using mite injury groups as qualitative variables and LFRs as quantitative variables.

Combined models were developed using indicator variables (22) to test differences in slopes and intercepts and to arrive at an overall R^2 value. The apices of the quadratic curves were used as an approximation of the saturation LFR for fruit weight. For the 'Yorking' experiment, LFR was the only variable included in the models. In the 'Rome Beauty' experiment, however, the LFR on the "partner limb" (PLFR) (i.e., the other experimental limb on the tree) was found to have a significant influence on the response variable in the check group. Separate lines were fitted for both fruit size and return bloom to the checks where PLFR was <40 or >40. This additional refinement helped elucidate the effect of mite injury and improved the R^2. Variables such as initial apple diameter, limb or trunk CSA, and number of fruit per trunk CSA ('Rome Beauty') improved the predictive capabilities of the models but shed no further light on the effect of mite injury. Regression parameter estimates are significant at $P = 0.05$, unless otherwise indicated. The reported R^2 values were adjusted for the error degrees of freedom, to take into account the number of parameters (24).

Results and Discussion

Cumulative mites days for the mite treatment groups over the course of each season are shown in Fig. 2. Mean cumulative mite days (± SE) at the end of the season were 129 ± 18 (check), and 1709 ± 86 (high) for the 'Rome Beauty' experiment, and 0 (check), 931 ± 25 (moderate), and 1554 ± 55 (high) for the 'Yorking' experiment. Mite damage occurred almost equally at all LFR levels in the 'Yorking' experiment, but limbs with the two highest LFR levels in the 'Rome Beauty' experiment received significantly less mite damage than did the two lower levels (1413 CMD vs. 2006 CMD, $P = 0.05$). This difference would be confounded with the tendency to have small fruit in the lower LFR levels and large fruit in the higher LFR levels. However, the differences were not great enough to obscure the effect of LFR.

Fruit weight. Fruit weight of the 'Rome Beauty' check group increased with LFR in a curvilinear manner, with a maximum fruit size of ≈213 g (PLFR < 40) and 250 g (PLFR > 40) (Fig. 3A). These maxima corresponded to a saturation LFR of 60 (PLFR < 40) and 80 (PLFR > 40), somewhat higher than the values developed by Haller and Magness (12). The overall mean fruit size of the checks (210 g) was larger than that of the mite-injured trees (190 g), and the influence of PLFR in the checks reduced mean fruit size from 220 g (PLFR > 40) to 199 g (PLFR < 40). The response of the high ERM injury group was linear over the range of LFRs in this study, implying the saturation point was not reached. It is unknown why PLFR had no apparent effect on this group.

Use of scaffold limbs as experimental units is desirable because the amount of labor involved in counting leaves on an entire tree is usually prohibitive. However, in this study there was a 37-g difference in maximum size due to the influence of PLFR. Ideally, limb samples should be representative of the entire tree (9).

Fruit weight of all three mite injury groups in the 'Yorking' experiment showed a curvilinear relationship with LFR (Fig. 3B). The check group produced the largest apples (176 g) and the moderate group the smallest (147 g). The high group (157 g) was intermediate. The data indicated that fruit weight of 'Yorking' will be reduced equally at any LFR level when mite injury is sustained. The estimated saturation was ≈173 leaves per fruit, much higher than the reported 50–70 leaves per fruit (12). A 15-cm rain deficit during the growing season may be responsible for the increase.

Return bloom. Return bloom of 'Rome Beauty' was linearly related to LFR, and the differences between mite injury groups increased at higher LFRs (Fig. 3C). This finding is the opposite of what was expected. Because of the poor fit for these data, conclusions are difficult to draw, other than noting differences in means (check PLFR > 40, check PLFR < 40, and high had 4.7, 3.2, and 1.8 blossoms/CSA, respectively). The model suggests, however, that return bloom may be saturated at a higher LFR than fruit size.

The return bloom for the 'Yorking' trees was linearly related to LFR (Fig. 3D), indicating that saturation did not occur within the ranges of the experiment. The check and high groups had similar amounts of return bloom, while the bloom in the moderate groups was significantly lower than the other two, probably due to the bias in experimental material mentioned earlier.

In general, mite injury reduced the fruit size and return bloom, but whether this reduction occurs equally at all LFRs remains to be determined. Although these data provide minimal support for our original hypothesis (i.e., response does not occur equally at all LFRs, as in 'Rome Beauty' fruit size), greater control of

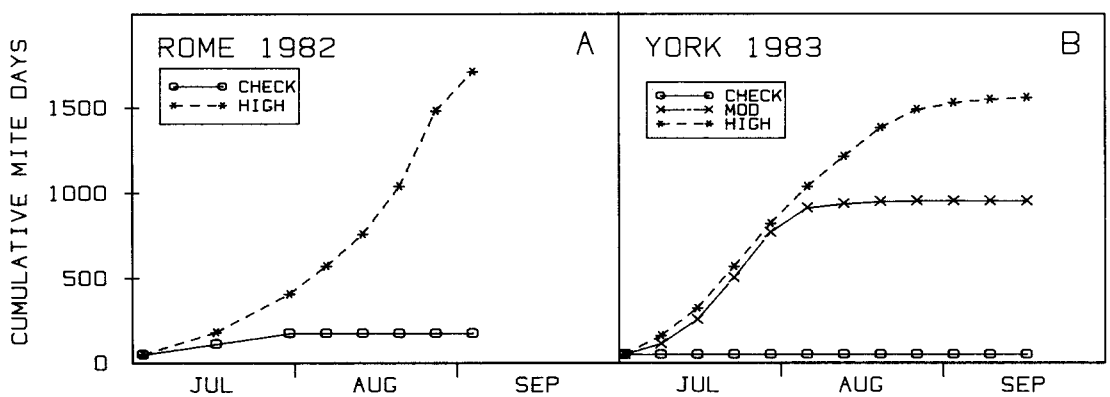

Fig. 2. Mean cumulative mite days (CMDs) for 'Rome Beauty' (1982) and 'Yorking' (1983).

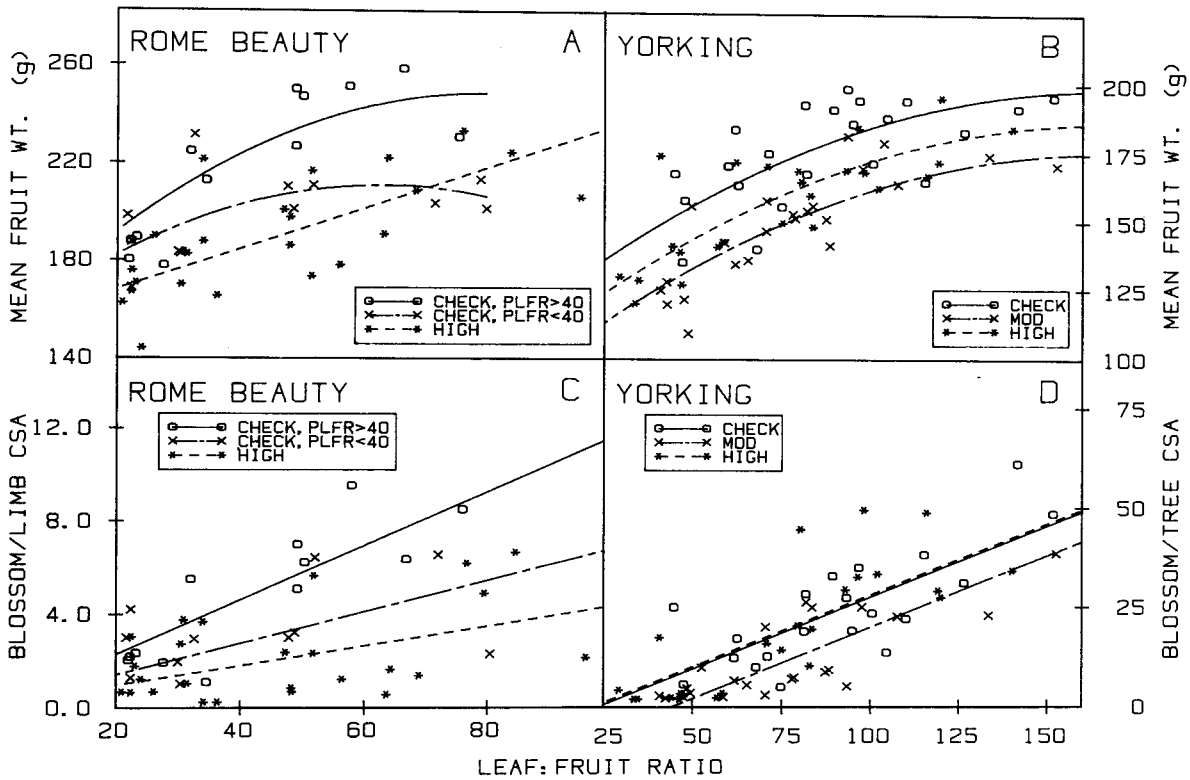

Fig. 3. Regression lines, data points, and R^2 values for the response variables mean fruit weight (g) and blossoms/cross-sectional area (CSA) (cm^2). All models are significant at $P = 0.0001$; all parameter estimates are significant at $P = 0.05$. (**A**) 'Rome Beauty' fruit weight ($R^2 = 0.558$), check, PLFR > 40 = 154 + 2.40(LFR) − 0.015(LFR^2); check, PLFR < 40 = 154 + 1.86(LFR) − 0.015(LFR^2); high = 154 + 0.81(LFR). (**B**) 'Yorking' fruit weight ($R^2 = 0.693$), check = 112 + 1.04(LFR) − 0.003 (LFR^2); moderate = 89 + 1.04(LFR) − 0.003(LFR^2); high = 100 + 1.04(LFR) − 0.003(LFR^2); (**C**) 'Rome Beauty' blossoms/CSA, check ($R^2 = 0.392$), PLFR > 40 = 0.46 + 0.11(LFR); check, PLFR < 40 = 0.46 + 0.06(LFR); high = 0.46 + 0.03(LFR). (**D**) 'Yorking' blossoms/CSA ($R^2 = 0.638$), check and high = −10.2 + 0.37(LFR); moderate = −18.1 + 0.37(LFR).

experimental conditions may make such distinctions possible. Future investigations will be aimed at distinguishing between models in which a) response is reduced equally at all LFRs; b) response is reduced at low LFRs, but not at very high LFRs; or c) response is reduced at both low and high LFRs, but with some absolute reduction that cannot be compensated for by LFR. Models of this type provide a viable approach to optimizing crop loads under a range of environmental conditions (such as insect or moisture stress), and may prove useful in providing an economic framework for integrating orchard production practices.

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