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# Sensitivity of Peach Seedling Vegetative Growth to Paclobutrazol

**J.D. Early, Jr. and G.C. Martin**
*Department of Pomology, University of California, Davis, CA 95616*

*Additional index words.* Growth retardant, PP333, *Prunus persica*

***Abstract.*** **'Nemaguard' peach seedlings [*Prunus persica* (L.) Batsch] were grown for 21 days in nutrient solution cultures containing a range (0 to 3.4 μM) of paclobutrazol concentrations. Shoot growth rate and total extension growth were reduced by all paclobutrazol treatments. Within 2 days of treatment, paclobutrazol at 3.4 μM significantly reduced the growth rate, as did the $3.4 \times 10^{-2}$ μM concentrations after 5 days. Increases in paclobutrazol concentrations decreased leaf area and leaf, stem, and shoot weights. However, specific leaf weight increased as paclobutrazol concentration increased. Leaf expansion was more sensitive to paclobutrazol treatments than stem elongation. As paclobutrazol concentration increased, root extension growth was reduced, but roots were thicker and produced more laterals near the tip. Compared with the control, paclobutrazol at $3.4 \times 10^{-1}$ and $3.4 \times 10^{-2}$ μM significantly increased the root : shoot ratio. Chemical name used: β-[(4-chlorophenyl)methyl]-α-(1,1-dimethylethyl)-1*H*-1,2,4-triazole-1-ethanol (paclobutrazol).**

Although the potential usefulness of vegetative growth retardants for orchard management has been known for years, there has been little success in developing such compounds for commercial use. A recently developed compound exhibiting potential for use in orchard management is paclobutrazol (ICI Americas, Goldsboro, N.C.), a potent triazole inhibitor of gibberellin (GA) biosynthesis (12, 14). Paclobutrazol has growth retardant activity on a wide range of crop species (5), and has been demonstrated to control vegetative growth on a number of fruit corps (1, 11, 20, 21). Whereas results produced by paclobutrazol are encouraging, controlling the degree and duration of its activity has been difficult. Its activity and degree of control are strongly influenced by the method of application (4, 22), tree vigor (18), and soil characteristics (9) of the orchard. Growth control is complicated further by the potential persistence of paclobutrazol's influence for several years after treatment. In order to manage the use of paclobutrazol effectively, understanding its interaction with these various components is important. To begin such an analysis, it is first desirable to examine effects of growth when the factors inducing variability are minimized. The objective of this trial was to determine the sensitivity of peach seedlings to paclobutrazol when grown under conditions that tend to maximize the effect of the compound on growth.

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## Materials and Methods

'Nemaguard' peach seeds were stratified at 2 °C for a minimum of 60 days prior to planting in a 1 peat : 1 vermiculite mixture (v/v) in 0.5-liter cardboard cartons. Seedlings were grown in the greenhouse at ambient summer conditions. Lateral shoots were regularly removed to maintain vigorous terminal growth. When plants were 15 to 20 cm in height (28 days after planting), the seedlings were removed from the cartons, their roots washed with distilled water, and transferred to bottles containing 1 liter of nutrient solution, one seedling per bottle. The nutrient solution contained the following: 0.4 mM $NH_4NO_3$, 1.1 mM $KNO_3$, 0.25 mM $CA(NO_3)_2$, 0.25 mM $KH_2PO_4$, 0.25 mM $MgSO_4$, 75 μM Fe (as FeEDDHA), 46 μM B, 9 μM Mn, 0.8 μM Zn, 0.3 μM Cu, and 0.05 μM Mo. Solution pH was adjusted to 5.6 using 0.1 N NaOH and checked every other day. The solution was aerated with charcoal-filtered air at 5.0 $cm^3 \cdot s^{-1}$.

After the seedlings were acclimatized (5 days), the solution was replaced with fresh nutrient solution and paclobutrazol (50% wettable powder; formulation #GFU025) was added to the nutrient solution. Treatments consisted of a control and 3.4 μM (1000 ppb), $3.4 \times 10^{-1}$ μM, $3.4 \times 10^{-2}$ μM, and $3.4 \times 10^{-3}$ μM paclobutrazol in solution. Nutrient solution levels were checked daily and maintained by the addition of fresh solution every other day throughout the experiment.

Following treatment, the uppermost fully expanded leaf on each plant was marked for reference. During the first week, plant heights were measured daily; subsequent height measurements were taken every other day. At the conclusion of the experiment, 21 days after treatment (DAT), total leaf area and

leaf area of a subsample were determined using a Delta T Area Meter (Decagon). Leaf subsamples consisted of five random fully expanded leaves taken from leaves that were immature when the plants were initially treated. Fresh weights of roots, stems, and leaves were determined and subsamples were taken for microscopic analysis. Plant samples were dried in a forced-air oven for 2 weeks and dry weights were recorded.

The experiment was designed as a randomized complete block with eight single plant replications per treatment. Data were analyzed using regression analysis and analysis of variance.

## Results

Seedling shoot growth rates responded rapidly to paclobutrazol treatment (Fig. 1) By 2 days after treatment (DAT), 3.4 μM of paclobutrazol significantly ($P < 0.05$) reduced shoot growth rates; by 5 DAT, shoot growth rates of the $3.4 \times 10^{-1}$ and $3.4 \times 10^{-2}$ μM treatments were also below the control rate. The decline in shoot growth rate accelerated as the paclobutrazol concentration increased. Shoot elongation was completely inhibited by paclobutrazol at $3.4 \times 10^{-1}$ μM and 3.4 μM by 14 DAT, whereas the $3.4 \times 10^{-2}$ and $3.4 \times 10^{-3}$ μM concentrations reduced the shoot growth rate by 87% and 13%, respectively, compared to the control. The reduced growth rates resulted in significant reductions in overall extension growth from 0 to 21 DAT for all paclobutrazol treatments (Table 1).

Concomitant with the reduction in shoot growth was a reduction in stem weight (Table 1). As paclobutrazol concentration increased, stem weights declined. However, above the $3.4 \times 10^{-1}$ μM concentration there was no further decline in stem weight. All results are based on dry weights, since fresh weight and dry weight data followed similar trends. Calculations of specific stem weight ($mg \cdot cm^{-1}$) showed no significant changes due to paclobutrazol treatments (data not shown). However, there was a trend toward lower specific stem weights at the $3.4 \times 10^{-2}$ and $3.4 \times 10^{-3}$ μM concentrations.

The paclobutrazol-induced reduction in shoot growth was due to a reduction in the internode length rather than a reduction in the number of nodes (data not shown). Similar observations previously have been reported for sunflowers (19) and apple seedlings (16).

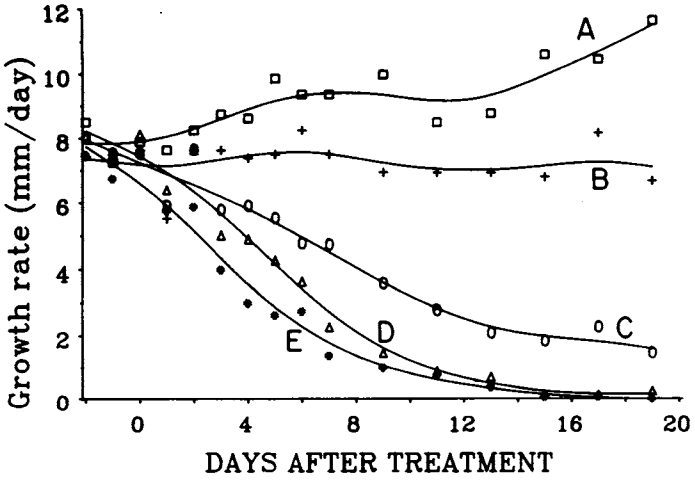


Fig. 1. Reductions in growth rates of peach seedlings treated with 0 (line A), $3.4 \times 10^{-3}$ μM (line B), $3.4 \times 10^{-2}$ μM (line C), $3.4 \times 10^{-1}$ μM (line D), and 3.4 μM (line E) of paclobutrazol. Each point represents the average growth rate of eight seedlings. Significance of treatment effect was NS (day 0), NS (day 1), * (day 2), ** (day 4), ** (day 9), ** (day 15), and ** (day 19). Nonsignificant (NS) and significant at the 5% (*) and 1% (**) levels.

Table 1. Influence of paclobutrazol on total extension growth and stem weight of peach seedlings.

| Paclobutrazol concn (μM) | Total extension[z] growth (mm) | Inhibition (%) | Stem[y] wt (mg) |
|---|---|---|---|
| 0 | 187 | --- | 1211 |
| $3.4 \times 10^{-3}$ | 143 | 23.1 | 966 |
| $3.4 \times 10^{-2}$ | 68 | 63.4 | 916 |
| $3.4 \times 10^{-1}$ | 40 | 78.5 | 741 |
| 3.4 | 29 | 84.5 | 767 |
| Significance | *** | -- | ** |
| Linear | *** | --- | *** |
| Quadratic | *** | --- | NS |
| Cubic | * | --- | NS |

[z]Stem growth from 0 to 21 DAT.
[y]Based on dry weight.
NS,*,**,***Nonsignificant or significant at the 5%, 1%, or 0.1% levels, respectively.

Although the total number of leaves produced was unaffected by paclobutrazol, leaf area was reduced by all paclobutrazol treatments (Fig. 2A). Similar reductions in leaf area have been reported on several crops (16, 19, 25). Leaf area declined as paclobutrazol concentration was increased; however, above the $3.4 \times 10^{-1}$ μM level, there was no further significant reduction (Fig. 2A). The greatest incremental reduction in leaf area occurred between 0 and $3.4 \times 10^{-3}$ μM paclobutrazol. The decline in leaf area resulting from this treatment accounted for about half of the total loss in leaf area observed in the highest concentration used, $3.4 \times 10^{-1}$ μM.

Paclobutrazol also altered leaf weight, although to a lesser extent than leaf area. Increasing concentrations of paclobutrazol up to $3.4 \times 10^{-2}$ μM caused significant declines in leaf weight (Fig. 2B). Above this concentration, there was no further decline in leaf weight. The net result of these changes in leaf area and weight was that specific leaf weight ($mg \cdot cm^{-2}$) was increased by paclobutrazol (Fig. 2C). The greatest relative changes in specific leaf weight occurred between 0 to $3.4 \times 10^{-3}$ μM and between $3.4 \times 10^{-1}$ μM to 3.4 μM treatments of paclobutrazol.

Examination of leaf blade cross sections showed that leaves from treated plants were thicker than control leaves (data not shown). Dalziel and Lawrence (7) have reported analogous changes in lamina thickness and specific leaf weight in paclobutrazol-treated sugarbeets.

Total shoot weight also was reduced by paclobutrazol (Fig. 2D). The decline in weight was linear up to $3.4 \times 10^{-1}$ μM, after which there was no further significant reduction.

Paclobutrazol reduced root weight only at the highest concentration, 3.4 μM (Fig. 2E). However, other trends were apparent. At $3.4 \times 10^{-3}$ μM paclobutrazol, root weights tended to decrease. At increasing concentrations (up to $3.4 \times 10^{-1}$ μM), root weights increased.

Root morphology also was altered as paclobutrazol concentration was increased (Fig. 3). There was no apparent effect at the lowest rate, $3.4 \times 10^{-3}$ μM. However, when paclobutrazol was increased to $3.4 \times 10^{-2}$ μM, roots were somewhat shortened and thickened but otherwise appeared normal. At the $3.4 \times 10^{-1}$ μM and 3.4 μM concentrations, roots were progressively shorter and thicker, and there was an increased production of lateral roots near the root tips. Similar changes have been

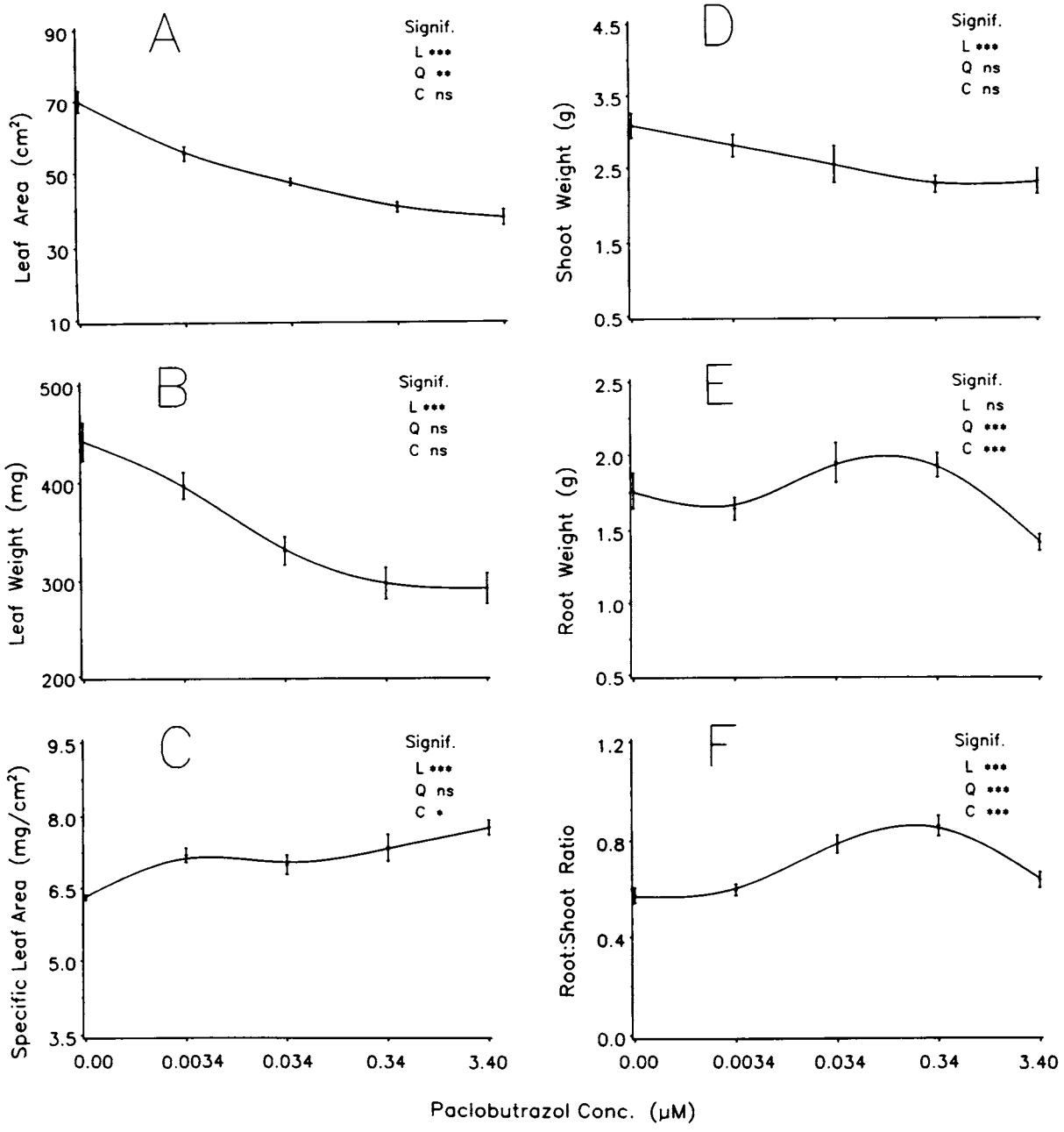


Fig. 2. The influence of paclobutrazol on leaf area (**A**), leaf weight (**B**), specific leaf weight (**C**), shoot weight (**D**), root weight (**E**), and the root : shoot ratio (**F**) on a dry weight basis 21 DAT. Vertical bars represent ± SE, n = 8. Linear (L), quadratic (Q), and cubic (C) significance at the 5% (*), 1% (**), and 0.1% (***) levels.

observed on apple seedlings (3, 17) and soybeans (8). Microscopic examination of the roots in this study indicated that the increased diameter of treated roots was predominantly attributable to increases in the width of the root cortex. Transverse and longitudinal sections showed that cortical parenchyma cells were enlarging more isodiametrically rather than longitudinally as normal (data not shown).

The interaction of paclobutrazol-induced changes in root and shoot development resulted in changes in the root : shoot ratio. As paclobutrazol concentration increased shoot growth was inhibited, whereas root growth remained relatively unchanged. The net result was that root : shoot ratios were increased (Fig. 2F). However, at a paclobutrazol concentration of 3.4 μM, both root and shoot growth were inhibited to the same degree and the root : shoot ratio was comparable to the control value.

## Discussion

Shoot growth rate data indicate that paclobutrazol concentration influenced both the rate at which the growth rate decreased and the total reduction in growth rate that was achieved. Increases in paclobutrazol concentration up to $3.4 \times 10^{-1}$ μM depressed growth at an increasing rate. However, both growth rate and extension growth data show that the dose response of shoot growth to paclobutrazol was saturated above the $3.4 \times 10^{-1}$ μM level. At the lower end of the range, paclobutrazol concentrations below $3.4 \times 10^{-4}$ μM are likely to be ineffective in altering shoot growth given the response of the $3.4 \times 10^{-3}$ μM treatment. However, rates below $3.4 \times 10^{-3}$ μM have yet to be evaluated.

Using growth rate and extension growth data, the paclobutrazol concentration that causes a 50% inhibition ($KI_{50}$) in shoot

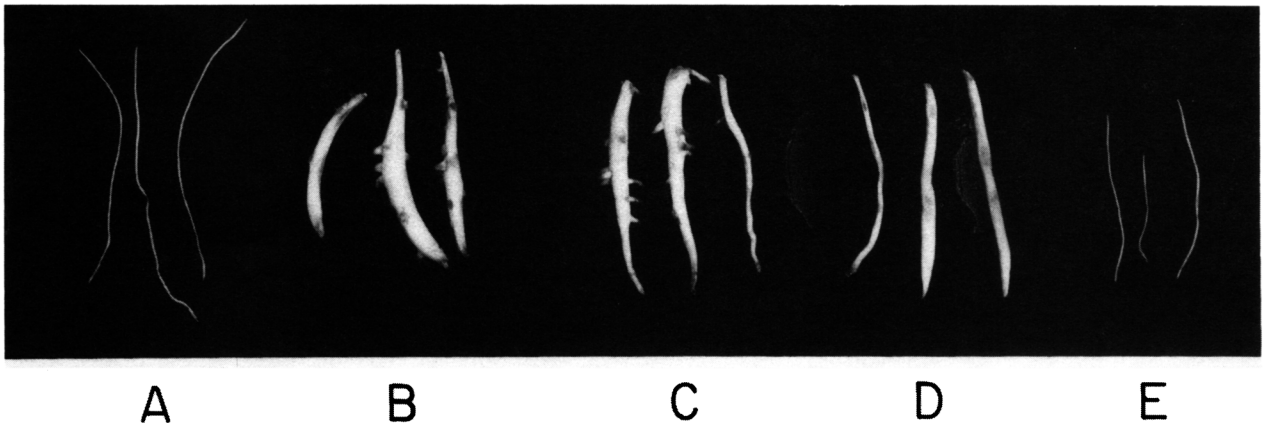


Fig. 3. Root tips, 2 to 3 mm in length from control (**A**) and plants treated with 3.4 μM (**B**), 3.4 × $10^{-1}$ μM (**C**), 3.4 × $10^{-2}$ μM (**D**), and 3.4 × $10^{-3}$ μM (**E**) of paclobutrazol 21 DAT.

growth was calculated to be between 0.01 and 0.025 μM (2.9 – 7.4 ppb). This range corresponds closely to the $KI_{50}$ of paclobutrazol inhibition of GA biosynthesis, 0.02 μM, observed by Hedden and Graebe (12) in cell-free extracts and is in agreement with previous work (6, 15) indicating that paclobutrazol may inhibit shoot growth primarily through inhibition of GA biosynthesis.

From comparison of changes in stem elongation (Table 1) to changes in leaf area (Fig. 2A) at increasing paclobutrazol concentrations, it appears that leaf area is more sensitive to alteration by paclobutrazol than stem elongation. The largest relative reduction in leaf area occurred between 0 and 3.4 × $10^{-3}$ μM, whereas the largest relative reduction in stem elongation occurred between 3.4 × $10^{-1}$ and 3.4 × $10^{-2}$ μM concentrations. However, this difference in sensitivity may merely be a manifestation of paclobutrazol transport in plants. Being predominantly a xylem-mobile compound (10), paclobutrazol most likely accumulates to a greater extent in developing leaves than in elongating stem tissue. Therefore, at a given dose of paclobutrazol, the concentration of the compound to which cells are exposed would be higher in the leaves than in the stem.

Since paclobutrazol treatments cause a general reduction in shoot mass, it might be expected that a shift in resource allocation could bring about a general increase in root mass. However, the situation appears more complex. The highest concentration of paclobutrazol tested decreased root weight, but lower concentrations showed a tendency toward increasing root mass. Previous reports have also noted that paclobutrazol can either increase (2, 3, 17) or decrease (13, 24) root growth. This variability may be due to the concentrations and methods of application used. Treatments that maximize effects on shoot growth relative to root growth (i.e., foliar sprays) may result in increased root growth, whereas treatments that expose the root to high concentrations of paclobutrazol may reduce both root and shoot growth.

It is uncertain whether the changes observed in roots of treated plants are a direct effect of paclobutrazol on root growth, or an indirect effect resulting from the modification of shoot growth. Williamson et al. (23) have reported similar reductions in root growth of peach seedlings that received foliar treatments. If transport of the compound is primarily via the xylem, this would suggest an indirect effect on root growth by paclobutrazol. However, additional data are necessary before the situation can be clarified.

The effects of paclobutrazol on peach seedling growth presented here are consistent with those observed on a wide variety of species. However, these data indicate that peach seedlings are sensitive to quite low (3.4 × $10^{-3}$ μM or 1 ppb) levels of paclobutrazol when interfering factors, such as soil interaction, are removed. Since the majority of shoot growth parameters measured showed little further change above the 3.4 × $10^{-1}$ μM treatment, it appears that relatively little paclobutrazol is required to produce significant growth inhibition. To improve the degree of control over vegetative growth with paclobutrazol, future work needs to focus on how soil interactions and the method of application influence the amount of retardant actually reaching the active sites in the plant.

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# Gradients in Maturity and Sugar Levels of Fruit Within Peach Trees

**Ian R. Dann and Peter H. Jerie**
*Institute of Irrigation and Salinity Research, Tatura, Victoria, Australia 3616*

*Additional index words.* *Prunus persica,* flowering

***Abstract.*** **Peach [*Prunus perscia* (L.) Batsch] flowers opened first at the base of young trees and last at the top. In contrast, fruit ripened first at the top of trees and at the tips of laterals. Dry weight and percentage dry weight (% dwt) of the mesocarp of fruit from the upper canopy were consistently greater throughout the season than for fruit from the lower canopy. These differences were large enough to have marketing significance and important implications for the future of mechanical harvesting.**

Uneven ripening of fruit within individual trees is an important economic problem worldwide. For processing peaches in Victoria, the earliest mature at least 2 weeks before the latest on a tree. Consequently, at least two picks are needed to hand-harvest trees and reduce culling loses from unripe and over-ripe fruit. In mechanical harvesting trials at Tatura, up to 50% of the crop was lost from preharvest drop and from the harvest of over-ripe and green fruit (L. van Heek, personal communication). Appropriate selection of cultural practices and cultivar may reduce uneven ripening, but it still remains a significant problem.

Canopy position affects maturity and quality of peach fruit (9, 10). Peaches from the tops of trees are softer, more blushed, and have a higher proportion of soluble solids than peaches from the tree's interior (9). In this paper we detail some of the tree parameters affecting maturity and quality of clingstone peaches and attempt to separate the influence of environment from endogenous effects on these parameters.

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## Materials and methods

Experiments were performed on peach trees at the Institute for Irrigation and Salinity Research, Tatura, Victoria, Australia.

*Expt. 1a.* On each of nine 1-year-old trees ('Golden Queen') grown from cuttings, five evenly spaced shoots were selected and other shoots were removed. In the second year after planting, the proportion of open flowers on each shoot was assessed at full bloom.

*Expt. 1b.* Six limbs from two mature, vase-shaped 'Golden Queen' trees (seedling rootstock) were divided into 0.5-m sections starting 1 m above ground. At full bloom, the numbers of opened and unopened flowers were counted on two laterals from each section. All fruit from each limb were harvested when the majority were assessed to be canning ripe and before significant preharvest drop occurred. Skin color of 25 fruit from each section was measured with a HunterLab Color/Difference Meter, Model D25–2 (5). Care was taken to avoid blushed or blemished areas of skin. The Hunter 'a' scale measures redness and greenness in the positive and negative ranges, respectively, and the readings are highly correlated with visual grading of fruit and hence with canning quality (results not shown). The cultivar Golden Queen and its sports color from the stone outwards at maturity and are characterized by even skin and flesh color. Consequently, either skin or flesh color can be used to estimate fruit ripeness.