Effect of Irrigation and Tree Density on Peach Production

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Abstract. An experimental peach (Prunus persica [L.] Batsch cv. Harken/Siberian C) orchard was planted on Fox sand in 1973 at 266, 358 and 536 trees/ha. The plots were either not irrigated or irrigated at a frequency necessary to prevent the available soil moisture (ASM) from falling below 25% or 50%. Irrigation stimulated tree growth in the earlier but not in the later years of the experiment. Growth was reduced by an increase in tree density especially in the later years at the highest density. Only in 50% ASM plots was growth not affected by high tree density. Irrigation (50% ASM) increased cumulative, marketable yields in the first 5 years of production by up to 9.7% while tree density (536 trees/ha) increased similar yields by up to 74.6% without irrigation and up to 99.5% with irrigation (50% ASM + 536 tree/ha). Irrigation consistently improved the proportion of large and medium-sized fruit while reducing the proportion of small, unmarketable fruit. Tree density had a smaller and less consistent influence on fruit size. Neither irrigation nor tree density adversely affected split pits, raw product fruit quality, cold hardiness or canker (Leucostoma spp.) susceptibility. There were no significant interactions of irrigation and density treatments in any year, indicating that each treatment might be used to advantage without adversely affecting the other, at least in the first 7 years of growth and first 5 years of production.

No research data are available on the water requirement of peach in the sub-humid climate of Southwestern Ontario and grower experience is inconclusive. However climatic and soil moisture information for this region and response of other crops such as cucumbers, potatoes and corn (7, 8, 9) predict a yield response to irrigation. Irrigation of peaches is a common commercial practice in arid and semi-arid regions of the world (2, 16, 20). The 3 major benefits from irrigation have been improved tree growth, greater fruit production, and larger fruit size (2, 4, 10, 16, 20).

Peach yields can be dramatically increased by increasing tree density. Recent studies conducted in Canada (19), the United States (6, 21), and Australia (3), for example, show that peach yields increase as a function of tree density. However, irrigation has usually not been included as an experimental variable in orchard management studies involving high density culture. Instead, it has been used as a management tool to ensure optimum growth and yield. Thus, there is little information on the effects and interactions of irrigation and tree density on peach, although it appears that as density increases the irrigation requirement may also increase (2).

Materials and Methods

An experimental peach orchard of Harken/Siberian C was planted in April 1973 on Fox sand at the Ridge Farm of the Harrow Research Station about 6 km southeast of Harrow, Ontario. The orchard site was fumigated the previous fall with the nematicide D-D (a mixture of 1, 2 dichloropropane and 1, 3 dichloropropane) applied at 234 liters/ha. The experimental design consisted of a split plot in a randomized complete block with 4 replications. Irrigation treatments were assigned to whole plots and density treatments to sub plots. Guard rows separated the irrigation treatments.

Irrigation treatments consisted of (a) no supplemental irrigation, (b) supplemental irrigation during the growing season to prevent the available soil moisture (ASM) from falling below 25% and (c) supplemental irrigation to prevent ASM from falling below 50%. In 1973, all plots were irrigated equally to aid in tree establishment. In 1974 and thereafter, irrigation treatments were applied as indicated to achieve the desired soil moisture levels. A solid-set sprinkler irrigation system with low risers (30 cm) and...
low angle (7°) nozzles was used. Soil moisture during the growing season was monitored on a weekly or bi-weekly basis at 20 cm below the soil surface using a Nuclear Chicago neutron scaler (No. 5920) and probe (No. 4810). In the 25% ASM plots, whenever the moisture level approached 25% ASM, irrigation water (44 mm) was applied to return the soil moisture to field capacity (100% ASM). Similar procedures were followed in the 50% ASM plots except that 32 mm water was required to raise the moisture level from 50% ASM to field capacity.

Density treatments consisted of standard spacings between rows of 6.10 m and within rows of 6.10, 4.57 and 3.01 m to provide respective densities of 266, 358 and 536 trees/ha. The lowest density is traditional for peaches in southwestern Ontario. The intermediate density is now commonly used in new plantings but the highest density is seldom used by commercial growers.

All "dormant" pruning was done during or shortly after bloom. In the early years (1973 to 1975), emphasis was placed ontraining the trees to a standard open center with 3 or 4 main scaffold branches. In later years (1976 to 1979), the emphasis was to remove dead and weak growth, and lightly thin out lateral growth on strong branches to reduce shading and promote flower bud differentiation. Beginning in 1975 and continuing thereafter, fruit thinning consisted of spacing the fruit about 20 cm apart. Fruit set was heaviest in 1979 but some thinning was required each year.

The fertilizer program consisted of an annual broadcast application of 0.0–10–30 (NPK) in the early spring at 334 kg/ha followed by a separate application of N during bloom. N was applied in the form of NH₄NO₃ and was placed in a band around the drip line of each tree. Each tree received the same amount of N. No N was applied in the year of planting but the amounts applied from 1974 to 1979, were respectively: 28, 57, 76, 113, 152, and 227 g/tree. The rate in 1979 was inadvertent and should have been 189 g/tree.

All other management practices were standard ones recommended for Ontario peach growers (18).

Trunk circumference was measured annually in the fall 20 cm above the soil surface and expressed as trunk cross sectional area. Fruit yields were obtained annually between 1975 and 1979. In each year, samples were obtained from each picking to determine fruit size and grade. Yields were expressed on the basis of total and marketable yields. Fruits less than 5.4 cm in diameter were considered unmarketable.

Fruit quality was assessed in 1979 using standard analytical procedures (15, 17) for pH, soluble solids (° Brix) and percent titratable acidity of raw fruit pulp at canning maturity from fruit samples obtained from each plot.

Natural bud mortality was monitored in March 1977 and 1978 and in February 1979 and assessed according to standard methods (13, 14). Cold hardness in 1979 was determined by controlled freezing tests from which T₅₀ values for flower buds, shoot phloem and xylem were calculated (14).
The winter of 1978-79 was the most severe since initiation of the experiment in 1973. Ratings of each tree in every plot were made for winter injury and perennial canker on a scale of 1 (worst possible) to 10 (best possible) on May 16, 1979 during bloom but before the trees were pruned. Canker ratings were made again on June 24, 1980 after the trees had been pruned. On the same dates, each tree in every plot was visually rated for percent bearing surface. Dead and missing trees were given a zero rating and included in the plot means.

All data were analyzed first by analysis of variance (AOV) for split plots. The irrigation and density effects were then analyzed separately using a single degree of freedom AOV.

Results

Water applications (1974-1979). The driest growing season (May to August) was 1978 with a total of 188 mm of rain and the wettest was 1975 with 357 mm. In 3 of the 6 years (1974, 1976, 1978), the natural precipitation during the growing season was below the long term mean of 273 mm. In general very little supplemental irrigation was required in May when the trees were leafing out, more was needed in June when shoots were making rapid growth, even more was needed in July when the fruits were rapidly increasing in size, and slightly less was needed in August when the fruits were ripening and being harvested. The 25% ASM plots were usually irrigated 4 times while the 50% ASM plots were usually irrigated 12 times per year.

Cumulative growth. There was a progressive increase in growth as a function of tree age (Fig. 1). The response was linear regardless of irrigation or density treatments. Tree growth in 1974 and 1975 was significantly greater in irrigated than in unirrigated plots but from 1976 to 1979 the irrigation effect on annual cumulative growth was not significant. A similar analysis of the density effects revealed that beginning in 1974 and continuing thereafter, there was a consistent and significant influence of tree density on annual cumulative growth. Irrigation and density treatments did not interact significantly. In low and medium density plots trees grew at similar rates, but in high density plots they were consistently smaller, except in plots receiving the 50% ASM irrigation. It is not clear why growth was suppressed more by high density + 25% ASM than by the same tree density without supplemental irrigation (Fig. 1).

Annual yield. The annual yield response between 1974 and 1978 was approximately linear but increased sharply in 1979 in all plots (Fig. 2). The sharp increase in yield in 1979 was thought to be the combination of several factors including a heavier than usual fruit set, a higher than usual level of N, and a cooler and more humid growing season. The split plot analysis of the annual yield data revealed that total marketable yields were significantly increased by irrigation (P = 5%) in 1975 and 1976 but not thereafter. However, in the single degree of freedom AOV of the individual irrigation effects, there was a small increase (P = 5%) attributable to supplemental irrigation in each year except 1978. Marketable yields were significantly (P = 1%) increased by tree density in each of the 5 years in the split plot and single degree of freedom AOV. The interaction of irrigation x tree density was not significant in any of the 5 years.

Cumulative yield. Total yields averaged over all tree densities were increased by 6.3% with 50% ASM irrigation and reduced by 5.7% with 25% ASM irrigation compared with unirrigated checks (Table 1). Yield reduction in 25% ASM plots was caused by the high tree density but not by the medium or low tree densities. Yield reduction in this case was probably a reflection of the re-
duced tree size (Fig. 1). The proportions of total yields that were marketable were all high (89.6% to 94.1%), regardless of irrigation or density effects. However, marketable yields averaged over all densities were 9.7% higher with 50% ASM irrigation and 2.3% higher with 25% ASM irrigation than without supplemental irrigation. While irrigation had a relatively small effect on increasing cumulative marketable yields, tree density had a dramatic effect on yield. Thus, high density and medium density plots outyielded low density plots by 72 and 34%, respectively, when averaged over all levels of irrigation. Nevertheless, it required a combination of the highest density and the highest level of supplemental irrigation to obtain the highest marketable yield. This combination resulted in a yield increase of 99.5% compared with the traditional commercial practice of low density and no supplemental irrigation, and outyielded the more recent practice of medium density and no supplemental irrigation by 51%. In irrigated and unirrigated plots, the largest increases in marketable yields over the check were associated with the highest tree densities (64.3 to 99.5%) followed by the medium tree densities (31.9 to 44.2%), while low tree densities in irrigated plots resulted in only small yield increases (1.9 to 9.3%) compared with the low density, unirrigated check.

**Fruit size.** Each year irrigation increased fruit size but only in some years was the effect statistically significant in the split plot AOV (data not shown). The proportion of large-size (>6.4 cm) fruit was increased (P = 5%) in 1975 and 1979, the proportion of medium-sized (>5.4 to <6.4 cm) fruit was increased (P = 5%) only in 1975, while the proportion of small-sized (<5.4 cm) fruit was not affected by irrigation in any year. Tree density also influenced fruit size but the effect was only significant in 1975, 1976 and 1978. In 1975 the proportions of both medium and large-sized fruit were significantly increased (P = 5%, P = 1%, respectively), while in 1976, the proportion of large-sized fruit alone was increased (P = 5%). Only in 1978, the driest year, did tree density increase the proportion of small, unmarketable fruit (P = 5%). In that year, the proportion of undersized fruit was greatest in unirrigated plots at the highest tree density. There was no interaction of irrigation and density treatments that affected fruit size in any of the 5 years.

In 1979, a larger sample size (48 kg of fruit per plot per picking date) was used to estimate fruit size compared with that used in previous years (28 kg). It was already stated that the density effect in 1979 was not significant, therefore the data were averaged to show the irrigation effects (Table 2). The main effects of irrigation were to greatly reduce the proportion of small, unmarketable fruit; reduce the proportion of medium-sized fruit; and greatly increase the proportion of large fruit. The 2 irrigation levels had essentially the same effect on the proportion of fruit in each of the 3 size classes.

**Other factors.** During the course of this study data were also obtained on the following: (a) split pits, (b) raw product fruit quality (pH, titratable acidity), (c) natural flower bud mortality, (d) visual ratings of winter injury, (e) visual ratings of fruit bearing surface remaining following test winters, (f) cold hardiness of flower buds, shoot phloem and xylem determined from controlled freezing tests and (g) visual ratings of incidence and severity of perennial canker (*Leucostoma* spp.) on experimental trees. In no instance were any of these factors significantly influenced by irrigation or tree density treatments nor was there any interaction of these treatments (data not presented).

**Discussion**

Irrigation improved tree growth, fruit production and fruit size but the magnitude of these responses was generally smaller than those previously reported (2, 4, 10, 16). In other regions (2, 4, 10, 16) where similar studies have been made, the growing seasons are typically longer, hotter and drier, resulting in greater soil moisture and growth stress and a consequently greater response to irrigation.

In our studies irrigation had larger effects on growth and yield in the early (1974 to 1976) than in the later (1977 to 1979) years. Favorable responses to irrigation in 1974 and 1976 were easily explained because both years were drier than usual. However, the 1978 growing season was one of the driest on record, yet irrigation had only minor effects on growth, yield and fruit size. We suggest that in the early years most of the root systems of the young trees were within 1.5 m of the soil surface and more subject to soil moisture stress than in later years when the trees were deeper-rooted and perhaps at least a portion of the root system was capable of exploiting moisture reserves deeper in the soil profile closer to the water table which was 3 m below the soil surface. Evidence in support of this was that weeds in unirrigated plots in

**Table 1.** Effect of irrigation and tree density on cumulative yields of 'Harken'/Siberian C for the first 5 years of production (1975 to 1979).

<table>
<thead>
<tr>
<th>Irrigation treatments</th>
<th>Density (trees/ha)</th>
<th>Total yield (MT/ha)</th>
<th>Marketable yield (MT/ha)</th>
<th>Increase in marketable yield over check (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Unirrigated</td>
<td>266</td>
<td>55.7</td>
<td>50.7</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>358</td>
<td>72.4</td>
<td>66.9</td>
<td>2.3</td>
</tr>
<tr>
<td></td>
<td>536</td>
<td>98.9</td>
<td>88.6</td>
<td>9.7</td>
</tr>
<tr>
<td>Irrigated (25% ASM)</td>
<td>266</td>
<td>59.3</td>
<td>55.5</td>
<td>9.3</td>
</tr>
<tr>
<td></td>
<td>358</td>
<td>77.2</td>
<td>71.9</td>
<td>41.7</td>
</tr>
<tr>
<td></td>
<td>536</td>
<td>89.2</td>
<td>83.3</td>
<td>51.2</td>
</tr>
<tr>
<td>Irrigated (50% ASM)</td>
<td>266</td>
<td>55.8</td>
<td>51.7</td>
<td>64.3</td>
</tr>
<tr>
<td></td>
<td>358</td>
<td>77.9</td>
<td>73.2</td>
<td>94.0</td>
</tr>
<tr>
<td></td>
<td>536</td>
<td>107.6</td>
<td>101.2</td>
<td>94.1</td>
</tr>
</tbody>
</table>

*The check treatment was the unirrigated + low density combination.*

**Table 2.** Effect of irrigation on percent of sample in each of 3 fruit size classes of 'Harken'/Siberian C in the fifth year of production (1979).

<table>
<thead>
<tr>
<th>Irrigation treatment</th>
<th>Percent of sample in size classes</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Large (&gt;6.4 cm)</td>
</tr>
<tr>
<td>Unirrigated</td>
<td>15.7</td>
</tr>
<tr>
<td>25% ASM</td>
<td>45.3</td>
</tr>
<tr>
<td>50% ASM</td>
<td>51.1</td>
</tr>
</tbody>
</table>

*Values in table are based on 144 kg sample of fruit per irrigation treatment. This size class is unmarketable in Ontario.*
1978 wilted and died while adjacent peach trees showed no signs of moisture stress. Furthermore, data on leaf water potential and stomatal diffusion resistance of unirrigated and irrigated trees which will be published elsewhere indicated that the former were under no greater moisture stress than the latter.

The low and high levels of supplemental irrigation had essentially the same effects on growth and fruit size (Fig. 1, Table 2). Marketable yields, on the other hand, were greater with the high than the low level of irrigation (Fig. 2, Table 1). At low and medium densities yield responses to either level or irrigation were small but at high densities the largest yield responses were obtained with the high level of supplemental irrigation. These results help explain why local grower results with irrigation of peaches have been inconclusive. Typically only mature orchards are irrigated and these orchards are planted either at low or medium densities but not at high densities. Thus, their response to irrigation would be expected to be small and difficult to detect.

On the basis of our results thus far, it appears that irrigation of peaches in southwestern Ontario would be particularly beneficial in promoting good tree establishment, rapid growth in the early years and high early production, especially at high tree densities. In later years, the major benefits of irrigation may be from improvement of fruit size. No interaction of irrigation and tree density treatments were found in the first 7 years of this experiment. This may change as the trees reach full size and production, and for this reason the study will be continued for at least 4 more years.

During the course of this study, we obtained no evidence that irrigation reduced fruit quality as others have (16). Irrigation did not increase split pits, reduce cold hardiness or increase perennial canker (Leucostoma sup.) susceptibility, each of which was theoretically possible. However, it should be noted that ‘Harken’ is not particularly susceptible to any of these disorders and may not have been a sensitive test of the irrigation treatment in these respects. Accordingly, other commercially important scion/rootstock combinations should be tested before general recommendations are made with respect to irrigation.

Tree density had a much greater effect on growth rate and fruit production than irrigation (Fig. 1 and 2). Evidence for growth competition in relation to soil moisture stress was obtained at the highest density where growth was suppressed in unirrigated plots and those receiving a low level of supplemental irrigation, but at the high level of supplemental irrigation growth was not suppressed. Root competition at the highest density may also be adversely affecting growth (1).

The effects of tree density on annual yields and on cumulative marketable yields were dramatic. In the absence of irrigation, yields were increased by 74.6% with high tree density. When high densities were combined with a high level of supplemental irrigation yields were increased by 99.5% (Table 1). Large increases in yield as a function of tree density have been recently reported from the Northern and Southern Hemisphere (3, 6, 19, 21), indicating that the density response is sufficiently great to overcome other climatic and edaphic variables. Tree density had a smaller effect on fruit size than irrigation. Fruit size was largest at the closest spacing but this effect was not consistent from year to year. This spacing may have induced deeper rooting, as has been found to be the case with apples (11), which in turn may have served to reduce moisture stress. We found that different tree densities did not adversely affect fruit quality, split pits, cold hardiness or perennial canker incidence and severity. Thus, there appeared to be no major undesirable consequences in these respects that might result from an increase in tree density from 266 to 536 trees/ha, at least with ‘Harken’/Siberian C. However, the highest density was considered to be close to the limit that would still permit the use of conventional pruning and management practices with conventional orchard machinery and equipment. Our purpose was not to determine the maximum tree density for maximum yields, but rather to use a density that would still permit other traditional management practices and use of conventional orchard machinery and equipment. A density of 536 trees per ha with rows spaced 6.1 m apart achieved this objective.

In no instance during the first 7 years of this experiment was there any evidence for an interaction of irrigation and density treatments. Thus, it appeared that each treatment could be adopted without adversely affecting the other. In most cases the combined effects of both treatments were better than either treatment on its own, especially in the case of fruit production (Table 1). It is possible, however, that as the trees become older and growth and production begin to level off, the treatments may then begin to interact. This will be studied further and reported upon later when the experiment is completed.

It was not possible to superimpose N fertilization treatments on this experiment, thus each tree received the same amount of N in any given year. The rates of N we used were usually higher than those presently recommended (18). The sharp increase in yield observed in 1979 in all plots, regardless of irrigation or density treatments (Fig. 2) suggest that nutritional studies involving different levels of N may be helpful in establishing optimum rates of N for Fox sand.

On the basis of the results obtained for the first 7 years of this experiment, the best treatment combination (50% ASM + 536 trees/ha) out-yielded the standard commercial practice (unirrigated, 266 trees/ha) by 99.5%. However, it was also possible to surpass the yield of the standard practice by 74.6%, simply by increasing tree density without irrigation (Table 1). Economic studies are planned to determine which of the 9 treatment combinations are likely to be the most profitable.

Literature Cited
Reducing Leaf Epinasty in Mechanically Stressed Poinsettia Plants

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Abstract. Foliar sprays of either 10 mM aminoethoxyvinylglycine or 3 mM silver ions applied 24 hours before potted poinsettia plants (Euphorbia pulcherrima Klotzsch ex. Willd., cv. Annette Hegg Diva) were sleeved for 24 hours, significantly reduced the development of leaf epinasty after removal of the sleeves.

We previously showed that mechanically bent petioles of certain poinsettia cultivars produced sufficient stress-ethylene to induce leaf and branch epinasty (19). Under similar stress, other cultivars produced much less stress-ethylene and did not develop leaf or branch epinasty. The same pattern of cultivar susceptibility to mechanical stress-induced epinasty was also observed when epinasty was induced by exposing these cultivars to 10 μl liter⁻¹ ethylene in air for 4 hr. Ethylene has also been implicated in the development of leaf epinasty following mechanical stress in other poinsettia cultivars (16, 17).

Leaf epinasty results when the adaxial portion of the petiole grows faster than the abaxial portion. This enhanced growth of the upper portion of the petiole results from an increased adaxial concentration of auxin, and has been reported in plants either rotated horizontally on a clinostat (11), or exposed to ethylene (12). Auxin is further implicated in the development of epinasty by the observation that removal of the leaf blade, which is the source of auxin, prevented epinasty, while application of indoleacetic acid (IAA) to the debladed petiole reinstated a near normal epinastic response to both mechanical stress (11), and ethylene (10). Since auxin appears necessary for the development of leaf epinasty in a number of species (10, 11, 12), and since ethylene is known to perturb both auxin synthesis and transport (6), the increased concentration of ethylene within the petioles of mechanically stressed poinsettia plants (19) may induce epinasty by perturbing auxin distributed within the petiole. This idea is supported by the observation that antagonists of ethylene action prevent leaf epinasty (5, 10, 19). However, the role of ethylene in modifying auxin distribution within the petiole has been questioned (14).

During ethylene biosynthesis, the amino acid methionine is converted to 1-aminocyclopropane-1-carboxylic acid (ACC) which is then converted to ethylene (1). Analogues of methionine reduce ethylene synthesis in a number of plant tissues. For example, foliar sprays of 0.5 mM aminoethoxyvinylglycine (AVG) to apple trees 1 month before harvest delayed the development of the ethylene climacteric in harvested fruit (4). Application of 0.13 mM naphthaleneacetic acid (NAA) with the AVG synergistically reduced ethylene production from the harvested fruit.

A number of ACC analogues, such as cyclopropylamine (CPA), are available, but there has been no research reported on their ability to reduce ethylene production. Free-radical scavengers, such as N-propyl gallate (NPG), are known to reduce ethylene production (3).

Another inhibitor of ethylene biosynthesis, alpha-aminoxyacetic acid (AOA), has, subsequent to the completion of our experiments, been shown to prevent auxin-induced epinasty in tomato plants (2). A foliar spray of 1.0 mM AOA and 0.1 mM NAA reduced NAA-induced ethylene production by about 90% (to the level of the water control), and reduced NAA-induced epinasty to the level of the water control. Like AVG, AOA inhibited both ethylene biosynthesis and leaf epinasty.

Other plant hormones and growth regulators reduce the effects of ethylene. For example, foliar sprays of gibberellic acid (GA₃) reduced ethylene-induced leaf epinasty in sunflower plants (13), but had little effect on leaf epinasty of waterlogged tomato plants (8, 21). These plants were effectively treated with the cytokinin benzylamino purine (BA), which relieved most of the ethylene-induced symptoms of flooding injury, including leaf epinasty.

1 Received for publication August 25, 1980. Paper No. 6550 of the Journal Series of the North Carolina Agricultural Research Service, Raleigh, N.C. The use of trade names in this paper does not imply endorsement by the North Carolina Agricultural Research Service of products named, nor criticism of similar ones not mentioned.

2 The authors wish to acknowledge Paul Ecke Poinsettia Inc., Encinitas, Calif., for the donation of poinsettia cuttings, and MAAG Agrochemicals, Vero Beach, Fla., for the donation of AVG.