

# Peach Tree Growth, Yield, and Profitability as Influenced by Tree Form and Tree Density

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*Additional index words.* *Prunus persica*, yield, fruit weight, vegetative growth, net present value

**Abstract.** ‘Norman’ peach [*Prunus persica* (L.) Batsch] trees were trained to the central-leader or open-vase form and were planted at high (740 trees/ha), or low (370 trees/ha) density. A third density treatment was a HIGH → LOW density, where alternate trees in high-density plots were removed after 6 years to produce a low-density treatment. From 3 to 5 years after planting, trunk cross-sectional areas (TCA) increased most for low-density trees. After 9 years, TCA was greatest for low-density and least for high-density trees. Because of differences in tree training, central-leader trees were taller than open-vase trees and tree spread was greater for low-density than for high-density trees. Annual yield per hectare was 15% to 40% greater for high-density treatments than for low-density treatments, but tree form had little influence on yield. Average fruit weight tended to be greater for low-density than for high-density treatments, but cumulative marketable yield was greatest for high-density and lowest for HIGH → LOW treatments. Income minus costs for 9 years was nearly \$4200/ha higher, and net present value was about \$2200/ha higher, for open-vase than for central-leader trees ( $P = 0.08$ ). Cumulative net present value for the 9 years was about \$2660/ha higher for high- than for low-density trees ( $P = 0.36$ ).

Peach yields in the mid-Atlantic region have increased little in the past three decades, primarily because orchard training and pruning systems have not changed. The low, spreading, open-vase tree, planted at wide spacings, is the dominant system, because it is easy to manage, orchard work is performed from the ground, and there is good light distribution throughout the canopy (Marini, 1990; Marini and Marini, 1983). However, in many studies, peach yields were positively related to the number of trees per hectare (Emerson and Hayden, 1975; Grossman and DeJong, 1998; Hartman, 1976; Layne and Tan, 1984; Phillips and Weaver, 1975; Taylor, 1988). Because there are no commercially available dwarfing peach rootstocks, as high-density orchards mature, tree crowding often hinders orchard operations, and shading of tree interiors may limit flower bud development and reduce fruit quality (Marini et al., 1991; Taylor, 1988).

Although several peach tree forms have been studied, they were rarely compared at the same tree density, so it is difficult to separate the individual effects of tree form and tree spacing. One exception was a recent report showing that at the same tree density, the KAC-V and the cordon systems produced similar yields per hectare (Grossman and

DeJong, 1998). When planted at low densities, open-vase trees had higher yield and crop value per tree, but lower yield and crop value per unit of land area under the canopy or per unit of canopy volume than did central-leader trees (Marini et al., 1995). In that study, however, central-leader trees were planted too far apart, whereas open-vase trees were planted too close together. Therefore, a comparison of the two tree forms at more realistic spacings is needed.

Although yield may be positively related to tree density, fruit weight may increase (Ferree, 1980) or decrease (Grossman and DeJong, 1998) with increasing the tree density. Peach researchers rarely report the crop values and costs associated with orchard systems. When four apple orchard systems were compared, internal rates of return tended to increase with increasing tree densities (Funt et al., 1986). The objective of this study was to determine the individual and interrelated effects of tree form and tree density on vegetative growth, yield, fruit size, and economic potential of open-vase and central-leader peach trees planted at three spacings.

## Materials and Methods

Semi-hardwood cuttings of ‘Norman’ were rooted in Aug. 1985 and were grown in a nursery for 2 years. In Mar. 1988, the trees were planted at the Virginia Tech College of Agriculture and Lifesciences Kentland Farm near Blacksburg, Va. The factorial experiment consisted of two tree forms [open-vase (OV) and central-leader (CL)] and three tree spac-

ings [high density (HIGH); low density (LOW); and high density → low density (HIGH → LOW)]. For the HIGH → LOW treatment, alternate trees at high density were removed after 6 years. The experimental design was a randomized-complete-block, split-plot, and there were four replicates of two rows per replicate. Each tree form was assigned randomly to one row per replicate and was considered the whole plot. Each of the three tree densities was assigned randomly within each row and served as the subplot. The experimental unit was five permanent trees per spacing. There was a guard tree between each density treatment and spacing of the guard trees was the same as that of the adjacent experimental trees. Guard trees also were planted around the entire planting.

The LOW trees were spaced 5.5 m between rows and 5.0 m in the row (370 trees/ha), and the HIGH trees 5.5 × 2.5 m (740 trees/ha). The HIGH → LOW trees were originally spaced 5.5 × 2.5 m (740 trees/ha). As trees started to crowd in 1990 (the third growing season), alternate trees were considered “temporary trees” and were dormant-pruned to a fan shape; each year in-row canopy width was limited to prevent crowding the adjacent “permanent tree.” After cropping in 1993 (the sixth growing season), temporary trees were removed with a chain saw without removing stumps, so the final tree spacing was 5.5 × 5.0 m (370 trees/ha).

Trees were trained to the OV or the CL form. The OV trees were typical for peach trees in the mid-Atlantic region (Marini, 1990). During the first two seasons, three or four scaffold branches per tree were selected and bench cuts were used to develop a low-spreading canopy. Bench cuts were not used on HIGH trees because a spreading growth habit was not needed to fill the allotted space. Tree height was limited to ≈2.1 m by dormant pruning. The CL trees were developed by selecting three or four wide-angled scaffold branches per tree located about 0.7 m above ground. Five or six short (<50 cm long) 1- and 2-year-old shoots were retained on the central leader from 0.9 to 1.7 m aboveground. A second tier of branches, 0.75 to 1.2 m long, was retained at ≈2.2 m by cutting into 2-year-old wood to a weak side branch.

All trees were dormant-pruned annually before bloom in late March. All trees were summer pruned annually in June, ≈50 to 60 d after bloom, to remove upright watersprouts and improve light distribution throughout the canopy. Pests were controlled according to local recommendations (Pfeiffer, 1998). During March, trees were fertilized annually with urea. For the first 4 years, fertilizer was applied on a per-hectare basis regardless of tree spacing. For years 1 through 4, the amount of actual N applied was 33.6, 33.6, 72.2, and 84.0 kg·ha<sup>-1</sup>, respectively. For years 5 through 9, N was applied at the rate of 0.25, 0.30, 0.15, 0.35, and 0.35 kg/tree. The rate was reduced in the seventh year because there was no crop. To supplement precipitation, trees were trickle-irrigated with an emitter placed ≈45 cm from each tree and each tree received ≈40 L of water per day during the 7 weeks before harvest.

Received for publication 20 May 1999. Accepted for publication 6 Dec. 1999. 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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Herbicides were used to maintain a 2-m-wide weed-free strip under the trees. Grass in the row middles was mowed when needed.

**Data collection.** Trunk circumference, measured each winter, was used to calculate trunk cross-sectional area (TCA). Tree height and spread were measured each winter from 1988 to 1993, but pruning thereafter seriously restricted tree size. Tree spread was the mean of canopy diameter measured parallel to and perpendicular to the row.

Trees bloomed in 1990, but a spring frost eliminated the crop. Trees cropped in 1991, 1992, 1993, 1995, and 1996, but a frost eliminated the crop in 1994. For the cropping years, fruit were thinned to leave  $\approx 15$  cm between fruit 45 to 55 d after bloom. Fruit were harvested when the ground color was yellowish-green and required one to five spot-pickings, depending on the year. During harvest, the number of fruit per five-tree-plot was recorded, and fruit were graded into four categories with a chain sizer. The number and weight of fruit in each size category were recorded. Average fruit weight was calculated by dividing the total weight per plot by the total number of fruit in that plot. The percentage of the crop that was marketable ( $>57$  mm diameter) was also calculated.

A partial economic analysis was performed for each experimental unit (plot of five permanent trees). Costs for trees, pruning, thinning, harvest, and packing were calculated on a per-hectare basis. The wage for all hourly labor was assumed to be \$5.25 per hour. Self-rooted trees were not available from commercial nurseries to verify tree costs, but cost was assumed to be \$3.25 per tree. Based on estimates provided by Virginia commercial peach growers, harvest costs for all fruit were assumed to be \$0.072 per kg (\$1.25 per 17.24-kg box), and packing costs for marketable fruit were assumed to be \$0.203 per kg (\$3.50 per box). Crop value was calculated using wholesale prices typical for Appalachian peaches during July 1992 to 1997, where the value of 57- to 64-mm-diameter fruit = \$0.58 per kg (\$10.00 per box), 65–70 mm diameter = \$0.69 per kg (\$12.00 per box), and  $>70$  mm diameter = \$0.812 per kg (\$14.00 per box). Fruit  $<57$  mm diameter had no value. In commercial orchards, nonmarketable fruit may be left on the tree, but in this study small fruit were harvested to determine the effect of

treatments on fruit size. An estimate of profit was calculated by subtracting costs for dormant pruning, summer pruning, fruit thinning, harvest, and packing from the crop value. Many production and overhead costs were ignored, and we recorded only the costs that were affected by treatment. Net present value (NPV) analysis was used to compare the overall costs and benefits of each combination of tree form and density. The annual estimated profit was used to calculate the NPV, assuming an annual discount rate of 8.0%. The NPV of an investment is today's value of a series of true costs and incomes. Costs and crop values may not be typical for other regions, but, based on conversations with peach growers, these costs were typical for Virginia from 1988 to 1997.

**Statistical analyses.** All of the data collected in this study resulted from annual measurements of the same trees or plots of trees. Measurements taken on the same tree over time are usually correlated. Therefore, the H-F condition (Huynh-Feldt, 1970), which is required for univariate analysis of variance (ANOVA) F tests for effects involving time and interactions with time, may not hold. The H-F condition requires that all pairs of measurements have a certain correlation structure (Littell, 1989). The H-F condition was evaluated with the sphericity test using the PRINTE option of the REPEATED statement of SAS's GLM Procedure (SAS Institute, 1990). For response variables where the sphericity test was rejected, indicating that the correlation structure for the residuals was not appropriate for ANOVA, a multivariate repeated measures analysis was performed using the REPEATED statement of SAS's GLM Procedure. In those cases, *P* values from the multivariate analysis of variance (MANOVA) are presented for the main effect of YEAR and all interactions involving YEAR. *P* values for the main effects of tree form and tree spacing and their interaction were obtained from the repeated measures ANOVA tests of hypotheses for between-subject effects. *P* values also are presented for contrast variables generated with the PROFILE transformation of the SUMMARY option in the REPEATED statement of SAS's GLM Procedure. More detailed information on the rationale for using repeated measures in horticultural research was previously pub-

lished (Barden and Marini, 1998; Marini et al., 1995). For response variables where the assumption of sphericity was not rejected (percentage of marketable yield, fruit weight, and annual yield), an ANOVA was performed for each year and means were compared with Tukey's honestly significant difference (HSD) at ( $P \leq 0.05$ ).

## Results and Discussion

**Vegetative growth.** Averaged over all years, tree density, but not tree form, influenced TCA and the year  $\times$  tree density interaction was significant (Table 1). The sphericity test indicated that the H-F condition did not hold for TCA, indicating that TCA for a tree in any given year is related to the TCA for the same tree in the previous year. As a result, a comparison of treatment means within a given year is of little interest because the TCA change from one year to the next is more informative. The PROFILE analysis tests the hypothesis that the mean change in TCA from one year to the next is the same for all three tree densities. In other words, this is a test for homogeneity of slopes between two points on a graph. For tree density, TCA was plotted against year (Fig. 1) and asterisks, indicating significance at the 5% level from the PROFILE analysis, are presented between the years. The increase in TCA from 1988 to 1990 was not affected by tree density (Fig. 1). The annual increase in TCA was greatest for the LOW trees from 1990 to 1993. The increase in TCA from 1994 to 1995 was greatest for LOW and least for HIGH trees. From 1993 to 1994, and from 1995 to 1996, increase in TCA was not significantly influenced by tree density.

Averaged over all treatments, tree height and spread changed significantly with time (Table 1). Tree form, but not tree density, influenced tree height and the year  $\times$  tree form interaction was significant (Table 1). From 1988 to 1989, tree height increased most for OV trees (Fig. 2a). From 1990 to 1991, tree height increased most for CL trees, but severe pruning reduced tree height most for CL trees from 1991 to 1992. In Mar. 1993, trees were again pruned to limit tree height and height of CL trees was slightly reduced.

Averaged over all years, tree form significantly affected tree spread, but did not interact

Table 1. *P*-values for main effects and interactions from repeated-measures analysis of variances for year (YR), tree form (TF), and tree density (TD) for nine response-variables measured on 'Norman' peach trees during a 9-year experiment.

Source of variation	Annual							Cumulative	
	TCA	Tree ht	Tree spread	Yield	Fruit/ha <sup>2</sup>	Fruit wt <sup>2</sup>	Marketable yield (%) <sup>2</sup>	Yield	Marketable yield
YR <sup>2</sup>	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001
TF <sup>2</sup>	0.384	0.001	0.002	0.026	0.916	0.684	0.624	0.488	0.549
YR $\times$ TF <sup>2</sup>	0.410	0.001	0.481	0.059	0.078	0.424	0.704	0.016	0.001
TD <sup>2</sup>	0.001	0.062	0.001	0.159	0.001	0.001	0.008	0.006	0.379
YR $\times$ TD <sup>2</sup>	0.001	0.109	0.001	0.018	0.001	0.001	0.240	0.003	0.001
TF $\times$ TD <sup>2</sup>	0.456	0.310	0.292	0.096	0.327	0.815	0.635	0.518	0.739
YR $\times$ TF $\times$ TD <sup>2</sup>	0.456	0.062	0.935	0.134	0.049	0.175	0.731	0.180	0.174

<sup>2</sup>The sphericity test did not reject the H-F condition ( $P > 0.05$ ); therefore, *P* values for all sources of variation are from univariate ANOVA F tests.

<sup>2</sup>Results from MANOVA tests of hypotheses for within-subject (measurements taken repeatedly on each tree) effects.

<sup>2</sup>Tests the hypothesis that treatments (between-subject effects) have no effect on the response variables, ignoring within-subject effects. This is the treatment effect when averaged over all years.

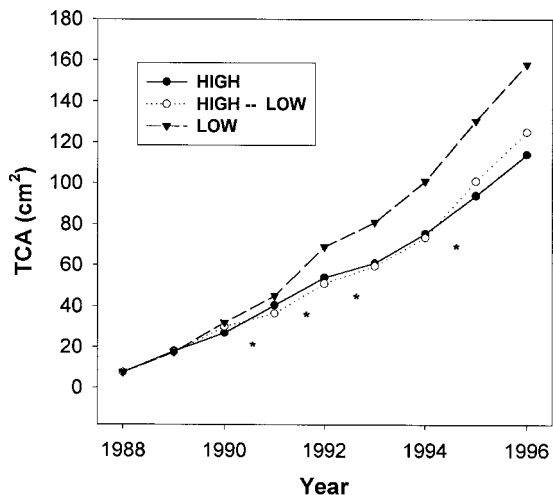


Fig. 1. Effect of tree density on increase in trunk cross-sectional area (TCA) of 'Norman' peach trees. Tree densities were high density (HIGH; 740 trees/ha), low density (LOW; 370 trees/ha), and HIGH → LOW (740 trees/ha → 370 trees/ha). Asterisks indicate that the increase in TCA between consecutive years was greater for LOW than for HIGH and HIGH → LOW trees by Profile analysis ( $P = 0.05$ ). Values are means of eight replicates of five trees/replicate.

with year (Table 1). This suggests that although tree spread for OV trees was greater than for CL trees, the annual increase was similar for both forms (data not shown). The year × tree density interaction was significant for tree spread (Table 1). From 1989 to 1991 tree spread increased more for LOW trees than for the other treatments (Fig 2b). HIGH trees filled their space in 1990; thereafter they were pruned more severely than other treatments to prevent crowding. LOW trees required containment pruning after 1992.

There are few reports where tree density was held constant to compare different tree forms or where one tree form was compared at more than one density. Grossman and DeJong (1998) recently reported that dry weight of leaves plus current-season stems per unit ground area allotted to the tree was greater for the cordon system than for the KAC-V when 919 trees per hectare were used for both systems. Open-vase trees planted at 299 trees/ha produced less dry weight per unit ground area allotted to the trees, but OV trees had not yet filled their space. When planted at 308 trees/ha, TCA of 'Sweet Sue' trees was similar for OV and CL trees (Marini et al., 1995). Central-leader trees were taller, but had smaller spread than OV trees. Open-vase peach trees had greater TCA per hectare, but lower TCA per tree when planted at 536 vs. 266 trees/ha (Layne and Tan, 1984). HIGH treatments in our study also had greater TCA per hectare than LOW treatments (data not shown). Therefore, at the tree densities used in this study, biomass per hectare probably is related to the number of trees per hectare. Because severe pruning was required to maintain trees in their allotted spaces, the difference in tree growth

was not totally related to tree form or spacing. However, the data of Grossman and DeJong (1998) indicate that tree form can influence seasonal biomass production.

**Yield and fruit size.** The sphericity test indicated that data for annual yield did not violate the H-F condition, so data were analyzed with ANOVA each year. Annual yields were higher for OV trees than for CL trees (data not shown). There was a significant interaction for year × tree density, so interaction means are presented in Table 2. In 1991, HIGH treatments had the greatest yield. In 1992 and 1993, before alternate tree removal, HIGH treatments and HIGH → LOW treatments had higher yields than did LOW treatments. In 1995 and 1996, the HIGH treatments had the highest yield.

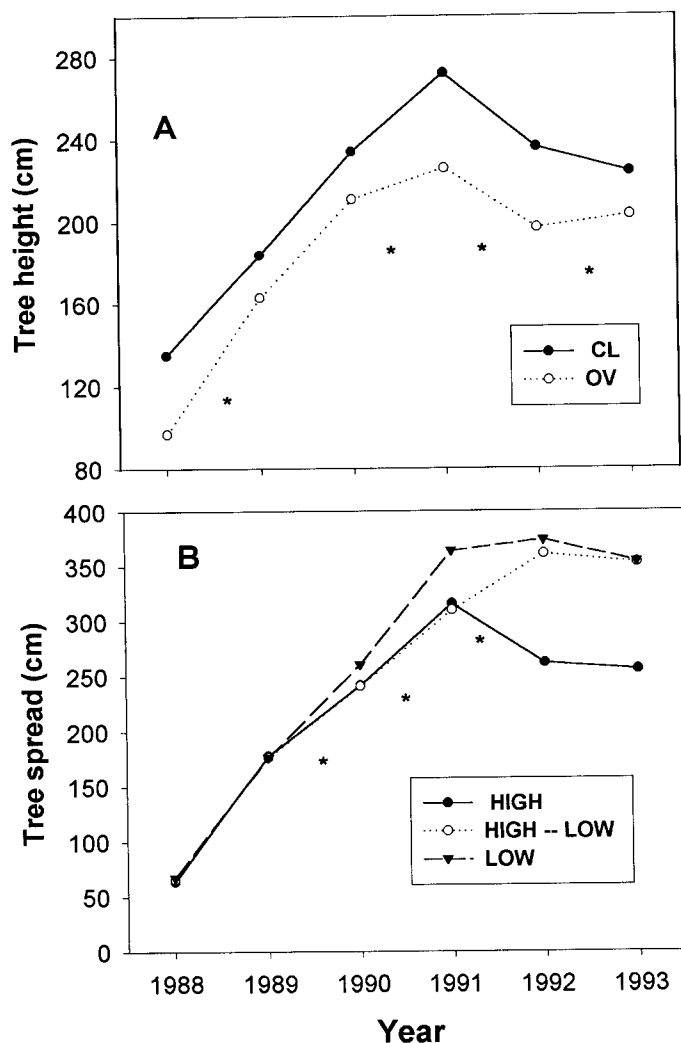


Fig. 2. Influence of (A) tree form and (B) tree density on tree height and tree spread of 'Norman' peach trees. Tree forms were central-leader (CL) and open-vase (OV), and tree densities were high density (HIGH; 740 trees/ha), low density (LOW; 370 trees/ha), and HIGH → LOW (740 trees/ha → 370 trees/ha). For both response-variables, the interaction of tree density and tree form was nonsignificant ( $P \leq 0.05$ ). Asterisks indicate that the increase in the response variable between consecutive years was not the same for all treatments by Profile analysis ( $P = 0.05$ ). The increase in tree height was greater for CL than for OV trees (A). From 1989 to 1990 and from 1990 to 1991 tree spread increased more for LOW trees than for the other treatments, but from 1991 to 1992 tree spread increased most for HIGH → LOW trees. For tree form, values are means of 12 five-tree replicates. For tree density, values are means of eight replicates of five trees/replicate.

ANOVA indicated that years and tree density influenced the number of fruit harvested per hectare, and the year × tree form × tree density interaction was significant (Table 1). From 1991 to 1995, HIGH treatments produced about twice as many fruit as did LOW treatments (Table 3). In 1996, ≈35% more fruit were harvested from HIGH than from LOW treatments. The number of fruit harvested per hectare was similar for HIGH and HIGH → LOW treatments in 1992; in 1993 it was similar for HIGH and HIGH → LOW treatments for CL trees, but for OV trees the HIGH treatment produced more than did the other tree densities. Following the removal of temporary trees after the 1993 harvest, the number of harvested fruit per hectare was similar for LOW and HIGH → LOW treatments.

Table 2. Annual yield ( $t\cdot ha^{-1}$ ), average fruit weight, and percentage of yield that was marketable of 'Norman' peaches as influenced by tree density. Tree densities were high-density (HIGH), low-density (LOW), and (HIGH  $\rightarrow$  LOW). There was no crop in 1994 due to frost.

Tree density <sup>z</sup>	1991	1992	1993	1995	1996
<i>Annual yield (<math>t\cdot ha^{-1}</math>)</i>					
HIGH	4.7 a <sup>y</sup>	23.1 a	21.1 a	15.9 a	32.5 a
HIGH $\rightarrow$ LOW	2.1 b	21.4 a	21.7 a	8.5 b	23.1 b
LOW	2.4 b	13.9 b	17.9 b	9.1 b	26.4 b
<i>Average fruit wt (g/fruit)</i>					
HIGH	97 ab	112 b	109 b	173 b	118 b
HIGH $\rightarrow$ LOW	96 b	112 b	116 ab	189 b	122 b
LOW	99 a	137 a	120 a	198 a	129 a
<i>Marketable yield (&gt;57 mm diameter) (%)</i>					
HIGH	25 ab	72 b	63 b	100 a	83 b
HIGH $\rightarrow$ LOW	21 b	70 b	73 ab	100 a	88 ab
LOW	35 a	92 a	81 a	100 a	92 a

<sup>z</sup>HIGH = 740 trees/ha, LOW = 370 trees/ha, and HIGH  $\rightarrow$  LOW = 740 trees/ha through 1993 when temporary trees were removed to leave 370 trees/ha.

<sup>y</sup>Values are means of eight five-tree replicates. Mean separation within columns and variables by Tukey's HSD ( $P \leq 0.05$ ). The influence of tree form and the interaction of tree form  $\times$  tree density were nonsignificant ( $P \leq 0.05$ ).

Table 3. Number of fruit harvested per hectare ( $\times 1000$ ) as influenced by tree form and tree density.

Tree form <sup>z</sup>	Tree density <sup>y</sup>	1991	1992	1993	1995	1996
CL	HIGH	46 a <sup>x</sup>	198 ab	236 ab	82 ab	270 ab
	HIGH $\rightarrow$ LOW	20 bc	186 b	252 a	44 b	172 c
	LOW	19 c	99 c	158 c	42 b	191 c
OV	HIGH	50 a	220 a	230 a	106 a	283 a
	HIGH $\rightarrow$ LOW	24 bc	200 a	163 c	47 b	204 c
	LOW	30 b	105 bc	181 bc	50 b	218 bc

<sup>z</sup>Tree forms were central-leader (CL) or open-vase (OV).

<sup>y</sup>HIGH = 740 trees/ha, LOW = 370 trees/ha, HIGH  $\rightarrow$  LOW = 740 trees until 1993, after which temporary trees were removed to leave 370 trees/ha.

<sup>x</sup>Values are interaction means of four replicates of five trees per replicate. Mean separation within columns by Tukey's HSD ( $P \leq 0.05$ ).

Average fruit weight was influenced by year and tree density and by the interaction of year  $\times$  density (Table 1). In 1991, all treatments were overcropped and all treatments had small fruit (Table 2). From 1992 to 1996, fruit weight was greatest for LOW treatments and was usually smallest for HIGH treatments. When number of fruit harvested per hectare was added to the model as a covariate, and tree density was included as a categorical variable, fruit weight was related to the number of fruit per hectare in only 1992 and 1995. In 1992, the least-squares means for fruit weight from the analysis of covariance (data not shown) were very similar to the nonadjusted means. In 1995, when there was a partial crop, analysis of covariance indicated that fruit harvested per hectare, but not tree density, affected fruit weight, but the least-squares means were again similar to the nonadjusted means.

The percentage of yield that was marketable (>57 mm diameter) was influenced by year and tree density (Table 1). In 1992, 1993, and 1996, LOW treatments produced a higher percentage of marketable yield than did HIGH treatments (Table 2). The percentage of marketable yield for the HIGH  $\rightarrow$  LOW treatment was lower than for the LOW treatment in 1991 and 1992. Cumulative marketable yield per hectare was affected by year, and year interacted with tree form and tree density (Table 1). Tree form and tree density affected the increase in marketable yield per hectare only from 1994 to 1995. From 1994 to 1995, cumu-

lative marketable yield increased most for OV trees (Fig. 3a) and HIGH treatments (Fig. 3b). At the completion of the study, HIGH treatments had 19% and 26% more marketable yield than did LOW or HIGH  $\rightarrow$  LOW treatments. OV trees produced 9% more marketable yield than did CL trees.

In most studies, tree spacing has been confounded with tree form; high-density peach plantings usually produce greater yields than low-density plantings (Grossman and DeJong, 1998; Taylor, 1988). OV and CL trees have been compared in several studies. In California, CL trees planted at 919 trees/ha had 16% more cumulative yield than OV trees planted at 299 trees/ha (DeJong, 1988). For 4-year-old trees in Illinois, OV trees produced 55% more yield than did CL trees when both forms were planted at 1680 trees/ha (Taylor, 1988). In Indiana, cumulative yields of OV trees planted at 716 trees/ha were more than twice those of CL trees planted at 798 trees/ha (Hayden and Emerson, 1988). Although tree density usually varied with tree form, yield per hectare was usually less for CL than for OV trees. However, when planted at 308 trees/ha, CL trees produced 25% more yield per unit of land area under the canopy than did OV trees (Marini et al., 1995). Results from the present study indicate that yield is not substantially different for OV and CL trees when they are planted at moderate densities and are summer pruned to maintain fruiting wood throughout the canopy. One reason for the discrepancy between this

and our earlier trial may be that CL trees were  $\approx 1.0$  m taller than OV trees in our previous trial, but in this study, CL trees were  $\approx 0.4$  m taller than OV trees. Therefore in the earlier trial, CL trees would have had greater canopy volume per hectare.

Average fruit weight was not influenced by tree form in this or in our previous study (Marini et al., 1995). In this study, fruit weight and the percentage of the crop that was marketable were inversely related to tree density. Even when adjusted for number of fruit per hectare, fruit weight was higher for LOW treatments, indicating that fruit size is somehow directly related to tree density. Dry weight of individual fruits was also inversely related to tree density in California, but was probably a function of yield per hectare (Grossman and DeJong, 1988); however, when trees were planted at the same density, yield and fruit dry weight were  $\approx 5\%$  and 27% greater for the KAC-V than for the cordon system, respectively. Therefore, tree form as well as tree density can influence average fruit weight. Additional work is needed to determine the cause of reduced fruit size in HIGH plantings and if cultural practices such as irrigation or fertilization can be modified to improve fruit size.

Although average fruit weight was negatively related to the number of trees per hectare, the HIGH treatments produced  $\approx 18\%$  more marketable yield than did the LOW treatments, and OV trees produced  $\approx 9\%$  more marketable yield than did CL trees. Depending on cultivar and tree spacing, annual peach yields published for the mid-Atlantic region typically range from  $\approx 20$ – $40$   $t\cdot ha^{-1}$  (Marini et al., 1995; Miller and Walsh, 1988; Walsh et al., 1989). Although 'Norman' produces relatively small fruit, yields in this study (20–32  $t\cdot ha^{-1}$ ) were comparable with those reported previously.

*Economics.* Time required for dormant pruning was not consistently influenced by tree form, but HIGH treatments usually required 40% to 85% longer to prune than did LOW treatments (data not shown). CL trees required more time to summer prune in 3 out of 7 years (data not shown). From the second to the fifth years after planting, HIGH treatments required the most time to summer prune. Before temporary tree removal, the HIGH  $\rightarrow$  LOW treatments were intermediate for summer pruning time; thereafter, they usually required the least summer pruning time. Time required for fruit thinning was not consistently influenced by tree form. The HIGH treatments consistently required about 50% longer to thin than did the LOW treatments (data not shown). The HIGH  $\rightarrow$  LOW treatments took the least amount of time to thin after temporary trees were removed. Summed over all 9 years, total costs were not influenced by tree form, but the HIGH treatments had higher costs than did the other tree density treatments ( $P = 0.15$ ) (Table 4).

Annual crop value (gross returns) was influenced by tree form in 1995 and 1996 when OV trees had the highest crop value (data not shown). HIGH treatments had the highest crop value in 4 out of 5 years, but the

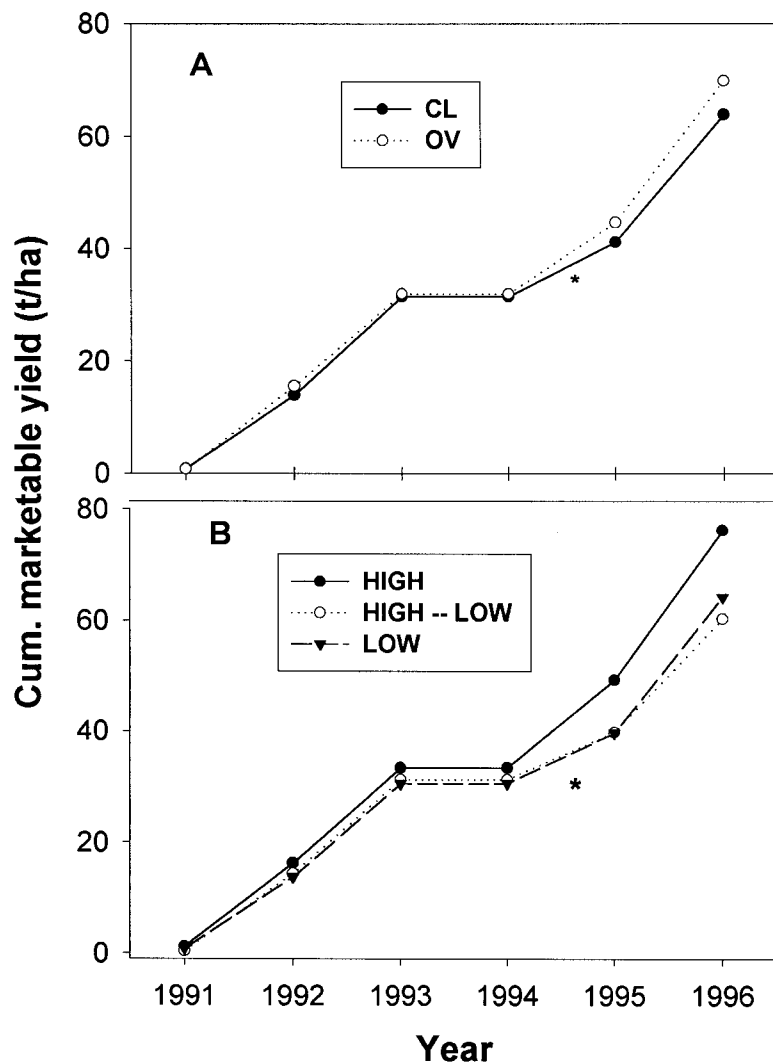


Fig. 3. Influence of tree form and tree density on the increase in cumulative marketable yield of 'Norman' peach trees. Tree forms were central-leader (CL) and open-vase (OV), and tree densities were high density (HIGH; 740 trees/ha), low density (LOW; 370 trees/ha), and HIGH → LOW (740 trees/ha → 370 trees/ha). The interaction of tree density and tree form was nonsignificant ( $P \leq 0.05$ ). Asterisks indicate that the increase in cumulative yield between consecutive years was not the same for all treatments by Profile analysis ( $P = 0.05$ ). From 1994 to 1995, cumulative marketable yield increased most for (A) OV and (B) HIGH trees. For tree form, values are means of 12 five-tree replicates. For tree density, values are means of eight replicates of five trees/replicate.

Table 4. Effects of tree form and tree density on total costs, total crop value, income minus costs, and net present value (NPV) of 'Norman' peach trees. Values are cumulative over 9 years.

Treatment	Total costs (\$/ha)	Total crop value (\$/ha)	Income minus costs (\$/ha)	NPV (\$/ha)
<i>Tree form</i> <sup>c</sup>				
CL	13,158 <sup>y</sup>	41,032	28,019	15,503
OV	13,158	45,838	32,218	17,712
<i>Tree density</i> <sup>x</sup>				
HIGH	14,724	49,352	35,535	19,577
LOW	11,595	42,187	30,068	16,913
HIGH → LOW	12,815	38,766	25,692	13,841
<i>P values from ANOVA</i>				
Tree form	0.328	0.119	0.038	0.066
Tree density	0.154	0.212	0.391	0.365
Interaction	0.484	0.912	0.444	0.446

<sup>a</sup>Tree forms were central-leader (CL) and open-vase (OV).

<sup>b</sup>For tree form, values are means of 12 five-tree replicates. For tree density, values are means of eight replicates of five trees/replicate.

<sup>c</sup>HIGH = 740 trees/ha, LOW = 370 trees/ha, and HIGH → LOW = 740 trees/ha through 1993 when temporary trees were removed to leave 370 trees/ha.

differences were significant ( $P \leq 0.05$ ) only in 1995 (data not shown). Total crop value was not significantly ( $P \leq 0.05$ ) influenced by any of the treatments. Cumulative income minus costs for the 9 years was \$4199/ha more for OV than CL treatments ( $P = 0.04$ ). Income minus costs was not significantly ( $P = 0.39$ ) affected by tree density. The NPV was \$2209/ha more for OV than for CL treatments ( $P = 0.07$ ) and was not affected by tree density ( $P = 0.36$ ) (Table 4).

Results from this trial generally support those from a 5-year trial reported by DeJong et al. (1999). When comparing a high-density (1196 trees/ha) with a lower-density (919 trees/ha) V-system for processing clingstone peaches, the high-density system had the highest yields but also had the highest initial costs. When costs were deducted from the crop value, there was no statistically significant difference between cumulative returns for the two systems. As mentioned by DeJong et al. (1999), while evaluating orchard systems, recording estimated costs and returns is critical, because systems with the highest yields are not necessarily the most profitable ones.

The partial economic analysis presented here is valid only when using the assumed costs and returns. If costs for trees or labor increase without similar increases in fruit prices, high-density systems, which require the most trees and labor, may become less attractive. High-density systems with high establishment costs may be less attractive during times with high interest rates on borrowed money. The opposite would be true if fruit prices increase more than do wages for agricultural workers. Results from this study indicate that in the mid-Atlantic region, there is no economic advantage to training peach trees as central-leaders or to planting temporary trees between permanent trees. However, under the current economic conditions, orchards with  $\approx 700$  trees/ha may be more profitable than orchards with 350 trees/ha.

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