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Response of Two Novel Peach Tree Growth Habits to In-row Tree Spacing, Training System, and Pruning: Effect on Growth and Pruning

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Abstract

Novel peach [*Prunus persica* (L.) Batsch.] tree growth habits, such as the pillar (P) (also called columnar) and upright (UP), offer unique opportunities to develop high-density peach production systems similar to that for apple. This study was initiated to examine the performance of a novel P and UP growth habit compared to a standard (S) peach growth habit when planted at four different within-row spacings and trained to a multiple leader (ML) or central leader (CL) system. The effect of summer pruning (SP) was examined over five growing seasons. In the final year of the study, canopy height was significantly reduced on one half of the trees in each growth habit x spacing x training system plot to determine the response to radical tree height adjustment for bearing upright and columnar peach growth habits. The three growth habits differed in trunk cross-sectional area (TCSA) after seven growing seasons with P trees being smallest and UP habit trees the largest. Close in-row spacing (1.5 and 2.0 m) reduced TCSA compared to wider spacing (4.0 and 6.0 m). There was a significant interaction between spacing and growth habit for TCSA and for canopy width. At the close spacings growth was similar among the three growth habits, but at the wider spacings the TCSA and canopy width of UP and S trees were similar and much greater than P trees. SP annually from the second through the sixth leaf reduced TCSA and canopy width compared to non-SP trees. The year after SP was discontinued there were no significant differences in TCSA, canopy width, or terminal shoot growth between SP and non-SP trees. The effects of growth habit and spacing on terminal shoot growth were inconsistent and SP had little or no effect on mean terminal shoot length. P trees required less dormant pruning time and about 50% fewer pruning cuts per tree, but more time per individual pruning cut than UP or S trees. UP trees required about the same time to dormant prune in the seventh season as S trees, but required 35% fewer pruning cuts·cm^{-2} TCSA than S trees. The effect of growth habit on pruning time is discussed. SP reduced the time required for dormant pruning between 28 and 50%, depending on year. SP was more effective in reducing dormant pruning time per tree for trees spaced at 6.0 m than trees spaced at 1.5 or 2.0 m within the row. Total pruning time (dormant with or without SP) per hectare was less for P trees compared to UP or S trees when planted at the same in-row spacing. However, total pruning time was greater for a high-density P planting than a low-density planting of S growth habit trees. Our results indicate that P and UP growth habit peach trees are well suited to high-density planting systems at spacings of 1.5 to 2.0 m. However, the results do raise some questions about the horticultural benefit(s) of SP for these novel peach tree growth habits.

The commercial peach [*Prunus persica* (L.) Batsch.] industry in the United States is currently based on a vigorous spreading tree form commonly represented by the "standard" (S) growth habit tree. These standard trees have traditionally been planted at wide spacing resulting in low tree density (≤ 297 trees/ha) per unit of land. In this low-density planting system, yields have also been low to moderate (29) at best. In contrast, the apple industry has benefited from dwarfing rootstocks, spur growth habit trees, and/or plant bioregulators to control tree size and enable high-density planting, which has led to significantly higher yields per unit of land, especially in the early life of the orchard (9, 33). High-density apple plantings have also increased the opportunity for mechanization and greater efficiency in spraying, pruning, and harvesting. Plant bioregulators are lacking for shoot growth control in peach, and dwarfing rootstocks, commonly used in apple production, are not presently available to the commercial peach industry, although, recent research has identified some likely candidates (7, 40).

Orchard systems for high-density peach production using S growth habit trees have been described (1, 3, 6, 8, 12, 15, 26, 32, 39).

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Standard peach trees grown in a high-density system can produce high yields (14, 17, 24, 38), but often require extensive pruning which can lead to excessive vegetative growth, shading in the lower canopy, tree-to-tree crowding, and poor fruit quality (personal communication, T.M. DeJong, Univ. of Calif., Davis). Shading in peach trees results in the loss of bearing wood, especially in the lower portions of the canopy (11). The result is that the bearing surface moves to higher levels in the canopy which lowers production efficiency.

An alternative to using S growth habit peach trees for high-density production would be the development of growth habits suited to closer spaced planting (34). Scorza (35) identified two growth habits, pillar (P) (also called columnar) and upright (UP), with potential for high-density peach planting systems. Columnar trees were first reported from Japan where they were developed as ornamentals (41). Columnar growth habit is semi-dominant with homozygous *brbr* producing columnar and *BrBr* producing standard tree forms. Left to grow naturally, columnar trees will attain a height of 5 m and a crown diameter of around 1.5 m. The most striking feature of the columnar tree is its narrow branch angles (36). The heterozygote (*Brbr*) produces a unique upright or semi-columnar growth habit. This phenotype is neither columnar nor standard but possesses an intermediate growth habit (37). These growth habits have been tested in several locations and preliminary data describing their training and performance have been reported (27, 31).

The purpose of this paper is to provide a more detailed description of the performance of P and UP trees in comparison with an S growth habit peach during the early bearing years when grown at several different in-row spacing distances (planting densities) and subjected to two training systems [central leader (CL) and multiple leader (ML)] and summer pruning (SP). This paper will focus on growth and pruning time effects. The effect on yield, fruit quality, and light penetration in the canopy will be presented in a later paper.

Early observations and preliminary data show that P and UP trees have an unusually tall stature (36). Fruit growers have long been concerned about the issue of tree height especially in regard to production costs, efficiency, yields, and fruit quality. In 2004, Day (5) reported that nectarine tree height could be reduced significantly (from 3.7 m to 2.4 m) without the loss of production of high quality fruit. Low-stature trees are also more amenable to "pedestrian" or "U-Pick" orchards that are becoming increasingly popular. With this in mind, an objective to examine the initial reaction of the peach growth habits in this study to reduced tree height was added in 2005, the final year of the study.

Materials and Methods

Details concerning the planting, initial training, pruning techniques, and cultural management of the trees in the first and second year of this study have been published (27).

The four treatment factors of the experiment (growth habit, within-row spacing, training system, and SP) were arranged in a split-split-split-plot design with three replicates. Within-row spacing was the whole plot factor and was arranged in a randomized complete block design with three blocks and 24-tree rows as whole plots. Growth habit [P ('Crimson Rocket'), UP ('Sweet-N-UP'), and S ('Harrow Beauty')] was the sub-plot factor and was allocated to 8-tree sub-plots within each whole plot. Training system (CL or ML) was the sub-sub-plot factor and was allocated to four-tree sub-sub-plots within each sub-plot. Summer pruning (SP and non-SP) was the sub-sub-sub-plot factor and was allocated to two-tree sub-sub-sub-plots within each sub-sub-plot.

All trees were budded on Lovell rootstock and planted with a mechanical tree planter in Dec. 1998. Four in-row tree spacing distances were used to establish four planting densities (trees/ha) as shown in Table 1. Border trees were used to separate blocks between and within rows. A common between-row spacing of 6.0 m was maintained throughout the planting. Supplemental water was applied on

Table 1. Tree spacing, planting density, and fertilizer history for pillar (P), upright (UP), and standard (S) growth habit trees in the peach tree growth habit performance study at the Appalachian Fruit Research Station, Kearneysville, WV. Trees planted Dec. 1998.

		Ground fertilizer application[z]			
Treatment tree spacing (m)	Tree density (trees/ha)	Application date	Material	Rate/tree (kg)	Growth habit treated
1.5 x 6.0	1111	14 Apr. 1999	10N-4.4P-8.3K	0.68	P, UP, S
2.0 x 6.0	833	6 June 1999	10N-4.4P-8.3K	0.68	P, UP, S
4.0 x 6.0	417	20 Apr 2000	10N-4.4P-8.3K	0.68	P, UP, S
6.0 x 6.0	278	30 May 2001	Calcium nitrate	0.91	S
		12 May 2003	10N-4.4P-8.3K	0.91	S
		28 Apr 2004	10N-4.4P-8.3K	0.91	S
		3 May 2005	10N-4.4P-8.3K	1.59	P, UP, S
		13 June 2005	10N-4.4P-8.3K	1.59	P, UP, S

[z] Application by hand between tree drip line and trunk; all trees within a growth habit and at all planting densities treated on date shown.

an as needed basis using one emitter [Micro Flapper, 4 L·hr^{-1} (Jain Irrigation Systems, Ltd., Columbus, Ohio)] per tree, based on soil tensiometer readings averaged over four random locations in the planting from within the row at a spot half-way between the trunk and the tree's drip line. Based on observations, this emitter arrangement provided adequate moisture when needed.

The ML training system produced a tree form similar to that of a traditional open center or open-vase system as described by Marini (20) and Marini et al. (25) for S growth habit trees (Fig. 1). Four or five primary scaffolds were developed and maintained on ML trained trees. CL training was similar to that described for apple (13) and as adapted to peach by Marini et al. (25). The use of training aids to spread and position primary scaffold limbs at planting was discontinued in the third leaf (2001). Beginning in the fourth season, tree height was limited to about 4.6 m or less by dormant pruning cuts into 2-year-old wood at weak side branches originating about 3.5 m above the ground. Dormant pruning was carried out annually between late March and

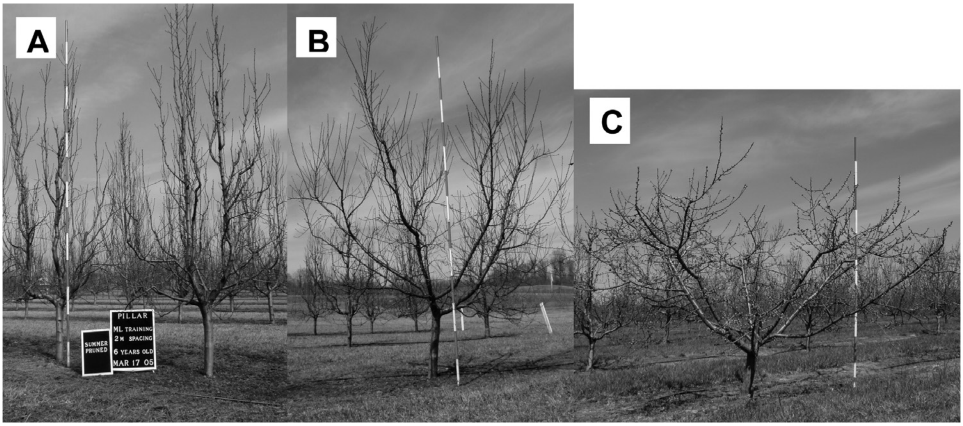


Fig. 1. Peach tree growth habits trained to a multiple leader (ML) system after six growing seasons in the orchard. A) Pillar tree ('Crimson Rocket') spaced at 2.0 m in the row, B) Upright habit tree ('Sweet-N-UP') spaced 4.0 m within the row and C) Standard growth habit tree ('Harrow Beauty') spaced 6.0 m in the row. Measuring pole marked in 30.5 cm increments.

early April before full bloom. In both training systems an attempt was made to retain one-year-old shoots ≈ 1.0 cm in diameter at the base and ≈ 40 to 60 cm in length. The approach was to minimize structural wood and optimize the number of bearing shoots by selectively removing older, large wood and thinning out the one-year-old shoots to create a better balance between structural wood and fruiting shoots (favoring high-quality fruiting shoots).

SP was performed annually through the sixth leaf about seven weeks before the first fruit were harvested. The first two trees in each four-tree sub-sub-plot were summer pruned and the time required to prune was recorded (per tree) beginning in the second leaf (2000). SP consisted primarily (about 95%) of thinning cuts to remove current year shoot and watersprout ("sucker") growth to open the canopy for better light penetration and to help maintain the desired tree form (CL or ML). SP was more detailed than that described by Myers (28) and approached that described by Marini (19), but was not as extensive as dormant pruning. The majority of cuts were directed toward vertical shoots throughout the canopy, but horizontal and pendent shoots were also removed to open the canopy and direct growth to the most promising shoots for next year's cropping. Where heading cuts were used, shoots were pruned back to 2 to 4 nodes from the point of origin. No terminals on primary scaffolds were headed in SP; thinning cuts were used to contain canopy spread. The time required to SP was recorded on an individual tree basis. The SP treatment was discontinued after the sixth (2004) growing season.

In Mar. 2005 before the beginning of the seventh growing season, two trees in each four-tree sub-sub-plot were selected at random and the canopy was reduced to a height of ≈ 2 m ("adjusted canopy height" was substituted for SP as the fourth experimental factor). This heavy dormant pruning was accomplished with pruning cuts made to an established lateral shoot or branch. To achieve the desired effect required major cuts with a saw, often in limbs ranging from 5 to 10 cm in diameter. The remaining two trees in each sub-sub-plot were dormant pruned to a height no greater than ≈ 3.5 m. These canopy heights were designated as short (ST) or tall (TL) respectively. The time required to dormant prune was recorded in minutes and seconds for individual trees and converted to total seconds for analysis. In selected years the number of pruning cuts per tree was recorded. To minimize variability due to individual pruning biases, the senior author performed all pruning operations.

Growth measurements were recorded each year at the end of the growing season. Trunk circumference was measured at a designated spot 30 cm above the soil line and used to calculate trunk cross-sectional area (TCSA). Canopy spread was measured at the widest point both within the tree row and across the tree row. Canopy height was measured with a telescoping measuring rod graduated in cm. The rod was placed in the canopy and read at the top of the upper most shoot. Beginning at the end of the third leaf (2001) and through the seventh leaf (2005) ten terminal shoots were selected at random around the periphery of the canopy for average shoot growth, five in the lower half of the canopy and five in the upper half of the canopy.

A commercially recommended pest control schedule was followed throughout the study (30). Trees were maintained in a 2 m wide weed-free strip with the use of herbicides according to local recommendations. A complete fertilizer or calcium nitrate was applied to individual trees on the date and at the rates shown in Table 1. No fertilizer was applied in the 2002 growing season. A heavy frost during bloom of the 2002 growing season reduced yields noticeably in that year and a light frost reduced yields slightly in 2004.

Data were analyzed using a four factorial analysis of variance (ANOVA) (SuperANOVA, Abacus Concepts, Berkeley, Calif.) within a split-plot design and means separated by Duncan's new multiple range test at α (*alpha*) = 0.05. Square root transformation was employed when a check of the residuals from ANOVA indicated transformation was appropriate. Actual means are reported.

Results

Trunk cross-sectional area. The three peach tree growth habits produced three different size trees based on TCSA after seven growing seasons in the orchard with UP trees the largest and P trees the smallest (Fig. 2A). Within-row tree spacing (planting density) affected TCSA (Fig. 2B). Trees planted at the 6.0 m spacing (278 trees·ha^{-1}) had the largest TCSA after seven seasons and trees planted at the 1.5 or 2.0 m spacing (1111 or 833 trees·ha^{-1}, respectively) had the smallest TCSA. Trees planted at the two closest spacings (highest densities) did not differ in TCSA throughout the first seven years in the orchard. The interaction of growth habit and tree spacing for TCSA was significant in 2004 ($P = 0.0248$) (Fig. 2C) and in 2005 ($P = 0.0096$). As the spacing between trees in the row increased, TCSA increased, but the increase for P trees was less than for S or UP trees, especially for trees planted at the 6 m spacing. The interaction in 2005 was similar to that in 2004 and is not illustrated.

Summer pruning annually from 2000 (2nd-leaf) through 2004 (6th-leaf) affected TCSA (Fig. 2D). Beginning in 2001, and thereafter, the TCSA of SP trees was smaller than for non-SP trees and the difference increased with each successive year of SP through 2004, the last year trees were summer pruned. The average difference in TCSA between SP and non-SP trees in 2004 was 8.2 cm^2. Following the 2005 growing season, the mean TCSA of the SP trees was 106.9 cm^2 and 114.5 cm^2 for the non-SP trees, a non-significant difference of 7.6 cm^2 ($P = 0.132$). There were no significant interactions between SP and growth habit, spacing, or training system for TCSA.

Severe pruning in 2005 to adjust canopy

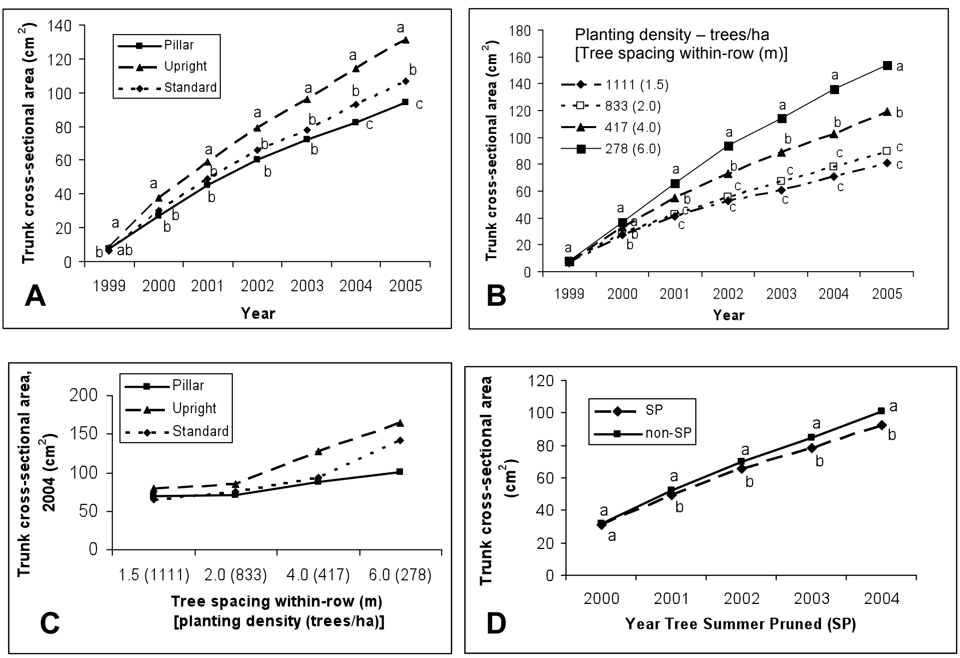


Fig. 2. Trunk cross-sectional area (TCSA) as affected by A) peach tree growth habit, B) planting density (within-row spacings: 1.5 m x 6.0 m = 1111 trees/ha, 2.0 m x 6.0 m = 833 trees/ha, 4.0 m x 6.0 m = 417 trees/ha, and 6.0 m x 6.0 m = 278 trees/ha.), C) the interaction of growth habit and spacing for TCSA in the sixth leaf (2004) ($P = 0.0053$), and D) summer pruning (SP) during the first six growing seasons in the orchard. Means separation by Duncan's Multilple Range Test, $P \leq 0.05$.

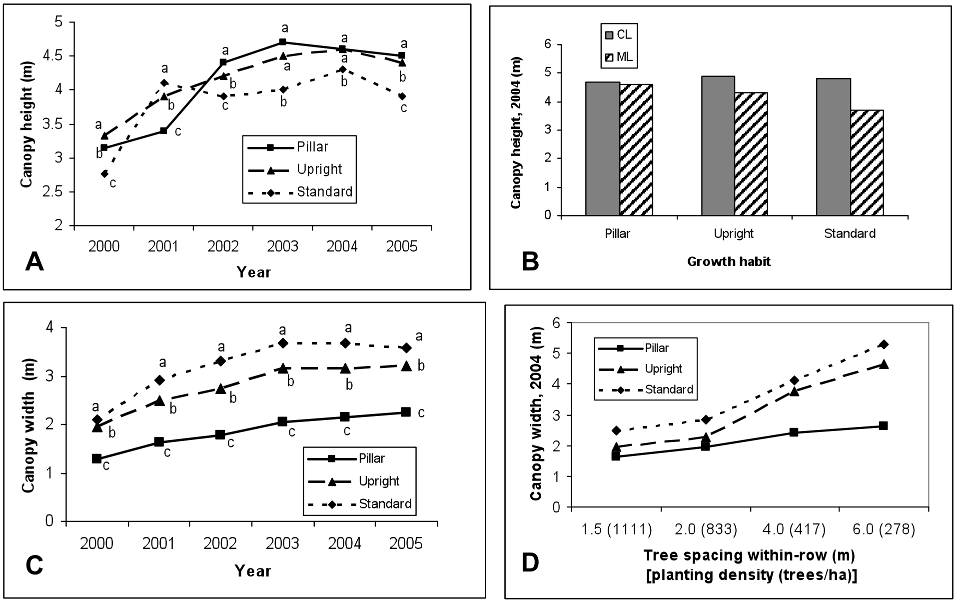


Fig. 3. A) Canopy height and C) canopy width (in-row) for three peach tree growth habits (standard, upright, and pillar) from the second growing season (2000) through the seventh growing season (2005) and B) the interaction of growth habit with training system (CL - central leader, ML - multiple leader) (P = 0.0001) and D) with tree spacing (P = 0.0001) in the row in the sixth growing season (2004). Spacing between rows = 6.0 m. Means separation by Duncan's Multiple Range Test, $P \leq 0.05$.

height had no effect on TCSA (data not shown).

Tree height. Canopy height was controlled, to some extent, after several years in the orchard by dormant pruning which affected the tree height as measured at the end of the growing season. Beginning in the fourth (2002) growing season and continuing through the seventh (2005) season, P and UP habit trees were taller than S trees (Fig. 3A). The height of P trees was generally greater than UP habit trees, but not in all years (Fig. 3A). There was a significant (P = 0.0001) interaction of habit and training system for canopy height as illustrated for the 2004 growing season (Fig. 3B). CL trained UP and S trees were taller than ML trained trees (P = 0.0011 and 0.0001, respectively), but canopy height did not differ (P = 0.2293) between the two training systems for P habit trees. The severe level of pruning used just prior to the 2005 growing season resulted in a significant difference in tree height with TL trees averaging 4.6 m in height compared to ST trees averaging 3.9 m in height (P = 0.0001).

Canopy width. Canopy width (measured within the row) differed among the three growth habits over the period of this study (Fig. 3C). The significant difference in canopy width between S habit trees and P habit trees is visually evident in Fig. 4. The interaction of growth habit and tree spacing for canopy width was significant for each growing season. A typical response is illustrated in Fig. 3D for the 2004 growing season. Canopy width increased for trees of each growth habit as space between trees in the row increased and planting density decreased, but the change was far greater for UP and S trees at the two widest tree spacings (4.0 and 6.0 m) than for P trees planted at the same spacing. SP reduced canopy width an average of only 4.3% over non-SP trees. There was a significant difference in canopy width in each year trees were

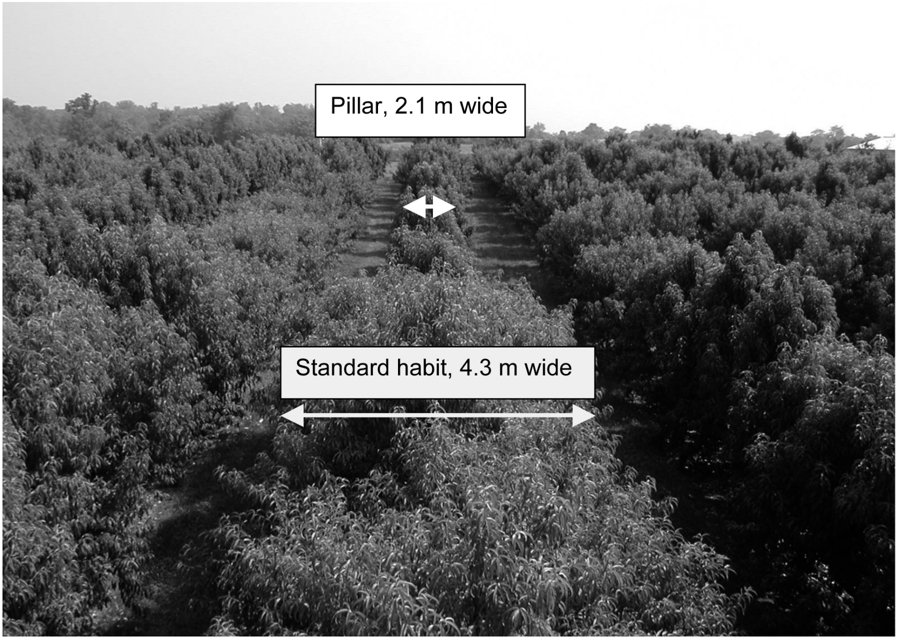


Fig. 4. A visual comparison of canopy width in the seventh leaf for standard habit peach trees (foreground) and pillar growth habit trees (background) subjected to similar training and pruning methods at the Appalachian Fruit Research Station, Kearneysville, WV, USA.

summer pruned (data not shown), but the year after SP was discontinued, the difference was non-significant (2.96 m for SP trees vs. 3.05 m for non-SP trees, $P = 0.538$).

Terminal shoot growth. There were significant treatment main effects on terminal shoot growth, but the effects were small and inconsistent (data not shown). In general terminal shoot growth was greater for trees planted at the wider within-row spacing, but this difference disappeared in the last two years of the study. Overall, the greatest terminal shoot growth was recorded in the third leaf (2001) when trees were young and just beginning to bear and following the more severe pruning in 2005 when ST trees produced significantly ($P = 0.0001$) more terminal shoot growth (about 12 % more) than TL trees (data not shown). Several interactions occurred, but these too were generally inconsistent among years with the exception for SP. SP reduced terminal shoot length to a greater extent in trees planted at the narrow spacing (1.5 and 2.0 m) than for trees planted at the wider spacings (4.0 and 6.0 m) (Fig. 5; significant interaction in 2004, $P = 0.0037$).

Dormant pruning time. Dormant pruning time was affected by peach tree growth habit. P trees required less dormant pruning time per tree than UP or S trees throughout this study (Table 2). Dormant pruning time was also affected by tree spacing within the row. There was a significant growth habit x tree spacing interaction for dormant pruning time in 2003 ($P = 0.0098$), 2004 ($P = 0.0024$), and 2005 ($P = 0.0027$). Fig. 6A illustrates the interaction response in 2004. Dormant pruning time per tree was increased about 52% when planting distance increased from 1.5 m to 6.0 m for P trees. However, when planting distance increased from 1.5 m to 6.0 m for UP and S trees the dormant pruning time increased by 125% and 145% respectively. Similar interactions and responses were observed in 2003

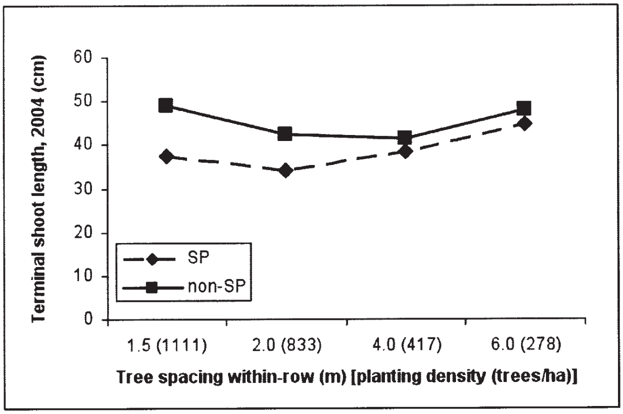


Fig. 5. Interaction of summer pruning (SP) and tree spacing within the row in 2004 (P = 0.0037) for mean terminal shoot length.

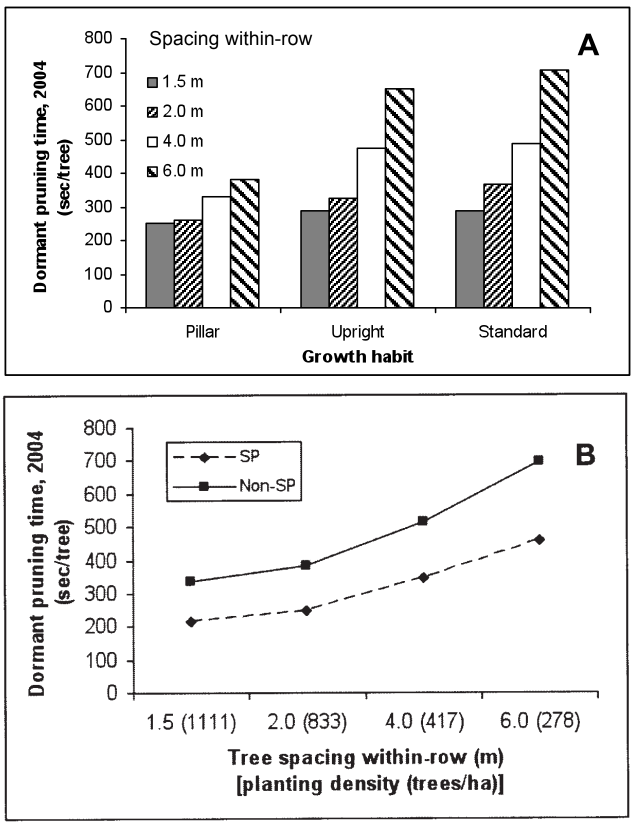


Fig. 6. Interactions between treatment main effects for dormant pruning time: A) peach tree growth habit and tree spacing within-row in 2004, P = 0.0024; and B) summer pruning (SP) and tree spacing within-row in 2004, P = 0.0296

Table 2. Effect of peach tree growth habit, tree spacing within the row, training system, summer pruning, and canopy height adjustment on the dormant pruning time of peach trees in the 3rd (2001) through the 7th (2005) leaf in the orchard.

Main treatment effect[z]	Dormant pruning time (sec/tree)				
	2001[y]	2002	2003	2004	2005
Growth Habit			♦[x]	♦	♦
Pillar	244 c[w]	237 b	289	306	539
Upright	296 b	318 a	410	435	704
Standard	335 a	364 a	528	460	754
Spacing (m)					
1.5	246 c	235 c	305 c	276 c	451 d
2.0	253 c	242 c	336 c	317 c	554 c
4.0	314 b	328 b	436 b	432 b	720 b
6.0	356 a	420 a	560 a	579 a	938 a
Training System					
CL	292 a	306 a	414 a	405 a	668 a
ML	292 a	306 a	404 a	395 a	662 a
Summer Pruned		*♦	♦	♦	
Yes	231 b	205	342	317	---
No	353 a	407	475	483	---
Adjusted Canopy Height				*#[x]	♦■[x]
Short	---	---	---	334	618
Tall	---	---	---	466	712

[z] Trees planted Dec. 1998 on Lovell rootstock. Standard trees are 'Harrow Beauty', upright trees are 'Sweet-N-UP', and pillar trees are 'Crimson Rocket'. ML = multiple Leader, CL = central leader. Summer pruning performed about 7 wk before harvest; discontinued in 2005. Canopy height adjusted by dormant pruning beginning in 2005; short trees were pruned to ≈ 2.0 m height and tall trees were pruned to ≈ 3.5 m height in Mar./Apr. 2005.

[y] 2001 = the third leaf

[x] ♦ = interaction with spacing; * = interaction with growth habit; # = interaction with summer pruning; ■ = interaction with training system

[w] Mean separation within year and treatment main effect by Duncan's new multiple range test, P ≤ 0.05. No mean separation presented where interaction occurred.

and 2005 (not shown). Training system had no effect on dormant pruning time (Table 2).

SP trees required less dormant pruning time than non-SP trees (Table 2). There was a significant interaction between SP and tree spacing for dormant pruning time in 2002, 2003, and 2004, and a significant interaction for SP and growth habit in 2002. The interaction with tree spacing for 2004 is illustrated in Fig. 6B. SP trees planted at the 1.5 m spacing required an average of 2 min. less dormant pruning time than non-SP trees; SP trees planted at the 6.0 m spacing required 4 min. less dormant pruning time. The interaction response was similar in 2002 and 2003. Canopy height adjustment to produce ST or TL trees in 2005 resulted in a reduction in the dormant pruning time per tree for ST trees compared to TL trees (Table 2). Interactions between treatment main effects and adjusted canopy height were inconsistent.

Number of dormant pruning cuts. The effect of treatment main effects on the number of dormant pruning cuts per tree is presented for selected years in Table 3. S trees required the greatest number of pruning cuts and P trees the least, about 57% fewer cuts than S trees. There was a significant interaction between growth habit and tree spacing for the number of dormant pruning cuts in each of the three years data was recorded (Table 3).

Table 3. Effect of peach tree growth habit, tree spacing within the row, training system, summer pruning, and canopy height adjustment on the number of dormant pruning cuts for peach trees in the 4th (2002), 5th (2003), and 7th (2005) leaf in the orchard.

Main treatment effect[y]	Dormant pruning cuts (mean no./tree)			Cuts/cm² TCSA[z]
	2002[x]	2003	2005	2005
Growth Habit	♦[w]	♦	♦	
Pillar	56	70	126	1.4 c[v]
Upright	103	128	226	1.7 b
Standard	128	188	276	2.6 a
Spacing (m)				
1.5	69 c	90 c	135 d	1.7 b
2.0	75 c	104 c	174 c	2.0 a
4.0	103 b	140 b	233 b	2.0 a
6.0	135 a	179 a	295 a	1.9 a
Training System				♦
CL	95 a	129 a	216 a	1.9
ML	96 a	127 a	203 b	1.9
Summer Pruned	♦*[w]	♦*		
Yes	53	103	-----	----
No	138	153	-----	----
Adjusted Canopy Height			♦	
Short	----	----	200	1.8 b
Tall	----	----	218	2.0 a

[z] CSA = trunk cross-sectional area
[y] Trees planted Dec. 1998 on Lovell rootstock. Standard trees are 'Harrow Beauty', upright trees are 'Sweet-N-UP', and pillar trees are 'Crimson Rocket'. ML = multiple Leader, CL = central leader. Summer pruning performed about 7 wk before harvest; discontinued in 2005. Canopy height adjusted by dormant pruning beginning in 2005; short trees were pruned to ≈ 2.0 m height and tall trees were pruned to ≈ 3.5 m height in Mar./Apr. 2005.
[x] 2002 = the fourth leaf
[w] ♦ = interaction with spacing; * = interaction with growth habit
[v] Mean separation within year and treatment main effect by Duncan's new multiple range test, $P \leq 0.05$. No mean separation presented where interaction occurred.

The interaction for 2005 is illustrated in Fig. 7A and was typical for that found in 2002 and 2003. As tree spacing increased, the number of pruning cuts per tree increased for all three growth habits; however, the degree of change differed among the growth habits. The number of pruning cuts per tree for P trees increased by 61% as tree spacing increased from 1.5 m to 6.0 m; the number of pruning cuts for UP trees increased by 143% and for S trees the number of cuts increased by 128% for the same change in tree spacing.

There were significant interactions between SP and tree spacing (Fig.7B) and growth habit (Fig. 7C) for the number of dormant pruning cuts per tree in 2002 and 2003 (Table 3). SP reduced the number of dormant pruning cuts required by 61% in 2002 and by 33% in 2003 compared to non-SP trees. SP had a greater impact on the number of dormant pruning cuts

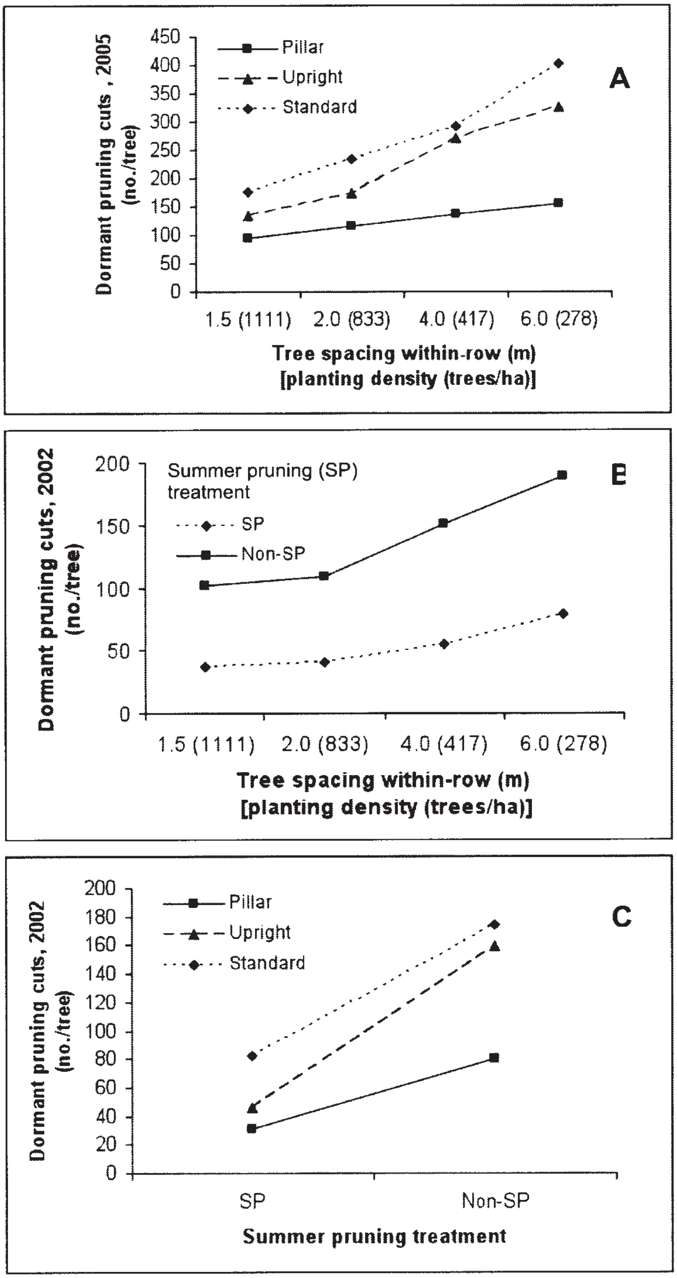


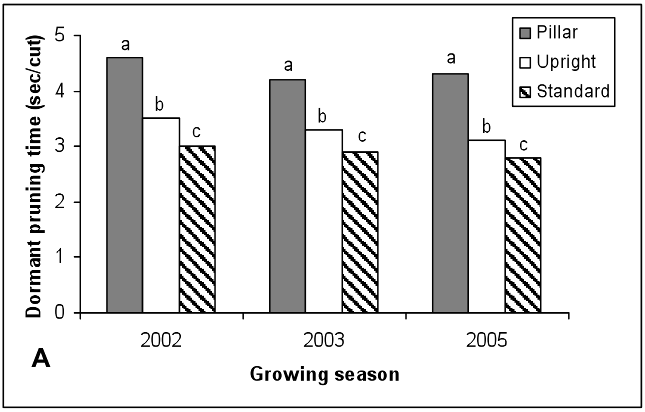
Fig. 7. Interaction of treatment main effects with mean number of dormant pruning cuts: A) peach tree growth habit and within-row planting distance (spacing) in 2005, $P = 0.0001$; B) planting distance within-row and summer pruning (SP) in 2002, P = 0.0001; and C) peach tree growth habit and summer pruning treatment in 2002, $P = 0.0001$.

in UP trees (71% reduction) than for P or S growth habit trees (53% and 61% reduction, respectively) (Fig. 7C).

Number of dormant pruning cuts based on trunk size. Computing the number of dormant pruning cuts/cm^2 TCSA in 2005 produced a clear and significant separation among the three growth habits (Table 3). P trees required 46% fewer dormant pruning cuts/cm^2 TCSA than S trees and UP trees required 35% fewer cuts than S trees. Trees planted at the 1.5 m spacing required fewer dormant pruning cuts/cm^2 TCSA than trees planted at all other in-row spacings. When canopy height was adjusted at the beginning of the 2005 growing season ST trees required fewer dormant pruning cuts/cm^2 TCSA than TL trees (Table 3).

Time required for dormant pruning cuts. P and UP growth habit trees required more dormant pruning time per cut than S growth habit trees and P trees required more time than UP trees (Fig. 8A). The interaction of growth habit by SP for dormant pruning time per cut was significant in 2002 (Fig. 8B), but not in 2003.

Summer pruning time. The effect of treatment main effects on the time required to SP is presented in Table 4. In the second leaf (2000), P and UP trees required more SP time than S



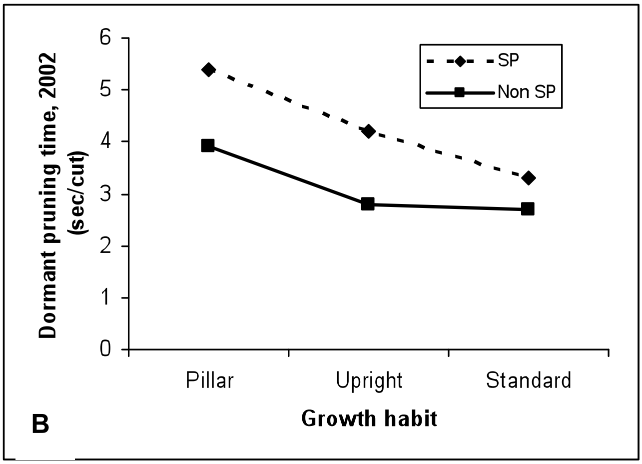


Fig. 8. Dormant pruning time per cut: A) for three peach tree growth habits in select years from 2002 through 2005; and B) interaction of growth habit and summer pruning (SP), P = 0.0001.

Table 4. Effect of peach tree growth habit, tree spacing within the row, and training system on the time required to summer prune peach trees in the 2nd (2000) through the 6th (2004) leaf in the orchard.

Main treatment effect[z]	Summer pruning time (sec/tree)				
	2000[y]	2001	2002	2003	2004
Growth Habit					
Pillar	352 a[w]	436 b	571 b	500 b	592 b
Upright	360 a	559 a	756 a	626 a	629 ab
Standard	235 b	377 b	645 b	486 b	713 a
Spacing (m)					
1.5	288 a	379 c	477 c	369 c	429 c
2.0	305 a	400 c	534 c	404 c	491 c
4.0	337 a	483 b	679 b	567 b	709 b
6.0	337 a	566 a	941 a	817 a	950 a
Training System	*[x]				
CL	370	489 a	682 a	562 a	670 a
ML	263	425 b	633 b	512 a	617 a

[z] Trees planted Dec. 1998 on Lovell rootstock. Standard trees are 'Harrow Beauty', upright trees are 'Sweet-N-UP', and pillar trees are 'Crimson Rocket'. ML = multiple Leader, CL = central leader. Summer pruning performed about 7 wk before harvest; discontinued after 2004. Time in 2000 included installation of elastic bands and/or weights for limb positioning.
[y] 2000 = the second leaf
[x] * = interaction with growth habit
[w] Mean separation within year and treatment main effect by Duncan's new multiple range test, $P \leq 0.05$. No mean separation presented where interaction occurred.

trees. In the third (2001) through fifth (2003) leaf, UP trees required more time to SP than P or S trees. In the sixth leaf, S trees required the most time to SP and P trees required the least time. Spacing of trees within the row had no effect on the time required to SP in 2000, but beginning in 2001 and continuing through 2004 trees at the widest spacing required more time to SP than trees at the other within-row spacings. The time required to SP trees at the 1.5 m or 2.0 m spacing did not differ. Training system had a minimal effect on the time required to SP. In general CL trained trees required about 10% more time to SP than ML trained trees. The exception was in the second leaf (2000) when CL trees required about 41% more time to SP than ML trees.

Total pruning time. Total pruning time was increased between 1.6 and 2.3 times by SP over dormant pruning alone depending on growth habit and tree spacing in the fifth leaf (Table 5). Trees planted at the highest density (1.5 m spacing; 1111 trees·ha^{-1}) required about twice as much pruning time per ha as trees planted at the lowest density (6.0 m spacing; 278 trees·ha^{-1}). The effect on total pruning time for the fifth leaf was representative of the response observed in the third, fourth, and sixth leaf in the orchard.

Discussion

In a detailed analysis of unpruned P and UP growth habit peach trees Scorza et al. (36) found these two growth habits produced somewhat similar results for tree height, trunk diameter, and length of 1st-order branches. Bassi et al. (2) established a field planting in Italy to compare the growth and response to pruning among six peach tree growth habits including S ('Suncrest', a vigorous genotype), P ('Italian Pillar'), and UP (KV77119) habit trees. After two growing seasons, they

Table 5. Total pruning time per tree and per hectare for three peach tree growth habits at two within-row spacing with and without summer pruning for the fifth leaf (2003) in the orchard[z].

		Total pruning time			
		Spacing (m)		Spacing (m)	
		1.5 m	6.0 m	1.5 m	6.0 m
Growth habit	Summer pruned	(sec/tree)		(hr/ha)	
Pillar	Yes	554	961	171	74
	No	278	417	86	32
Upright	Yes	598	1474	184	114
	No	352	692	109	53
Standard	Yes	716	1418	221	110
	No	440	847	136	65

[z] Trees planted Dec. 1998 on Lovell rootstock. Standard trees are 'Harrow Beauty', upright trees are 'Sweet-N-UP', and pillar trees are 'Crimson Rocket'. Summer pruning performed about 7 wk before harvest. Planting densities: 1.5 m x 6.0 m = 1111 trees/ha and 6.0 m x 6.0 m = 278 trees/ha.

reported trunk diameter for P trees was less than UP trees but P trees did not differ from S trees. P and UP growth habits produced trees of similar canopy heights, but differed significantly in canopy diameter with P trees producing a tree of about 58% less canopy diameter than UP or S habit trees.

These studies (2, 36) were based on a limited number of trees (≤ 25) and after only a few (two to four) growing seasons in the orchard. The current report is based on a larger number of trees (96 for each growth habit) and a greater number of growing seasons (seven). Our results indicate that 'Sweet-N-UP', a UP habit tree, is a vigorous to highly vigorous growth habit and under similar growing conditions would produce trees with greater TCSA than 'Harrow Beauty', a S growth habit tree characterized as a tree of medium vigor (10) or 'Crimson Rocket' a P growth habit. In addition our results show that UP trees produce terminal shoot growth equal to S trees (data not shown), generally require more SP time than S trees and at the widest in-row spacings (4.0 and 6.0 m) are more like S trees in dormant pruning time (Fig. 6A) and the number of dormant pruning cuts per tree (Fig. 7A) than P trees.

Tree size and vigor are affected by many factors including soil depth, moisture, fertility, pest control, and crop load. The cultural management provided to the trees in this study along with the randomized planting plan and the annual crop loads (data not shown) would not have been judged as having a disproportionate effect on tree growth. In addition, N application was withheld on P and UP trees from 2001 through 2004 [based on observed tree vigor, leaf color, and elemental N analysis (data not shown)] with no apparent growth advantage to the S habit trees which received fertilizer in three of the four years that P and UP did not receive any fertilizer. Based on the current findings it would be reasonable to conclude that the UP growth habit 'Sweet-N-UP' is a highly vigorous genotype and the P growth habit 'Crimson Rocket' is a moderately vigorous to vigorous genotype.

Reighard et al. (31) compared the P ('Crimson Rocket') and UP ('Sweet-N-UP') genotypes/tree forms, along with a vigorous S habit tree (10), 'Blazeprince'. Our TCSA values for the same genotypes at the same stage of growth, and at the same in-row spacing were comparable. Reighard et al. (31) reported that after three years in the orchard, all types produced the largest trees (based on TCSA) at the 4.0 m spacing. Our results are similar (Fig. 2B) and show that this trend not only continues through seven years in the orchard, but when given additional in-row spacing to 6.0 m, these three phenotypes produce progressively larger trees. The present study indicates the tendency for vigorous growth is greater in UP trees (specifically 'Sweet-N-UP') than either S ('Harrow Beauty') or P ('Crimson Rocket') habit trees as in-row spacing is increased and trees age (Fig. 2C). Our results suggest that planting the 'Sweet-N-UP' genotype at in-row spacings greater than 2.0 m would negate the desire of a smaller, more compact efficient tree suited to a high density planting. How future UP genotypes, currently being developed by breeders, will respond is unknown, but they could exhibit more or less vigor than the genotypes in our study.

Reighard et al. (31) found no difference in tree sizes planted at the 1.5 and 2.0 m spacings through the first three years, but based on the trends in their planting suggested that differences might occur in the fourth growing season. Our findings do not support their suggestion and indicate that at close spacing (≤ 2.0 m) all three phenotypes would continue to be dwarfed, at least through the seventh growing season.

A number of studies using S habit peach trees have demonstrated that growth is reduced when trees are planted at closer spacing (higher tree density) (16, 24, 26, 32). Our results show that the novel P and UP growth habits respond much like S trees and produce smaller trees, both in terms of TCSA and canopy width when planted at closer spacings. However, the magnitude of change in tree size differs among the three growth habits as spacing increases from 1.5 m to 6.0 m within the row (Fig. 2C and 3D). In the sixth growing season TCSA increased with increasing tree spacing, but to a lesser degree in P trees. The data clearly illustrate the smaller tree size of P trees compared to UP or S habit trees and the lack of aggressive growth when P trees are presented with additional growing space. These findings agree with Reighard et al. (31) regarding the nature of P habit trees to produce a narrow, upright canopy adapted to limited space.

The current study confirms the strong upright growth habit exhibited by P habit trees and the tendency to remain compact even when additional growing space is provided (36, 37). UP trees exhibited a narrower branch angle and upright form than S trees and could be characterized as intermediate between S and P (Fig. 1) as described by Scorza (36); however, as within-row spacing increased from 2.0 m to 4.0 m and then to 6.0 m, the canopies of UP trees spread to fill the available space and were similar in canopy width to S growth habit trees after seven years in the orchard (Fig. 3D).

In this study at the closest spacing (1.5 m) all three growth habits filled or exceeded the allotted canopy space after three growing seasons. In addition the UP and S habit trees also filled or exceeded the space allotted in the 2.0 m spacing after three growing seasons. This resulted in crowding and likely affected canopy light levels and growth. The significant increase in TCSA between the 2.0 and 4.0 m spacings would support this suggestion. The leaf yellowing and dying twigs observed in our study beginning about July in the inner canopy of UP and S habit trees at the closest spacings (1.5 and 2.0 m) suggested that crowding may have been a problem at these spacings on this site for these growth habits. While there was a statistically significant difference in terminal shoot growth between the closest and widest spacings in the third (2001) through the fifth (2003) growing seasons, in practical terms the differences in actual shoot lengths were minimal. Marini (21) suggested that the ideal peach fruiting shoot is about 30.5 to 61 cm long. He indicated that "long" branched shoots (no specific length given) are less fruitful and shoots < 20 cm long produce small fruit. The three growth habits in this study generally produced terminal shoots within the length suggested by Marini (21). Excessive terminal growth was produced by all trees in the third (2001) and seventh (2005) growing seasons. In 2001 the trees were still young and had not entered full bearing and in 2005 the excessive growth was probably the result of the heavy dormant pruning used to adjust canopy height. No measurements were taken, but P trees in this study were observed to produce a large number of short (< 20 cm) 2nd- or 3rd-order fruiting shoots. Bassi et al. (2)

found no difference in the average length of fruiting shoots among the three growth habits after two growing seasons, but their trees were all planted 4.3 m apart in the row and likely experienced no crowding at the time of their measurements.

Previous studies have reported differences in various growth parameters due to training system (16, 24, 31, 32, 39). In the present study, training P, UP, or S growth habit trees to a CL or ML form had no effect on TCSA or canopy spread. Given the upright growth habit of P and UP trees and the natural spreading habit of the S trees the interaction between growth habit and training system on canopy height is not unexpected (Fig. 3B). The two training systems used in this study did not result in dramatically different tree forms as in some studies (32, 39). Marini and Sowers (24) also reported no effect of training system (tree form) on TCSA when 'Norman' peach was trained to an open-vase or CL form.

It was the authors' expectation that the severe pruning to adjust (reduce) tree height and produce a "short tree orchard system" (5) would enhance tree vigor significantly. While terminal shoot growth was increased (about 12%) in the ST trees compared to the conventional pruned TL trees, and the subsequent dormant pruning time and number of dormant pruning cuts per tree was reduced in the ST trees, TCSA and canopy width were not affected. Crop loads on ST trees appeared normal for the given canopy volume, but were lower than that for TL trees (data not shown). In general the effects of this severe pruning on growth were not as dramatic as expected. However, such severe pruning techniques on established trees could be expected to have a negative effect on yields, at least initially.

Few studies have reported the dormant pruning time required for peach. Taylor (39) found that pruning time per tree differed depending on the training system. In our study, dormant pruning time differed depending on growth habit and spacing, but not with training system. The smaller, more compact growth habit of P trees resulted in less dormant pruning time per tree than for the more vigorous UP and S habit trees. When the three growth habits were compared at the same spacing, P trees required less total pruning time per ha than UP or S trees. However, our data clearly show that a high-density (1.5 m spacing) P planting would require more total pruning time per ha than a low-density (6.0 m spacing) S planting due primarily to the greater number of trees in the high-density P planting. This could be a significant disadvantage for a high-density P planting when labor is a concern. The difference in dormant pruning time between the P and the UP or S trees was more pronounced as trees matured especially at the widest tree spacings (Fig. 6A).

Our study used different genotypes for both P and UP trees than in Bassi et al. (2), but our findings regarding the number of pruning cuts per tree among the three growth habits are very similar to their findings. The difference between Bassi et al. (2) and our results is primarily the total number of cuts (about twice as many in our study for similar age trees) and is likely due to several factors, mainly inherent differences in genotype, the planting site, and the growing environment.

While P and UP trees required less dormant pruning time and fewer pruning cuts per tree than S habit trees (Tables 2 and 3), they both required significantly more time per cut than S trees (Fig. 8). Bassi et al. (2) indicated that more of the cuts in the P and UP habit trees were training cuts as opposed to many of the cuts in S habit trees designed to remove weak (and unproductive) wood. The increased time per cut for P and UP trees in our study can be partially attributed to this "training" factor described by Bassi et al. (2). Decisions regarding training cuts require more time than cuts to remove overly vigorous or weak unproductive wood. A second and more likely contributing factor in our study is related to the growth habit and tree vigor. Buds that broke and the new shoots on P trees, and to some extent on UP trees, were strongly oriented in a vertical position. In the top and periphery of the tree, especially where thinning or heading pruning cuts were made, numerous shoots were often produced (the natural vigor of the trees and our site were likely contributing factors to the proliferation of shoots). These new shoots had a near zero degree crotch angle with the originating branch (that is, the new shoot was oriented 90° above horizontal). Positioning the pruning shears to remove some (or all) of these vertical shoots was difficult and required more time. A third factor contributing to the greater time per cut in P and UP trees is associated with the use of a ladder to prune the taller growth habits. In a commercial setting the use of a mobile platform system could reduce the time attributed to the ladder work in our study.

Marini and Rossi (23) reduced dormant pruning time of mature peach trees when the trees were summer pruned. Our study produced a similar result and, in addition, indicates that the potential benefit of reduced dormant pruning time and fewer pruning cuts is greater for trees at a wider spacing (6.0 m) than for trees at a narrow spacing (1.5 m) (Figs. 6B and 7B).

Considerable attention has been given to the effects of SP on peach (4, 18, 19, 22, 28). Marini and Barden (22) indicate that the response to SP varies with tree vigor, cultivar, time, and type of pruning. They further state that most research suggests that SP is no more effective than a similar level of dormant pruning for controlling peach tree size and growth. The current study involving three growth habits indicates that annual summer pruning can reduce tree size (based on TCSA and canopy width). Our findings further suggest that tree spacing influences the terminal shoot growth response to SP (Figs. 5) and in addition, growth habit and SP are likely to interact to affect the number of dormant pruning cuts (Fig. 7C). These results appear to contradict Marini and Barden (22), but it should be pointed out that their conclusions were based primarily on S habit trees planted at wide spacing (≥ 4.0 m). The significant interactions in this study would suggest that at close spacing (≤ 2.0 m) the novel P and UP growth habits may perform differently and exhibit reductions in growth from SP. Marini and Barden (22) indicated that SP or summer-hedged peach trees had as much or more shoot extension as dormant pruned trees when measured the year following the SP treatment. Marini (19) found that SP stimulated shoot growth on young (fourth-leaf) vigorous 'Cresthaven' peach trees the year following treatment. Our findings support the suggestion that growth is enhanced on SP trees in the year after SP is discontinued.

While our results suggest some benefits in growth reduction and dormant pruning time from SP, the significant time required to SP is a concern. Marini and Rossi (23) reported that mature S 'Sunqueen' trees planted at 143 trees/ha required between 14.3 and 20 hr/ha to SP. Based on the data, our S trees in the sixth leaf required about twice this amount of time at a comparable tree density. It should be pointed out that our method of SP was quite detailed and more extensive than in their study. In addition, the greater amount of SP time for P and UP trees in the early years is associated with the vigor of these trees at a young age and the attempt to manually position limbs at this stage, primarily in 2001. Our preliminary work (27) suggested that the time required for limb positioning provided little or no benefit to canopy development and the practice was discontinued. Also, ladder work was required for all P and UP trees regardless of the training system used which undoubtedly added to the SP time. Nonetheless, SP almost doubled the total pruning time for all growth habits in this study (Table 5) rendering it a questionable practice.

The current study supports Scorza et al. (36) suggestion that the novel P peach tree growth habit is well suited for high-density production systems at tree spacings of 1.5 m within the row. When planted at wider spacings (4.0 and 6.0 m) P trees did not fill the allotted space even after seven years in the orchard. The training system selected for P trees seems to have little or no effect on growth or pruning, but given their strong vertical growth habit, systems using a single leader with bearing laterals, such as a slender spindle form, and a limited amount of structural wood would appear to be most appropriate for P trees. The UP trees in this study also appear well suited for high-density planting systems at 1.5 to 2.0 m spacings. At these spacings UP trees performed similar to P trees or intermediate between P and S trees. However, when provided with additional growing space (4.0 and 6.0 m) our UP trees demonstrated a very vigorous and more spreading growth that resembled S type trees planted at wider within-row spacings. It should be pointed out, however, that this study represents only a single UP genotype and other UP genotypes being developed may not exhibit the highly vigorous growth seen in 'Sweet-N-UP'. UP trees with branch orientation between strongly vertical as in P trees or more spreading as in S trees seems well suited to a "Y" or "V" training system. In this study close spacing combined with annual SP provided a dwarfing response with additional benefits in reducing dormant pruning time and the number of dormant pruning cuts. The detailed SP performed here was a very timely procedure and thus raises serious questions as to the overall benefit from this practice even for the novel P and UP growth habits planted at high-density.

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Literature Cited

1. Bargioni, G., F. Loreti and P.L. Pisani. 1985. Ten years of research on peach and nectarine in a high density system in the Verona area. Acta Hortic. 173:299-309.
2. Bassi, D., A. Dima and R. Scorza. 1994. Tree structure and pruning response of six peach growth forms. J. Amer. Soc. Hort. Sci. 119:378-382.
3. Chalmers, D., B. van den Ende and L. van Heek. 1978. Productivity and mechanization of the Tatura trellis orchard. HortScience 13:517-521.
4. Chalmers, D.J., P.D. Mitchell and L. van Heek. 1981. Control of peach tree growth and productivity by regulated water supply, tree density, and summer pruning. J. Amer. Soc. Hort. Sci. 106:307-312.
5. Day, K.R. 2004. Following tree height, labor costs, and orchard efficiency. Peach Times, Spring, p. 2, Columbia, S. C.
6. DeJong, T.M., K.R. Day, J.F. Doyle and R.S. Johnson. 1994. The Kearney Agricultural Center perpendicular "V" (KAC-V) system for peaches and nectarines. HortTechnology 4:362-367.
7. DeJong, T.M., R.S. Johnson, J.F. Doyle and D. Ramming. 2005. Research yields size controlling rootstocks for peach production. Calif. Agric. 59(2):80-83.
8. Erez, A. 1982. Peach meadow orchard: two feasible systems. HortScience 17:138-142.
9. Ferree, D.C. 1980. Canopy development and yield efficiency of 'Golden Delicious' apple trees in four orchard management systems. J. Amer. Soc. Hort. Sci. 105:376-380.
10. Frecon, J.L. and D. Ward. 2008. Yellow fleshed peach varieties for New Jersey. N. J. Agric. Expt. Sta. Fact Sheet 1072, 6 pp., New Brunswick, N.J.
11. Grappadelli, L.C. 2001. Peach training systems in Italy. Hort. News 81(3):3-6, 20-22.
12. Hayden, R.A. and F.H. Emerson. 1988. High density plantings for peaches. Pp. 404-411. In: Childers, N.F. and W. B. Sherman (eds.). The peach. Horticultural Publications, Gainesville, Fla.
13. Heinicke, D.R. 1975. High density apple orchards – planning, training, and pruning. USDA Agri. Handbook 458, Washington, D.C.
14. Hoying, S.A., T.L. Robinson and R.L. Andersen. 2007. More productive and profitable peach planting systems. New York Fruit Quart. 15(4):13-18.
15. Layne, D.R. 2007. The impact of orchard systems on yield and yield efficiency of Redglobe peach in the first six fruiting seasons. HortScience 42:998 (Abstr.).
16. Layne, D.R., D.B. Cox and E.J. Hitzler. 2002. Peach systems trial: the influence of training system, tree density, rootstock, irrigation and fertility on growth and yield of young trees in South Carolina. Acta Hort. 592:367-375.
17. Layne, R.E.C., C.S. Tan and J.M. Fulton. 1981. Effect of irrigation and tree density on peach production. J. Amer. Soc. Hort. Sci. 106:151-156.
18. Leuty, S.J. and D.J. Pree. 1980. The influence of

tree population and summer pruning on productivity, growth, and quality of peaches. J. Amer. Soc. Hort. Sci. 105:702-705
19. Marini, R.P. 1985. Vegetative growth, yield, and fruit quality of peach as influenced by dormant pruning, summer pruning, and summer topping. J. Amer. Soc. Hort. Sci. 110:133-139.
20. Marini, R.P. 1990. Pruning peach trees. Virginia Coop. Ext. Bul. No. 422-020, Blacksburg, Va.
21. Marini, R.P. 2002. Pruning peach trees. Virginia Coop. Ext. Bul. No. 422-020 Revised, Blacksburg, Va.
22. Marini, R.P. and J.A. Barden. 1987. Summer pruning of apple and peach trees. Hort. Rev. 9:351-375.
23. Marini, R.P. and D. Rossi. 1985. A partial economic analysis of three pruning treatments on mature peach trees. HortScience 20:242-243.
24. Marini, R.P. and D.S. Sowers. 2000. Peach tree growth, yield, and profitability as influenced by tree form and tree density. HortScience 35:837-842.
25. Marini, R.P., D.S. Sowers and M.C. Marini. 1995. Tree form and heading height at planting affect peach tree yield and crop value. HortScience 30:1196-1201.
26. Miles, N.W., R. Guarnaccia and K. Slingerland. 1999. High density peach production in Ontario. New York Fruit Quart. 7(4):11-15.
27. Miller, S. and R. Scorza. 2002. Training and performance of pillar, upright, and standard form peach trees – early results. Acta Hort. 592:391-399.
28. Myers, S.C. 1993. Preharvest watersprout removal influences canopy light relations, fruit quality, and flower bud formation of 'Redskin' peach trees. J. Amer. Soc. Hort. Sci. 118:442-445.
29. National Peach Council. 2007. 2007 Peach statistical yearbook. National Peach Council, Columbia, S. C. p. 85.
30. Pfeiffer, D.G. (ed.). 2005. Spray bulletin for commercial tree fruit growers. Va. Tech., West Va. Univ., Univ. Md. Coop Ext Services, Publ. No. 456-419, Blacksburg, Va.
31. Reighard, G.L., D.R. Ouellette, K.H. Brock and R. Scorza. 2004. Orchard systems for pillar and upright peach phenotypes. Acta Hort. 636:695-700.
32. Robinson, T.L., R.L. Andersen and S.A. Hoying. 2006. Performance of six high-density peach training systems in the northeastern United States. Acta Hort. 713:311-320.
33. Robinson, T.L., A.N. Lakso and S.G. Carpenter. 1991. Canopy development, yield, and fruit quality of 'Empire' and 'Delicious' apple trees grown in four orchard production systems for ten years. J. Amer. Soc. Hort. Sci. 116:179-180.
34. Scorza, R. 1984. Characterization of four distinct peach tree growth types. J. Amer. Soc. Hort. Sci. 109:455-457.
35. Scorza, R. 1988. Progress in the development of new peach tree growth habits. Compact Fruit Tree 21:92-98.
36. Scorza, R., G.W. Lightner and A. Liverani. 1989. The pillar peach tree and growth habit analysis of compact x pillar progeny. J. Amer. Soc. Hort. Sci. 114:991-995.
37. Scorza, R., S. Miller, D.M. Glenn, W.R. Okie and T. Tworkoski. 2006. Developing peach cultivars with novel growth habits. Acta Hort. 713:61-64.
38. Singh, H. and J.S. Kanwar. 2004. Effect of planting distances and training systems on light interception in high density plantations of peach trees grown under subtropical conditions. Acta Hort. 662:225-229.
39. Taylor, K.C. 2003. Optimizing peach yields through training systems. Penn. Fruit News 83(6):19, 21-24.
40. Weibel, A., R.S. Johnson and T.M. DeJong. 2003. Comparative vegetative growth responses of two peach cultivars grown on size-controlling versus standard rootstocks. J. Amer. Soc. Hort. Sci. 128:463-471.
41. Yamazaki, K., M. Okabe and E. Takahashi. 1987. New broomy flowering peach cultivars 'Terutebeni' 'Terutemomo' and 'Teruteshiro' Bulletin of the Kanagawa Horticultural Experiment Station, No. 34, Ninomiya-machi, Kanagawa, Japan.