nonventilated vessels. However, the general trend for greater root growth from liquid medium versus agar medium should be emphasized. Extrapolation of exponential and linear growth curves suggests differences in root biomass will continue to increase in the nursery past the 60-d sample period used for this investigation. Liquid culture in vitro resulted in larger plants of 'Newberry Gold' with a more vigorous root system in the nursery.

Shoots of *Hosta* 'Blue Cadet' produced in vitro had greater dry weight from liquid culture than agar culture (Table 1). Ventilated vessels produced shoots with greater dry weight than conventional vessels. During the 60-d of ex vitro growth, shoots from liquid culture were larger than agar produced shoots, shoots from ventilated vessels in agar culture were larger than shoots produced in conventional vessels, but from liquid culture the effects of ventilation on ex vitro growth were transient (Table 2). All shoots of 'Blue Cadet' grew exponentially over the 60-d ex vitro sample period (Fig. 4). However, shoots of plants cultured on agar in conventional vessels exhibited a lag phase of at least three weeks prior to exponential growth. Shoots from agar-cultured plants in ventilated vessels grew without a lag. Both groups of agar produced shoots were outperformed by shoots of plants from liquid culture during ex vitro growth.

Roots of 'Blue Cadet' were initiated after about 15 d ex vitro. Rooting of plants from agar culture in conventional vessels proceeded at a relatively slow, linear rate (Fig 5.). Roots of liquid cultured plants, and plants from ventilated agar vessels entered exponential growth without a discernible lag phase. To generalize growth of 'Blue Cadet', the larger liquid cultured plants maintained similar or greater dry weights than agar cultured plants over the entire period of ex vitro growth period.

The use of liquid culture, for both 'Newberry Gold' and 'Blue Cadet', resulted in plants with greater dry weight in vitro than plants cultured on agar. Nursery growth of liquid-cultured plants is at least as good as plants from agar. Ventilation apparently improves acclimatization of plants from agar. Hyperhydric tissues were not observed in any of the treatments for these two cultivars, and we found no apparent benefits of ventilation for ex vitro growth of liquid cultured plantlets of these cultivars. Survival of plantlets ex vitro was excellent for all treatments.

Since effective acclimatization was evident by active growth ex vitro from liquid medium without a lag phase, we concluded that *Hosta* from liquid culture did not suffer upon transfer from in vitro conditions. Plants from agar were more sensitive. Liquid culture systems for *Hosta* are envisioned to be less costly during micropropagation and deliver plants with greater productivity for the nurserymen, a classic win-win situation.

Literature cited

Chu, I. 1995. Economic analysis of automated micropropagation, p. 19–28. In: J. Aitken Christie, T. Kozai, and M.A.L. Smith (eds.). Automation and environmental control in plant tissue culture. Kluwer Academic, Dordecht, The Netherlands.

Draper, N.R. and H. Smith. 1966. Applied regression analysis. Wiley, New York.

Kitto, S. 1997. Commercial micropropagation. HortScience 32:1012–1014.

Majada, J.P., M.A. Fai, and R.S. Tames. 1997. The effect of ventilation rate on proliferation and hyperhydricity of *Dianthus carophyllus* L. In Vitro Cell Dev. Biol.–Plant 33:62–69.

Murashige T. and F. Skoog. 1962. A revised media for rapid growth and bioassays with tobacco cultures. Physiol. Plant. 15:473.

Smith, M.A. and L.A. Spomer. 1995. Vessels, gels, liquid media, and support systems, p. 371–404. In: J. Aitken Christie, T. Kozai, and M.A.L. Smith (eds.). Automation and environmental control in plant tissue culture. Kluwer Academic, Dordecht, The Netherlands.

Schmid, W.G. 1991. The genus *Hosta*. Timber Press, Portland, Ore.

Zimmerman, R. 1996. Commercial application of tissue culture to horticultural crops in the United States. J. Kor. Soc. Hort. Sci. 37:486–490.

Ziv, M. 1995. In vitro acclimatization, p. 493–516. In: J. Aitken Christie, T. Kozai, and M.A.L. Smith (eds.). Automation and environmental control in plant tissue culture. Kluwer Academic, Dordecht, The Netherlands.

Response of Winter-injured Peach Trees to Pruning

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Additional index words. *Prunus persica*, yield, economic return, dehorn pruning, peach canker, pruning severity

Summary. Seven-year-old 'Blake'/ 'Lovell' peach [*Prunus persica* (L.) Batsch] trees were subjected to four pruning levels (none, light, heavy, and dehorned) each at three times (April, May, and June) in a factorial arrangement following freezing injury in January 1994. Pruning had a significant effect on canopy height, canopy volume and fruit yields. Peach trees pruned in April or dehorned (severe pruning) had less canopy volume in the first fruiting season (1995) after the pruning treatments were initiated than trees pruned in May or June and light or heavy pruned trees. In 1995, yields were lower for trees pruned in June, nonpruned or dehorned trees in 1994. These treatments also produced fewer large fruit at harvest and thus reduced dollar returns per hectare in 1995. In 1996, fruit numbers and fruit sizes did not differ among treatments, but dehorned trees had lower returns per hectare because trees were smaller. The results of this study indicate that peach trees subjected to moderate winter injury should be pruned no later than 2 to 3 weeks after bloom using a heavy level of pruning. There appears to be no economic advantage to dehorn pruning even though canopy volume can be reduced resulting in a smaller

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tree with high quality wood. The results clearly illustrate the long-term negative effect of dehorn pruning on yields resulting from reduced canopy volume. Mean number of cankers per tree increased over time from 1995 through 1998, but pruning treatments did not affect the number of cankers produced. Pruning treatments did affect the size of cankers and the number with visible gumming.

Low winter temperatures can lead to bark injury in peach trees, gumming, increased incidence of leucostoma canker (*Leucostoma persoonii* Höhn.) (Biggs, 1989b), complete crop loss, reduced shoot growth, and/or tree death (Greene et al., 1988). Peach trees in the middle and northern United States are often subjected to low winter temperatures which can result in significant damage to the buds and xylem tissue. Terminal dieback of the previous season's shoot growth and death of older weak branches is common when temperatures drop to –26 °C (–15 °F) or below. Xylem tissue may be injured or killed. Very little data exists regarding how to prune winter-injured peach trees.

Fruit trees that set fruit on 1-year-old wood respond better to heavy pruning than those that set flowers on short spurs (Westwood, 1978). Much has been written on methods for pruning peach trees and recommendations vary widely (Ashton et al., 1950; Childers, 1983; DeJong et al., 1994: Johnston and Larsen, 1965; Lamb and Edgerton, 1979; Marini, 1997; Overcash, 1988; Puls, 1983). Studies show that unusually heavy or severe pruning reduces yield (Hibbard, 1948; Kappel and Bouthillier, 1995; Savage et al., 1964) and the highest yields are obtained with minimal pruning (Westwood and Gerber, 1958). However, most agree that healthy peach trees need a moderate level of pruning annually to maintain adequate vigor and productivity and to keep trees within a manageable size (Marini, 1997; Micke et al., 1980; Puls, 1983).

Recommendations on how to prune winter-injured peach trees vary widely among growers and researchers and data from replicated experiments to support a given approach have not been published. Gunderson (1918) evaluated several pruning methods on young, bearing peach trees following winter injury in Illinois. He concluded that a moderate level of pruning in which last year's growth was either cut back or totally removed was the best practice resulting in better growth and fruit bud development. Dehorn pruning [heading back cuts of large limbs and/or scaffolds to within 46 to 61 cm (18 to 24 inches) of the trunk] severely reduced the size of the tree, resulted in less flower bud development and, in the case of 5-year-old 'Elberta', killed the trees. Gunderson (1918) found that no pruning was better than dehorn pruning. His observations were limited to the first growing season after the winter injury. In Rhode Island, Stene (1937) concluded that young winter-injured peach trees responded best, based on the amount and vigor of new growth and the color

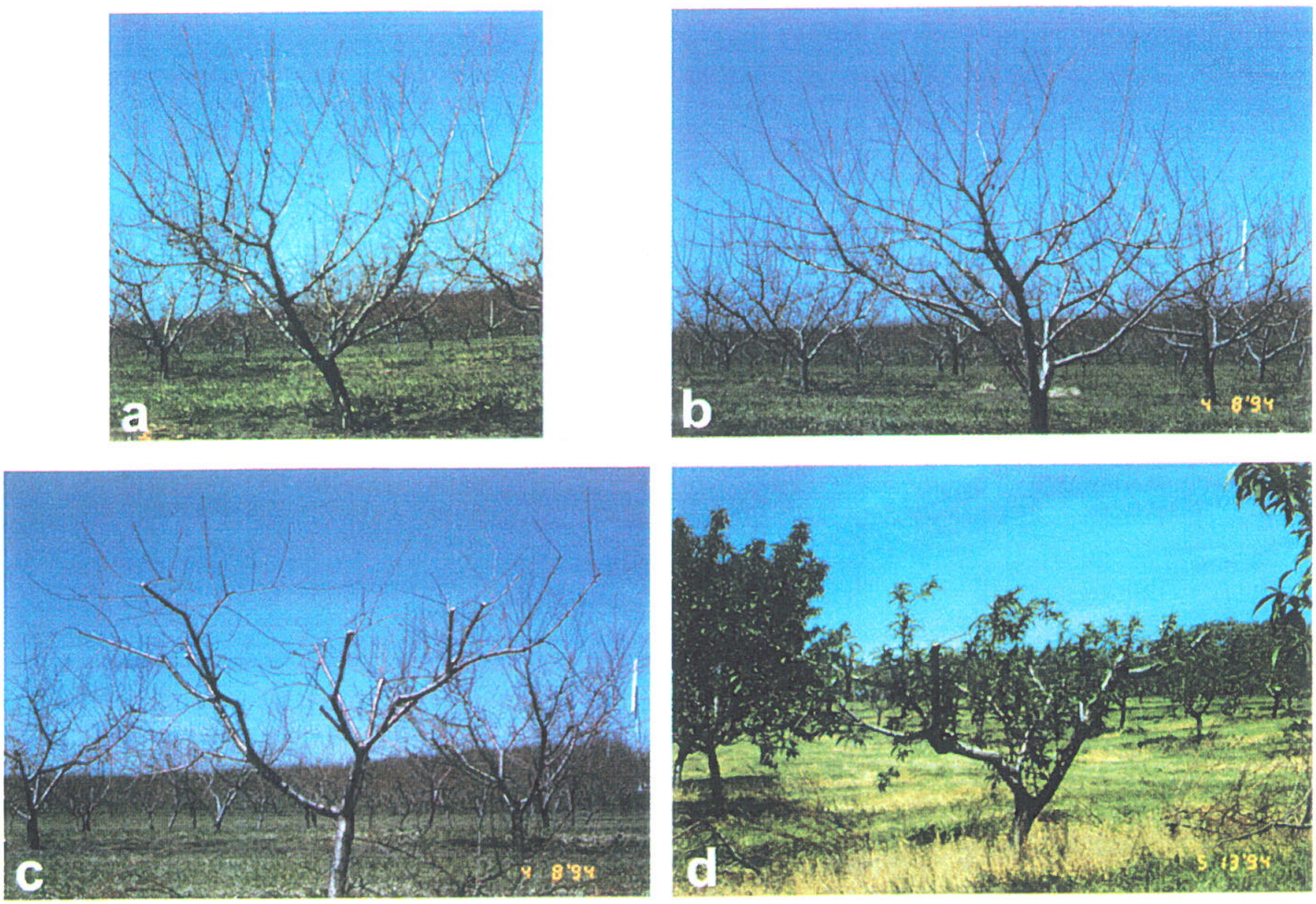

Fig. 1. Level of pruning treatments applied to winter-injured 'Blake'/'Lovell' peach trees, April to June 1994. (a) No pruning, (b) light pruning, (c) heavy pruning, and (d) dehorn pruning.

and density of foliage he observed, when he pruned trees in the spring, by removing dead wood and shaping the tops. He did not advise dehorning, as was recommended by some orchardists at that time. Neither Gunderson (1918) or Stene (1937) provided data to support their observations. At the time of Stene's work, most orchardists were advised to prune lightly or prune only when the extent of damage could be determined after the trees had emerged from dormancy.

Childers (1983) recommended not to prune winter-injured trees or to prune lightly after growth started in the spring combined with a heavy application of nitrogen fertilizer before budbreak. Johnston and Larsen (1965) suggested the best treatment for low temperature injured peach trees was to leave the trees unpruned. They did not advise pruning peach trees after bloom, and they raised doubts concerning the common practice of severe cutting back of bearing peach trees if low temperature injury eliminated all flower buds. Research that has focused on pruning peach trees under stress (such as peach tree short life syndrome) has shown that tree mortality is reduced when trees are pruned in the spring compared to winter (November through January) (Daniell, 1973; Prince and Horton, 1972). Recently, work in Michigan indicated that delayed pruning (June or July) of winter-injured peach trees produced weaker, less desirable growth (Great Lakes Fruit Grower, 1995) compared to pruning soon after budbreak in May. Heavy pruning produced strong upright growth with less hardy shoots compared to light pruning.

In January 1994, the eastern panhandle of West Virginia experienced three successive nights of temperatures near –26 °C or lower. There was a 100% kill of peach flower buds on trees in the region and injury to the tree's xylem tissue, although injury to vegetative buds or die back of 1993 shoots was minimal. These conditions provided an opportunity to initiate a study to examine the severity of several pruning levels applied at three times after the freeze on tree performance. Factors studied included the extent and quality of regrowth, leucostoma canker development, tree survival, fruit size, yield, and economic returns for several years subsequent to the injury.

Materials and methods

A block of 7-year-old 'Blake'/ 'Lovell' peach trees was chosen at the Appalachian Fruit Research Station, Kearneysville, W.Va, for this study. Trees were spaced 6 × 6 m (20 × 20 ft)[277 trees/ha (109 trees/acre)] with 13 trees per row and had received recommended commercial cultural practices since planting. All trees had been trained to the open center system. They were fairly uniform in size throughout the block and were considered typical, healthy peach trees for this region before January 1994. The main treatment effects were 1) level of pruning and 2) time of pruning. The level of prunings (Fig. 1) were 1) no pruning; 2) light pruning—removing broken or dead limbs and minimal thinning out of uprights to reduce crowding; 3) heavy pruning—considered a normal or conventional level of pruning with thinning out and heading cuts of some 2-year-old or older limbs, opening centers, and renewal cuts; and 4) dehorning—a severe pruning with heading back of larger scaffold limbs [up to 8.8 cm (3.5 inches) in diameter] to force new growth and reduce tree size. The timings selected were 1) April, at the swollen bud to half-inch green stage; 2) May, about 14 to 21 d after full bloom (DAFB); and 3) June, between 42 and 49 DAFB. Each level of pruning was applied at each of the three timings to individual trees in randomized complete blocks with 10 tree replications for each treatment except dehorn pruning, which was applied only in April and May with seven tree replications (due to a lack of available trees). To minimize variability due to individual pruning biases, S. Miller performed all pruning treatments in this study. Following the initial pruning treatments in 1994, all trees received identical dormant pruning in April of each year from 1995 through 1998 using a conventional method for pruning peaches grown in this region. In practice, this corresponded to our heavy 1994 pruning treatment. Visual observations regarding vigor and amount of new vegetative growth produced, death of shoots, leaf color, gumming and/or canker development, and general health of the trees were periodically recorded during the 1994 growing season.

In March 1995, before dormant pruning, average canopy height was determined from four measurements per tree taken at the highest point on each of four sides of the canopy (two in-row sides and two across-row sides). A quality of fruiting wood rating was assigned to each tree based on a visual examination of the tree's bearing mantle; the bearing mantle was considered to be the canopy from the ground to a height of about 2.75 m (9 ft). A rating scale of 1 to 5 was used where a rating of 1 was associated with thin [<5 mm (3/16 inch) diameter], poorly colored (light brown or grayish) fruiting wood, small buds, some dead wood and a general deficiency of good diameter [8 to 12 mm (3/8 to 1/2 inch)] fruiting wood. Wood rated 2, 3, or 4 had progressively larger diameter fruiting wood, less grayish black/ brown wood, larger fruit buds, and less visible dead wood. A canopy rating of 5 had medium to thick [8 to 12 mm] new bearing shoots, good color (dark reddish brown), large fruit buds, no dead wood, and an abundance of good diameter fruiting wood. The number of pruning cuts greater than 2.5 cm (1 inch) in diameter and the number with visible canker symptoms (bark splitting, cracking, gumming) from the 1994 pruning cuts was recorded in March 1995. Dead wood in the nonpruned trees was removed and weighed at this time. A single application of 10N–4.3P–8.3K fertilizer at 348 kg·ha^{-1} (310 lb/acre) was broadcast in late March of each year (1994–98). The fresh weight of prunings was recorded for each tree in 1995 and 1996. All trees were hand thinned in early June each year of the study to space fruit 15 to 20 cm (6 to 8 inches) apart. Local recommendations were followed for all other cultural and pest management practices during the study.

In mid-June 1995, a healthy scaffold limb was selected on half of the treatment trees and removed with a pruning saw at a point where its diameter was between 44 and 57 mm (1.75 to 2.25 inches). The open saw cut wound was coated with a commercial grade of wound dressing to prevent drying and retard any pest injury. From this severed limb a wood block was removed and the width of the annual growth (xylem tissue) was determined for 1994 and 1995 (up to mid-June) with the aid of a stereoscope and calipers. A black and white image representing the cross-sectional area of each wood block was made using a standard office photocopier. The discolored area representing the winter-injured tissue was carefully removed from the paper photocopy with scissors and the area determined with an area meter (LI-3100; LI-COR, Lincoln, Neb.). Percent of tissue showing winter injury was calculated from the total cross-sectional area of individual branch samples.

Canopy height, width, and depth were recorded and used to compute canopy volume at harvest. Yield efficiency ($kg \cdot m^{-3}$) per tree was computed from fruit weight and canopy volume. Canopy height was taken as described above. Canopy width was taken through the center of the canopy parallel to the row at chest height [1.3 m (4.3 ft)]. Canopy depth was measured perpendicular to the row through the center of the tree at the same height as width measurements. When the majority of the peaches reached the firm ripe stage of maturity, all fruit were harvested, weighed, and sized on a fruit grader (Omni-Sort; Durand-Wayland, Inc., LaGrange, Ga.). Value of the crop in 1995 was calculated using average prevailing market prices for a 17.24 kg (38 lb) box as reported by the USDA-AMS, Federal State Market News for the Appalachian Fruit District for 5 Aug. 1995. Fruit were divided into three size categories [>6.4 cm (2.5 inch), 5.7 to 6.4 cm (2.25 to 2.5 inch), and 5.1 to 5.7 cm (2.0 to 2.25 inch)] to determine value; fruit less than 5.1 cm (2 inch) in diameter was considered as having no value in this study. Beginning in 1996 and continuing through 1998 crop value was computed from prevailing market prices for a 11.34 kg (25 lb) box as reported by the USDA Market News Service for the Appalachian District for the second week in August of each year. Fruit size categories used in 1996 through 1998 were >7.0 cm (2.75 inch), 6.4 to 7.0 cm (2.5 to 2.75 inch), 5.7 to 6.4 cm (2.25 to 2.5 inch), and 5.1 to 5.7 cm (2.0 to 2.25 inch); no value was assigned to fruit smaller than 5.1 cm (2 inch) in diameter.

Leucostoma cankers on main scaffold limbs and larger lateral branches were counted in May 1996. Two trees per treatment, one from each of two replicated blocks, were selected for surgical removal of the cankers according to the techniques of Biggs (1989b) and Travis and Hickey (1985) in June and July 1996. The presence of peach tree borer and number inhabiting surgically removed cankers were recorded. Surgically removed cankers were examined in July 1997 and classified as healed [callused over and showing no characteristics typical of leucostoma canker (Biggs, 1989b)] or not healed (exhibited fresh gumming). All data collected in the study were subjected to ANOVA and means separated using Duncan's Multiple Range Test. Percent data was transformed to the arcsin for analysis. Since no treatment interactions were detected, statistical comparisons are reserved for main treatment effects.

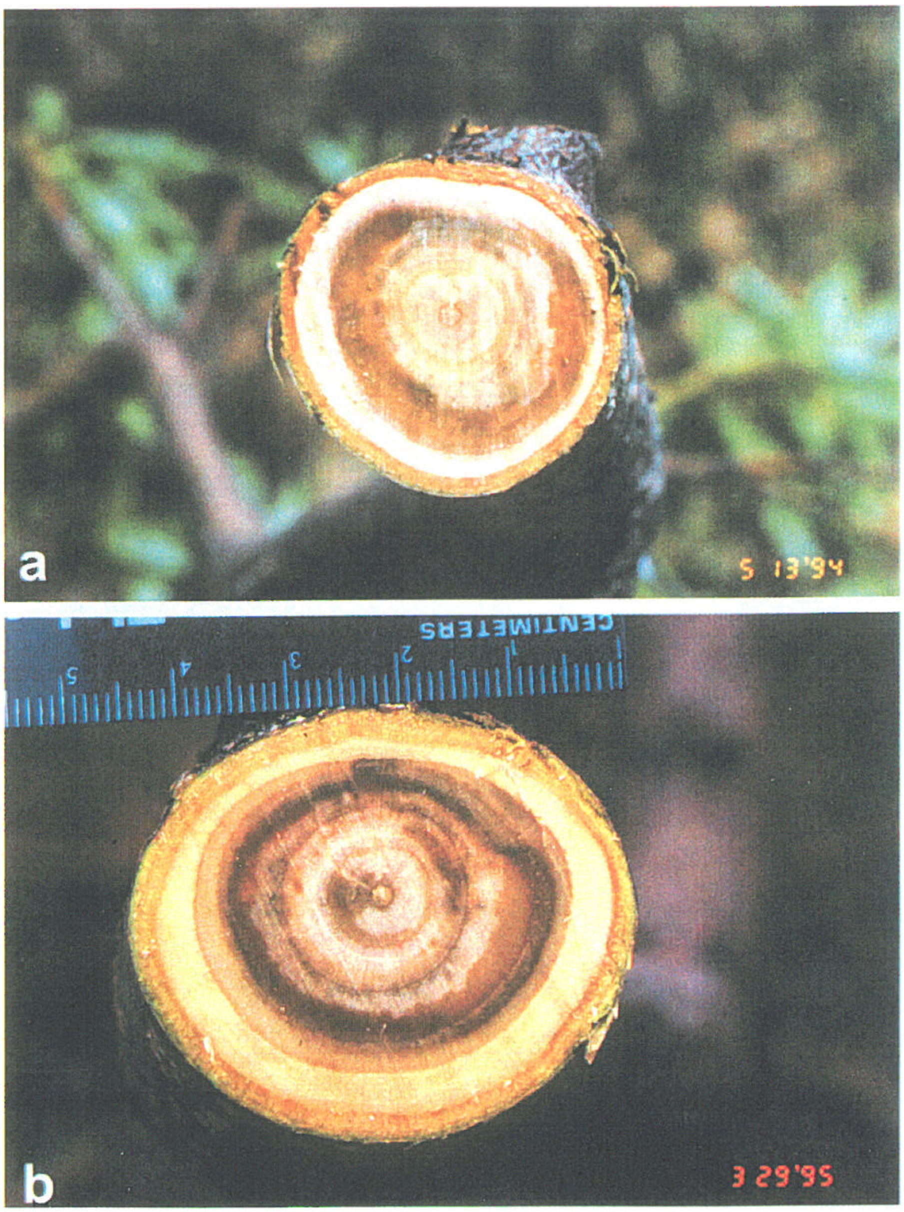

Fig. 2. Symptoms of winter injury to xylem tissue of 'Blake' peach trees sustained following three successive nights of temperatures near –28 °C (–15 °F) or lower, January 1994. (a) Cross-sectional view of 2-year-old branch 4 months after low temperature injury, and (b) cross-sectional view of a 4-year-old branch 14 months after winter injury.

Results and discussion

At the time of pruning in 1994 the xylem tissue on all trees exhibited some degree of discoloration (generally browning), which was attributed to the low winter temperatures of January 1994 (Fig. 2). More than 99% of the branches removed by pruning had discoloration to the woody tissue ranging from minor damage in the pith of

Table 1. Effect of time and level of pruning treatments in 7-year-old winter-injured (January 1994) 'Blake'/'Lovell' peach trees on perennial cankers in 1996 and 1997 and the condition of surgically removed cankers in 1997.

Pruning treatment 1994	Perennial cankers (no.) 1996		Perennial cankers/ tree (1997)	Canker diam (cm[z]) (% of total)		% Surgically removed cankers	
	Per tree	Gumming		2.5–5	≥5.1	Callused	Gumming
Time							
April	2.8 b[y]	1.2 a	5.8 a	27 a	43 a	59 a	41 a
May	3.2 b	0.7 ab	5.8 a	24 a	55 a	51 a	41 a
June	4.5 a	0.2 b	7.1 a	27 a	54 a	59 a	41 a
				$P = 0.51$		$P = 0.20$	
Level							
None	3.9 a	0.3 b	6.2 a	26 ab	58 a	73 a	27 b
Light	3.4 a	0.9 ab	6.1 a	17 b	62 a	64 a	35 ab
Heavy	3.4 a	0.6 b	5.5 a	43 a	31 b	61 a	39 ab
Dehorn	2.3 a	1.3 a	7.1 a	17 b	49 ab	12 b	72 a
	$P = 0.75$		$P = 0.73$				

[z]2.5 cm = 1 inch.
[y]Mean separation within columns for main treatment effects by Duncan's new multiple range test, $P = 0.05$.

smaller shoots to major damage in the xylem tissue in larger branches. The cambial and phloem tissues showed minimal discoloration. All trees produced reasonably good growth in 1994 following the January freeze. Leaf color was medium to dark green and observations made in midsummer 1994 suggested that the most vigorous and best fruiting wood was associated with heavy or dehorn pruned trees. Numerous small [<5 mm (3/16 inch) diameter] shoots, both terminal and lateral, and a limited number of small branches failed to leaf out on the nonpruned trees in 1994, apparently a result of low temperature injury. A few additional shoots died during the 1994 growing season. The average weight of dead wood removed from the nonpruned trees in April 1995 was 1.3 kg (2.8 lb) per tree, which represented about 15% of the fresh weight prunings removed from these trees.

The percent of the total cross-sectional area that exhibited discoloration in the excised branch samples did not differ among treatments (range of 43 to 47%) when measured in June 1995 (data not shown). Pruning treatments also had no effect on the amount of new xylem tissue produced in 1994 or up to the date of limb sampling in June 1995 (data not shown). These findings suggested that xylem tissue was uniformly affected by the low temperature and that pruning treatments may affect terminal shoot growth but have little or no effect on the amount of xylem wood laid down in the subsequent years in the older lateral branches and permanent scaffold limbs.

The occurrence of gumming or development of leucostoma canker was limited during the 1994 growing season. At the time of pruning in Apr. 1995 and subsequently through the early growing season, there was an observed increase in the incidence of gumming and number of cankers on scaffold branches. All trees grew well in 1995 and no trees or major portions of any tree died in the second growing season after the winter freeze. No major scaffold limbs were lost due to cankers in 1995. A limited number of small shoots and branches continued to die in 1995 on all treatments and were removed during the dormant pruning in Apr. 1996.

When trees were evaluated for well-defined leucostoma cankers in 1996, trees pruned in June 1994 had more cankers per tree than trees pruned in April or May 1994 (Table 1). Delayed pruning may further weaken already weak, winter-injured trees thus increasing the susceptibility to canker development. However, more cankers exhibited gumming on trees pruned in April than trees pruned in June when observed in 1996 (Table 1). Hickey and Travis (1985) reported more pruning wound infections on trees pruned in April than for trees pruned in June. Their trees were without winter injury unlike the trees in this study. Level of pruning had no effect on the number of cankers produced after two growing seasons (Table 1). While dehorned trees tended to have fewer cankers, these cankers exhibited more gumming (Table 1) than trees receiving no pruning or heavy pruning in 1994. In 1996 dehorned pruned trees had about one-third fewer well-defined cankers than other levels of pruning (data not shown). This may be related to the more severe pruning on dehorned trees, which led to a greater quantity of new wood that was less susceptible to invasion by canker causing organisms. Pruning treatments had no apparent effect on the number of cankers inhabited by peach tree borers (data not shown) when examined in 1996.

The average number of leucostoma cankers per tree across all treatments in 1996 was 3.4. In 1997 the average number of cankers had increased to 6.2 per tree. There were no differences in the number of cankers per tree within time or level of pruning treatments in 1997, however, there was a trend for more cankers on trees pruned in June or dehorned trees (Table 1). Time of pruning did not affect the size of cankers measured in 1997 and level of pruning had no effect on the percent of small sized cankers [2.5 cm (1 inch) diameter or less] in 1997 (data not shown). However, level of pruning affected the percent of medium [2.5 to 5.0 cm (1 to 1.9 inch)] and larger [5.1 cm (2 inch)] sized cankers (Table 1). Heavily pruned trees had more medium sized cankers than light or dehorn pruned trees and fewer large cankers than light or nonpruned trees.

Travis and Hickey (1985) were successful in eradicating cytospora canker [*Cytospora leucostoma* Fr. (anamorph = *L. persoonii* Höhn.)] by surgically removing the diseased tissue associated with the canker. When we

Table 2. Response of 7-year-old winter-injured (January 1994) 'Blake'/'Lovell' peach trees to time and level of pruning in spring 1994. Data were taken before or at the time of pruning (2.5 cm = 1 inch, 1.0 m = 3.3 ft, 1.0 kg = 2.2 lb).

Pruning treatment 1994	Canopy ht (m) March 1995	Pruning cuts made 1994 >2.5 cm diam (no./tree)	Pruning cuts made 1994 Visible gumming and cankering (%)	Quality of fruiting wood in the bearing mantle[z] (1–5)	Fresh wt (kg) in April prunings 1995	Fresh wt (kg) in April prunings 1996
Time						
April	2.9 b[y]	6.3 b	26.9 a	3.3 a	5.4 a	9.0 a
May	3.0 a	7.1 b	23.9 a	3.1 a	6.4 a	8.9 a
June	3.0 a	8.8 a	27.2 a	2.3 b	6.3 a	10.4 a
Level						
None	3.2 a	---	---	1.9 d	8.6 a	9.1 ab
Light	3.1 a	5.6 b	25.0 b	2.5 c	6.8 a	10.2 a
Heavy	2.8 b	8.2 a	25.6 ab	3.7 b	3.8 b	9.7 ab
Dehorn	2.64 c	8.8 a	28.4 a	4.5 a	3.3 b	7.1 b

[z]Rating: 1 = new wood thin [<5 mm (≈3/16 inch)], poorly colored, small buds, some dead wood, and deficiency of new wood; 5 = abundant new wood is medium to thick in diameter [8 to 12 mm (3/8 to 1/2 inch)], good color, large buds, no dead wood.
[y]Mean separation within columns for main treatment effects by Duncan's new multiple range test, $P = 0.05$.

surgically removed cankers from an equal and selected number of trees and cankers across all pruning treatments, time of pruning had no effect on the percent of cankers that callused or exhibited fresh gumming (Table 1). However, the percent of cankers that callused and healed among level of pruning treatments was significantly less for dehorned trees than all other treatments. Travis and Hickey (1985) reported that surgery failed to eradicate cankers only when there was incomplete removal of diseased tissue. While we cannot rule out the potential for incomplete removal of diseased tissue, the authors feel that tree stress may be a causal factor in the lack of success to surgically remove cankers in this study.

The effect of the January 1994 freeze was readily visible in limbs removed during the normal dormant pruning in 1995 and 1996 as discoloration of the inner wood, varying from light to dark brown or black. Upon examining dead shoots and branches in cross section, it was observed that those, which died, had a significant portion of dark brown wood tissue and very limited light-colored, viable wood or phloem tissue. Woody tissue in these branches was apparently unable to recover from the low temperature injury. No tree deaths occurred during this study. Near the end of the third growing season (1996), one scaffold limb was lost as a result of severe canker development near the base of the limb. From 1997 through 1998, six additional trees lost at least one major scaffold limb. At the conclusion of the study, among the seven trees with major scaffold loss, four trees lost half or more of their original canopy. Three of these trees were in the nonprune treatment; the other tree with significant canopy loss was a light prune treatment.

Trees pruned in April 1994 had a lower canopy height in March 1995 than trees pruned in May or June (Table 2). Likewise, heavy or dehorned trees reduced canopy height compared to light pruned or unpruned trees. Dehorned trees had the lowest canopy height among all levels of pruning. A greater number of large cuts [>2.5 cm (1 inch) diameter] was made on trees pruned in June or heavy and dehorned trees than trees pruned at the earlier timings and lightly pruned trees (Table 2). Treatments resulting in greater numbers of large cuts generally had a higher percent of cuts with visible gumming and in the case of the dehorned trees, the percent of cuts that exhibited gumming was significantly greater than lightly pruned trees. Wilson et al. (1994) and Biggs (1989a) have demonstrated that the type of pruning cut used on peach influences the degree of cytospora (*Leucostoma*) canker infection. The pruning cuts used in this study were similar to flush cuts and not collar cuts that were shown to have less cytospora infection (Wilson et al., 1984). There are no known reports relating size of pruning wounds to frequency of gumming. However, our results suggest that larger pruning cuts on winter-injured trees results in a tree that is more susceptible to gum production since the percent of cuts with gumming was greater for treatments with the greatest number of large cuts (Table 2). Weak and/or dying wood and pruning cuts are known to be an

Table 3. Effect of time and level of pruning treatments in 7-year-old winter-injured (January 1994) 'Blake'/'Lovell' peach trees on canopy volume from 1995 through 1998 (1 m^3 = 35.3 ft^3).

Pruning treatment 1994	Canopy vol (m^3) 1995	1996	1997	1998
Time				
April	37.9 b[z]	34.8 b	51.1 b	56.1 a
May	43.6 a	38.0 ab	55.3 ab	61.0 a
June	44.6 a	41.7 a	60.4 a	64.0 a
Level				
None	41.1 a	39.3 a	56.7 a	63.0 a
Light	44.6 a	39.3 a	56.9 a	59.6 a
Heavy	44.2 a	40.0 a	55.9 a	62.6 a
Dehorn	32.6 b	27.4 b	46.4 b	49.7 b

[z]Mean separation within columns for main treatment effects by Duncan's new multiple range test, $P = 0.05$.

Table 4. . Effect of time and level of pruning treatments in 7-year-old winter-injured (January 1994) 'Blake'/'Lovell' peach trees on yield [fruit weight (kg) and fruit number] from 1995 through 1998 (1 kg = 2.2 lb).

Pruning treatment 1994	Mean fruit yields/tree							
	1995		1996		1997		1998	
	(kg)	(No.)	(kg)	(No.)	(kg)	(No.)	(kg)	(No.)
Time								
April	38 a[z]	262 a	56 a	366 a	57 b	413 a	57 b	377 a
May	40 a	285 a	60 a	371 a	54 b	372 a	63 ab	407 a
June	31 b	201 b	61 a	385 a	62 a	420 a	69 a	435 a
						$P = 0.21$		$P = 0.48$
Level								
None	30 c	184 c	59 ab	378 a	58 a	396 a	60 ab	375 ab
Light	38 ab	253 b	64 a	398 a	59 a	400 a	66 a	448 a
Heavy	44 a	326 a	58 ab	368 a	60 a	432 a	69 a	441 a
Dehorn	34 bc	242 b	50 b	320 a	45 b	328 b	48 b	287 b
				$P = 0.47$				

[z]Mean separation within columns for main treatment effects by Duncan's new multiple range test, $P = 0.05$.

ideal infection court for *Leucostoma* species that cause leucostoma canker (Biggs, 1989b).

Quality ratings of canopy fruiting wood taken in March 1995 were greater for trees pruned in April or May than trees pruned in June (Table 2). All levels of pruning produced higher fruiting wood quality ratings than no pruning. Wood quality rating was greater for dehorned pruned trees than all other pruning levels. Quality of wood rating appeared to be negatively related to canopy height ($r = 0.54$; $P \leq 0.05$) and in general the lower the canopy, the higher the quality of wood. New, high quality wood in the bearing mantle area was evident where heavy or severe pruning methods lowered the canopy height.

Time of pruning had no effect on fresh weight of prunings in 1995 (Table 2). Heavy and dehorned trees had significantly less pruning weight in 1995 than nonpruned or lightly pruned trees. Time of pruning treatments had no effect on the fresh weight of dormant prunings in March 1996; however, the level of pruning continued to affect pruning weight (Table 2). Dehorn pruned trees had the lowest pruning weight, but it only differed from the light pruned trees. Less pruning weight is a reflection of the smaller canopy for dehorn pruned trees.

Winter-injured trees pruned in May or June 1994 had more canopy volume than similar trees pruned in April when measured at harvest in 1995 (Table 3). Canopy volume of June pruned trees continued to exceed that for April pruned trees when measured in 1996 and 1997, but time of original pruning treatments had no effect on canopy volume when measured at harvest in 1998. Dehorned trees had the lowest canopy volume among all levels of pruning (Table 3). The effect of dehorn pruning on canopy volume persisted through the 1998 season. The effect of time or level of pruning on canopy height was similar to the effect on canopy volume (data not shown).

Table 5. Effect of time and level of pruning treatments in 7-year-old winter-injured (January 1994) 'Blake'/'Lovell' peach trees on yield efficiency ($kg \cdot m^{-3}$ canopy volume) from 1995 through 1998 ($1\ kg \cdot m^{-3} = 0.062\ lb/ft^3$).

Pruning treatment 1994	Yield efficiency/tree ($kg \cdot m^{-3}$ canopy vol)		
	1995	1996	1997
Time			
April	1.07 a[z]	1.73 a	1.15 a
May	0.97 a	1.70 a	0.98 b
June	0.72 b	1.55 a	1.05 ab
Level			
None	0.73 c	1.66 ab	1.04 a
Light	0.89 bc	1.69 ab	1.06 a
Heavy	1.04 ab	1.53 b	1.10 a
Dehorn	1.18 a	1.93 a	1.01 a

[z]Mean separation within columns for main treatment effects by Duncan's new multiple range test, $P = 0.05$.

Table 6. Effect of time and level of pruning in 1994 in 7-year-old winter-injured (January 1994) 'Blake'/'Lovell' peach trees on fruit size in 1995 and 1997.

Pruning treatment 1994	Fruit size (cm^z) 1995			No. of large fruit (>7.0 cm) 1997
	5.1–5.7	5.7–6.4	>6.4	
Time				
April	8 a[y]	34 ab	217 a	241 b
May	11 a	43 a	227 a	257 ab
June	10 a	26 b	162 b	309 a
Level				
None	4 b	15 c	163 c	278 a
Light	9 ab	33 bc	208 b	290 a
Heavy	16 a	55 a	248 a	263 a
Dehorn	9 ab	36 b	194 bc	187 b

[z]2.5 cm = 1 inch.
[y]Mean separation within columns for main treatment effects by Duncan's new multiple range test, $P = 0.05$.

Table 7. Effect of time and level of pruning in 1994 in 7-year-old winter-injured (January 1994) 'Blake'/'Lovell' peach trees on gross returns (1,000 $US) per hectare from 1995 through 1998 ($1,000/ha is about $405 per acre).

Pruning treatment 1994	Gross returns (U.S. $1,000)/ha 1995	1996	1997	1998
Time				
April	8.3 a[z]	18.7 a	14.7 ab	19.0 b
May	8.8 a	20.0 a	14.3 b	20.8 ab
June	6.8 b	19.6 a	16.7 a	22.3 a
Level				
None	6.6 c	19.6 ab	15.4 a	19.6 ab
Light	8.3 ab	20.6 a	15.8 a	22.0 a
Heavy	9.5 a	19.4 ab	15.6 a	22.2 a
Dehorn	7.4 bc	16.2 b	11.7 b	16.1 b

[z]Mean separation within columns for main treatment effects by Duncan's new multiple range test, $P = 0.05$.

Yields (weight in kg) per tree were higher for early (April and May) pruned trees and light or heavy pruned trees (Table 4) and lower for trees pruned in June and for those not pruned or dehorned in 1995, the first cropping year after the winter injury. Trees pruned in June and the unpruned (in 1994) trees had the least number of fruit per tree in 1995 (Table 4). Trees that received the heavy pruning in 1994 had 1.8 times more fruit per tree than the nonpruned trees and 1.3 times more fruit than the light or dehorn pruned trees in 1995. Time of pruning had no effect on mean fruit numbers per tree in 1996 and subsequent years of the study, but June 1994 pruned trees did have higher yields (measured as total fruit weight) than trees pruned in April 1994 when measured in 1997 and 1998. While differences for yields among level of pruning treatments was not consistent from year to year, dehorned trees generally had lower yields and the fewest fruit number per tree among the level of pruning treatments (Table 4) from 1995 through the last year of the study in 1998. Yields for dehorned trees did not differ from the nonpruned trees except in 1997.

Time and level of pruning affected yield efficiency ($kg \cdot m^{-3}$) in 1995 (Table 5). Yield efficiency was greater for trees pruned in April or May than trees pruned in June. Dehorned trees and heavy pruned trees had higher yield efficiencies than the nonpruned trees. As severity of pruning increased, yield efficiency increased in 1995. The original time of pruning treatments had no effect on yield efficiency in 1996 or 1998 (data not shown for 1998), but trees pruned in April did have a higher yield efficiency than May pruned trees in 1997. Yield efficiency differed only between dehorned and heavy pruned trees in 1996 and there were no differences among level of pruning treatments in 1997 or 1998 (data not shown for 1998).

When fruit was graded there were no differences among any of the pruning treatments in percent of fruit grading into selected size classes in any year of the study (data not shown). We concluded, therefore, that the pruning treatments used here did not affect fruit size. However, differences did occur in the number of fruit grading into the selected size classes (Table 6). In the first cropping year (1995) after the winter injury, trees pruned in June and nonpruned trees had fewer larger fruit than trees pruned in April or May and light or heavy pruned trees, respectively. Fruit size distribution did not differ within main treatment effects at harvest in 1996, although there was a trend to fewer large fruit for the dehorned and heavy pruned trees (data not shown). The April pruned trees had fewer large fruit than June pruned trees and dehorned trees had the fewest number of large sized fruit among level of pruning treatments in 1997 (Table 6). In 1998 there were no differences within main treatment effects for any of the fruit size classes, however, there was a trend toward fewer large fruit in the April and the dehorn pruned trees. The number of fruit measuring 5.1 cm (2 inches) or less was uniform across all treatments throughout the study and generally less than 10 fruit for any tree (data not shown).

Gross returns per hectare in 1995 were highest for trees pruned in April or May and trees that received either light pruning or heavy pruning in 1994 (Table 7). Higher returns for these treatments can be attributed to more fruit per tree and more large fruit per tree. In general, higher fruit numbers and thus greater economic returns appeared to be associated with pruning which encouraged production of high quality fruiting wood in the bearing mantle area. The dwarfing effect of dehorn pruning had a negative impact on fruit number to the extent that returns per hectare were reduced for this treatment despite the high quality of bearing wood produced. The effect of time of pruning on gross returns from 1996 through 1998 was inconsistent, but in general, June-pruned trees had higher returns than May (1997) or April (1998) pruned trees. Whether these differences are associated with the initial time of pruning treatments is speculative, especially since all trees received the same level of pruning each year from 1995 through 1998. However, June pruned trees did have higher yields in 1997 and 1998 and yields are obviously associated with returns. The initial level of pruning treatments continued to affect returns for the 1996 through 1998 seasons. Returns for dehorned trees were lower in each of these 3 years than for light pruned trees and in 1997 and 1998 they were also lower than heavy pruned trees. Lower returns are related to smaller size canopies, lower yields, and in some cases, fewer large fruit.

Results from the present study suggest that winter-injured (damage to woody tissue and near 100% bud damage) peach trees should be pruned at the time of budbreak or no later than 2 to 3 weeks after bloom. The results also indicate that a delay in pruning of winter-injured trees until June or no pruning will lower yields and the number of large fruit resulting in lower returns per hectare. Dehorn pruning of winter-injured trees should be avoided because it will reduce yields and dollar returns for as long as 4 years after pruning primarily because of the reduction in tree size and fruit numbers, especially the larger fruit size. Large cuts used in dehorn pruning are also more prone to gumming which may increase leucostoma canker development. Dehorn pruned trees are less responsive to surgical removal of cankers. Earlier pruning (April or May) and heavy pruning produces a more desirable quality of fruiting wood than no pruning or light pruning.

Literature cited

Great Lakes Fruit Grower. 1995. Hard winter of 1994 spurs look at peach tree, shoot hardiness. Great Lakes Fruit Grower News 34(4):14.

Ashton, C.D., S.W. Edgecombe, R.K. Gerber, and O. Kirk. 1950. How to prune peach trees in Utah. Utah State Agr. Ext. Bul. 199.

Biggs, A.R. 1989a. Effect of pruning technique on leucostoma infection and callus formation over wounds in peach trees. Plant Dis. 73:771–773.

Biggs, A.R. 1989b. Integrated approach to controlling leucostoma canker of peach in Ontario. Plant Dis. 73:869–874.

Biggs, A.R. 1995. Leucostoma canker, p. 28–30. In: J.M. Ogawa, E.I. Zehr, G.W. Bird, D.F. Ritchie, K. Uriu, and J.K. Uyemoto (eds.). Compendium of stone fruit diseases. APS Press, St. Paul, Minn.

Childers, N.F. 1983. Modern fruit science. 9th ed. Hort. Publ., Gainesville, Fla.

Daniell, J.W. 1973. Effects of time of pruning on growth and longevity of peach trees. J. Amer. Soc. Hort. Sci. 98:383–386.

Dejong, T.M., K.R. Day, J.F. Doyle, and R.S. Johnson. 1994. The Kearney Agricultural Center perpendicular "V" (KAC-V) orchard system for peaches and nectarines. HortTechnology 4:362–367.

Greene, II, G.M., G. Burns, R.M. Crassweller, M.R. Dickert, L.B. Forer, K.D. Hickey, L.A. Hull, B.A. Jaffee, C.A. Powell, C.B. Smith, and J.W. Travis. 1988. Causes of peach tree death in Pennsylvania. In: N.F. Childers and W.B. Sherman (eds.). The peach. 4th ed. Hort. Publ., Gainesville, Fla.

Gunderson, A.J. 1918. The pruning of winter-injured peach trees. Proc. Amer. Soc. Hort. Sci. 15:32–38.

Hibbard, A.D. 1948. The effect of severity of pruning on the performance of young Elberta peach trees. Proc. Amer. Soc. Hort Sci. 52:131–136

Hickey, K.D. and J.W. Travis. 1985. Effect of preventative and post-infection fungicide treatments and the time of pruning on incidence of cytospora infection on pruning wounds of peach. Proc. 1984 Stone Fruit Decline Workshop, p. 65–70.

Johnston, S. and R.P. Larsen. 1965. Peach culture in Michigan. Mich. State Coop. Ext. Ser. Bul. 509.

Kappel, F. and M. Bouthillier. 1995. Rootstock, severity of dormant pruning, and summer pruning influences on peach tree size, yield, and fruit quality. Can. J. Plant Sci. 75:491–496.

Lamb, R.C. and L.J. Edgerton. 1979. Peach growing. N.Y. State Coll. Agr. Life Sci. Info. Bul. 44.

Marini, R.P. 1997. Pruning and canopy management practices for improving peach yield, fruit size, and quality. Mountaineer Grower 541:6, 8–12.

Micke, W, A.A. Hewitt, J.K. Clark, and M. Gerdts. 1980. Pruning fruit and nut trees. Univ. Calif. Coop. Ext. Ser. Lflt. 21171.

Overcash, J.P. 1988. Training, pruning peach trees, southeastern U.S. In: N.F. Childers and W.B. Sherman (eds.). The peach. 4th ed. Hort. Publ., Gainesville, Fla.

Prince, V.E. and B.D. Horton. 1972. Influence of pruning at various dates on peach tree mortality. J. Amer. Soc. Hort. Sci. 97:303–305.

Puls, Jr., E. 1983. Tree training and pruning, p. 8. In: M.E. Ferree and P.F. Bertrand (eds.). Peach growers handbook. Ga. Coop. Ext. Ser. Hdbk. 1.

Savage, E.F., R.A. Hayden, and W.E. Ward. 1964. Severity of pruning Elberta peach trees as it affects growth and yield. Ga. Agr. Expt. Sta. Bul. 127.

Stene, A.E. 1937. Pruning of winter-injured peach trees. Proc. Amer. Soc. Hort. Sci. 35:147–150.

Travis, J.W. and K.D. Hickey. 1985. Efficacy of surgical removal and fungicide wound treatments on eradication of cytospora canker on peach. Proc. 1984 Stone Fruit Decline Workshop, p. 60–64.

Westwood, M.N. 1978. Temperate zone pomology. W.H. Freeman and Co., San Francisco.

Westwood, M.N. and R.K. Gerber. 1958. Seasonal light intensity and fruit quality factors as related to the method of pruning peach trees. Proc. Amer. Soc. Hort. Sci. 72:85–91.

Wilson, C.L., S.S. Miller, B.E. Otto, and B.J. Eldridge. 1984. Pruning technique affects dieback and cytospora infection in peach trees. HortScience 19:251–253.

Root and Shoot Growth Responses to Phosphate Fertilization in Container-grown Plants

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ADDITIONAL INDEX WORDS. ***Dypsis lutescens*, *Spathiphyllum*, *Ixora*, *Lycopersicon esculentum*, *Tagetes erecta*, *Capsicum annuum*, *Pentas lanceolata*, root to shoot ratio**

SUMMARY. **Areca palms [*Dypsis lutescens* (H. Wendl.) Beentje & J. Dransf.], spathiphyllums (*Spathiphyllum* Schott. 'Figaro'), ixoras (*Ixora* L. 'Nora Grant'), tomatoes (*Lycopersicon esculentum* Mill. 'Floramerica'), marigolds (*Tagetes erecta* L. 'Inca Gold'), bell peppers (*Capsicum annuum* L. 'Better Bell'), and pentas [*Pentas lanceolata* (Forssk.) Deflers. 'Cranberry'] were grown in a pine bark-based potting substrate and were fertilized weekly with 0, 8, 16, 32, or 64 mg (1.0 oz = 28,350 mg) of P per pot. Shoot, and to a much lesser extent, root dry weight, increased for all species as weekly P fertilization rate was increased from 0 to 8 mg/pot. As P fertilization was increased from 8 to 64 mg/pot, neither roots nor shoots of most species showed any additional growth in response to increased P. Root to shoot ratio decreased sharply as P fertilization rate was increased from 0 to 8 mg/pot, but remained relatively constant in response to further increases in P fertilization rate.**

Among the nutrient elements required for plant growth, phosphorus has been associated with growth of meristem-

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