Growth, Yield, and Water Use Responses of Peach to Repeated Root Pruning in a Sub-humid Climate

D.M. Glenn¹ and S.S. Miller²

U.S. Department of Agriculture, Agricultural Research Service, Appalachian Fruit Research Station, 45 Wiltshire Road, Kearneysville, WV 25430

Additional index words. *Prunus persica*, fruit size, irrigation, root length density, leaf nutrient concentration, vegetative growth

Abstract. The objectives of this 7-year study were to determine the effect of repeated root pruning and irrigation on peach (*Prunus persica* L. Batsch) tree growth and soil water use. Root pruning began in the year of planting. Peach trees trained to a freestanding “Y” were root-pruned at flowering for 4 years (1985 to 1988) and subsequently at flowering and monthly through July for 3 years (1989 to 1991). Irrigation was withheld or applied the full season or only during stage 3 of fruit growth on root-pruned and non-root-pruned trees. Root pruning limited soil water availability throughout most of the growing season when irrigation was withheld; however, when irrigation was applied, there was no difference in soil water availability. The root length density of peach roots was greatest in the 0 to 30-cm depth, was promoted by irrigation, and was reduced by root pruning in the 0 to 90-cm root zone. Full-season irrigation increased vegetative growth over the nonirrigated treatments. Root pruning had no effect on vegetative growth measured as fresh pruned material. The treatments had no effect on leaf nutrient content, except that root pruning reduced Zn in five consecutive years. Fruit yield was reduced 1 in 5 years by root pruning, and full-season irrigation reduced yield in 3 of 5 years. Repeated root pruning restricted the lateral spread of the root zone and the use of soil resources, yet on the deep soil of this site, restricting the lateral extent of the root zone did not reduce vegetative tree growth.

Excessive vegetative growth by fruit trees generally results in higher labor costs for pruning; reduced yield and fruit size due to fruit-shoot sink competition for water, nutrients, and assimilate (Mika, 1986); and reduced fruit bud initiation (Dorsey, 1935). Strategies that control vegetative growth in peach include summer pruning (Marini and Barden, 1987), irrigation and nutrient management (Bravda, 1992; Chalmers et al., 1981), root confinement (Myers, 1992; Richards and Rowe, 1977a, 1977b; Williamson et al., 1992), growth regulators (Miller, 1988), girdling (Andrews et al., 1978; Fernandez-Escobar et al., 1987), and root pruning (Geisler and Ferree, 1984). Size-controlling rootstocks are not available yet for peach. Geisler and Ferree (1984) reviewed the early literature on the effects of root pruning. Root pruning and root confinement have received considerable research because of their potential to reduce vegetative growth without using chemical growth regulators. Cultural methods to control tree growth operate on the premise that there is a functional equilibrium between the root biomass and the aboveground biomass (Richards, 1977, 1978) and that limiting the root volume of a tree results in re-

duced shoot growth. Richards and Rowe (1977a) demonstrated that growth reduction in peach due to root restriction could be overcome partially by applying a cytokinin-like growth regulator; however, Schupp and Ferree (1988a) found no response to cytokinin-like growth regulators in root-pruned apple (*Malus domestica* Borkh.) trees. The growth reduction caused by root pruning is attributed to a reduction in water uptake capacity. Ferree (1992) documents that apple fruit size is reduced by root pruning and increased by irrigation. Conversely, root restriction for apple and peach has reduced shoot growth without reduction in fruit size (Williamson and Coston, 1990), although yield per tree was reduced due to the smaller size of the tree.

The field method of restricting root volume using permeable materials laid into the soil is expensive and labor intensive. Our objective was to use repeated root pruning to restrict root expansion and, therefore, reduce the effective root volume of the tree, rather than to physiologically shock the tree by root pruning a significant portion of the root system at one time. We wanted to determine the long-term effect of repeated root pruning and irrigation on shoot growth, fruit yield and size, mineral uptake, root distribution, and soil water use.

Materials and Methods

The experiment was established in a split-plot design with four replications within a larger replicated field study. The main plot was root pruning (root-pruned vs. control) and

the subplot was irrigation (full season, during fruit growth stage 3, vs. none). Each replication contained two 40-tree rows randomly assigned to the main plot treatments (root-pruned or unpruned). Within each main plot, the rows were divided into four 10-tree irrigation subplots. The stage-3 irrigation subplot was duplicated within each main plot. Before the trees were planted, a subsoiler shank was drawn through the soil to a 60-cm depth, 50 cm on either side of a line where peach trees to be root-pruned would be planted. The other plots were not subsoiled.

‘Autumn-glo’/Lovell trees were planted in Spring 1985 using a mechanical tree planter (Wilde Corp., Bailey, Mich.). Trees were 2.5 m apart within the row, and row spacing was 4.5 m alternating with 6 m. The trees were trained to a freestanding “Y” (Horton, 1985) and were dormant-season- and summer-pruned in all years. A 3-m-wide, weed-free, tree row was maintained using periodic applications of 1,1-dimethyl-4-4-bipyridinium (paraquat). Beginning in 1987, 40 kg N/ha was applied as 10N–8.3P–4.4K in the spring of each year. Disease and insect control followed commercial recommendations. The study was conducted on a deep Hagerstown silt loam soil (fine, mixed, mesic, Typic Hapludalf).

Root pruning was performed at flowering (March or April) from 1986 (second leaf) through 1988 using a subsoiler in the established trench 50 cm on two sides of the tree. From 1989 through 1991, roots were pruned at flowering and monthly through July. The full-season irrigation treatment delivered 240 liters of water per tree per week from May through September. There were two emitters per tree in line with the tree row and on opposite sides of the tree (50 and 100 cm from the trunk). In the stage 3 irrigation treatment, water was applied at the same rate but only during early August until late September. Peaches were harvested in early September.

Four neutron-probe access tubes were installed in each of the nonirrigated and full-season irrigated subplots. The access tubes were installed in the tree row shortly after planting near the emitter positions 50 and 100 cm from the trunks of two trees. Soil water content was determined using a calibrated neutron moisture probe (model 503; Campbell Pacific Nuclear, Pacheco, Calif.). Soil water content, measured from cores 4.2 cm in diameter (volume water per volume soil), was calibrated to count ratios from the neutron moisture probe at depths of 0 to 30, 30 to 60, and 60 to 90 cm weekly from 1986 to 1991; representative data for 1990 and 1991 are presented. Soil water content data were analyzed using a split-split-plot design for each soil depth. The main plot was the root pruning treatment, the subplot was the irrigation treatment, and the sub-subplot was the date of measurement. Two- and three-way interactions were significant, and a 95% confidence interval was calculated using the residual error as the measure of soil water content variance.

Leaf samples were collected in late July 1986 to 1991 for mineral analysis. Fifty leaves per subplot were collected, rinsed six times in

Received for publication 6 June 1994. Accepted for publication 4 Jan. 1995. The cost of publishing this paper was defrayed in part by the payment of page charges. Under postal regulations, this paper therefore must be hereby marked *advertisement* solely to indicate this fact.

¹Soil Scientist.

²Research Horticulturist.

deionized water, dried at 60°C, and ground to pass a 250- μ m (60 mesh) screen. Nitrogen was determined by a N analyzer (model FP 228; Leco, St. Joseph, Mich.). The macro- and microelements were determined by plasma emission spectrophotometry at The Pennsylvania State Univ. Agricultural Analytical Laboratory. Data for leaf mineral concentration were analyzed by year, using a split-plot design.

The fresh weight of dormant and summer prunings were collected from 1989 to 1991. Total fruit yield per tree and yield per tree of fruit >75 mm in diameter were measured from 1987 to 1991. Trunk diameter 30 cm above the ground was measured in the dormant season from 1985 through 1991. Data for total pruning weight, fruit yield, and trunk diameter were analyzed by year using a split-plot design.

Soil samples were collected in Mar. 1992 to determine root length density (RLD) and root distribution. Two trees in the nonirrigated and full-season irrigated subplots were sampled to a 120-cm soil depth in 30-cm increments. Samples were collected in the following positions: 1) midway between the trees, 2) midway

between the tree and the grass driveway, and 3) at the edge of the grass driveway opposite the tree. The root pruning trench was between positions 2 and 3. Soil was washed from the roots with an elutriator (Smucker et al., 1982), and the root length was determined using a modified line-intersect method (Tennant, 1975). RLD was calculated as the root length per volume of soil core. RLD data were analyzed in 30-cm increments in a split-split-plot design with root pruning treatment as the main plot, irrigation as the subplot, and location of the sample as the sub-subplot. Two and three-way interactions were significant; thus, a 90% confidence interval was calculated using the residual error as the measure of RLD variance.

Results and Discussion

Soil water content. Soil water content was significantly affected by root pruning and irrigation (Fig. 1). The 1990 and 1991 growing seasons represented two extremes in rainfall, with 470 and 148 mm received, respectively. In 1990, at the 0 to 30-cm depth, the nonirrigated plots were drier than those irrigated when both were measured during rainless pe-

riods; only during one period (in July) were the nonirrigated root-pruned plots drier than all others. At the 30- to 60-cm depth, the soil for nonirrigated root-pruned plots was consistently drier than for all other plots, and the nonirrigated control did not differ from those irrigated. At the 60- to 90-cm depth, the nonirrigated plots were drier than those irrigated in early spring, but during the last half of the growing season, only the nonirrigated root-pruned plots were drier than the others. In 1991, the nonirrigated plots were drier than those irrigated through most of the growing season when measured at 0 to 30 cm. At the 30- to 60- and 60- to 90-cm depths, the nonirrigated soil was drier than the soil irrigated throughout most of the growing season; however, soil of the nonirrigated root-pruned treatment was the driest during the entire growing season. These data indicate that root pruning resulted in limited water availability throughout most of the growing season when soil was not irrigated. There was greater water depletion by roots in the smaller soil volume of the nonirrigated root-pruned plots, which, presumably, compensated for the loss of lateral roots extending beyond 50 cm from the tree.

Fig. 1. Volumetric soil water content for three depths in 1990 and 1991. (○) Nonirrigated control, (●) irrigated control, (Δ) nonirrigated root-pruned, and (▲) irrigated root-pruned.

Fig. 2. Root length density of peach in Mar. 1992. Position 1 is midway between two trees. Position 2 is midway between the tree and the sod middle. Position 3 is at the edge of the sod middle. (○) Nonirrigated control, (●) irrigated control, (Δ) nonirrigated root-pruned, and (▲) irrigated root-pruned.

With irrigation, soil water availability was unaffected by root pruning.

Nutrient concentration. Nutrient analyses from 1986 to 1991 demonstrated no consistent effect of irrigation or root pruning on macro- or micronutrient concentrations (data not presented), with the exception of Zn, which was significantly lower in the leaves of root-pruned trees in all years (19 vs. 16 ppm Zn for control and root-pruned, respectively, $P \leq 0.05$). According to Barber (1984), Zn uptake is limited by mass flow and diffusion. Root pruning limited the spread of the root system and, consequently, the volume of soil capable of supplying Zn. Limiting the spread of the root system also may have reduced the mycorrhizal infection of the root system. The Zn tissue concentrations were in the less-than-optimal range (<20 ppm) throughout the study (Johnson, 1993) due to low soil Zn levels; root pruning consistently aggravated the deficiency. All other nutrients were in the sufficient range for peach.

Root distribution. Contrary to Ferree's (1994) work with apple, root distribution following 6 years of repeated root pruning indicated no significant effect of either root pruning or irrigation on the distribution of roots >1 mm in diameter (data not presented). There were three-way interactions for the distribution of fine roots (<1 mm thick) at the 0- to 90-cm depth (Fig. 2), but no significant treatment effect appeared at 90 to 120 cm. Fine roots in the 0 to 30-cm depth were most abundant in the irrigated control midway between the trees (position 1) and least in the nonirrigated control; density for the root-pruned plots was intermediate. Layne et al. (1986) also demon-

strated that irrigation promoted shallow rooting near the drip line. Fine roots in the root-pruned plots were least abundant midway between the tree and the sod middle (position 2) and at the sod-bare soil interface (position 3). Because root pruning was intended to remove roots between positions 2 and 3, position 3 was expected to have the lowest RLD. Again, fine roots in the 30- to 60-cm depth were most abundant in the irrigated control at position 1, intermediate for trees in the irrigated root-pruned plots, and sparsest in the nonirrigated plots. At position 2, the RLD of roots in the irrigated control was higher than for the nonirrigated control, with means for the root-pruned treatments being intermediate and not different from the extremes. There were no significant differences at position 3, although the RLD for the irrigated control tended to be higher than for the others. Fine roots in the irrigated control at the 60- to 90-cm depth were most common at positions 1 and 2, but RLD was similar for the root-pruned trees and the nonirrigated control at positions 1 and 2. There were no differences in the RLD of fine roots at position 3. In general, root development was inhibited by root pruning at the 0- to 30-cm depth, as Ferree (1994) had shown, and irrigation of root-pruned trees did not increase root development to the level of RLD values for the irrigated control in the 0- to 90-cm root volume.

Pruning weight and yield. Cumulative pruning weights from 1989 to 1991 indicated that full-season irrigation increased vegetative growth relative to no irrigation and stage-3 irrigation and that root pruning had no effect on vegetative growth when measured as pruned

material (Table 1). Although not irrigating the root-pruned plots reduced soil moisture and root distribution within the root volume, there was no measurable effect on vegetative growth, contrary to results others have demonstrated (Bravda, 1992; Chalmers et al., 1981; Schupp and Ferree, 1988b; Williamson and Coston, 1990).

Total fruit yield and yield of fruit >75 mm in diameter was reduced by root pruning in 1 of 5 years (Table 2). Others have shown that root pruning reduced fruit size due to water stress effects (Schupp and Ferree, 1988b) and that irrigation could mitigate the water stress (Ferree, 1992). Full-season irrigation reduced total and large fruit yield in 3 of the 5 years measured and tended to reduce yield in all years compared to non-irrigation or stage-3 irrigation only, presumably because excessive vegetative growth reduced floral initiation and the number of harvestable fruit. Trees irrigated during stage 3 had the highest total yield, highest yield of large fruit in 3 of 5 years, and

Table 1. Effect of repeated root pruning and irrigation on cumulative fresh pruning weight (1989 to 1991) of peach trees.

Root pruning	Irrigation	Pruning wt (kg/tree)
-	None	10.8 B ^z
	Full season	18.5 A
	Stage 3	12.7 B
+	None	12.2 B
	Full season	16.7 A
	Stage 3	13.2 B

^zMean separation for irrigation effect by Duncan's multiple range test ($P = 0.05$). Root pruning had no significant effect ($P \leq 0.05$).

Table 2. Effect of root pruning and irrigation treatments on peach yield (1987 to 1991).

Soil management	Year	Total fruit yield (kg/tree)				Fruit >75 mm in diam (kg/tree)			
		Irrigation				Irrigation			
		None	Full season	Stage 3	Mean	None	Full season	Stage 3	Mean
Control	1987	4.7	3.7	5.3	4.6	4.6	3.6	5.2	4.5
Root pruned	1987	3.6	4.7	3.4	3.9 ^{ns}	3.5	4.6	3.3	3.8 ^{ns}
Mean	1987	4.2 ^{nsy}	4.2 ^{ns}	4.4 ^{ns}		4.1 ^{ns}	4.1 ^{ns}	4.3 ^{ns}	
Control	1988	23.7	17.9	23.0	21.5	23.5	17.7	22.8	21.3
Root pruned	1988	20.9	19.9	21.3	20.7 ^{ns}	20.7	19.8	21.1	20.5 ^{ns}
Mean	1988	22.3 A	18.9 B	22.2 A		22.1 A	18.8 B	22.0 A	
Control	1989	24.1	22.6	22.1	22.9	23.8	22.4	22.0	22.7
Root pruned	1989	17.9	16.0	16.8	16.9 [*]	17.5	15.6	16.6	16.6 [*]
Mean	1989	21.0 ^{ns}	19.3 ^{ns}	19.5 ^{ns}	20.7 ^{ns}	19.0 ^{ns}	19.3 ^{ns}		
Control	1990	7.4	3.9	11.0	7.4	7.3	3.8	10.9	7.3
Root pruned	1990	9.7	9.4	12.9	10.7 ^{ns}	9.7	9.4	12.8	10.6 ^{ns}
Mean	1990	8.6 AB	6.7 B	12.0 A		8.5 AB	6.6 B	11.9 A	
Control	1991	22.3	18.8	22.2	21.1	20.6	18.5	21.7	20.3
Root pruned	1991	21.2	21.4	23.7	22.1 ^{ns}	18.6	21.0	23.1	20.9 ^{ns}
Mean	1991	21.8 AB	20.1 B	23.0 A		19.6 AB	19.8 B	22.4 A	

^{*}Mean separation for soil management effect averaged over irrigation treatments by F test ($P = 0.10$); ns = nonsignificant.

^yMean separation for irrigation effect averaged over both soil management regimes within years by Duncan's multiple range test ($P = 0.05$); ns = nonsignificant.

tended to have the highest yield throughout the study. Root pruning did not reduce trunk diameter in any of the years from 1985 to 1991 (data not shown). Full-season irrigation increased trunk diameter over the nonirrigated control and stage-3 irrigation in all years (116, 107, 103 mm, respectively, for 1991).

In this study, we developed a restricted root system through repeated root pruning, and this system led to lower soil moisture availability from the root volume than for the control. The restricted root system lowered Zn tissue levels compared to the control on a low-Zn-supplying soil. We conclude that repeated root pruning could effectively restrict the root system of peach. However, this root management system had little effect on the growth or yield of peach. In the sub-humid environment of the mid-Atlantic states and on the deep silt loam Hagerstown soil, restricting the root volume did not reduce tree growth, which is unlike results reported by others (Ferree, 1992; Williamson et al., 1992). The lateral spread of the root system was restricted, but the vertical descent of roots was not. The greater extraction of soil water from the 60- to 90-cm depth (Fig. 1) suggests these peach trees compensated for the reduced lateral spread of the root system by using the soil and water resources deeper within the soil profile. Williamson and Coston (1990) restricted the entire root zone using buried fabric and were able to reduce vegetative growth. On deep soils, it seems that severe treatments are needed to effectively restrict the root volume of peach trees to reduce vegetative growth. Others have used infrequent root pruning to reduce vegetative growth in apple (Ferree, 1992; Schupp and Ferree, 1988b) with a resulting tendency to reduce fruit size. This alternate technique may be useful when vegetative growth is excessive and other cultural methods have failed. However, infrequent root pruning of peach needs

further study before recommendations can be made on using this technique.

Literature Cited

- Andrews, C.P., W.B. Sherman, and R.H. Sharpe. 1978. Response of peach and nectarine cultivars to girdling. *Proc. Fla. State Hort. Soc.* 91:175-177.
- Barber, S.A. 1984. Soil nutrient bioavailability—A mechanistic approach. Wiley, New York.
- Bravda, B.A. 1992. Control of root size and root environment of fruit trees for optimal fruit production. *J. Plant Nutr.* 15:699-712.
- 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.
- Dorsey, M.J. 1935. Model development of the peach shoot as related to fruit bud formations. *Proc. Amer. Soc. Hort. Sci.* 33:245-257.
- Fernandez-Escobar, R., R. Martin, P. Lopez-Riveras, and M. Pazsaurey. 1987. Girdling as a means of increasing fruit size and earliness in peach and nectarine cultivars. *J. Hort. Sci.* 62:493-498.
- Ferree, D.C. 1992. Time of root pruning influences vegetative growth, fruit size, biennial bearing and yield of 'Jonathan' apple. *J. Amer. Soc. Hort. Sci.* 117:198-202.
- Ferree, D.C. 1994. Root distribution following 9 years of root-pruning 'Melrose' M.26 apple trees. *HortScience* 29:76-78.
- Geisler, D. and D.C. Ferree. 1984. Response of plants to root pruning. *Hort. Rev.* 6:155-188.
- Horton, B.D. 1985. Training peaches for completely mechanized production. *HortScience* 20:244-246.
- Johnson, R.S. 1993. Stone fruit: Peaches and nectarines, p. 171-175. In: W.F. Bennett (ed.). Nutrient deficiencies and toxicities in crop plants. APS Press, St. Paul, Minn.
- Layne, R.E.C., C.S. Tan, and R.L. Perry. 1986. Characterization of peach roots in Fox sand as influenced by sprinkler irrigation and tree density. *J. Amer. Soc. Hort. Sci.* 111:670-677.
- Marini, R.P. and J.A. Barden. 1987. Summer pruning of apple and peach trees. *Hort. Rev.* 9:351-375.
- Mika, A. 1986. Physiological responses of fruit trees to pruning. *Hort. Rev.* 8:337-378.
- Miller, S.S. 1988. Plant bioregulators in apple and pear culture. *Hort. Rev.* 10:309-401.
- Myers, S.C. 1992. Root restriction of apple and peach with in-ground fabric containers. *Acta Hort.* 322:215-219.
- Richards, D. 1977. Root-shoot interactions: A functional equilibrium for water uptake in peach. *Ann. Bot.* 41:279-281.
- Richards, D. and R.N. Rowe. 1977a. Effects of root restriction, root pruning and 6-benzylaminopurine on the growth of peach seedlings. *Ann. Bot.* 41:729-740.
- Richards, D. and R.N. Rowe. 1977b. Root-shoot interactions in peach: The function of the root. *Ann. Bot.* 41:1211-1216.
- Richards, D. 1978. Root-shoot interactions: Functional equilibrium for nutrient uptake in peach. *Ann. Bot.* 42:1039-1043.
- Schupp, J.R. and D.C. Ferree. 1988a. Cytokinin injections are ineffective in overcoming the response of young apple trees to root pruning. *Ohio Agr. Res. and Development Center Res. Circ.* 295:20-23.
- Schupp, J.R. and D.C. Ferree. 1988b. Effects of root pruning at four weeks of severity on growth and yield of 'Melrose' M.26 apple trees. *J. Amer. Soc. Hort. Sci.* 113:194-198.
- Smucker, A.J.M., S.C. McBurney, and A.H. Srivastava. 1982. Quantitative separation of roots from compacted soil profiles by the hydro-pneumatic elutriatron system. *Agron. J.* 74:500-503.
- Tennant, D. 1975. A test of a modified line intersect method of estimating root length. *J. Ecol.* 63:995-1001.
- Williamson, J.G. and D.C. Coston. 1990. Planting method and irrigation rate influence vegetative and reproductive growth of peach planted at high density. *J. Amer. Soc. Hort. Sci.* 115:207-212.
- Williamson, J.G., D.C. Coston, and J.A. Cornell. 1992. Root restriction affects shoot development of peach in a high density orchard. *J. Amer. Soc. Hort. Sci.* 117:362-367.