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Effect of Root Pruning at Different Growth Stages on Growth and Fruiting of Apple Trees

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Abstract. **Three- and 4-year-old 'Melrose'/M.7A apple trees were root-pruned on two sides, 50 cm from the trunk, at a depth of 35–40 cm at one of the following growth stages: dormant, full bloom, June drop, and preharvest. Root pruning at dormant or full bloom growth stages reduced trunk cross-sectional area increase and shoot length, reduced average leaf size and fruit size, and increased yield efficiency. Dormant root pruning increased the level of Ca in the fruit flesh. Root pruning at June drop and preharvest had no influence on shoot growth, but increased preharvest fruit drop. Root pruning at full bloom or later increased fruit soluble solids. Considerable root regeneration in close proximity to the cut was evident in November on trees root pruned at the dormant and full-bloom stages. Root regeneration was less on roots pruned at June drop and minimal in preharvest-treated trees. Leaf mineral nutrient levels were not influenced by root pruning treatment. Vegetative growth and fruit size were reduced less by root pruning in the 3-year-old trees than in the 4-year-old trees.**

A mechanized method for controlling tree size to supplement dwarfing rootstocks would be a valuable addition to high-density orchard management. Rivers (10), a 19th century horticulturist, recommended annual or biennial root pruning applied in the autumn or early spring to contain tree size and stimulate precocious bearing. Drinkard (3) observed a reduction in vegetative growth for apple trees root pruned in early April, late May, or late June and increased flower bud formation with root pruning in late May or late June. Luthi (7) recommended root pruning be done any time between mid-March and mid-May to control excessive growth in high-density orchards. Schumacher et al. (11, 12) found that tree growth was reduced by root pruning more in February than in December or April. Thus, previous work does not clearly establish the optimum time for root pruning to achieve vegetative growth control.

Past reports have suggested that the reduction in growth from root pruning was extreme when trees were pruned very severely (1, 3) and that fruit set (3), fruit size (1, 4), and fruit quality (3) were reduced. However, little data were presented to verify these results or to confirm recommendations on timing. The objective of this study was to determine the effects of root pruning on vegetative growth and fruit growth and quality of apple trees at different stages of growth.

Thirty-five 4-year-old and twenty 3-year-old 'Melrose'/M.7A apple trees were root pruned in 1983 at the following times: 1) control—no root pruning; 2) dormant—24 Mar.; 3) full bloom—11 May; 4) end of June drop—27 June; and 5) preharvest—24 Aug. Roots were pruned with a sharpened subsoiler mounted on a tool bar and offset to one side of a tractor. The cuts were made on two sides of the trees at a 50-cm distance from the trunk and to a depth of 35–40 cm. Treatments were arranged in a randomized complete block design with seven and four individual tree replications for the 4- and 3-year-old trees, respectively.

Measurements for trunk circumference prior to and after the growing season; length of five terminal shoots; and number of root suckers per tree were recorded. The leaf area of 40 mid-terminal leaves was measured with a LI-COR LI3000 leaf area meter, after which the leaves were dried at 63°C in a forced-air oven, and levels of P, K, Ca, Mg, Mn, Fe, B, Cu, Zn, Al, and Na were determined by plasma emission spectrophotometry. Leaf N levels were determined by the modified Kjeldahl method. In July, tree canopy height was divided vertically into thirds, and photosynthetically active radiation (PAR) was measured at the center of each third with a LI-COR model LI-1853 quantum photometer equipped with a LI-COR model LI 1915B line quantum sensor. The probe was positioned in the center of the canopy, perpendicular to the row direction, and the readings obtained were compared to a full sun reading taken adjacent to each block.

The number of flower clusters per tree at full bloom and the number of fruit per tree after June drop were counted to determine fruit set. At harvest, the number of dropped fruits were counted, and all fruit were counted and graded on an FMC weight-sizer that divided the fruit into the following size classes: 1) ≥80 mm diameter; 2) 79–67 mm; 3) 66–57 mm; and 4) <57 mm. A sample of 10 fruits per tree (79–67 mm in diameter) was taken, and fruit firmness, soluble solids, seed number, and the number of external cork spot blemishes were recorded. Fruit skin color and russet were rated by comparing each fruit to a color photograph standard, using a 1–5 scale. A 1-cm-thick cross-sectional slice was cut from each fruit, and ten 8-mm-diameter cores were taken from the flesh just under the skin. These flesh samples were freeze-dried, ground, and the levels of P, K, Ca, Mg, Mn, Fe, B, Cu, Zn, and Na measured.

In November, after leaf abscission had begun, three 10-cm-diameter × 40 cm deep soil cores were taken per tree side at the site of the root pruning cuts. The soil was removed from the roots with water and the amount of root regeneration for each time of root pruning was observed.

The shoot system of each tree was dormant pruned in Mar. 1984 and the amount of pruning time was recorded. Temperatures of −25°C occurred on 24 Dec. 1983. Injury to the trees was rated by six independent observers using a 1 (none) to 10 (severe) scale. The resulting data were subjected to analysis of variance (ANOVA), and means were separated by LSD when the F value was significant.

Root pruning at dormant or full bloom growth stages reduced shoot length, leaf size, and trunk cross-sectional area (TCSA) of 4-year-old trees in comparison with controls (Table 1). Likewise, dormant shoot pruning time was reduced by root pruning at either of these times. Vegetative growth was not reduced by root pruning at June drop. However, preharvest root pruning caused a 26% reduction in TCSA increment. Three-year-old trees root pruned at dormant or full bloom stages also had reduced shoot growth, pruning time, and leaf size. Although the effects of the treatments on TCSA increments were not significant in the 3-year-old trees, a trend for effects on TCSA closely followed that found in the 4-year-old trees. Generally, the 3-year-old trees were less affected by root pruning than were the 4-year-old trees.

Light penetration of the top two-thirds of the canopy was not affected by root pruning (data not presented). The amount of light expressed as percent full sun was increased in the bottom third of the canopy by dormant root pruning in 4-year-old trees (Table 1).

The number of root suckers per tree and fruit set was unaffected by root pruning, regardless of timing (Table 1). In November, considerable root regeneration was evident at cuts produced by root pruning in the dormant and full bloom stages. Little root regeneration occurred following root pruning at either June drop or preharvest (Fig. 1).

Foliar nutrient levels were unaffected by root pruning, regardless of timing (data not presented). Fruit from 4-year-old trees root pruned at dormant, full bloom, or June drop timings had lower P, K, Mg, and B and higher Ca levels than controls (Table 2). Nutrient

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Table 1. Effect of time of root pruning on trunk cross-sectional area, shoot length, root suckering, pruning time, leaf size, light penetration of canopy, fruit set, and cropping efficiency of 'Melrose'/M.7A apple trees.

Growth stage at pruning	TCSA increment (cm)	Shoot length (cm)	Root suckers (no./tree)	Dormant pruning time (min/tree)	Leaf area (cm)	Light penetration, bottom 1/3 of canopy (% full sun)	Fruit set, no. fruit/ no. flower clusters	Crop efficiency (kg yield/ cm^2 TCSA increment)
				4-year-old trees				
Control	12.3	35.9	8.0	11.0	27.9	19	0.29	4.5
Dormant	5.8	19.9	1.6	4.1	15.6	39	0.25	6.8
Full bloom	5.8	21.1	4.4	4.8	16.9	28	0.35	8.8
June drop	10.6	35.4	3.1	9.7	27.4	19	0.30	4.6
Preharvest	9.1	37.5	5.3	9.5	27.1	17	0.39	5.2
LSD 5%	3.1	6.0	NS	2.8	1.6	11	NS	2.1
				3-year-old trees				
Control	12.0	40.0	1.5	6.8	27.5	22	0.39	1.5
Dormant	9.8	28.9	2.8	4.6	20.9	34	0.36	1.3
Full bloom	10.9	31.1	1.5	5.2	21.7	20	0.54	1.8
June drop	11.3	38.6	4.0	6.3	26.9	22	0.45	1.5
Preharvest	11.7	36.2	0.0	6.3	26.6	17	0.49	1.6
LSD 5%	NS	6.3	NS	0.8	2.6	12	NS	NS

[z]TCSA increment = TCSA 11/83 − TCSA 11/82.

levels in fruit from 3-year-old trees were not different from unpruned controls.

Total fruit number and weight were not influenced by root pruning (Table 3). Fruit size was reduced on 4-year-old trees by dormant, full bloom, and preharvest root pruning, as shown by a reduced proportion of crop in the ≥80-mm category and an increase in the 64–57 mm class. The 3-year-old trees had similar trends in fruit size distribution, but the differences were not significant. Preharvest fruit drop was increased by either the June drop or the preharvest root pruning treatment in the 4-year-old trees (Table 3). Root pruning at dormant and full bloom growth stages had no effect on fruit drop. Four-year-old trees root pruned at dormant or full bloom growth stages had higher cropping efficiencies compared to controls. Cropping efficiency was not affected in the 3-year-old trees (Table 1).

Seed number and fruit color rating were not affected by root pruning for fruit from 4-year-old trees, but soluble solids were in-

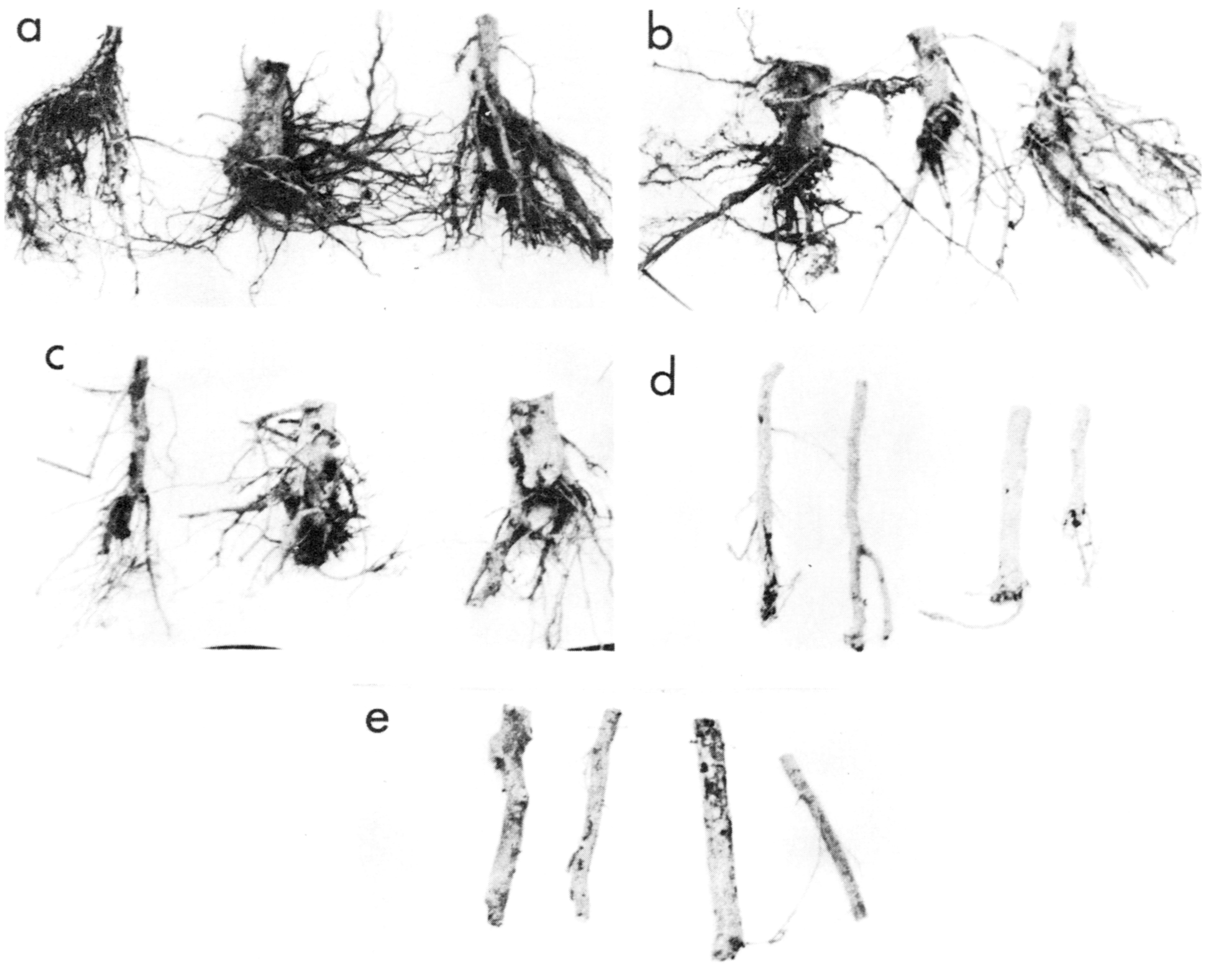

Fig. 1. Influence of root pruning at (**a**) dormant; (**b**) full bloom; (**c**) June drop; (**d**) preharvest; and (**e**) Control on root regeneration of 4-year-old 'Melrose'/M.7 apple trees.

Table 2. Effect of time of root pruning on fruit flesh mineral nutrient levels of 'Melrose'/M.7 apple trees.

Growth stage at pruning	PPM									
	P	K	Ca	Mg	Mn	Fe	B	Cu	Zn	Na
	4-year-old trees									
Control	560	4584	118	218	2	8	9	9	4	9
Dormant	426	3465	138	195	1	9	7	9	4	8
Full bloom	430	3607	126	182	1	8	7	12	6	8
June drop	444	4143	107	182	2	8	6	9	4	9
Preharvest	534	4319	120	212	2	9	8	6	3	10
LSD 5%	67	371	15	19	NS	NS	1	NS	NS	NS
	3-year-old trees									
Control	598	5526	98	265	2	6	10	6	3	7
Dormant	477	5031	106	240	2	6	8	7	3	5
Full bloom	569	5727	110	241	2	6	10	6	2	6
June drop	496	5524	101	228	2	7	9	8	5	7
Preharvest	504	5230	99	265	2	8	8	8	4	7
LSD 5%	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

creased by root pruning at full bloom, June drop, and preharvest. Root pruning reduced cork spot in fruit from 4-year-old trees, and fruit firmness was increased by treatment at full bloom and preharvest (Table 3). Seed number, incidence of cork spot, flesh firmness, fruit color, and russet were not influenced by root pruning in the 3-year-old trees (Table 3).

Winter injury resulting from −25°C temperatures on 24 Dec. 1983 was severe in the orchard containing this experiment. Damage to 'Melrose' was characterized by trunk splitting, shoot die back, death of spur and terminal shoot buds, small chlorotic leaves, and very little growth. It became evident by midsummer that the trees were permanently damaged, so the experiment was terminated and the orchard subsequently removed. Winter injury was not associated with root pruning (14).

Wareing (17) described a balance between root and shoot growth of plants such that removal of one part results in its regeneration, while the growth of the other part is diminished. Previous studies with peach (9) and cranberry (5) have confirmed that root pruning results in a redistribution of growth. In the present study, early season root pruning reduced shoot growth, leaf area, and TCSA increment (Table 1). Root pruning at these same times also resulted in considerable root regeneration (Fig. 1). Thus, it appears that this control mechanism is operational in apple. Root pruning at later stages of growth did not reduce vegetative growth, exhibited little root regeneration, and resulted in preharvest fruit drop.

The amount of shoot growth reduction from the dormant and full bloom root prunings did not differ from each other (Table 1), in contrast with previous studies (11, 12) that reported earlier timings more restrictive to shoot growth than were treatments at or after the resumption of growth. Spring root-pruned 3-year-old trees had only about a 25% reduction in shoot growth, compared to a more than 40% reduction for 4-year-old trees. The 4-year-old trees had more than twice as much fruit by weight than the 3-year-old trees, suggesting that the amount of crop interacts with root pruning effects on vegetative growth.

In dense tree canopies, low light levels can limit productivity and fruit quality (18). Light penetration of the bottom one-third of the canopy was increased 2-fold by dormant root pruning the 4-year-old trees (Table 1). Although not statistically different, light penetration levels also tended to be increased in the bottom one-third of the canopy of full bloom treated trees, where PAR levels approached 30% of full sunlight, the level of light necessary to saturate the photosynthetic capacity of apple leaves (8).

Total yield was not influenced by root pruning, regardless of timing or tree age (Table 3). This finding is in contrast with previous reports of reduced yield from root pruning (2, 11). Although spring root-pruned trees had increased crop efficiency, as a result of no reduction in yield by weight, fruit size was reduced (Table 2). Reduced fruit size from root pruning has been reported previously (2, 11, 12) and is the critical problem that must be overcome in order for root pruning to have value as a horticultural method for controlling tree size. The small fruit resulting from dormant or full bloom root pruning had fewer symptoms of cork spot and higher fruit firmness than fruit from control trees (Table 3), which is in agreement with previous findings (11, 12). Fruit from trees pruned at this time, while still within the range of deficiency for Ca (16), had significantly higher levels of Ca and lower K and Mg than fruit from controls (Table 2). A high Ca : (K + Mg) ratio is desirable for maintaining fruit quality in storage (15), and treatments that reduce vegetative growth have previously been shown to reduce bitter pit symptoms (13) and increase fruit Ca levels (6).

Early season root prunings increased crop efficiency by reducing vegetative growth and reduced dormant shoot pruning time by 63% and 56% for the dormant and full bloom treatments, respectively. Thus, it appears that early season root pruning has promise as a mechanical means of season long-growth control.

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Table 3. Effect of time of root pruning on yield, fruit size, preharvest fruit drop, seed number, flesh firmnes, color, russet, and bitter pit of fruit of 'Melrose'/M.7 apple trees.

Growth stage at pruning	Fruit total		Percent total yeild										
	No.	wt(kg)	≥80 mm	76–67 mm	64–57 mm	<57 mm	Preharvest drop	No. seed	SS (%)	Firmness (N)	Cork spot (no./fruit)	Color[z] rating	Russet[y] rating
	4-year-old trees												
Control	158	52.3	28.4	35.4	35.8	0.5	7.2	8.5	15.3	72.4	3.7	3.7	2.4
Dormant	149	39.0	5.0	20.6	68.6	5.8	4.7	8.5	16.1	74.6	2.0	3.0	1.7
Full bloom	169	45.9	10.6	22.0	64.2	3.3	6.2	8.2	17.0	77.1	2.1	2.7	2.3
June drop	128	39.5	20.9	30.0	48.2	0.9	19.2	9.0	17.5	74.8	3.1	2.7	2.4
Preharvest	163	44.7	8.1	20.7	69.0	2.3	23.7	8.4	17.7	77.7	2.1	4.0	2.0
LSD 5%	NS	NS	15.2	NS	20.1	3.9	8.1	NS	1.3	3.3	0.5	NS	0.5
	3-year-old trees												
Control	42	18.6	79.6	17.9	2.5	0	7.1	8.1	17.7	72.2	6.5	3.3	2.8
Dormant	36	15.0	53.8	30.0	16.2	0	3.8	9.0	17.8	73.5	5.2	3.3	2.7
Full bloom	46	18.8	65.0	23.8	11.3	0	3.1	8.6	16.9	76.0	5.1	2.5	2.4
June drop	38	16.4	66.3	27.7	6.0	0	4.4	9.3	17.4	74.5	6.1	3.5	2.7
Preharvest	43	18.0	60.8	31.1	8.1	0	13.3	8.8	18.5	74.3	5.2	3.5	2.4
LSD 5%	NS	NS	NS	NS	NS	NS	7.0	NS	0.8	NS	NS	NS	NS

[z]Color rated: 1 = 100% red to 5 = <40% red.
[y]Russet rated: 1 = none to 5 = 100% russeted.

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Summer Pruning Affects Fruit Quality and Light Penetration in Young Peach Trees

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Additional index words. *Prunus persica*, PAR

Abstract. **Two-year-old peach trees [*Prunus persica* (L.) Batsch cv. Candor] on 'Lovell' rootstock were summer-pruned (selective thinning and heading of current season's growth) 23 days before harvest. Pruning did not affect fruit quality. Summer pruning increased yield the subsequent year, apparently by increasing fruiting wood in the center of the tree. Summer pruning vigorous 3-year-old 'Loring' peach trees 8 weeks before harvest increased PAR through the canopy, 1 m above the ground, immediately after pruning and when measured at harvest. Fruit from summer-pruned 'Loring' were firmer, with lower soluble solids than those not summer-pruned.**

The effects of summer pruning deciduous fruit trees has been well-documented over the past decade. Much of the attention has been directed toward apple, but recent investigations have focused also on peach (1, 5, 6, 10, 11). A number of reasons have been given to support the practice of summer pruning for peaches. Summer pruning was reported to reduce vegetative growth, decrease time required for dormant pruning, improve light penetration, enhance fruit quality, concentrate fruit maturity, increase the number of fruit buds formed, and increase yield (2, 3, 10, 11).

However, not all reports on summer pruning of peach have been favorable (1, 5, 6, 9). Chalmers et al. (1) reported that hedging (nonselective pruning back of shoots with cutter-bar mower or special circular saw) reduced fruit number and yield by more than half compared to a light summer pruning (selective thinning and heading of shoots). Marini (6) reported that summer pruning or topping (removing about half of current season's growth on top of the tree) of 3-year-old 'Cresthaven' trees in June or June and July resulted in more shoot growth the following year than when trees were only dormant pruned. Light levels were increased at the center of these young trees immediately after summer pruning but not always after topping. He did not report the effect on yield. In a subsequent study, Marini and Rossi (9) found no economic or horticultural advantage for summer pruning or topping over dormant pruning of 11-year-old 'Sunqueen' peach trees.

Except for Marini's report on 3-year-old trees (6), little information is available concerning the effect of summer pruning on young peach trees planted under field conditions at wide spacings and just beginning to bear fruit. Summer pruning may seem impractical for these trees, since one of the objectives at this stage is to encourage vigorous growth to fill the allotted space with fruiting canopy (mantle). However, excessively vigorous growth frequently is produced, resulting in dense shade in the lower center portion of the tree even in the second year. Less vigorous shoots that cannot compete are soon shaded-out and become weak, small-diameter shoots (4) that may die. Eventually the fruiting mantle is found only on the periphery of the tree. Summer hand pruning to remove or suppress selectively the most vigorous shoots might increase light adequately to maintain bearing wood throughout the canopy. The present study was designed to examine this hypothesis on young, vigorous peach trees in a low density (298 trees/ha) planting.

Expt. 1. Two-year-old 'Candor' peach trees on 'Lovell' rootstock planted 5.5 × 6.0 m and oriented in northeast–southwest rows were trained to an open center system using standard dormant pruning methods. Trees were vigorous, averaging 2 m in height with a 2-m canopy spread, and had set a crop of fruit. All trees were hand thinned to space fruit 15 to 20 cm apart. A single summer pruning treatment was imposed on 16 June 1982 (early stage III), 23 days before the first harvest. Summer pruning consisted of thinning cuts to remove vigorous, upright, current season shoots, and severely heading back current season shoots to about 10-cm stubs in the top and center of the tree. Fresh weight of summer prunings was not recorded; however, ≈60% of the current season's shoot growth was removed by the summer-pruning treatment. An effort was made to maximize light penetration while maintaining a sufficient number of new shoots for next year's crop and future canopy/mantle development. Experimental design was a randomized com-

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