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Effects of Root Pruning at Four Levels of Severity on Growth and Yield of 'Melrose'/M.26 Apple Trees

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Abstract. **Vigorous 15-year-old 'Melrose'/M.26 apple (*Malus domestica* Borkh) trees were mechanically root-pruned annually for 4 years at full bloom on two sides of the trunk at a distance of 60 or 80 cm and to a depth of 25 or 50 cm at each distance. Compared to unpruned controls, trees that were root-pruned had reduced trunk cross-sectional area, shoot length, leaf size, pre-harvest fruit drop, fruit size, and pruning time. Although fruit yield was unaffected, yield efficiency, fruit color, and soluble solids were increased by root pruning. Canopy light penetration was increased, as was spur quality. Generally, pruning 60 cm from the trunk had a greater effect than pruning at 80 cm, while pruning depth had no influence.**

Root pruning at bloom is an effective mechanical method for controlling growth in fruit trees (15). In evaluating root pruning as a potential commercial orchard practice, it is necessary to define a proper range of severity, with respect to proximity to the tree and depth, to obtain an optimal response. Early investigations of manual root pruning recommended digging a trench around the entire root mass at a distance of 25 cm and to a depth of 38 cm (18). The radius of the trenched circle was increased 10 cm each successive year. Schumacher et al. (13) mechanically root-pruned 'Gravensteiner' trees on an unspecified semi-dwarf rootstock at 40 or 60 cm from the trunk and showed that it was necessary to prune on two sides of the trunk to obtain a reduction in tree growth. Schumacher (12) found that root pruning 4-year-old 'Maigold' on an unspecified rootstock at 60 cm from the trunk actually increased shoot growth and had little influence on fruit size, whereas root pruning at 40 cm reduced shoot growth and fruit size. Root pruning at either distance reduced yield (12). In contrast, Brunner and Droba (3) found root pruning 'Jonathan'/M.4 trees at 60 cm more effective than at 40 cm in reducing shoot growth. Luthi (11) recommended root pruning to a depth of 35 to 38 cm and between 50 to 100 cm from the trunk, depending on rootstock and tree age. Thus, previous work on root pruning severity does not clearly establish an applicable range of treatment for vigorous, mature apple trees. The objective of this study was to determine the effects of root pruning at two distances from the trunk and two depths on growth and fruiting of vigorous, mature semi-dwarf apple trees.

Materials and Methods

The orchard was planted in 1968 in a fine, loamy mixed mesic Typic Fragiudalf soil in east–west rows at a spacing of 3.7 × 6.7 m with a 2-m-wide herbicide strip and sod drive rows. The trees used in this study were excessively vigorous 'Melrose'/M.26, trained to a central leader, and containment pruning was practiced to maintain a tree height and spread of 3 m.

For 4 years beginning in 1983, these apple trees were root-pruned annually with the following combination of treatments: 60 or 80 cm from the trunk, at depths of 25 or 50 cm, and unpruned controls. Root pruning was done mechanically on two sides of the tree, parallel with the row, with a tractor-mounted sharpened subsoiler (14) when trees were at full bloom (15). The treatments were arranged as 11 single-tree replications of a split-plot with root pruning distance from the trunk as the main plot and pruning depth as the sub-plot.

After seasonal growth was complete, trunk circumference and the length of 10 shoots from the top one-third of the canopy of each tree were measured. The number of leaves on each shoot was counted and leaf area was measured with a LI-COR LI-3000 leaf area meter. The leaves were then dried at 63°C in a forced-air oven, weighed, and levels of P, K, Ca, Mg, Mn, Fe, B, Cu, Zn, Al, and Na were determined by plasma emission spectrophotometry using standard procedures of the Research–Extension Analytical Laboratory at the Ohio Agricultural Research and Development Center. Leaf N levels were determined by the macro-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 quantum sensor. The probe was positioned in the center of the canopy, perpendicular to the row direction, and readings obtained were compared to a full sun reading taken adjacent to each replicate.

Five nonbearing spurs from 2-year-old wood were collected from well-exposed positions around the circumference of the canopy. Spur leaf number, area, and dry weight and bud diameter were measured. Each tree was dormant-pruned annually, and pruning time was recorded. At full bloom, 150 to 200 blossom clusters on tagged limbs, and the corresponding number of fruit remaining after June drop, were counted on each tree. At harvest, the number of dropped fruit 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 in diameter; 2) 79–67 mm; 3) 66–57 mm; and 4) <57 mm. The fruit were graded according to commercial standards, with poor fruit color being the major cullage factor. A sample of 10 fruit per tree (79 to 67 mm in diameter) was taken, fruit firmness was measured on two sides of each fruit with an Effegi pressure tester,

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soluble solids were measured with a Bausch and Lomb Model Abbe-3L refractometer, 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 = 100% red to 5 = <40% red scale. In 1986, fruit color was also measured using a Minolta CR-100 chromameter with an 8-mm^2 sensor in the chromaticity mode. Ten fruit were harvested from the center of the bottom one-third of the canopy, percent of surface covered by blush was estimated, and chromaticity values were obtained from both the blush and non-blushed portions of the skin surface. The data were subjected to analysis of variance, and means were separated by LSD when the F value was significant.

Results

There was no difference in tree response to the two root pruning depths; hence, the means reported for each pruning distance are the average of both depths, and there were no interactions between depth and distance. Pruning treatments had dramatic effects on many parameters compared to unpruned trees.

Root pruning reduced shoot elongation and the number and size of shoot leaves in each year (Table 1). Root pruning at 60 cm from the trunk reduced shoot elongation more than pruning at 80 cm. Spur leaf number was increased by root pruning, and, in 2 of 3 years, leaf area per spur was increased. Root pruning had no effect on shoot or spur specific leaf weight. Spur bud diameter was increased by root pruning only in 1985. Root pruning had no effect on leaf mineral nutrient levels or fruit set (data not shown).

Fruit yield per tree was not affected by root pruning (Table 2), and there were no differences among root pruning levels on fruit size or cullage. Root pruning reduced fruit size in 3 of 4 years, as shown by a decline in proportion of fruit in the ≥80 mm category and an increase in the 79- to 64-mm or 64- to 57-mm categories (Table 2). Root pruning significantly reduced the percentage of cullage in 2 years.

Fruit red color was enhanced in the first and third of 3 years and shows a tendency to be improved in the the second year, when differences were not significant (Table 3). Light penetration in both the top and mid-thirds of the canopy was not increased by root pruning (data not shown). However, light penetration of the bottom third of the canopy was about doubled by root pruning (Table 3), and a sample of fruit taken from the lower canopy in 1986 had twice the blush of the control (root-pruned 52%, control 25%), and the blush was intensely colored when trees were root-pruned. The skin color on the non-blushed side of the fruit from root-pruned trees had the same intensity of greenness as fruit from control trees (data not shown).

Fruit flesh firmness was increased in 1985, and percent soluble solids was increased in 1985 and 1986 by root pruning (Table 3). The amount of preharvest fruit drop of root-pruned trees was less than one-half that of the controls.

Cumulative trunk cross-sectional area over the duration of experiment was reduced 30% by root pruning and, since yields were unaffected, cropping efficiency was increased by root pruning at either distance (Table 4). The amount of time to dormant-prune the smaller root-pruned trees was reduced in comparison to controls.

Discussion

'Melrose' ('Jonathan' x 'Delicious'), is similar to 'Delicious' with respect to vigorous growth characteristics and to sensitivity of flowering and fruit quality to shade. The trees used in this experiment were excessively vigorous at the beginning of the experiment.

There were differences in vegetative response to root pruning distance at the levels tested, but there was no difference in tree response between the two depths. In his review, Atkinson (1) concluded that 70% of apple root weight occurred in the top 30 cm of the soil profile across many different orchard sites. Thus, pruning to a depth of 25 cm is likely to sever a substantial portion of the root system. This pruning is favorable from a practical standpoint, as root pruning at the 50-cm depth was quite difficult, and often a second tractor was required to prevent the tractor from being pulled into the tree row. The root pruner was easily drawn through the soil at the 25 cm depth by a single 50-HP tractor.

Root pruning at 60 or 80 cm from the trunk was very effective

Table 1. Effect of root pruning at different levels of severity on shoot growth, shoot leaf size and number, spur leaf number, area, specific leaf weight, and bud diameter of 'Melrose'/M.26 apple trees.

Root pruning distance from trunk (cm)	Shoot length (cm)	Shoot leaf Size (cm)	Shoot leaf No.	Spur leaf No.	Spur leaf Area (cm)	Spur leaf SLW (mg·cm^{-2})	Bud diam (mm)
			1984				
Control	50 a[z]	33 a	24.4 a	5.4 b	83	---	2.3
80	42 b	27 b	21.4 b	6.2 a	80	---	2.2
60	32 c	24 b	18.0 c	6.3 a	81	---	2.4
			1985				
Control	57 a	28 a	26.4 a	5.6 b	64 b	8.7	1.7 b
80	36 b	22 b	20.7 b	6.2 a	74 a	9.0	2.0 a
60	28 c	21 b	18.8 b	6.6 a	74 a	9.1	2.0 a
			1986				
Control	87 a	28	42.6 a	6.1 b	90 b	9.1	2.5
80	49 b	27	24.9 b	6.5 a	96 a	9.6	2.5
60	38 c	27	22.0 b	6.8 a	97 a	9.8	2.7

[z]Mean separation in columns within a year by LSD, $P = 5\%$.

Table 2. Effect of root pruning on yield, fruit size distribution, and cullage of 'Melrose'/M.26 apple trees.

Treatment	Fruit no./tree	Yield wt (kg/tree)	Percent total yield >80(mm)	79–67 (mm)	66–57 (mm)	<57 (mm)	Cull
			1983				
Control	451	87	49	26	22	3	18
Root-pruned[z]	349	65	52	22	23	3	16
			1984				
Control	339	72	77 a	17	5 b	1	28 a
Root-pruned	479	88	49 b	29	19 a	2	19 b
			1985				
Control	704	167	67 a	14 b	10	9 a	32 a
Root-pruned	705	167	56 b	26 a	14	5 b	26 b
			1986				
Control	771	192	63 a	32 b	4	1	16
Root-pruned	725	169	40 b	49 a	10	1	13

[z]Because there was no difference in effects on fruits among the four levels of root pruning severity, all root-pruning treatments were averaged.
[y]Mean separation in columns within a year by LSD, $P=5\%$.

Table 3. Effect of root pruning on fruit color, light penetration, and fruit color in the bottom one-third of the canopy, fruit firmness, soluble solids, and preharvest drop of 'Melrose'/M.26 apple trees.

Treatment	Color rating[z]	Light penetration, bottom one-third canopy (%)	Fruit flesh firmness (N)	Fruit soluble solids (%)	Preharvest drop (no./tree)
		1984			
Control	3.9 a[x]	5.3 b	57.9	15.1	---
Root-pruned[y]	3.3 b	9.4 a	58.8	15.5	---
		1985			
Control	3.4	---	35.3 b	13.6 b	81 a
Root-pruned	3.0	---	37.3 a	14.0 a	37 b
		1986			
Control	2.9 a	7 b	64.7	13.0 b	214 a
Root-pruned	1.9 b	16 a	65.7	14.1 a	93 b

[z]Color ratings: 1 = 100% red to 5 = <40% red.
[y]Because there was no difference in effects on fruit among the four levels of root pruning severity, treatment means were averaged.
[x]Mean separation in columns within a year by LSD, $P=5\%$.

in reducing shoot growth of mature trees on M.26 rootstock (Table 1). This effect contrasts with previous reports (11) that distance from the trunk was a critical factor to the success of root pruning. Schumacher (12) found root pruning 4-year-old 'Maigold' trees at a 40 cm distance reduced shoot growth, whereas pruning at 60 cm increased shoot growth by 60%. One possible explanation of the differences in results from pruning distance is that the rootstock used in the present study was more dwarfing than that used in previous work. Recent work indicates that efficiency of chemical growth retardants was improved with more dwarfing rootstocks (4). Further research into the response of different rootstocks to root pruning is currently in progress. The reduction in shoot growth by root pruning was especially dramatic in 1986, when mid-summer rainfall stimulated a second flush of growth in the control trees that was not observed in root-pruned trees.

Although the number and size of shoot leaves were reduced by root pruning, the number of spur leaves was increased and spur leaf area remained the same or increased (Table 1). This result may be explained by considering the difference in time of development of spur leaves and shoot leaves in context with the time of root pruning. Most spur leaves are formed in the bud during the previous season, whereas the majority of shoot leaves are produced subsequent to bloom (7, 8) and just after the root pruning in this experiment was applied. In greenhouse-grown trees, root pruning had the greatest effect on growth in the first 4 weeks after treatment (6, 16).

Reducing the number and size of shoot leaves improved light

Table 4. Effect of root pruning at different levels of severity on cumulative trunk cross-sectional area, yield efficiency, and pruning time of 'Melrose'/M.26 apple trees.

Root pruning distance from trunk (cm)	TCSA[z] increment (cm^2)	Yield[y] efficiency	Pruning time (min/tree) 1985	1986
Control	102 b[x]	1.1 b	18.3 a	21.8 a
80	73 a	1.7 a	11.9 b	14.0 b
60	69 a	1.5 a	9.6 b	11.7 c

[z]Trunk cross-sectional area (TCSA) increment = TCSA '86 − TCSA '82.
[y]Yield efficiency = total cumulative yield (kg)/TCSA increment (cm^2)/4 years.
[x]Mean separation in columns by LSD, $P = 5\%$.

penetration and fruit color in the bottom of the canopy. Light penetration, although still low in this region of the tree, was doubled by root pruning, and the increased fruit color, which is a major problem in 'Melrose' fruit quality, undoubtedly contributed to improved packout in 1984 and 1985 (Table 2). Barritt et al. (2) have also reported improved spur quality, fruit soluble solids, and red skin color in portions of the canopy with increased exposure to sunlight.

How root pruning at full bloom reduced fruit drop in autumn is open to speculation. It would not appear to be caused by a delay in maturity, since root pruning promoted red skin coloring and increased fruit soluble solids (Table 3), while the ratio of green to yellow in the fruit under color was not affected (data not shown). One possibility is that root pruning may counteract abscission without interfering with other ethylene-mediated ripening processes, as has been demonstrated with plant growth regulators (5).

Previous investigations into root pruning have reported reductions in yield, especially in the year of treatment (3, 12), but this and a prior study (15) have not found this to be the case with 'Melrose'. Fruit size was reduced in the latter 3 of 4 years in this study (Table 2). Previous work has reported increased fruit size (3) or, more often, decreased fruit size (12, 13, 15). Root pruning results in decreased water potential (15, 16), which may have an adverse effect on fruit size during the early development of the fruit, as root pruning after June drop did not affect fruit size (15). In the first year of this study, root pruning had no influence on fruit size; however, the 1983 growing season was very dry and fruit size was generally lower on all trees (Table 2).

Yield efficiency was increased by root pruning, as tree growth was reduced and yields remained comparable to controls (Table 4). The reduction in vegetative growth resulted in a 40% savings in pruning time, which is a major labor input in orchard management (9, 10, 19).

Annual root pruning has proven to be an effective method of controlling tree size and increasing yield efficiency and fruit quality in a vigorous apple cultivar. The cuts must be made in close proximity to the trunk to achieve the desired reduction in growth; however, the results of this study indicate that the exact distance or depth is not as critical as previously suggested (11–13). It was anticipated that root pruning would lead to great variability in tree growth responses, as the distribution of roots in the soil volume can be very random (1) and, therefore, the amount of roots cut at a given level of severity would vary from tree to tree. However, the growth reductions in response to root pruning were very uniform. Tonutti et al. (17) also reported a very strong and uniform response to root pruning.

The reduction in fruit size remains a concern. 'Melrose' is a large-fruited cultivar, and the substantial reduction in fruit size in this study had little effect on crop value (14). Whether a proportional reduction in fruit size could be acceptable in a small- or medium-fruited cultivar is questionable.

The 40% savings in pruning time, increased yield efficiency, light penetration, and improved packout due to better fruit color are worthwhile results and suggest that root pruning may still have value as a management tool for controlling tree size, especially in situations where tree spacing is too close and overcrowding becomes a problem.

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Plant Production from Longitudinally Halved Storage Roots of Two Sweet Potato Cultivars

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Abstract. **Initiation of sweet potato [*Ipomoea batatas* (L.)] plant harvests from the propagating bed was later from the sparse plant producer 'Georgia Jet' than from the profuse plant producer 'Georgia Red'. Also, the initiation of plant harvests from storage roots cut into longitudinal halves for inspection of internal quality before bedding was later than from whole roots. These differences were reflected in lower cumulative percentages of total plants harvested from 'Georgia Jet' than from 'Georgia Red' within 2 weeks and from longitudinal halves within 2 and 4 weeks after initiation of plant harvests. Total plant production was greater from whole than from halved 'Georgia Jet' roots. Total plant production was greater from halved roots immersed in Botran 75W compared to those immersed in calcium hypochlorite. Cutting and immersion treatments did not influence total plant production from 'Georgia Red', a profuse plant producer. 'Georgia Jet' roots deteriorated more than 'Georgia Red' in the propagating bed, and deterioration was increased by cutting and immersion in calcium hypochlorite. Presprouting did not reduce deterioration of roots in the propagating bed, but did reduce the number of days from bedding until first plant harvest. It also increased the cumulative percentage of the total plants harvested within 2 and 4 weeks after harvests were initiated and increased total number of plants produced from both small and large 'Georgia Jet' roots and from large 'Georgia Red' roots. Large roots of each cultivar produced more plants than were produced by small roots when presprouted. Large roots of 'Georgia Jet' also produced more plants than were produced by small roots when not presprouted, but root size did not influence total plant production from 'Georgia Red' roots that were not presprouted. Chemical name used: 2,6-dichloro-4-nitroaniline (Botran 75W).**

Most commercial sweet potato production in the United States is from plants that have been propagated from enlarged storage roots; plant propagation characteristics are cultivar-dependent. Maximizing the number of usable plants produced and minimizing the time required to produce them reduces propagation costs and facilitates early transplanting. Small storage roots usually produce fewer plants per root than are produced from large roots (11), but small roots are generally preferred for bedding because they produce more plants than are produced by an equal weight of large roots. Presprouting increases the number of early plants (1, 8) and the total number of plants produced from the sparse plant-producing cultivar Georgia Jet (7).

Maintaining true-to-type disease-free sweet potato cultivars requires careful attention to characteristics of the storage roots subject to frequent mutation, such as skin color and flesh color, and scrutiny for detectable diseases, such as internal cork virus (3). Roots may be cut into thin sections to examine for internal quality and then the proximal tip from selected roots can be bedded for plant production. This procedure provides a thorough evaluation for internal quality but eliminates much of the plant production potential of the storage root. A less rigorous method adopted by many Georgia growers maintaining their own seed maintenance programs involves cutting storage roots into longitudinal halves to inspect for flesh color and some diseases prior to bedding. Cutting storage roots into longitudinal halves prior to bedding also has increased plant production of some cultivars, with the increase more pronounced from large rather than from small storage roots (2, 9). However, storage root size did not influence total plant production by 'Georgia Jet', and longitudinal cutting delayed plant production and reduced the total number of plants produced (7). Such a reduction in plant production further increases propagation costs of already sparse plant-producing cultivars, such as 'Georgia Jet', and limits propagative potential of individual storage roots.

Storage roots customarily are immersed in a fungicide or surface sterilant solution to prevent deterioration in the propagation bed (4). In a previous study, the surface sterilant calcium hypochlorite influenced neither the total number of plants produced nor the deterioration of whole bedded storage roots of three cultivars and one unnamed clone (6), but calcium hypochlorite did encourage early plant production from three of these clones.

This work examined the effects of presprouting, cutting into longitudinal halves, and immersion into solutions of Botran 75W or calcium hypochlorite on plant production from small- and large-bedded sweet potato storage roots of a profuse and a sparse plant-producing cultivar.

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