HortScience 32(4):645–648. 1997.

Influence of Root Pruning and Rootstock on Growth and Performance of 'Golden Delicious' Apple

D.C. Ferree and M. Knee
Horticulture and Crop Science, The Ohio State University, Wooster, OH 44691

Additional index words. *Malus domestica*, shoot growth, yield

Abstract. **'Smoothee Golden Delicious' apple trees on nine rootstocks or interstems were mechanically root pruned annually for 9 years beginning the year after planting. Root pruning reduced trunk cross-sectional area (TCA) by 14% over the first 5 years and 22% in the last 4 years of the trial. Yield and fruit size were reduced by root pruning in most years with the fruit size effect obvious in June at the end of cell division. Interstem trees of MAC.9/MM.106 were larger than trees on M.9 and the following interstems: M.9/MM.106, M.9/MM.111, M.27/MM.111. Trees on seedling (SDL) rootstock were the largest and had the lowest yield per unit TCA and lower cumulative yield/tree than trees on M.7, MM.106, and MM.111. There was no interaction for any measure of growth or yield between root pruning and rootstock or interstem.**

Apple rootstocks are one of the most efficient means of reducing tree size and increasing yield efficiency, and they serve as the basis for intensive orchard systems (NC-140, 1991 and 1996; Ferree et al., 1989; Robinson and Lakso, 1991). However, a number of the rootstocks with low mortality are too vigorous and produce trees too large for efficient intensive production systems (NC-140, 1996; Ferree and Hill, 1982), and some of the smaller, efficient rootstocks are susceptible to diseases that have caused serious tree losses in some production areas (Ferree et al., 1983; Perry, 1992). Root pruning has generally reduced tree size and shoot growth (Elfving et al., 1996; Ferree, 1992; Geisler and Ferree, 1984; Schupp and Ferree, 1987, 1988), but in some studies results were inconsistent (Baugher et al., 1995; Miller, 1995). Root pruning has reduced growth consistently in trees growing on the dwarfing rootstocks M.9 (Ferree and Rhodus, 1993; Schupp et al., 1992) and M.26 (Ferree, 1992; Schupp and Ferree, 1988); mixed results were obtained on the semidwarfing rootstock M.7 (Baugher et al., 1995; Ferree and Rhodus, 1993; Miller, 1995). Rootstocks that produce large trees, such as seedling (SDL) and MM.111, which have excellent survival (NC-140, 1991 and 1996; Ferree and Hill, 1982), or interstems based on these rootstocks, have not been widely tested.

The present study was established to determine the effect of root pruning on the performance of a range of 'Smoothee Golden Delicious' rootstock and interstem combinations.

Received for publication 30 Sept. 1996. Accepted for publication 9 Jan. 1997. Salaries and research support provided by state and federal fund appropriated to the Ohio Agricultural Research and Development Center, The Ohio State Univ. Journal article no. 136-96. 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.

Materials and Methods

In Apr. 1983, 'Smoothee Golden Delicious' apple trees were purchased from commercial sources on nine rootstocks or interstems (Table 1). Interstem length was ≈15 cm. Trees were planted at a spacing of 3 × 5 m on a silt loam soil (fine loamy mixed mesic typic fragiudalf) at Wooster, Ohio. The trees were trained as central leaders with minimal pruning and were free-standing except for trees on M.9, which were supported by 1.5-m wooden posts. The trees received no supplemental irrigation and a 2-m herbicide strip was used for soil management. The trees received standard pesticide and chemical thinning sprays as needed. Half of the trees were mechanically root pruned on two sides, 50 cm from the trunk, to a depth of ≈45 cm using a sharpened subsoiler (Schupp and Ferree, 1987). Root pruning began the second year (1984) and was performed annually at bloom. The treatments were arranged as a subplot with root pruning as the main plot and rootstock as the split plot with eight replications for a total of 144 trees. Trees of 'Empire' M.9/MM.106 and 'Lawspur' M.9/MM.106 were planted in the rows as pollinizers.

Growth of 10 terminal shoots/tree and trunk circumference were measured annually. In 1988, 1989, and 1990, a sample of 10 fruit/tree was collected at the completion of the cell division phase of growth and weighed to determine fruit size. In 1987, 1988, and 1990, a sample of 25 fruit was collected at random from the lower canopy at harvest and weighed to determine average fruit mass. The entire crop from each tree was graded on an FMC weight sizer in 1990 and 1991 and divided into the following size classes: ≥8.0 cm in diameter (box size 80–88); 8.0–7.3 cm (100–113); 7.3–5.7 cm (128–138). In 1989 and 1990, three apples in a well-exposed area on the periphery of each tree were tagged 4 weeks before harvest and skin color (L*, A*, B*) on the unexposed side measured weekly with a Minolta chromometer (model CR-100). A sample of 10 fruit from the well-exposed area of the canopy was taken at harvest (9 Oct. 1990) from control and root pruned trees on M.7A, M.9, M.9/MM.106, and MAC.9/MM.106 and transported to Columbus, Ohio, where internal ethylene measurements were made by removing a 1-mL gas sample from the core cavity with a hypodermic syringe. The sample was injected into a 6C gas chromatograph (Packard 417, Packard Inst. Co., Meriden, Conn.) equipped with a 50 × 0.4-cm column filled with 80–100 mesh alumina at 100 °C and a flame ionization detector. The carrier gas was N with a flow rate of 60 $mL \cdot min^{-1}$. For Ca analysis, radial segments were cut from pedicel to calyx from opposite sides of individual apples, so that ≈200 g was collected from 10 fruits. These segments were homogenized in water (1 $mL \cdot g^{-1}$ fresh weight) in a blender. Six 10-g aliquots were weighed from the suspension and each was diluted with 10 mL water; 0.105 mL 100 mM calcium chloride standard was added to two samples and 0.1 mL to two others. Before reading, samples were held with gentle agitation for 30 min at room temperature. The Ca electrode (model 93-20; Orion, Boston) and double-junction reference electrode (Orion 90-01) were set up with an ion analyzer/pH meter (Corning 250, Corning, N.Y.) as directed by the manufacturer. Total Ca content of the apples was calculated according to Knee and Srivastava (1995).

Results

Root pruning reduced growth in trunk cross-sectional area (TCA) by 14% in the first 5 years with a larger (22%) reduction in later years (Table 1). Trees on seedling rootstock were the largest and showed the greatest change in growth during the study. Interstem trees on M.9/MM.106, M.9/MM.111, and M.27/MM.111 were similar in size to trees on M.9. Interstem trees on MAC.9/MM.106 were larger than trees on M.9, but smaller than trees on MM.106, MM.111, and M.7, which were similar in size. Differences in tree height at the end of the tenth growing season paralleled differences in TCA. Several (SDL, M.7, MM.106, MM.111, and MAC.9/MM.106) rootstocks exceeded the 3.0-m spacing allotted to trees in this trial, but significant crowding requiring containment pruning did not occur except for trees on SDL, which were still growing vigorously at the termination of the study. Representative years of average shoot growth (Table 1) indicate that root pruning consistently reduced growth. In 1985, the first year of cropping, trees on SDL were growing most rapidly and trees on M.9/MM.106 least rapidly. In later years, trees on M.9, M.9/MM.106, and M.27/MM.111 had shorter shoot growth than the more vigorous rootstocks of SDL and MM.106. There was no interaction between root pruning and rootstock/interstem effects on any measure of growth.

The first significant crop occurred in the third leaf (1985) with trees on MM.106 having a larger yield than all others except for trees on

Table 1. Influence of rootstock, interstem, and root pruning on growth and size of 'Smoothee Golden Delicious' apple trees over nine years (1983–91).

	Increase in TCA (cm^2)		Tree size 1992			Shoot length (cm)		
			TCA	Ht	Spread			
Treatment	1987–83	1991–87	(cm^2)	(m)	(m)	1985	1988	1991
Rootstock/interstem								
Seedling	55.2 a[z]	91.2 a	155.0 a	4.87 a	3.4 a	57.2 a	33.0 a	28.7 a
M.7A	41.9 b	66.0 b	110.7 b	4.32 b	3.4 a	49.2 bc	30.5 a–c	25.6 a–c
MM.106	40.8 b	68.0 b	111.6 b	4.54 ab	3.3 a	48.2 bc	31.1 ab	27.8 ab
MM.111	41.6 b	62.0 bc	105.1 bc	4.26 bc	3.2 a	52.9 ab	29.2 bc	25.9 a–c
M.9	22.8 c	30.9 ef	55.2 de	3.18 de	2.8 bc	48.7 bc	31.1 ab	23.0 c
M.9/MM.106	26.2 c	29.7 ef	58.0 de	3.39 d	2.8 bc	45.6 c	30.6 a–c	22.4 c
M.9/MM.111	26.6 c	40.4 de	69.4 d	3.84 c	2.9 b	50.6 bc	29.5 bc	25.5 a–c
M.27/MM.111	23.3 c	21.8 f	47.2 e	2.78 e	2.6 c	48.0 bc	27.9 c	23.7 c
MAC.9/MM.106	35.9 b	52.2 cd	90.0 c	4.11 bc	3.2 a	49.8 bc	29.7 bc	24.5 bc
Root pruning								
Control	37.4 a	57.2 a	96.4 a	4.0 a	3.1 a	52.6 a	62.7 a	27.3 a
Root pruned	32.4 b	45.1 b	79.4 b	3.7 b	2.9 b	47.6 b	54.4 b	23.0 b
F significance								
Root pruning (RP)	**	**	**	**	**	**	**	**
Rootstock (RS)	**	**	**	**	**	**	*	**
RP × RS	NS	NS	NS	NS	NS	NS	NS	NS

[z]Mean separation within main effects by Duncan's multiple range test, $P = 0.05$.
NS, *, **Nonsignificant or significant at $P = 0.05$ or 0.01, respectively.

Table 2. Influence of rootstock, interstem, and root pruning on yield per tree of 'Smoothee Golden Delicious' apple over 7 years.

	Yield/tree (kg)						
Treatment	1985	1986	1987	1988	1989	1990	1991
Rootstock/interstem							
Seedling	4.3 b[z]	5.6 d	5.8 d	18.2 d	33.9 c	73.2 b	30.7 c
M.7A	12.3 ab	9.6 cd	9.7 cd	34.9 a	46.8 a	92.9 a	30.3 bc
MM.106	15.0 a	16.7 a	16.6 a	33.9 a	54.6 a	92.8 a	33.2 ab
MM.111	9.1 b	10.4 b	10.4 b–d	32.6 ab	53.9 a	62.8 bc	34.1 ab
M.9	9.7 b	8.5 d	8.9 cd	21.0 cd	33.7 c	42.5 de	26.3 bc
M.9/MM.106	10.9 b	14.3 ab	14.4 ab	23.9 b–d	44.4 a–c	50.8 cd	32.2 bc
M.9/MM.111	10.7 b	13.1 a–c	13.1 a–c	25.2 a–c	45.1 ab	43.9 de	34.0 ab
M.27/MM.111	7.9 b	10.2 bc	9.6 cd	18.2 d	35.5 bc	33.3 e	24.4 c
MAC.9/MM.106	8.9 b	12.1 bc	12.2 bc	30.7 a–c	52.1 a	72.3 b	40.6 a
Root pruning							
Control	11.1	14.2 a	14.4 a	28.4	46.9 a	68.4 a	34.7 a
Root pruned	9.5	8.9 b	7.9 b	24.6	41.3 b	56.5 b	29.0 b
F significance							
Root pruning (RP)	NS	**	**	NS	*	**	**
Rootstock (RS)	**	**	**	**	**	**	**
RP × RS	NS	NS	NS	NS	NS	NS	NS

[z]Mean separation within main effects by Duncan's multiple range test, $P = 0.05$.
NS, *, **Nonsignificant or significant at $P = 0.05$ or 0.01, respectively.

M.7, which were similar (Table 2). Root pruning consistently reduced yield 12% to 18% except in 1987 when the reduction was 45%. Of the trees on interstems, M.27/MM.111 tended to have lower yields, similar to those of trees on M.9.

Trees on SDL had lower cumulative yield and yield efficiency than trees on the semi-dwarf clonal rootstocks (M.7, MM.106, MM.111) and the interstem MAC.9/MM.106 (Table 3). Surprisingly, cumulative yield efficiency did not differ among the rootstocks and interstems other than SDL. However, values for M.9 and M.9/MM.106, which usually are more efficient (NC-140, 1992; Ferree et al., 1979), tended to be slightly higher. Root pruning reduced cumulative yield/tree and generally reduced fruit size both in June, immediately following the cell division phase of growth, and at harvest. Although differences were not significant in all years, trees on MM.106 tended to produce large fruit and trees on M.27/MM.111 small fruit. In two years with modest crops (1989 and 1991) all fruit per tree were graded into four size classes on a commercial weight sizer (data not presented). General fruit size was much higher in 1989 than in 1991. In 1989, trees on M.9 and M.9/MM.106 had the highest percentage of large fruit (49.5% and 42.7%, respectively) and trees on M.27/MM.111 the smallest (25.3%). In 1991, trees on MM.106 generally had the highest percentage of large fruit (10.6%), while trees on M.9 (4%) and M.9/MM.106 (3.6%) had the smallest proportion of large fruit. In 1989, moisture during the growing season was normal, while in 1991 rainfall over the growing season was 37% below normal.

Root pruning had no influence on fruit color, starch index, internal ethylene, or fruit Ca in 1990 (Table 4). At harvest, the L value (100 = bright, 0 = dark) for fruit from trees on MM.106 was lower than on the other rootstocks. The degree of greenness was higher in fruit from trees on seedling, M.7, and MAC.9/MM.106 than in those from trees on M.9/MM.111 and M.27/MM.111. Fruit from trees on M.7 were less yellow than from trees on M.27/MM.111, M.9/MM.111, M.9/MM.106, and M.9. This pattern was evident, although not always significant, in the 3 weeks before harvest and a similar trend existed in 1989. Fruit from trees on M.7 had the lowest hue angle and did not differ from fruits from trees on all the rootstocks producing larger trees and on trees on M.9 and MAC.9/MM.106. Fruit on M.27/MM.111 trees had a higher hue angle than all combinations except M.9/MM.111. Hue angle has been correlated with sensory evaluations of color quality (Singha et al., 1991). Although not clearly separated statistically, fruit from rootstocks that produced larger sized trees tended to have higher starch than those from rootstocks or interstems that produced smaller trees. Fruit Ca levels were highest from trees on M.9/MM.111 and lowest from trees on M.9/MM.106 and MAC.9/MM.106. Autio (1991) found that Ca levels were high in fruits from trees grafted directly on MAC.9 but not in those from trees in which MAC.9 was used as an interstem.

Discussion

Apple trees in most root pruning studies have had full canopies and were already cropping when the treatments were initiated. Such

Table 3. Influence of rootstock, interstem, and root pruning on cumulative yield and mean fruit size of 'Smoothee Golden Delicious' apple over 9 years (1983–91).

	Cumulative yield per			Fruit mass June (g)			Fruit mass harvest (g)		
	Tree	cm^2	ha						
Treatment	(kg)	(kg)	(t)	1988	1989	1990	1987	1988	1990
Rootstock/interstem									
Seedling	352.8 b[z]	2.67 b	182.8 c	12.7 b	11.3 b	9.7 c	162 ab	171 cd	169 ab
M.7A	540.0 a	5.94 a	295.2 ab	13.0 ab	11.4 ab	10.4 ab	158 c	172 bc	170 ab
MM.106	504.6 a	5.48 a	304.4 a	12.8 b	11.9 ab	10.6 a	196 a	184 a	172 ab
MM.111	496.0 a	5.57 a	286.3 ab	12.7 b	11.3 b	10.6 a	187 ab	170 cd	171 ab
M.9	328.9 b	6.76 a	238.4 a–c	12.9 ab	11.8 ab	9.8 bc	176 a–c	180 ab	166 ab
M.9/MM.106	406.6 ab	7.66 ab	263.1 ab	13.5 ab	11.6 ab	9.8 bc	185 ab	176 a–c	163 b
M.9/MM.111	421.1 ab	5.99 a	254.6 b	13.0 ab	11.6 ab	10.3 ab	176 a–c	171 b–d	178 a
M.27/MM.111	297.0 b	6.16 a	215.8 bc	12.8 b	11.9 ab	9.3 c	165 bc	163 d	154 b
MAC.9/MM.106	520.6 a	6.39 a	289.1 a	13.9 a	12.1 a	9.5 c	176 a–c	178 a–c	162 b
Root pruning									
Control	460.9 a	5.76	265.7	13.5 a	11.8 a	10.1	178	179 a	171 a
Root pruned	398.5 b	6.03	250.3	12.5 b	11.5 b	9.9	178	169 b	165 b
F significance									
Root pruning (RP)	*	NS	NS	**	*	NS	NS	**	**
Rootstock (RS)	**	**	**	*	*	**	**	**	*
RP × RS	NS	NS	NS	NS	NS	NS	NS	*	NS

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

NS, *, **Nonsignificant or significant at $P = 0.05$ or 0.01, respectively.

Table 4. Influence of rootstock, interstem, and root pruning on fruit color and quality of 'Smoothee Golden Delicious' apples in 1990.

	Fruit color[y]		Starch index[x]		Fruit internal	Fruit
		Hue		Covariant	ethylene	Ca
Treatment	L	angle	Standard	yield/TCA	($\mu L \cdot L^{-1}$)	($mmol \cdot kg^{-1}$)
Rootstock/interstem						
Seedling	66.0 a	64.8 cd	5.64 ab	6.15 a	---	1.79 ab
M.7A	65.9 a	64.2 d	5.66 ab	5.40 bc	0.610	1.90 ab
MM.106	63.7 b	64.9 cd	6.19 a	5.97 ab	---	1.85 ab
MM.111	66.5 a	66.4 b–d	5.37 ab	5.49 a–c	---	2.02 a
M.9	65.9 a	66.2 b–d	5.13 bc	5.06 c–e	0.874	1.99 ab
M.9/MM.106	65.7 a	67.4 ab	4.32 c	4.53 e	---	1.69 b
M.9/MM.111	67.0 a	66.7 bc	5.47 ab	5.19 c–e	1.38	2.08 a
M.27/MM.111	67.9 a	68.9 a	4.71 bc	4.67 de	---	1.90 ab
MAC.9/MM.106	65.9 a	64.6 cd	5.39 ab	5.30 b–d	2.81	2.01 ab
Root pruning						
Control	65.6	65.8	5.38	5.37	0.987	1.90
Root pruned	66.3	66.2	5.22	5.24	1.580	1.92
F significance						
Root pruning (RP)	NS	NS	NS	NS	NS	NS
Rootstock (RS)	*	**	**	**	*	*
RP × RS	NS	NS	NS	NS	NS	NS

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

[y]Skin color measured by Minolta L (100 = bright, 0 = dark); a (+ = red, – = green); b (+ = yellow, – = blue); hue angle ($\tan^{-1}b/a$)

[x]Starch index according to 'Golden Delicious' chart 1 = black (all starch) to 9 (no starch).

NS, *, **Nonsignificant or significant at $P = 0.05$ or 0.01, respectively.

treatments reduced growth ≈30% (Ferree, 1992; Schupp and Ferree, 1987, 1988). In the present study where root pruning was initiated prior to fruiting, TCA was reduced 22% over 9 years and annual shoot growth was reduced 10% to 16%. Schupp and Ferree (1990) found that vegetative trees grown under nonlimiting conditions in the greenhouse made some adjustment in water relations and growth to the effects of root pruning and were less influenced by a second root pruning. In the present study, starting the root pruning prior to fruiting may have enabled these trees to adjust and not respond to the same degree or as consistently as other trees in the long-term trials (Ferree, 1992). The low level of cropping may have reduced the effect of root pruning in the early years of this study. In a previous study on mature 'Golden Delicious' on M.9 the TCA increment was reduced 44%, while in similar deblossomed trees, the reduction was only 14% (Schupp and Ferree, 1990).

Trees on SDL rootstock had lower cumulative yields and yield efficiency than those on the other larger rootstocks. This supports the results from the recent NC-140 trial across 31 sites where trees on SDL had lower yields and smaller fruit size compared to other rootstocks that produced similar sized trees. Since long-term survival of trees on rootstocks such as M.7 and MM.111 is similar to that of trees on SDL, SDL should not be considered as a rootstock for future plantings because of small fruit size, reduced yield and low yield efficiency.

Of the interstems compared in this trial, M.27/MM.111 tended to produce the smallest trees; these were similar in size, growth rate, and productivity to trees on M.9 rootstock. Interstem trees of MAC.9/MM.106 produced larger trees than the other interstem combinations and tended to be as productive as the larger trees on MM.106. In this planting, no abnormal growth occurred around the graft unions as was observed in a younger planting in New Zealand using MARK (previously MAC.9) interstem on MM.106 rootstock (personal observation). There was no consistent trend among interstems for fruit size or quality.

Yield of 'Golden Delicious' has been reduced (Ferree and Rhodus, 1993) or not affected (Miller, 1995; Schupp et al., 1992) by root pruning in several studies. In the present study, root pruning reduced yield and fruit size of 'Golden Delicious' in most years. The effects of root pruning on fruit maturity and nutrient levels are limited. Root pruning had no effect on color development of 'Golden Delicious' in this study or of 'Stayman' (Baugher et al., 1995); however, color of 'Melrose' and 'McIntosh' was enhanced by root pruning (Beaudry, 1989; Schupp and Ferree, 1988, 1989). Starch and ethylene content of fruits were not influenced in this study by root pruning and others have also found small or inconsistent effects (Beaudry, 1989; Elfving et al., 1991; Schupp, 1992).

The nine rootstock and interstem combinations in this and previous studies (NC-140, 1991 and 1996; Ferree et al., 1989) exhibited a 3.3-fold difference in TCA from smallest to largest. Stocks with high (M.9 and M.9/MM.106) and very low yield efficiency (SDL) were included. Root pruning affected all these genetic combinations similarly with no significant interaction for any of the parameters measured. Thus, the use of root pruning on rootstocks such as SDL and MM.111, with proven survivability (NC-140, 1996; Ferree and Hill, 1982) and wide soil adaptability, in an attempt to incorporate them into efficient intensive orchard systems would not be promising. Even combining tree size reducing techniques such as mechanical hedging with root pruning did not result in profitable orchard systems (Ferree and Rhodus, 1993). Other treatments combining root pruning with trunk scoring (Miller, 1995) or sod competition (Baugher et al., 1995) or summer pruning (Schupp, 1992) have given inconsistent results. Thus, the best use of root pruning appears to be as an immediate remedy to contain tree size following loss of crop, excessive pruning or inappropriate spacing resulting in excessive growth, or as a method of reducing fruit size. New orchards should be planted at spacings that promote a balance of growth and fruiting and do not require other means of tree size control such as root pruning.

Literature Cited

Autio, W.R. 1991. Rootstocks affect ripening and other qualities of 'Delicious' apples. J. Amer. Soc. Hort. Sci. 116:378–382.

Autio, W.R., J.A. Barden, and G.R. Brown. 1991. Rootstock affects ripening, size, mineral composition, and storability of 'Starkspur Supreme Delicious' in the 1980–81 NC-140 cooperative planting. Fruit Var. J. 45:247–251.

Baugher, T.A., K.C. Elliott, and D.M. Glenn. 1995. Effect of sod competition and root pruning on 'Stayman' apple tree growth and fruit cracking. HortScience 30:222–226.

Beaudry, R.M. 1989. Root pruning effect on apple size, color and maturity. Proc. Michigan State Hort. Soc. 119:19–29.

Elfving, D.C., E.C. Lougheed, and R.A. Cline. 1991. Daminozide, root pruning, trunk scoring, and trunk ringing effects on fruit ripening and storage behavior of 'McIntosh' apple. J. Amer. Soc. Hort. 116:195–200.

Elfving, D.C., I. Schechter, and M. Bom. 1996. Effect of root pruning and benzyladenine application on tree growth and fruit size in 'Empire' and 'McIntosh' apple. J. Tree Fruit Prod. 1:1–13.

Ferree, D.C., R.C. Funt, and B.L. Bishop. 1989. Yield and production efficiency of four apple cultivars in selected orchard management systems. J. Amer. Soc. Hort. Sci. 114:863–868.

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., M.A. Ellis, and F.R. Hall. 1983. Tree loss to fire blight infection of rootstocks and interstems in Ohio apple orchards. Compact Fruit Tree 16:116–120.

Ferree, D.C. and R.G. Hill, Jr. 1982. Influence of six rootstocks and herbicides on growth, cropping, and fruit quality of Blaxtayman apple trees. Fruit crops 1982: A summary of research. OARDC Res. Circ. 272:1–6.

Ferree, D.C. and W.T. Rhodus. 1993. Apple tree performance with mechanical hedging or root pruning in intensive orchards. J. Amer. Soc. Hort. Sci. 118:707–713.

Geisler, D. and D. Ferree. 1984. Response of plants to root pruning. Hort. Rev. 6:155–188.

Knee, M. And P. Srivastava. 1995. Binding of calcium by cell walls and estimation of calcium in apple fruit tissue with an ion selective electrode. Postharvest Biol. & Technol. 5:19–27.

Miller, S.S. 1995. Root pruning and trunk scoring have limited effect on young bearing apple trees. HortScience 30:981–984.

NC-140. 1991. Performance of 'Starkspur Supreme Delicious' apple on 9 rootstocks over 10 years in the NC-140 cooperative planting. Fruit Var. J. 45:192–199.

NC-140. 1996. Performance of the NC-140 cooperative apple rootstock planting: I. Survival, tree size, yield and fruit size. Fruit Var. J. 50:6–11.

Perry, R.L. 1992. The relative susceptibility of rootstocks to fire blight. Proc. Michigan State Hort. Soc. 122:72–75.

Robinson, T.L. and A.N. Lakso. 1991. Bases of yield and production efficiency in apple orchard systems. J. Amer. Soc. Hort. Sci. 116:188–194.

Schupp, J.R. and D.C. Ferree. 1987. Effect of root pruning at different growth stages on growth and fruiting of apple trees. HortScience 22:387–390.

Schupp, J.R. and D.C. Ferree. 1988. Effect of root pruning at four levels of severity on growth and yield of 'Melrose'/M.26. J. Amer. Soc. Hort. Sci. 113:194–198.

Schupp, J.R. and D.C. Ferree. 1989. Root pruning for growth control in apple trees. Acta. Hort. 243:103–110.

Schupp, J.R. and D.C. Ferree. 1990. Influence of time of root pruning on growth, net photosynthesis, and transpiration of young apple trees. Scientia Hort. 42:299–306.

Schupp, J.R., D.C. Ferree, and I.J. Warrington. 1992. Interactions of root pruning and deblossoming on growth, development and yield of 'Golden Delicious' apples. J. Hort. Sci. 67:465–480.

Schupp, J.R. 1992. Effect of root pruning and summer pruning on growth, yield, quality, and fruit maturity of 'McIntosh' apple trees. Acta Hort. 322:173–176.

Singha, S., E.C. Townsend, and T.A. Baugher. 1991. Relationship between visual rating and chromaticity values in 'Delicious' apple strains. Fruit Var. J. 45:33–36.