Effect of Sod Competition and Root Pruning on 'Stayman' Apple Tree Growth and Fruit Cracking

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Abstract. Three growth suppression treatments were compared during 1991 to 1993 on 'Stayman' apple (*Malus domestica* Borkh.) trees grown in the T-trellis and the MIA trellis systems. All treatments—root pruning, K-31 fescue (*Festuca arundinacea* Schreb.), and K-31 fescue plus root pruning—suppressed tree growth compared to the nontreated control, but results were inconsistent between years and systems. Sod or sod plus root pruning reduced terminal shoot length in both systems in 2 out of 3 years. Root pruning decreased shoot length in the T-trellis in 1992. Sod decreased trunk cross-sectional area in the T-trellis in 1993. Treatments did not affect 3-year average yield efficiency but did appear to increase biennial bearing. Sod, with or without root pruning, decreased fruit cracking in the T-trellis 69% and 42%, respectively, in 1992, and sod plus root pruning decreased cracking in the MIA trellis 50%. Sod reduced fruit diameter in the T-trellis in 1992. Secondary effects of growth suppression treatments included increased light penetration and improved fruit color. Sod decreased leaf N and Mg and increased leaf P, K, and Cu. The Oct. 1993 stem water potential gradient from root to canopy was more negative in the sod plus root pruning treatment, and the osmotic potential of rootsucker leaves in the combination treatment was greater than in the control, indicating that sod plus root pruning alters the distribution of water within a fruit tree.

Methods used by fruit growers in the past to contain apple tree growth or to reduce fruit cracking are labor-intensive (e.g., scoring, summer pruning) or no longer registered [e.g., butanedioic acid mono(2,2-dimethylhydrazide) (daminozide)]. 'Stayman' is particularly susceptible to cracking, and if a solution to the disorder is not found, it will lose its standing as an important fresh-market cultivar. Studies by Schupp and Ferree (1987, 1988, 1989) and Welker and Glenn (1989) indicated that root pruning or sod competition, respectively, may

offer practical alternatives for suppressing excessive fruit tree vegetative growth and improving fruit quality. Research on apple trees by Ferree (1989, 1992), Ferree and Rhodus

(1993), Geisler and Ferree (1984), Schupp and Ferree (1987, 1988, 1989), and Schupp et al. (1992) indicated that root pruning reduced shoot length, trunk growth, preharvest fruit drop, fruit size, leaf water potential, and net photosynthesis and increased canopy light penetration, fruit color, and fruit firmness. Research on 'Stayman' apple trees by Byers et al. (1990) demonstrated that root pruning also reduced fruit cracking. Studies on peach [*Prunus persica* (L.) Batsch] trees by Welker and Glenn (1989) showed that 'Kentucky 31' (K-31) tall fescue sod suppressed trunk cross-sectional area (TCSA), canopy width, and leaf N. Research on the effect of mowed sod (*Festuca rubra* L. and *Lolium perenne* L.) on apples also indicated that sod reduced TCSA and leaf N (Merwin and Stiles, 1994). To our knowledge, no data are published on the influence of sod competition on fruit cracking.

A study was conducted during 1991 to 1993 to compare the use of root pruning, sod competition, and the combination of root pruning and sod competition to reduce excessive apple tree vegetative growth and fruit cracking. Other factors important to commercial adaptability also were evaluated.

Materials and Methods

'Stayman'/M.7 EMLA planted in 1986 at the West Virginia Univ. (WVU) Experiment Station, Kearneysville, were subdivided into a randomized complete-block design with four tree plots (center two trees for data collection) and six replications. Treatments were arranged as a 2 × 2 factorial: 1) root pruning annually at full bloom, at a distance of 60 cm from the trunk and a depth of 30 cm; 2) sod competition with K-31 fescue seeded Fall 1990 at 112 kg·ha⁻¹; 3) root pruning annually plus sod competition; and 4) a control (nontreated; residual and contact herbicides used). Root prun-

Fig. 1. Rotary root pruner designed by West Virginia Univ. engineers for use in intensive planting systems. Three rotating blades cut roots to a 30-cm depth.

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ing was performed with a WVU-designed rotary root pruner that can be operated off a small tractor in intensive plantings (Fig. 1). The fescue was established in the tree row, leaving only a 30-cm bare strip centered on the trees (compared to a 120-cm herbicide strip in the control and root-pruned treatments), and it was mowed annually in August. Separate studies were conducted with two training systems—the T- and the MIA trellis (Baughner et al., 1990, 1990)—both of which are two-dimensional canopies with the advantage of increased accuracy in comparing growth differences. The T-trellis was root-pruned on two sides of the trunk, whereas the MIA trellis, due to the difficulty of operating equipment inside the “A” training configuration, was root-pruned on the outside of the row only. The soil type was a Hagerstown silt loam (fine, mixed, Mesic Typic Hapludalf). Current WVU Extension cultural and pest control recommendations were otherwise followed in the plantings (Virginia and West Virginia Cooperative Extension Services, 1993). The 1991 and 1993 seasons were dry, and the 1992 season was wet, with fruit cracking a severe problem in many orchards.

Data collected annually in 1991 through 1993 included: 1) terminal shoot length (mean of 10 vertical shoots per tree); 2) annual change in TCSA (measured at terminal bud set each year, 20 cm aboveground); 3) yield (weight of harvested plus dropped fruit); 4) fruit cracked (percentage of harvested plus dropped fruit with cracks); 5) fruit diameter (mean of 10 fruit per tree); 6) canopy light penetration (measured on uniformly overcast days in mid-August, 12:30 to 1:30 PM, in-row orientation in the midsection of tree canopy on the east side of the tree); and 7) fruit color (visual estimates of the percentage of surface that was red and CIE $L^* a^* b^*$ color space coordinates determined on blushed fruit surface of 10 fruit per tree). Light penetration into the canopy was measured with a LI-185B line quantum sensor light wand (LI-COR, Lincoln, Neb.), and measurements were calculated as the percentage of light readings taken from the middles next to each replication. $L^* a^* b^*$ coordinates were measured with a portable tristimulus colorimeter (Minolta, Ramsey, N.J.), calibrated to a white color standard.

Leaf nutrient levels and water potential were determined in 1993 on leaves from the T-trellis only. Twenty-five fully expanded, midshoot leaves per replicate were sampled on 15 July for nutrient analysis. The leaves were washed with deionized water, air-dried, and ground to pass through a 40-mesh screen (425 μ). Analyses were conducted by The Pennsylvania State Univ. Plant and Soil Analysis Laboratory using standardized plasma emission spectrophotometry and Kjeldahl methods. Stem water potential was measured 21 July, 30 Sept., and 7 Oct. for control and sod plus root-pruned trees. Mature leaves were covered with aluminium foil in the late afternoon of the day preceding measurement. Shoot leaves were selected within the canopy at a 2-m height and from tree root suckers. Single leaves from the canopy and a root sucker were

detached at three times during the day of measurement: predawn, 10:00 AM, and 2:00 PM. The leaves were placed on ice and the stem leaf water potential measured within 2 h of detachment using a Scholander pressure chamber (Soil Moisture Equipment Corp., Santa Barbara, Calif.). Following stem water potential measurement, the leaves were frozen at -80°C . The leaf osmotic potential was determined by thawing the leaves, expressing the sap, and measuring the osmotic potential with a thermocouple osmometer (model 5100C, Wescor vapor pressure osmometer; Wescor, Logan, Utah).

Data were analyzed using the General Linear Models Procedure of the Statistical Analysis System Institute (Cary, N.C.). Tree canopy and fruit quality means were separated by least

significant difference. An arcsin square-root transformation was performed on percent data. The stem water and osmotic potential means were separated by the Ryan-Einot-Gabriel-Welsch multiple range test.

Results and Discussion

Tree growth, yield efficiency, fruit cracking, and fruit size. Treatment effects were inconsistent between years and systems. All treatments suppressed tree growth (Fig. 2). Sod or sod plus root pruning decreased shoot length in both systems in 2 out of 3 years (Table 1). Root pruning decreased shoot length in the T-trellis in 1992. Sod decreased change in TCSA in the T-trellis in 1993, and sod plus root pruning suppressed TCSA increase in the

Fig. 2. Comparison of vertical shoot growth between the (top) root-pruned plus K-31 treatment and (bottom) nontreated control (T-trellis system, Sept. 1992).

Table 1. Effect of growth suppression treatments on shoot growth, change in trunk cross-sectional area (TCSA), and yield efficiency of 'Stayman'/M.7 EMLA apple trees in two training systems.

Training system and treatment	Shoot length (cm)			Change in TCSA (cm ²)			Yield efficiency (g·cm ⁻²)			
	1991	1992	1993	1991	1992	1993	1991	1992	1993	3-year mean
T-trellis										
Control	34 a ^z	77 a	66	11.0	9.8	18.7 a	389	611	341 ab	447
Root-pruned	27 b	56 b	52	19.6	8.2	14.8 a	399	536	512 a	482
K-31 fescue	26 b	48 b	43	7.9	4.8	6.2 b	350	625	294 b	422
K-31 fescue + root-pruned	30 ab	52 b	49	12.6	12.7	10.8 ab	342	759	171 b	424
Significance										
Root-pruned	NS ^z	**	NS	NS	NS	NS	NS	NS	NS	NS
K-31 fescue	NS	***	NS	NS	NS	**	NS	NS	*	NS
K-31 fescue × root-pruned	**	**	NS	NS	NS	NS	NS	NS	NS	NS
MIA										
Control	35	84 a	80 ab	5.6 ab	9.1	9.0	240	376 ab	359 a	325
Root-pruned	33	84 a	87 a	13.5 a	11.4	13.0	192	285 b	257 ab	245
K-31 fescue	30	77 ab	73 ab	8.1 ab	6.8	12.2	172	460 ab	301 ab	311
K-31 fescue + root-pruned	30	68 b	59 b	2.9 b	8.6	10.8	222	662 a	187 b	357
Significance										
Root-pruned	NS	NS	NS	NS	NS	NS	NS	NS	**	NS
K-31 fescue	NS	*	*	NS	NS	NS	NS	*	NS	NS
K-31 fescue × root-pruned	NS	NS	NS	*	NS	NS	NS	NS	NS	NS

^zMeans within columns and systems separated by LSD, $P \leq 0.05$; n = 60, 6, 6, respectively.

NS, *, **, *** Nonsignificant or significant at $P \leq 0.05$, 0.01, or 0.001, respectively, by analysis of variance.

MIA system in 1991 (Table 1). These results are consistent with those reported by Welker and Glenn (1989) and Merwin and Stiles (1994) for sod and by Ferree (1992, 1994) and Schupp and Ferree (1987, 1988) for root pruning. Root pruning only one side of trees in the MIA system resulted in no growth control, a finding consistent with that of Schumacher (1975). Average yield efficiency for the 3-year period was unaffected by the treatments, but there were some differences within individual years (Table 1). Fruit yields were below average in 1991 and 1993, and research by Schupp et al. (1992) indicates that these low yields may have contributed to less effective vegetative growth control in those years. Maggs (1965) also suggested that root pruning was most effective in suppressing shoot growth if growth factors (e.g., moisture, crop load) were limiting.

Overall, fruit cracking was moderate in 1991, light in 1993, and severe in 1992. In 1992, sod, with or without root pruning, decreased cracking in the T-trellis 69% and 42%, respectively, and sod plus root pruning decreased cracking in the MIA trellis 50% (Table 2). K-31 fescue was more effective than root pruning (as reported here and by Byers, 1990) in suppressing fruit cracking. A negative effect of sod suppression was a reduction in fruit diameter in the T-trellis in 1992.

Light penetration, fruit color, dormant pruning weights, and pruning times. Secondary effects of growth suppression treatments included increased light penetration and improved fruit color. Sod had the most consistent positive effect on light penetration (Table 3). Sod increased light penetration in 2 years in both pruning systems, and root pruning increased light penetration in 1 year in the MIA system. Sod increased the percentage of red surface in both systems in 1992 and also in the MIA system in 1993 (Table 3). Fruit chroma-

Table 2. Effect of growth suppression treatments on fruit cracking and fruit diameter of 'Stayman'/M.7 EMLA apple trees in two training systems.

Training system and treatment	Fruit cracked (% total harvested and dropped fruit)				Fruit diam (mm)		
	1991	1992	1993	3-year mean	1991	1992	1993
T-trellis							
Control	11	62 a ^z	17	34	76	81 a	83
Root-pruned	16	65 a	15	32	76	81 a	80
K-31 fescue	17	36 b	15	26	72	78 b	79
K-31 fescue + root-pruned	17	19 b	9	21	76	79 ab	80
Significance							
Root-pruned	NS	NS	NS	NS	NS	NS	NS
K-31 fescue	NS	***	NS	NS	NS	*	NS
K-31 fescue × root-pruned	NS	*	NS	NS	NS	NS	NS
MIA							
Control	29	75 a	15	35 a	75	75	81
Root-pruned	33	65 ab	19	39 a	76	77	81
K-31 fescue	28	46 ab	11	25 b	74	77	82
K-31 fescue + root-pruned	41	37 b	8	23 b	72	77	82
Significance							
Root-pruned	NS	NS	NS	NS	NS	NS	NS
K-31 fescue	NS	**	NS	*	NS	NS	NS
K-31 fescue × root-pruned	NS	NS	NS	NS	NS	NS	NS

^zMeans within columns and systems separated by LSD, $P \leq 0.05$; n = 12, 60, respectively (percent data analyzed by arcsin square-root transformation, nontransformed data shown).

NS, *, **, *** Nonsignificant or significant at $P \leq 0.05$, 0.01, or 0.001, respectively, by analysis of variance.

ticity differences in the MIA trellis (data not presented) were minimal, but in the T-trellis there were differences in lightness, redness, and yellowness (Table 4). Hue angle, a measurement that correlates with sensory evaluations of color quality (Singha et al., 1991), indicated that K-31 fescue improved red pigmentation. The light penetration and color data are similar to root-pruning effects reported by Schupp and Ferree (1988, 1989).

Tree nutrition and water potential. Possible mechanisms for growth and crack suppression were revealed by plant nutritional

analyses and stem water potential measurements. Sod reduced leaf N and Mg and increased leaf P, K, and Cu (Table 5). Root pruning decreased leaf P. Merwin and Stiles (1994) recently reported that sod decreased soil and apple leaf N.

The treatments did not affect the predawn and 10:00 AM stem water potential on the three dates. There was a significant date × treatment interaction for the stem water potentials at 2:00 PM. On 7 Oct., stem water potential of the root suckers and the difference of root and leaf stem water potentials (W) were more negative

Table 3. Effect of growth suppression treatments on light interception (canopy midsection, mid-August, calculated as percentage of full sun reading from row middles) and fruit color (visually estimated) of 'Stayman'/M.7 EMLA apple trees in two training systems.

Training system and treatment	Light penetration (% full sun)			Fruit surface red (%)		
	1991	1992	1993	1991	1992	1993
T-trellis						
Control	34 b	16 c	11	71	62 c ^z	78
Root-pruned	43 ab	23 bc	9	73	73 b	83
K-31 fescue	35 b	33 ab	10	75	86 a	82
K-31 fescue + root-pruned	46 a	37 a	9	75	79 ab	83
Significance						
Root-pruned	NS	NS	NS	NS	NS	NS
K-31 fescue	**	**	NS	NS	**	NS
K-31 fescue × root-pruned	NS	NS	NS	NS	*	NS
MIA						
Control	31	13 b	14 b	77	66 b	83 b
Root-pruned	31	16 ab	11 b	75	68 b	80 b
K-31 fescue	24	16 ab	36 a	71	78 a	83 b
K-31 fescue + root-pruned	37	22 a	22 ab	68	80 a	88 a
Significance						
Root-pruned	NS	*	NS	NS	NS	NS
K-31 fescue	NS	*	*	NS	***	*
K-31 fescue × root-pruned	NS	NS	NS	NS	NS	NS

^zMeans within columns and systems separated by LSD, $P \leq 0.05$; $n = 6, 60$, respectively (percent data analyzed by arcsin square-root transformation, nontransformed data shown).

NS, *, **, ***Nonsignificant or significant at $P \leq 0.05, 0.01$, or 0.001 , respectively, by analysis of variance.

for the sod plus root-pruned treatment than for the control (-1.30 MPa vs. -0.93 MPa for root suckers and -0.43 MPa vs. -0.19 MPa for W, $P \leq 0.05$). The first two sampling dates were partly cloudy, but 7 Oct. was sunny, with a presumably greater transpirational demand and higher water stress development in the trees. Simonneau and Habib (1991) demonstrated that the water potential of root suckers was closely correlated with root water potential.

The stem water potential gradient from root to canopy on 7 Oct. was more negative in the sod plus root-pruned treatment than in the control, indicating that water movement within the tree was away from the fruit. Reduced water movement to the fruit and reduced fruit size were previously reported effects of root pruning (Ferree, 1992; Geisler and Ferree, 1984; Schupp et al., 1992). The time of sampling did not affect the osmotic potential of leaves at

either position, so the data for osmotic potential were pooled over sampling time for each date and leaf position. The analysis of variance indicated that there was no date × treatment interaction for osmotic potential, so the treatment main effects were evaluated over the three dates. The osmotic potential of the root sucker leaves in the sod plus root-pruned treatment was greater than in the control (2.55 MPa vs. 2.34 MPa, respectively, $P \leq 0.05$) for three sampling dates. These data indicate that significantly more osmotic adjustment was occurring in the root suckers due to greater water stress, confirming that sod plus root pruning alters the distribution of water within the tree.

Fruit cracking occurs when the water influx rate exceeds the elasticity of the developing fruit (Verner, 1935). Although no direct comparisons could be made in the 1 year that water potential was measured, our data suggest that one mechanism involved in the reduced cracking of 'Stayman' when grown under the K-31 fescue plus root-pruned treatment is the reduced potential of water to move to the fruit. Shoot growth suppression also is a response to reduced water potential. Based on earlier reports of increased fruit Ca (Baughner and Miller, 1991; Schupp and Ferree, 1987) and the limited data in the current report on changes in leaf nutrient levels, nutrition also may contribute to growth or crack suppression. Future studies should be directed at management of K-31 fescue to maximize desirable influences on growth suppression and fruit cracking and to minimize detrimental influences on fruit size and yield.

Table 4. Effect of growth suppression treatments on fruit chromaticity recorded in CIE L* (lightness of color), a* (redness), b* (yellowness), and hue angle (0, red-purple, to 90, yellow) of 'Stayman'/M.7 EMLA apple trees in the T-trellis system.

Treatments	L*			a*			b*			Hue angle
	1991	1992	1993	1991	1992	1993	1991	1992	1993	3-year mean
Control	45	41 a	38	29	26 b	28	12	14 a	14 a ^z	26 a
Root-pruned	44	41 ab	38	30	28 ab	28	12	14 a	12 ab	23 ab
K-31 fescue	46	31 c	39	30	29 a	27	13	12 b	12 b	22 b
K-31 fescue + root-pruned	45	38 bc	38	31	29 a	29	12	12 b	13 ab	23 b
Significance										
Root-pruned	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
K-31 fescue	NS	**	NS	NS	*	NS	NS	**	NS	**
K-31 fescue × root-pruned	NS	NS	NS	NS	NS	NS	NS	NS	*	NS

^zMeans within columns separated by LSD, $P \leq 0.05$, $n = 60$.

NS, *, **Nonsignificant or significant at $P \leq 0.05$ or 0.01 , respectively, by analysis of variance.

Table 5. Effect of growth suppression treatments on plant nutrient levels of 'Stayman'/M.7 EMLA apple trees in the T-trellis system, 15 July 1993.

Treatments	Nutrient levels									
	N					P				
	K					Ca				
	Mg					Mn				
	Fe					Cu				
	B					Zn				
Control	1.72 a	0.15 bc	1.46 b ^z	1.01	0.25 a	36	53	6.2 b	27	29
Root-pruned	1.78 a	0.14 c	1.36 c	0.99	0.26 a	46	54	6.2 b	24	32
K-31 fescue	1.63 ab	0.24 a	1.56 a	1.03	0.24 ab	50	55	10.5 a	29	29
K-31 fescue + root-pruned	1.59 b	0.19 b	1.60 a	0.99	0.23 b	43	52	8.3 ab	25	30
Significance										
Root-pruned	NS	*	NS	NS	NS	NS	NS	NS	NS	NS
K-31 fescue	*	***	***	NS	*	NS	NS	**	NS	NS
K-31 fescue × root-pruned	NS	NS	*	NS	NS	NS	NS	NS	NS	NS

^zMeans within columns separated by LSD, $P \leq 0.05$, $n = 6$ (percent data analyzed by arcsin square-root transformation, nontransformed data shown).

NS, *, **, ***Nonsignificant or significant at $P \leq 0.05, 0.01$, or 0.001 , respectively, by analysis of variance.

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