Daminozide, Root Pruning, Trunk Scoring, and Trunk Ringing Effects on Fruit Ripening and Storage Behavior of 'McIntosh' Apple

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Abstract. A midsummer foliar daminozide (DZ) application (750 mg a.i./liter) to 'Macspur McIntosh'/M.7 apple trees (*Malus domestics* Borkh.) reduced preharvest drop and retarded flesh firmness loss and starch hydrolysis when tested at harvest; DZ also reduced fruit ethylene production at harvest and after 19 weeks of storage at 0.5°C. Root pruning at full bloom (May) resulted in increased soluble solids concentration (SSC) and firmer flesh and less starch hydrolysis at harvest, but not consistently each year. Full-bloom root pruning reduced the incidence of stem-cavity browning and brown core, but again not each year. Full-bloom root pruning did not influence ethylene evolution at harvest but did reduce post-storage ethylene evolution in two of three seasons. Full-bloom root pruning generally was less effective than DZ in altering fruit behavior, while root pruning later than full bloom had virtually no effect. Trunk scoring or ringing increased SSC and retarded loss of flesh firmness before harvest and following storage, but had little effect on starch hydrolysis. Scoring or ringing decreased incidence of some disorders and reduced post-storage ethylene evolution, although these treatments had little effect on ethylene production at harvest. Trunk scoring influenced some fruit characteristics more strongly than DZ. Fruit size was not affected by any treatment in any year. Chemical name used: butanedioic acid mono (2,2 -dimethylhydrazide) (daminozide).

Midsummer daminozide (DZ, Uniroyal Chemical, Middlebury, Conn.) sprays have been widely used on 'McIntosh' apple for control of preharvest drop, fruit maturation, and problems of quality deterioration during and after storage (Edgerton and Blanpied, 1970; Forshey, 1970; Greene et al., 1977; Looney, 1975a, 1975b; Miller and Lougheed, 1971; Williams et al., 1964). However, this product was withdrawn from commercial sales channels in Canada and the United States by the manufacturer in June 1989. Elfving et al. (1987) reported that paclobutrazol (PBZ) had similar effects to DZ on fruit characteristics. However, Elfving et al. (1990) reported that further evaluations did not demonstrate that PBZ or uniconazole could effectively replace DZ on 'McIntosh'.

Root pruning reduced preharvest drop and fruit size, increased fruit flesh firmness and soluble solids content (SSC) at harvest, and altered fruit mineral-nutrient content (Schupp and Ferree, 1987, 1988). Schumacher et al. (1986) reported no change in fruit firmness, although fruit size was reduced when trees were root-pruned at full bloom, but found that root pruning reduced that incidence of bitter-pit (Schumacher et al., 1978).

Scoring and ringing of trunks or branches also influence fruit behavior. Trunk scoring 19 days after full bloom reduced fruit size in 'Cortland' and 'Delicious' apples, reduced fruit firmness in 'Delicious', and increased SSC in both cultivars (Greene and Lord, 1978). After storage, 'Cortland' apples from scored trees

showed a higher incidence of bitter-pit and cork, while 'Delicious' fruit exhibited more breakdown.

Branch ringing of 'Granny Smith' apple trees 25 or 50 days before harvest increased fruit size and SSC without influencing flesh firmness at harvest (Gatti and Gil, 1982). Fruit from ringed branches had a higher starch content at harvest, suggesting a delay in the onset of fruit maturation. Following 30 days of cold storage, 'Granny Smith' fruit from ringed branches still exhibited a higher starch content, as well as higher SSC and acidity, but flesh firmness was not different from the control. After 15 days at 20°C, fruit from ringed branches retained higher SSC and acidity than untreated fruit, although tissue firmness differences had disappeared.

The experiments described here were conducted on cropping 'Macspur McIntosh'/M.7 trees to assess effects of root pruning, trunk scoring, and trunk ringing (girdling) on fruit characteristics at harvest and after air storage and to compare effects of these treatments with those of DZ.

Materials and Methods

Three field trials were conducted at the Horticultural Experiment Station, Simcoe, Ont., between 1987 and 1989. All trials used single, whole-tree plots in randomized complete-block designs. DZ was applied to runoff with a handgun. Root pruning was carried out with a tractor-mounted shank capable of reaching 40 cm in depth. Trunks were scored or ringed using a Juran manual girdling tool (Juran Metal Works, Rishon Le Zion, Israel) modified to make a single cut through the bark to the xylem. A 2-mm-wide strip of bark was removed on ringed trees. Postharvest and poststorage fruit characteristics were evaluated at the Dept. of Horticultural Sciences (DHS), Univ. of Guelph. Counted and weighed fruit samples of 12 to 15 kg from each replicate tree were sent to the DHS immediately after harvest. Subsamples from each replicate were used for harvest evalua-

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tions. The remaining fruit were stored in air at 0.5C and 90% to 95% RH for 19 weeks before post-storage evaluations.

Daminozide vs. root and trunk modification, one date (Expt. 1; 1987). Each of the following six treatments was applied to a separate set of seven replicate, 7-year-old trees: 1) control (no treatment); 2) DZ (750 mg a.i./liter) on 7 July; 3) root pruning along the row 80 cm from the trunk on each side of each tree at 40 cm depth at full bloom (8 May); 4) trunk scoring with a single, circumferential cut above the lowest scaffold limb on 11 June; 5) trunk ringing (removal of a 2-mm ring of bark) above the lowest scaffold limb on 11 June; 6) trunk scoring, as described, above the lowest scaffold limb on 30 July. The trees were planted at 4.3 × 6.7 m on a well-drained Bookton soil consisting of 40 to 100 cm of sandy sediments over glaciolacustrine clays and had been cropping for 4 years (Hohner and Presant, 1989). Apple samples were harvested from each tree on 1 and 8 Sept. Fruit were sampled from above the score or ring on trees receiving those treatments.

All fruit on each tree and all drops from each tree were counted and weighed following harvest of the second fruit sample. Fruit counts on the limb below the score or ring in August and counts and weights at harvest permitted assessment of drop as a percentage of the crop above the score or ring.

Daminozide vs. root and trunk modification, several dates (Expt. 2; 1988). Each of the following 10 treatments was applied to a separate set of 10 replicate, 7-year-old trees: 1) control (no treatment); 2) DZ (750 mg a.i./liter) on 28 June; 3) root pruning along the row 80 cm from the trunk on each side of each tree at a depth of 40 cm at one of each of the following times: a) full bloom (18 May), b) early summer (15 June), c) midsummer (15 July), or d) late summer (15 Aug.); 4a-d trunk scoring with a single, circumferential cut below the lowest scaffold limb at each of the times when root pruning was done. Trees were planted at 4.3 × 6.7 m on an intermediate to well-drained Watford-Maplewood soil complex of mixed sandy and loamy sediments over glaciolacustrine clays and had been cropping for 4 years (Hohner and Presant, 1989). Apple samples were harvested from each tree on 8 and 15 Sept. All harvested fruit and all drops from each tree were counted and weighed following harvest of the second fruit sample;

On the first fruit sampling date, 20 additional apples were collected from each test tree for flesh mineral-nutrient analyses. A composite subsample of fruit flesh from the 20 fruits was wet-ashed at 550C for analysis according to the methods of Bodnar et al. (1983).

DZ vs. type and time of root and trunk modification (Expt. 3; 1989). Each of the following eight treatments was applied to a separate set of six replicate, 9-year-old trees planted at 4.3 × 6.7 m on a well-drained Bookton soil (Hohner and Presant, 1989): 1) control (no treatment); 2) DZ (750 mg a.i./liter) on 6 July; 3) root pruning along the row 80 cm from the trunk on each side of each tree at full bloom (23 May) at either a) 20 or b) 40 cm depth; 4a,b root pruning as described above on 1 Aug.; 5) trunk scoring below the lowest scaffold limb on 22 June; 6) two scoring cuts, each around an opposite half of the trunk on 22 June. The ends of the two half-scoring cuts were vertically separated by ≈3 cm to leave a band of intact bark between the top and roots of the trees. These trees had been cropping for 6 years. Apple samples were harvested from each tree on 12 and 19 Sept. All harvested fruit and all drops from each tree were counted and weighed following harvest of the second fruit sample.

Fruit flesh firmness was measured on pared flesh on opposite

sectors of each of 10 apples per replicate with an Effegi penetrometer (Effegi, Alfonsine, Italy) using an 11.1-mm tip. Juice expressed from the apples during the firmness measurements was collected, and SSC was assessed on the composite juice sample with an Atago model N1 hand refractometer (American Optical, Buffalo, N.Y.). Fruit maturity was assessed on the same 10 apples using the starch-iodine test and rating starch patterns against a 'McIntosh' standard (Phillips and Poapst, 1952; Poapst et al., 1959; Priest and Loughheed, 1981; Smith et al., 1979). Following storage, 10 apples per replicate were assessed for tissue firmness and SSC. Disorders were rated visually on 25 apples per replicate after storage plus 1 week at room temperature (≈20C) on a scale from 0 (no symptoms) to 3 (severe symptoms),

At harvest and following storage, 10 apples per replicate were placed in a flow-through system to measure ethylene production at 20C (Loughheed and Franklin, 1968). The effluent air was automatically sampled and 3-ml samples injected into a Beckman GC-5 gas chromatography (Beckman Instruments, Fullerton, Calif.) with dual flame ionization and thermal conductivity detectors (Loughheed et al., 1969). Ethylene production was calculated from the concentration in the effluent airstream.

All percentage values were transformed using the arcsin of the square root before analysis. Analyses of variance were performed using the General Linear Models (GLM) procedure of the Statistical Analysis System (SAS) program package (SAS Institute, Cary, N.C.). Where a significant F test was observed, means were separated using Duncan's multiple-range test.

Results

There were no significant interactions between treatments and harvest sampling dates in any experiment.

Expt. 1. Preharvest drop and sample fruit weight were not influenced by any treatment (Table 1). Fruit from the DZ and all trunk or root treatments had firmer flesh than controls at harvest, but only trunk ringing resulted in firmer flesh than that produced by DZ. All trunk injury treatments increased SSC relative to the control or DZ, but only trunk ringing increased SSC above that produced by root pruning at full bloom (8 May). DZ, root pruning, and July trunk scoring retarded starch hydrolysis compared to controls, but DZ was more effective than all other treatments except July trunk scoring. However, ethylene evolution at harvest was lower than control only for DZ and July trunk scoring. Differences between harvest dates reflected changes due to continued fruit growth and the onset of ripening.

Following 19 weeks of storage, fruit from trees root-pruned at full bloom (8 May) or scored or ringed in June had firmer flesh than control or DZ-treated fruit after 1 day at 20C (Table 2). By 1 week after storage, fruit from the root-pruning and June scoring and ringing treatments still had firmer flesh than untreated fruit, and ringing produced firmer flesh than any other treatment. SSC was higher for all trunk injury treatments than for root pruning, DZ, or control. Moderate to severe scald was increased by DZ and reduced by June scoring. Root pruning and July scoring decreased the incidence of stem-cavity browning, while root pruning or any trunk injury treatment reduced the incidence of brown core compared to DZ or control fruit. Internal breakdown was uninfluenced by any treatment. Ethylene evolution 2 days after storage was lower for all treatments than for the control, with DZ and ringing leading to the least ethylene production. Where harvest-date effects were significant, they were primarily related to maturity of the fruit at har-

Table 1. Effects of daminozide (DZ), root pruning (RP), trunk scoring (SC), or trunk ringing (RG) in 1987 on 'McIntosh' fruit at harvest in 1987 (Expt. 1).

Factor	Preharvest drop (% of yield)	Fruit wt (g)	Flesh firmness (N)	Soluble solids concn (%)	Starch index ^z	C ₂ H ₄ ($\mu\text{l}\cdot\text{kg}^{-1}\cdot\text{hr}^{-1}$)
Treatment and date ^y						
Control	13 a	160 a	67.6 d	12.0 c	4.0 a	15.4 a
DZ 7 July	8 a	160 a	71.2 bc	12.2 c	3.3 d	1.6 c
RP 8 May	10 a	160 a	69.8 c	12.4 bc	3.7 bc	12.7 ab
SC 11 June	9 a	160 a	72.0 ab	12.7 ab	4.0 ab	7.9 abc
RG 11 June	8 a	160 a	73.2 a	13.1 a	3.8 abc	7.9 abc
SC 30 July	11 a	160 a	70.2 c	12.8 ab	3.5 cd	4.5 bc
Harvest date ^x						
1 Sept.	---	150 b	71.8 a	12.5 a	3.2 b	3.1 b
8 Sept.	---	170 a	69.5 b	12.6 a	4.3 a	13.0 a

^yMean treatment rating on a scale from 1 to 9 (immature to overmature).

^zDZ applied at 750 mg a.i./liter. Mean separation within columns by Duncan's multiple range test (P = 0.05). Each preharvest-drop mean contains seven observations. All other means contain 14 observations each.

^xMean separation within columns by F test (P = 0.05). Each mean contains 42 observations.

Table 2. Effects of daminozide, (DZ), root pruning (RP), trunk scoring (SC), or ringing (RG) in 1987 on 'McIntosh' fruit-quality characteristics following 19 weeks in air at 0.5C (Expt. 1).

Factor	After 1 week at $\approx 20\text{C}$						
	Flesh firmness (N) ^z		Soluble solids concn (%)	Scald (%) ^y	Stem cavity browning (%) ^y	Brown core (%) ^y	Internal breakdown (%) ^y
	1 day	1 week					
Treatment and date ^w							
Control	43.5 c	39.7 c	11.8 b	67 b	68 ab	33 a	15 a
DZ 7 July	43.1 c	40.4 bc	12.1 b	84 a	72 a	37 a	20 a
RP 8 May	45.1 ab	41.0 b	12.2 b	57 bc	40 d	16 b	9 a
SC 11 June	45.3 ab	40.8 b	12.9 a	52 c	54 bcd	12 b	9 a
RG 11 June	46.2 a	42.1 a	13.2 a	59 bc	61 abc	11 b	8 a
SC 30 July	44.2 bc	40.6 bc	13.0 a	70 b	49 cd	11 b	11 a
Harvest date ^v							
1 Sept.	45.6 a	41.5 a	12.3 b	65 a	55 a	20 a	18 a
8 Sept.	43.5 b	40.0 b	12.8 a	65 a	60 a	18 a	7 b

^wEvaluation after 1 day or 1 week at room temperature ($\approx 20\text{C}$).

^yPercentage of 25-fruit samples showing moderate (rating of 2) to severe (rating of 3) symptoms.

^zAfter 2 days at 20C.

^vDZ applied at 750 mg a.i./liter. Mean separation within columns by Duncan's multiple range test (P = 0.05). Each mean contains 14 observations.

^wMean separation within columns by F test (P = 0.05). Each mean contains 42 observations.

vest, although the higher incidence of internal breakdown at the earlier harvest date was not expected.

Expt. 2. Fruit flesh K content at harvest was uninfluenced by any treatment (Table 3). Compared to controls, flesh Ca was reduced by root pruning and scoring in July, but flesh Mg was reduced only by June scoring. DZ and July scoring decreased preharvest drop compared to the control. There was little effect of any treatment on sample fruit weight, although full-bloom scoring (18 May) produced smaller apples than July root pruning or either August scoring or root pruning. Flesh firmness at harvest was greater for DZ than for the control, and greater yet for trunk scoring in May, June, or July. SSC was increased by June root pruning and by scoring treatments in June or later. Only DZ delayed starch hydrolysis, but ethylene evolution at harvest was not influenced by any treatment. Changes due to sample harvest date were as expected.

Following 19 weeks of storage plus 1 day at 20C, fruit from trees scored 18 May were firmer than the rest. After 1 week at 20C, firmness was equal for those from trees scored 18 May or 15 July and firmer than fruit from the other treatments, except for those root pruned 15 June or scored 15 June or 15 Aug. (Table 4). SSC after storage was higher than for the control for June root pruning and both full-bloom and August scoring, higher yet for June scoring, and highest for July scoring. The incidence of moderate to severe storage scald was significantly reduced by scoring in May, June, or July. Stem-cavity browning was similarly reduced by full bloom or July scoring. The incidence of brown core was significantly higher than for the control in DZ-treated fruit, and significantly lower in fruit from trees scored in May, June, or July. Incidence of internal breakdown was generally low, but least in control and full-bloom scoring treatments. Ethylene evolution after 1 day at 20C was lower than

Table 3. Effects of daminozide (DZ), root pruning (RP), or trunk scoring (SC) in 1988 on 'McIntosh' fruit at harvest in 1988 (Expt. 2).

Factor	Fruit flesh content (mg/100 g f. wt)			Preharvest drop (% of yield)	Fruit wt (g)	Flesh firmness (N)	Soluble solids concn (%)	Starch index ^z	C ₂ H ₄ (μl·kg ⁻¹ ·hr ⁻¹)
	K	Ca	Mg						
Treatment and date ^y									
Control	139 a	3.9 ab	4.4 a	12 a	130 ab	63.4 d	12.4 e	3.6 a	7.9 a
DZ 28 June	116 a	3.8 bc	4.3 a	5 c	130 ab	66.8 b	12.3 e	3.2 b	0.9 a
RP 18 May	83 a	3.8 bc	3.9 ab	9 ab	130 ab	64.7 cd	12.7 de	3.5 a	3.4 a
RP 15 June	103 a	3.8 bc	4.2 a	10 ab	130 ab	64.6 cd	13.0 cd	3.4 ab	3.3 a
RP 15 July	71 a	3.6 c	4.0 ab	8 abc	140 a	64.1 cd	12.7 de	3.4 ab	2.2 a
RP 15 Aug.	113 ^a	3.9 ab	4.1 a	8 abc	140 a	65.4 bc	12.6 e	3.6 a	4.4 a
SC 18 May	92 a	4.4 a	3.9 ab	10 ab	120 b	68.7 a	12.7 de	3.5 a	3.8 a
SC 15 June	76 a	4.1 ab	3.5 b	9 ab	130 ab	68.3 a	13.4 b	3.5 a	0.9 a
SC 15 July	97 a	3.4 c	4.0 ab	6 bc	130 ab	68.4 a	14.1 a	3.4 ab	2.7 a
SC 15 Aug.	120 a	3.8 bc	4.4 a	8 abc	140 a	66.6 b	13.3 bc	3.3 ab	1.7 a
Harvest date ^x									
8 Sept.	---	---	---	---	130 b	67.8 a	12.5 b	3.0 b	1.6 b
15 Sept.	---	---	---	---	140 a	64.4 b	13.3 a	3.8 a	4.6 a

^yMean treatment rating on a scale from 1 to 9 (immature to overmature).

^zDZ applied at 750 mg a.i./liter. Mean separation within columns by Duncan's multiple range test ($P = 0.05$). Means for flesh nutrients and preharvest drop contain six observations each; all other means contain 12 observations each.

^xMean separation within columns by F test ($P = 0.05$). Each mean contains 60 observations.

Table 4. Effects of daminozide (DZ), root pruning (RP), trunk scoring (SC), or ringing (RG) in 1988 on 'McIntosh' fruit-quality characteristics after 19 weeks in air at 0.5C (Expt. 2).

Factor	After 1 week at $\approx 20\text{C}$							C ₂ H ₄ ($\mu\text{l}\cdot\text{kg}^{-1}\cdot\text{hr}^{-1}$) ^x
	Flesh firmness (N) ^z		Soluble solids concn (%)	Scald (%) ^y	Stem cavity browning (%) ^y	Brown core (%) ^y	Internal breakdown (%) ^y	
	1 day	1 week						
Treatment and date ^w								
Control	41.4 b	40.2 b	12.8 d	36 ab	26 a	19 b	1 bc	144 ab
DZ 28 June	41.2 b	40.4 b	12.7 d	32 abc	29 a	35 a	5 a	113 d
RP 18 May	40.5 b	40.1 b	12.9 d	32 abc	26 a	18 b	4 ab	147 a
RP 15 June	41.3 b	40.9 ab	13.4 c	37 ab	26 a	16 b	2 ab	144 ab
RP 15 July	41.4 b	40.3 b	13.0 d	40 a	29 a	20 b	4 ab	142 ab
RP 15 Aug.	41.3 b	39.9 b	12.9 d	33 abc	29 a	20 b	2 ab	144 ab
SC 18 May	43.5 a	41.8 a	13.5 c	22 c	11 c	4 c	0 c	135 bc
SC 15 June	41.3 b	40.8 ab	14.2 b	22 c	22 a	1 c	4 ab	116 d
SC 15 July	41.6 b	41.6 a	14.7 a	15 c	13 bc	1 c	5 a	110 d
SC 15 Aug.	41.5 b	41.0 ab	13.7 c	26 bc	21 ab	14 b	4 ab	130 c
Harvest date ^v								
8 Sept.	41.8 a	41.1 a	13.1 b	41 a	26 a	9 b	0 b	126 b
15 Sept.	41.2 b	40.3 b	13.7 a	19 b	20 b	17 a	8 a	139 a

^wEvaluation after 1 day or 1 week at room temperature ($\approx 20\text{C}$).

^yPercentage of 25-fruit samples showing moderate (rating of 2) to severe (rating of 3) symptoms.

^zAfter 1 day at 20C.

^vDZ applied at 750 mg a.i./liter. Mean separation within columns by Duncan's multiple range test ($P = 0.05$). Each mean contains 12 observations.

^xMean separation within columns by F test ($P = 0.05$). Each mean contains 60 observations.

control for DZ and for scoring in June, July, or August. Harvest-date differences reflected the maturity of fruit at harvest and condition at the time of analysis.

Expt. 3. Preharvest drop was significantly lower than for the control and August root pruning for DZ-treated trees and those root-pruned at 20-cm depth at full bloom (23 May; Table 5). Fruit weight was not influenced by any treatment. Flesh was firmer than for the control in DZ-treated fruit and in fruit from both full-bloom (23 May) root-pruning treatments. Both trunk-scoring treatments resulted in firmer flesh than DZ application.

SSC was increased over the control or DZ-treated fruit for full-bloom root pruning at the 20-cm depth and by both trunk-scoring treatments. DZ application and full-bloom root pruning at the 20-cm depth reduced starch hydrolysis significantly, as indicated by a low starch index, while DZ and trunk scoring reduced ethylene evolution at harvest.

Following 19 weeks of storage, there were few significant differences in flesh firmness after 1 day or 1 week (Table 6). SSC was highest for both trunk-scoring treatments. The incidence of moderate to severe scald was increased by DZ appli-

Table 5. Effects of diaminozide (DZ), root pruning (RP), trunk scoring (SC), or scoring each half of the trunk (HSC) in 1989 on 'McIntosh' fruit at harvest in 1989 (Expt. 3).

Factor	Preharvest drop (% of yield)	Fruit wt (g)	Flesh firmness (N)	Soluble solids concn (%)	Starch index ²	C ₂ H ₄ ($\mu\text{l}\cdot\text{kg}^{-1}\cdot\text{hr}^{-1}$)
Treatment, date, and depth (cm) ^y						
Control	30 a	140 a	63.8 d	11.6 cd	4.5 a	13.6 ab
DZ 6 July	10 b	140 a	66.2 c	11.5 d	3.7 b	1.0 d
RP 23 May, 20	11 b	140 a	67.0 bc	12.1 b	3.7 b	6.2 bcd
RP 23 May, 40	17 ab	140 a	66.2 c	12.0 bc	3.9 a	7.4 bcd
RP 1 Aug., 20	26 a	140 a	63.8 d	11.7 bcd	4.5 a	18.9 a
RP 1 Aug., 40	33 a	140 a	63.7 d	11.7 bcd	4.4 a	11.3 abc
SC 22 June	17 ab	140 a	69.6 a	13.0 a	4.2 ab	3.0 cd
HSC 22 June	22 ab	140 a	68.5 ab	12.7 a	4.2 ab	7.2 bcd
Harvest date ^x						
12 Sept.	---	130 b	67.6 a	11.9 b	3.4 b	8.3 a
19 Sept.	---	140 a	64.6 b	12.1 a	4.9 a	9.0 a

^yMean treatment rating on a scale from 1 to 9 (immature to overmature).

^xDZ applied at 750 mg a.i./liter. Mean separation within columns by Duncan's multiple range test ($P = 0.05$).

Each preharvest-drop mean contains six observations; all others contain 12 observations.

^zMean separation within columns by F test ($P = 0.05$). Each mean contains 42 observations.

Table 6. Effects of daminozide (DZ), root pruning (RP), trunk scoring (SC), or scoring each half of the trunk (HSC) in 1989 on 'McIntosh' fruit-quality characteristics after 19 weeks in air at 0.5C (Expt. 3).

Factor	After 1 week at $\approx 20\text{C}$							
	Flesh firmness (N) ^z		Soluble solids concn (%)	Scald (%) ^y	Stem cavity browning (%) ^y	Brown core (%) ^y	Internal breakdown (%) ^y	C ₂ H ₄ (μl·kg ⁻¹ ·hr ⁻¹) ^x
	1 day	1 week						
Treatment, date, depth (cm) ^w								
Control	42.2 abc	40.8 bcd	11.4 b	37 bc	45 a	11 a	2 a	163 a
DZ 6 July	41.8 bc	39.9 de	11.4 b	51 a	46 a	7 a	1 a	133 d
RP 23 May, 20	42.2 abc	40.8 bcd	11.9 b	39 bc	25 b	4 a	1 a	152 bc
RP 23 May, 40	41.9 bc	41.0 bc	11.8 b	33 c	25 b	4 a	2 a	148 c
RP 1 Aug., 20	41.2 c	39.8 e	11.4 b	49 ab	56 a	10 a	3 a	160 ab
RP 1 Aug., 40	41.8 bc	40.2 cde	11.5 b	42 abc	54 a	11 a	2 a	167 a
SC 22 June	42.8 ab	41.4 ab	12.9 a	43 abc	18 b	4 a	4 a	133 d
HSC 22 June	43.2 a	42.1 ab	12.5 a	32 c	22 b	4 a	1 a	131 d
Harvest date ^v								
12 Sept.	43.4 a	42.0 a	11.6 b	48 a	38 a	2 b	1 b	147 a
19 Sept.	40.8 b	39.5 b	12.1 a	33 b	33 a	14 a	3 a	150 a

^wEvaluation after 1 week at room temperature ($\approx 20\text{C}$).

^yPercentage of 25-fruit samples showing moderate (rating of 2) to severe (rating of 3) symptoms.

^zAfter 2 days at 20C.

^xDZ applied at 750 mg a.i./liter. Mean separation within columns by Duncan's multiple range test ($P = 0.05$). Each mean contains 12 observations.

^zMean separation within columns by F test ($P = 0.05$). Each mean contains 42 observations.

cation. Compared to other treatments, full-bloom root pruning (23 May) and both trunk-scoring treatments significantly reduced stem-cavity browning. The incidence of brown core and internal breakdown were not influenced by any treatment. Ethylene evolution after 2 days at 20C was significantly lower than for the control for DZ application, full-bloom root pruning, and both trunk-scoring treatments; ethylene evolution for full-bloom root pruning was significantly higher than for DZ application. Harvest-date differences were related to fruit maturity at harvest.

Discussion

Root pruning at full bloom and summer scoring and ringing of the trunk altered 'McIntosh' fruit behavior at harvest and

after 19 weeks of storage at 0.5C. Trunk scoring as late in the growing season as 3 weeks before harvest increased fruit firmness and SSC, confirming the observations of Gatti and Gil (1982). The mechanism(s) inducing these fruit responses to root pruning, trunk scoring, or trunk ringing well before harvest are unclear, but are likely related to changes in assimilate, mineral-nutrient, and/or hormonal levels as a result of interruption of the vascular system and subsequent wound-healing activity.

Trunk scoring and ringing sometimes influenced fruit-quality characteristics to a greater extent than DZ. Firmness retention at harvest and after storage was generally better in fruit from scored trees, while occurrence of disorders tended to be reduced. Delayed fruit maturity, as estimated by the starch index, was the only fruit-quality aspect more consistently influenced by DZ than by trunk scoring. The time during the growing

season when scoring was done had relatively little influence on fruit response to this treatment. Separately scoring each half of the trunk to leave an intact band of bark in 1989 produced effects in fruit virtually identical to those from a complete circumferential scoring cut. Scoring or ringing had little effect on fruit weight in these experiments. Because trunk scoring and -ringing can have significant negative effects on tree and fruit development (Batjer and Westwood, 1963; Greene and Lord, 1983; Toenjes, 1949), considerable caution should be exercised when employing this technique. The effects of repeated trunk scoring over several seasons on tree and fruit responses were not examined in this study.

In the trials reported here, root pruning at full bloom had less-consistent effects and influenced fewer fruit-quality characteristics than DZ. Root pruning later than full bloom had virtually no effect on fruit at harvest or after storage. Root-pruning did not influence fruit weight. In other studies, root-pruning effects on fruit-quality indices were accompanied by reductions in fruit size (Schumacher et al., 1978; Schupp and Ferree, 1987, 1988). Schupp and Ferree (1988) reported no effect of root-pruning severity on fruit quality of 'Melrose' apples at harvest, but all root-pruning treatments in their study reduced fruit size. The limited effects of root pruning on fruit behavior in the trials reported here may reflect less-severe root pruning than in other studies reporting similar responses (Schumacher et al., 1978; Schupp and Ferree, 1987, 1988). Further research is needed to determine whether fruit-size reduction is consistently associated with root-pruning treatments that may more strongly affect fruit quality characteristics as determined at harvest and after storage.

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