Manual and Chemical Branch Inducement in Fall- and Spring-planted 'Empire' Apple on Two Rootstocks

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Abstract. One-year-old unbranched 'Empire' apple (*Malus domestica* Borkh.) trees on Malling 26 EMLA and Malling–Merton 111 EMLA rootstocks were planted in Nov. 1991 or Mar. 1992 at an eastern Piedmont or mountain site of North Carolina. In Mar. 1992 and 1993, trees were dormant-headed and then subjected to one of five branch-inducing techniques: 1) control—untouched, 2) notching—removing a thin band of bark above each lateral bud, 3) leaf removal—periodic removal of immature apical leaves, 4) bending—placing at horizontal and setting upright in summer, or 5) renewal—setting a lateral branch upright as the new leader. The second year (1993), half of the trees were periodically sprayed with Promalin (GA₄₊₇ + BA). At the Piedmont site, notching, leaf removal, and bending resulted in more branching than the control after 1 year. At the mountain site, leaf removal was considerably less effective in inducing branches. Bending produced asymmetric trees and, at the mountain site, considerably reduced terminal shoot growth. Planting date had little influence on branching. Two years after planting, notched trees were significantly larger and had twice as many branches as other trees. Promalin increased branching on current-season growth and, when combined with leaf removal, resulted in the most uniform distribution of branches along the length of the central leader. Using notching or Promalin produced a tree structure suitable for high-density plantings. Chemical names used: *N*-(phenylmethyl)-1*H*-purin-6-amine (BA), gibberellins A₄ + A₇ (GA₄₊₇).

Intensive apple orchard management is aimed at improving productivity and profitability. Full-sized trees are being replaced by smaller, more efficient trees on dwarfing rootstocks, planted at higher densities. The production potential of a high-density orchard is maximized when cultural methods that control tree size and induce a significant number of well-distributed branches are used (Barritt, 1989; Heinicke, 1975). Early production and selection of properly spaced scaffold limbs encourage early production (Shepherd, 1979; Van Oosten, 1978).

A dormant-heading cut at planting and each year thereafter is routinely used to stimu-

late branching. However, heading into 1-year-old wood frequently induces only the uppermost buds to develop into branches. In addition, heading discourages early production by removing potential fruiting wood and promoting vigorous shoot growth. The success of a high-density orchard depends on a tree structure that has a maximum proportion of moderately vigorous, fruit-producing wood (Oberhofer, 1987).

Alternative methods of branch inducement are needed to overcome the many disadvantages of using a dormant-heading cut each year to induce branching. Notching, removing a thin section of bark directly above a lateral bud, can increase the number and length of branches on 1- and 2-year-old wood (Greene and Autio, 1994). Bending the central leader is commonly used in high-density plantings in an effort to control tree size and increase branching (Oberhofer, 1987); however, orientation of the terminal shoot away from a vertical position influences growth rates and branch location but not branch count (Mullins, 1965; Myers and Ferree, 1983). Promalin (Abbott Laboratories, North Chicago, Ill.) increases branching on 1-year-old wood (Elfving, 1984; Unrath and Shaltout, 1985) and current-season growth (Cody et al., 1985; Myers and Ferree, 1982). Removing immature, apical leaves increases the number of branches on current-season growth (Barlow and Hancock, 1960; Wertheim, 1978a). The combination of leaf removal and Promalin is more effective

than either treatment alone (Theron et al., 1987).

The vigor of a particular cultivar–rootstock combination may influence the effectiveness of branch-inducing techniques because these techniques are often most successful when shoot growth is most rapid (Greene and Miller, 1988; Larsen, 1979; Miller and Eldridge, 1986; Quinlan, 1978; Sachs and Thimann, 1967). Planting date can influence tree vigor (Beracieto and Rom, 1984; Young, 1989) and, therefore, may affect early branching. Our objectives were to evaluate various branch-inducing techniques with young 'Empire' apple trees and to determine the influence of planting date and rootstock vigor on the effectiveness of these techniques.

Materials and Methods

One hundred 1-year-old 'Empire' apple trees (trunk 10 to 13 mm in diameter) on M.26 EMLA rootstock and 100 trees on MM.111 EMLA rootstock were used. Fifty trees on each rootstock were planted in Nov. 1991 and the other 50 trees in Mar. 1992, half at an eastern Piedmont site (Raleigh, N.C.) and half at a mountain site (Mountain Horticultural Crops Research Station, Fletcher, N.C.). The eastern Piedmont site [U.S. Dept. of Agriculture (USDA) hardiness zone 7] has a considerably warmer climate and longer growing season than the mountain site (USDA hardiness zone 6), which is located in the largest commercial apple-growing area of North Carolina. Trees at the Piedmont site were planted in 57-liter plastic pots containing a 3 pine bark : 1 sand (v/v) medium, spaced 0.45 m apart within north–south rows 1.8 m apart on a gravel bed, and supplied with overhead irrigation. Trees at the mountain site were planted 1.8 m apart within east–west rows 5.5 m apart in a well-drained clay loam soil fumigated with methyl bromide. At both locations, metal conduit (3.3 m long, 19 mm in diameter) was used to support the entire tree, including the current-season terminal shoot.

In Mar. 1992, lateral branches were removed from all trees. At both locations, each of the 25 trees of the four rootstock–planting date combinations were subjected to one of five branch-inducing techniques: 1) control—dormant heading at 70 cm above the graft union; 2) notching—dormant heading at 100 cm and removal of a horizontal band of bark (2 mm wide and one-third leader circumference) down to the secondary xylem with a hacksaw blade directly above each lateral bud in a zone 35 to 65 cm (35–65 cm) above the graft union; 3) leaf removal—dormant heading at 40 cm and, beginning in May, removal of the five uppermost immature leaves of the terminal shoot (the first leaf clearly separate from the terminal growing point and the four immature leaves immediately above this leaf) after every 20 to 25 cm of new terminal growth throughout the growing season (total of four to five times); 4) bending—dormant heading at 100 cm and tying the terminal shoot down to a horizontal position, tying it horizontally to the opposite side 5 weeks after terminal budbreak,

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and then tying it upright to the conduit support after an additional 5 weeks; 5) leader renewal—dormant heading at 70 cm with a second heading 10 weeks after budbreak directly above the highest current-season branch 35–50 cm long, which was tipped and tied upright to the conduit support as the new leader.

The most vigorous shoot directly below each heading cut served as the new leader. The three lateral buds immediately below the newly selected leader were removed to minimize competition. Trees were headed higher than the control to determine if branches could be induced in a zone 35–65 cm above the graft union by notching and bending because heading generally is effective at inducing branches only within 30 cm of the cut. This 35–65-cm zone was considered the ideal region for lower scaffold development. Trees subjected to leaf removal were headed at 40 cm to ensure that all branches were induced on current-season wood. Branches produced below the 35–65-cm zone and the less vigorous of two branches growing from the same node were removed throughout the growing season. All branch angles were maintained <30° above horizontal using concrete weights.

At the end of the first growing season (1992), tree height (measured from graft union) and trunk diameter (at 12 cm above the graft union) were measured. The number of lateral budbreaks, number of branches (≥5 cm), and total branch length were recorded for the 35–65-cm zone and whole tree.

The following year (1993), each of the five branch-inducing techniques was repeated on the same set of trees as follows: 1) control—dormant heading 35 cm above the highest branch above an unbranched region <30 cm long; 2) notching—dormant tipping (removing 3 cm of terminal shoot tip) and removing a thin band of bark above each lateral bud of the 1-year-old (1992) portion of the leader; 3) leaf removal—dormant heading 5 cm above the highest branch above an unbranched region <30 cm long, and then removing the five uppermost immature apical leaves of the leader after every 20 to 25 cm of new terminal growth (total of four to five times, beginning in May); 4) bending—dormant tipping and tying the 1-year-old (1992) portion of the leader to horizontal and, 5 weeks after budbreak, either setting it upright (mountain) or tying it horizontally to the opposite side and setting it upright after an additional 5 weeks (Piedmont); and 5) leader renewal—dormant heading directly above the highest branch ≥35 cm long above an unbranched region <30 cm long, and then dormant-tipping this branch and tying it upright as the new leader.

In Mar. 1993, the length of the central leader and the number of associated lateral shoots removed from the control trees and from the trees receiving the leaf removal and renewal techniques with the second-year heading cut (Mar. 1993) were recorded. All flower clusters were removed by hand. At 10 to 12 cm of new terminal growth (May 1993), the 1-year-old (1992) portion of the central leader of half (five) of the trees of each of the 10 rootstock–technique combinations was hand-

sprayed to drip with Promalin at 375 mg a.i./liter plus 0.2% (by volume) Tween 20 surfactant. Current-season terminal shoots of the same trees were sprayed thoroughly with Promalin (without surfactant) at 125 mg a.i./liter after every 20 to 25 cm of new terminal

growth (total of four to five times, beginning in May).

Due to a severe Ca deficiency in the potted trees (detected through foliar analysis), which caused dieback of many terminal shoots by midsummer the second season (1993), sec-

Table 1. Influence of rootstock, planting date, and branching technique on the number of lateral budbreaks, branches (≥5 cm), and total branch length in a zone 35–65 cm above the graft union at the Piedmont site after one growing season (Nov. 1992).

Variable	Growth response					
	Lateral budbreaks		Branches (≥5 cm)		Total branch length (m)	
A) Rootstock	M.26	MM.111	M.26	MM.111	M.26	MM.111
Control	7.1 bc/b ^z	10.5 ab/a	4.7 c/a	4.9 c/a	3.75 b/a	3.78 b/a
Notching	8.8 b/b	12.2 a/a	6.2 b/b	9.8 a/a	4.45 ab/b	6.62 a/a
Leaf removal	11.2 a/a	9.0 bc/b	8.1 a/a	6.4 b/b	5.36 a/a	4.10 b/b
Bending	5.7 c/b	11.5 a/a	4.5 c/b	6.7 b/a	3.81 b/a	4.51 b/a
Renewal	6.8 c/a	7.6 c/a	5.2 bc/a	5.0 c/a	3.92 b/a	3.76 b/a
Mean	7.9	10.2	5.7	6.6	4.26	4.55
B) Planting date	Fall 1991	Spring 1992	Fall 1991	Spring 1992	Fall 1991	Spring 1992
Control	9.0	8.6	4.2 c/a	5.4 b/a	3.42 c/a	4.11 b/a
Notching	10.2	10.8	7.5 a/a	8.5 a/a	5.49 a/a	5.57 a/a
Leaf removal	9.4	10.8	6.2 ab/b	8.3 a/a	4.02 bc/b	5.43 a/a
Bending	9.3	7.9	6.0 b/a	5.2 b/a	4.47 b/a	3.86 b/a
Renewal	6.5	7.9	4.3 c/b	5.9 b/a	3.23 c/b	4.44 b/a
Mean	8.8 a ^y	9.2 a	5.6	6.7	4.13	4.68
C) Overall technique means ^x						
Control		8.8		4.8		3.76
Notching		10.5		8.0		5.53
Leaf removal		10.1		7.2		4.73
Bending		8.6		5.6		4.16
Renewal		7.2		5.1		3.84
F significance						
Rootstock (R)		**		NS		NS
Planting date (D)		NS		**		**
R × D		NS		NS		NS
Technique (T)		**		**		**
R × T		**		**		**
D × T		NS		*		*
R × D × T		NS		NS		NS

^zInteraction mean separation by least significant difference (LSD) at $P \leq 0.05$, where first letter indicates separation within column and second letter indicates separation between columns.

^yMean separation between columns by LSD at $P \leq 0.05$.

^xOverall technique means not followed by letter are not subject to mean separation procedures due to presence of technique × rootstock and/or technique × planting date interaction.

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

Table 2. Influence of rootstock, planting date, and branching technique on the number of lateral budbreaks, branches (≥5 cm), and total branch length per tree at the Piedmont site after one growing season (Nov. 1992).

Variable	Lateral budbreaks	Branches (≥5 cm)	Total branch length (m)
Rootstock			
M.26	22.9 a ^z	10.6 a	6.45 a
MM.111	27.4 a	11.8 a	6.56 a
Planting date			
Fall 1991	24.7 a	10.5 b	6.10 b
Spring 1992	25.5 a	11.8 a	6.91 a
Technique			
Control	25.8 bc	8.2 d	5.06 c
Notching	27.6 b	12.9 b	8.73 a
Leaf removal	33.4 a	15.0 a	6.82 b
Bending	21.6 c	11.0 c	7.08 b
Renewal	17.0 d	8.6 d	4.82 c
F significance			
Rootstock (R)	NS	NS	NS
Planting date (D)	NS	*	*
R × D	NS	NS	NS
Technique (T)	**	**	**
R × T	NS	NS	NS
D × T	NS	NS	NS
R × D × T	NS	NS	NS

^zMean separation within columns by least significant difference at $P \leq 0.05$.

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

ond-year measurements were not taken at the Piedmont site. At the mountain site, the length of the central leader (beginning at 35 cm above the graft union) was divided into 30-cm sections at the end of the second year (1993). The number of lateral budbreaks and number of branches (≥ 5 cm) were recorded for each 30-cm zone. The length of the central leader and the number of associated lateral shoots that would have been removed with a third-year dormant heading (if branch-inducing treatments had been continued in year 3) were determined. Tree height, trunk diameter, and fresh weights of the aboveground tree portion and of the branches were recorded.

At the mountain site, a bare-ground strip was maintained in the tree row, and grass sod was used between rows. Standard orchard fertilization practices (Shelton, 1984) were followed at the mountain site. At regular intervals, each tree at the Piedmont site received 100 g of 10N-2.2P-4.2K fertilizer in the first year and 200 g in the second year, along with 8 g of micronutrient fertilizer. Insects, diseases, and weeds were managed using commercially recommended control practices (North Carolina Cooperative Extension Service, 1994).

The two planting sites were considered separate experiments. At each site, a blocked split split-plot design with five single-tree replications was used, with the rootstock serving as the whole-plot unit, planting date as the subplot unit, and the branch-inducing technique as the sub-subplot unit. The Promalin treatment replaced planting date as the subplot variable in the second year. Data were subjected to analysis of variance procedures and treatment means were separated using the least significant difference test ($P \leq 0.05$).

Table 3. Influence of rootstock, planting date, and branching technique on tree height at the Piedmont site after one growing season, before (Nov. 1992) and after (Feb. 1993) second-year heading.

Variable	Tree ht (m)	
	Before heading	After heading
Rootstock		
M.26	2.05 b ^z	1.48 b
MM.111	2.20 a	1.60 a
Planting date		
Fall 1991	2.16 a	1.55 a
Spring 1992	2.09 a	1.53 a
Technique		
Control	2.36 a	1.25 c
Notching	2.29 a	2.26 a
Leaf removal	2.18 b	0.89 d
Bending	2.02 c	2.00 b
Renewal	1.77 d	1.33 c
F significance		
Rootstock (R)	**	**
Planting date (D)	NS	NS
R $\times$ D	NS	NS
Technique (T)	**	**
R $\times$ T	NS	NS
D $\times$ T	NS	NS
R $\times$ D $\times$ T	NS	NS

^zMean separation within columns by least significant difference at $P \leq 0.05$.

NS, ** Nonsignificant or significant at $P \leq 0.01$, respectively.

Results

Piedmont site, year 1 (35–65-cm zone, only), Nov. 1992. With trees on M.26, leaf removal produced the most lateral budbreak in the zone 35–65 cm above the graft union after 1 year (Table 1). With trees on MM.111, the control treatment produced at least as much lateral budbreak as did the other techniques. Leaf removal produced more budbreak with trees on M.26 than trees on MM.111; in contrast, the control and the notching and bending techniques produced more budbreak with trees on MM.111. With trees on M.26, notching and leaf removal produced more branches than the control, whereas bending and renewal produced a similar number of branches as the control. With trees on MM.111, notching produced the most branches, but leaf removal and bending also produced more branches than the control. Rootstock differences in branching were similar to those for budbreak. Leaf removal produced more total branch length than all but notching with trees on M.26, and notching was most effective on trees on MM.111. Planting date did not influence lateral budbreak. Notching, leaf removal, and bending with fall planting and notching and leaf removal with spring planting produced more branches than the control. Notching and bending with fall planting and notching and leaf removal with spring planting resulted in more total branch length than the control. Leaf re-

moval and renewal produced more branches and more total branch length with spring-planted rather than with fall-planted trees.

Piedmont site, year 1 (whole tree), Nov. 1992. Rootstock had no influence on whole-tree lateral budbreak, branch count, or total branch length after 1 year (Table 2). Planting date did not influence lateral budbreak. Branching and total branch length on spring-planted trees slightly exceeded those on fall-planted trees. Overall, notching, leaf removal, and bending produced more branches and greater total branch length than the control. Leaf removal resulted in the most lateral budbreak and number of branches per tree. Leaf removal produced twice the lateral budbreak and more than four times the number of branches on current-season growth than the control (data not shown). Total branch length was greatest with notching. Bending produced asymmetric trees, as branches developed on the upper side of the central leader only while it was in the first horizontal position.

Trees on MM.111 were taller than trees on M.26 before and after the second-year heading in Feb. 1993 (Table 3). Planting date did not influence tree height. Control and notched trees were tallest after 1 year, but after the second-year heading, notched trees were tallest. Few branches were produced on current-season growth of control trees, and branches of trees with leaf removal were frequently in distinct groups separated by unbranched sec-

Table 4. Influence of rootstock, planting date, and branching technique on the number of lateral budbreaks, branches (≥ 5 cm), and total branch length in a zone 35–65 cm above the graft union at the mountain site after one growing season (Nov. 1992).

Variable	Growth response					
	Lateral budbreaks		Branches (≥ 5 cm)		Total branch length (m)	
A) Rootstock	M.26	MM.111	M.26	MM.111	M.26	MM.111
Control	7.9 ab/a ^z	10.0 a/a	4.9 ab/a	4.3 b/a	3.49 ab/a	2.79 c/a
Notching	7.8 ab/b	12.1 a/a	5.7 a/b	8.7 a/a	3.78 a/b	4.92 a/a
Leaf removal	8.7 a/a	5.4 b/b	5.6 a/a	3.5 b/b	2.16 c/a	1.29 d/a
Bending	6.1 ab/b	11.6 a/a	3.5 b/b	7.6 a/a	2.16 c/b	3.92 b/a
Renewal	5.9 b/a	7.0 b/a	4.0 ab/a	4.2 b/a	2.69 bc/a	2.59 c/a
Mean	7.3	9.1	4.8	5.6	2.89	3.07
B) Planting date	Fall 1991	Spring 1992	Fall 1991	Spring 1992	Fall 1991	Spring 1992
Control	8.9	8.9	5.0 b/a	4.3 c/a	3.39	2.96
Notching	9.6	10.1	6.2 a/b	7.9 a/a	3.86	4.73
Leaf removal	5.6	8.5	3.0 c/b	6.1 b/a	1.31	2.14
Bending	9.6	8.8	6.8 a/a	4.8 c/b	3.42	2.86
Renewal	5.7	7.2	3.3 c/b	4.9 c/a	2.46	2.82
Mean	7.8 b ^y	8.7 a	4.8	5.6	2.85 a	3.10 a
C) Overall technique means ^x						
Control		8.9		4.6		3.16
Notching		9.8		7.1		4.32
Leaf removal		7.0		4.6		1.73
Bending		9.2		5.8		3.14
Renewal		6.4		4.1		2.64
F significance						
Rootstock (R)		**		NS		NS
Planting date (D)		*		NS		NS
R $\times$ D		NS		NS		NS
Technique (T)		**		**		**
R $\times$ T		**		**		**
D $\times$ T		NS		**		NS
R $\times$ D $\times$ T		NS		NS		NS

^zInteraction mean separation by least significant difference (LSD) at $P \leq 0.05$, where first letter indicates separation within column and second letter indicates separation between columns.

^yMean separation between columns by LSD at $P \leq 0.05$.

^xOverall technique means not followed by letter are not subject to mean separation procedures due to presence of technique $\times$ rootstock and/or technique $\times$ planting date interaction.

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

tions >30 cm long. Therefore, control trees and trees with leaf removal had a large portion of their height removed with the second-year heading. Central leaders of notched and bent trees were lightly tipped despite the location of branches.

Mountain site, year 1 (35–65-cm zone, only), Nov. 1992. With trees on M.26, all techniques resulted in a similar amount of lateral budbreak and number of branches in the 35–65-cm zone as the control (Table 4). However, with trees on MM.111, leaf removal and renewal produced much less budbreak than the control, and notching and bending produced many more branches than the control. Notching and bending produced more branches with trees on MM.111 than on M.26, and leaf removal produced more branches with trees on M.26. With trees on M.26, only notching and renewal resulted in as much total branch length as was produced by the control. With trees on MM.111, notching and bending produced much more, and leaf removal much less, total branch length than the control. Notching and bending produced greater total branch length with trees on MM.111 than with trees on M.26. Spring planting produced slightly more lateral budbreaks than fall planting. More branches than the control were produced by notching and bending with fall planting and by notching and leaf removal with spring planting. Notching, leaf removal, and renewal produced more branches with spring than fall planting. Planting date did not influence total branch length.

Mountain site, year 1 (whole tree), Nov. 1992. Lateral budbreak was greater with trees on MM.111 than with trees on M.26 (Table 5). Branch count and total branch length were not affected by rootstock. Planting date did not influence lateral budbreak, branching, or total branch length. Notching and bending resulted in many more lateral budbreaks and branches than the other techniques. Leaf removal was the only technique that produced considerable

lateral budbreak on current-season growth (data not shown). Renewal produced some branches on current-season growth, but most of those branches were removed with the second-year (Feb. 1993) heading. Total branch length was greatest with notching and least with leaf removal and renewal.

Trees on M.26 were slightly taller than trees on MM.111 before and after heading (Table 6). Planting date did not influence tree height. Bending produced trees that were considerably shorter than the other trees at the end of the first growing season. Terminal growth of bent trees ceased while the tree was in the second horizontal position, and growth did not resume after the tree was placed upright. As at the Piedmont site, bending produced asymmetric trees.

Mountain site, year 2 (whole tree), Nov. 1993. There were no differences between rootstocks in lateral budbreak or branching in any of the 30-cm zones after two growing seasons, thus data were averaged over rootstock (Fig. 1). Promalin had no effect on 2-year-old sections of the central leader; increased budbreak, but not branching, on 1-year-old sections; and dramatically increased budbreak and branching on current-season growth. Without Promalin, notching produced three times as many branches and, with Promalin, twice as many branches as the other techniques, which all produced a similar number.

Promalin resulted in a more uniform distribution of budbreak and branching along the length of the central leader, especially with control trees and trees subjected to leaf removal and renewal, on which budbreak and branching were confined almost entirely to the bottom half of the tree without Promalin (Fig. 1). Overall, Promalin more than doubled the amount of budbreak and branching in the upper half of the tree. Budbreak was increased by Promalin through the uppermost zone of most trees. The combination of Promalin and leaf removal resulted in the most uniform

distribution of branches. Promalin in combination with leaf removal produced two to three times the lateral budbreak and two to five times the number of branches on current-season growth as Promalin in combination with other techniques. Two-thirds of the lateral shoots induced by Promalin on current-season growth were <5 cm long and, therefore, were not considered branches.

Rootstock did not influence tree height after two growing seasons, before or after heading (Table 7). Notched trees were tallest before and after heading, without or with Promalin. Before heading, trees subjected to bending and leaf removal were shortest, without or with Promalin, respectively. After heading, control trees and trees with leaf removal were shortest without Promalin and trees subjected to renewal were shortest with Promalin. Promalin increased the height of trees subjected to bending and renewal. Following the fourth application of Promalin, terminal shoots subjected to leaf removal died back ≈10 cm in mid-August, negating any increase in length up to that time. Promalin increased the after-heading height of control trees and trees subjected to leaf removal and bending. Despite inducing many branches in the upper part of all trees, Promalin did not reduce the amount of the central leader needed to be removed by heading with trees subjected to renewal because no branches of suitable length (≥35 cm) to replace the central leader were produced on current-season growth. Moreover, notched and bent trees were lightly tipped, regardless of the location of branches.

Neither rootstock nor Promalin influenced aboveground tree fresh weight or total branch fresh weight (Table 8). Tree and total branch

Table 5. Influence of rootstock, planting date, and branching technique on the number of lateral budbreaks, branches (≥5 cm), and total branch length per tree at the mountain site after one growing season (Nov. 1992).

Variable	Lateral budbreaks	Branches (≥5 cm)	Total branch length (m)
Rootstock			
M.26	11.3 b ²	6.7 a	3.71 a
MM.111	14.0 a	6.9 a	3.46 a
Planting date			
Fall 1991	12.1 a	6.4 a	3.55 a
Spring 1992	13.2 a	7.1 a	3.63 a
Technique			
Control	9.3 b	5.0 b	3.33 c
Notching	20.7 a	9.6 a	5.51 a
Leaf removal	7.7 b	5.2 b	2.01 d
Bending	19.5 a	10.0 a	4.56 b
Renewal	7.0 b	4.6 b	2.70 cd
F significance			
Rootstock (R)	*	NS	NS
Planting date (D)	NS	NS	NS
R × D	NS	NS	NS
Technique (T)	**	**	**
R × T	**	NS	NS
D × T	NS	*	NS
R × D × T	NS	NS	NS

²Mean separation within columns by least significant difference at $P \leq 0.05$.

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

Table 6. Influence of rootstock, planting date, and branching technique on tree height at the mountain site after one growing season, before (Nov. 1992) and after (Feb. 1993) second-year heading.

Variable	Tree ht (m)	
	Before heading	After heading
Rootstock		
M.26	1.76 a ²	1.31 a
MM.111	1.66 b	1.22 b
Planting date		
Fall 1991	1.74 a	1.28 a
Spring 1992	1.67 a	1.25 a
Technique		
Control	2.00 a	1.16 c
Notching	2.00 a	1.97 a
Leaf removal	1.72 b	0.73 d
Bending	1.30 d	1.26 b
Renewal	1.50 c	1.23 bc
F significance		
Rootstock (R)	*	*
Planting date (D)	NS	NS
R × D	NS	NS
Technique (T)	**	**
R × T	NS	NS
D × T	NS	NS
R × D × T	NS	NS

²Mean separation within columns by least significant difference at $P \leq 0.05$.

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

Fig. 1. Influence of branching technique and Promalin on lateral budbreak and branching (≥ 5 cm) in each 30-cm zone at the mountain site after two growing seasons (Nov. 1993). Data averaged over rootstock. Error bars indicate SE of mean of 10 replications. Position of ">" or "<" indicates average uppermost extent of 2-year-old (1991), 1-year-old (1992), and current-season (1993) portions of central leader, from bottom to top of tree, respectively.

fresh weights were greatest for notched trees and least for trees subjected to leaf removal. Notching, leaf removal, and Promalin resulted in the lowest mean branch fresh weights due to the numerous short branches (< 20 cm) produced in the upper half of the tree.

Discussion

Overall, each branch-inducing technique produced what is generally considered a well-branched tree, having at least four 20-cm-long branches at least 45 cm above the soil line (Barritt, 1990) 1 year after planting. However, only notching and leaf removal produced high-quality "feathered" trees having at least six branches ≥ 20 cm long at the desired location (Sanders, 1989). Notching produced many branches the first year, greatly increasing the probability of attaining well-positioned scaffolds. Bent trees were not of acceptable quality, despite a large number of branches, because most branches developed on one side of the tree. Reducing the time the central leader remained in a horizontal position or decreasing the severity of the bend might have resulted in more uniformly distributed branches.

Exclusively using a dormant heading cut to induce branching each year, as with the control trees in this study, is satisfactory for producing a traditional central-leader tree, but using Promalin or notching produced a tree structure suitable for high-density plantings, exemplified by vertical-axe- (Lespinnasse and Delort, 1986) and slender-spindle-type trees (Oberhofer, 1987; Wertheim, 1978b). After 2 years, notching produced a vertical-axe-type tree, 3 m tall, with two tiers of scaffold branches and numerous, evenly distributed, relatively short branches (20 to 59 cm long) in the upper half of the tree. Leaf removal plus Promalin produced a slender-spindle-type tree 2.0 to 2.5 m tall with a single tier of scaffold branches and numerous short lateral shoots (1 to 19 cm long). If used the first year, this combination might have produced a similar tree in a single season, significantly shortening the time to production. Short lateral shoots produced in the upper part of the tree likely will develop into useful branches due to good light exposure.

Promalin applied at rates higher than those used in our study has increased branching (Basak and Soczek, 1986; Elfving, 1984; Koen et al., 1989), but it also significantly reduced tree height (Koen et al., 1989; Myers and Ferree, 1982). Despite using the lowest labeled rate and the exclusion of surfactant, leaf injury and terminal dieback occurred after the fourth application, reducing tree height. Weather conditions at the time of the fourth application were ideal for rapid absorption of Promalin (cloudy, light precipitation) and may have contributed to the phytotoxicity observed. However, there were similar conditions at the time of other Promalin applications that did not result in leaf injury or terminal dieback. The reason for the occurrence of phytotoxicity only on terminal shoots subjected to leaf removal is unknown. The effect of Promalin on 1-year-old wood might have been more pro-

nounced if it had been applied shortly after spring budbreak (Unrath and Shaltout, 1985). Current recommendations in North Carolina for branch inducement on 1-year-old wood indicate application should be made at 2.5 to 7.5 cm of new terminal growth (North Carolina Cooperative Extension Service, 1994). However, Elfving (1984) showed that applying Promalin to 'Empire' trees was equally effective at 5, 10, or 20 cm of new terminal growth.

Branching was likely influenced by terminal shoot vigor. With all techniques, more branching occurred at the Piedmont site, where trees were larger due to the warmer climate, longer growing season, and an abundant water supply. The absence of a rootstock $\times$ technique interaction for total branch count at both locations can be attributed to the small difference in vigor between trees on the two rootstocks, evidenced by similar tree height and trunk diameter. However, terminal shoot growth of trees on M.26 was slightly more rapid than that of trees on MM.111 for ≈ 6 to 8 weeks following spring budbreak. Trees on M.26, especially after leaf removal, branched more on current-season growth during this time and following budding in the nursery, as evidenced by the greater number of branches removed from these trees before planting. Removing numerous branches from trees on M.26 provided fewer sites for new lateral shoots to develop since it resulted in many nodes having only latent buds. This might account for much of the difference between rootstocks in branch count in the lower part of the tree. Promalin's ability to greatly enhance branching of apically defoliated terminal shoots may be due to the heightened sensitivity of young, unsubtended buds (Popenoe and Barritt, 1988; Theron et al, 1987) or to the faster growth of Promalin-treated terminal shoots. Each Promalin appli-

cation produced a similar number of lateral shoots, independent of the vigor of the central leader.

Central leader shoots were pruned to various lengths in an effort to maximize branching. Thus, the branching responses were a result of differing leader management techniques—the combination of heading height and branch-inducing technique. For example, many of the branches of trees subjected to leaf removal probably were not induced solely by removing immature leaves but developed as a result of the vigorous terminal growth that occurred after severe heading cuts.

We subjected each tree to the same branch-inducing technique each year, but using a combination of techniques may be required in high-density orchards. Notching is effective but is time consuming if used exclusively. Because individual buds can be induced to grow out, notching could be used successfully in combination with other techniques, such as periodic leaf removal, which result in large areas or small disjunct sections of unbranched wood. Promalin application with leaf removal consistently induced branching on current-season growth throughout the growing season. The combination of notching, leaf removal, and Promalin application will produce a tree structure suitable for a high-density orchard 2 years after planting under the growing conditions of this study. This same combination of techniques likely would induce branching equally well under less vigor-inducing growing conditions (more dwarfing rootstock, cooler climate, etc.), but an additional 1 or 2 years might be needed to develop a similar tree structure. Leader renewal or bending would be useful under all growing conditions to control tree size once the desired tree height and branching structure are attained.

Table 7. Influence of rootstock, Promalin, and branching technique on tree height at the mountain site after two growing seasons, before (Nov. 1993) and after a third-year heading (Feb. 1994).

Variable	Tree ht (m)			
	Before heading		After heading	
A) Rootstock	M.26	MM.111	M.26	MM.111
Control	2.62	2.62	1.92	1.88
Notching	3.00	2.91	2.98	2.88
Leaf removal	2.13	2.23	1.66	1.83
Bending	2.11	2.08	2.08	2.05
Renewal	2.53	2.44	1.79	1.68
Mean	2.49 a ^z	2.45 a	2.09 a	2.05 a
B) Promalin	No	Yes	No	Yes
Control	2.54 b/a ^y	2.72 b/a	1.59 bc/b	2.25 bc/a
Notching	2.88 a/a	3.03 a/a	2.85 a/a	3.00 a/a
Leaf removal	2.17 c/a	2.19 d/a	1.42 c/b	2.07 c/a
Bending	1.76 d/b	2.42 c/a	1.73 b/b	2.39 b/a
Renewal	2.33 bc/b	2.64 bc/a	1.73 b/a	1.75 d/a
Mean	2.34	2.60	1.85	2.29
F significance				
Rootstock (R)	NS		NS	
Promalin (P)	**		**	
R $\times$ P	NS		NS	
Technique (T)	**		**	
R $\times$ T	NS		NS	
P $\times$ T	**		**	
R $\times$ P $\times$ T	NS		NS	

^zMean separation between columns by least significant difference (LSD) at $P \leq 0.05$.

^yInteraction mean separation by LSD at $P \leq 0.05$ where first letter indicates separation within column and second letter indicates separation between columns.

NS, ** Nonsignificant or significant at $P \leq 0.01$, respectively.

Table 8. Influence of rootstock, Promalin, and branching technique on fresh weight of aboveground portion of tree and branches (≥ 5 cm) at the mountain site after two growing seasons (Nov. 1993).

Variable	Fresh wt (kg)		
	Tree	Branches (≥ 5 cm)	
		Total	Mean
Rootstock			
M.26	1.83 a ^z	1.21 a	0.06 a
MM.111	1.83 a	1.22 a	0.06 a
Promalin			
No	1.78 a	1.20 a	0.08 a
Yes	1.87 a	1.23 a	0.05 b
Technique			
Control	1.83 bc	1.23 bc	0.08 a
Notching	2.64 a	1.68 a	0.05 b
Leaf removal	1.17 d	0.79 d	0.05 b
Bending	2.02 b	1.41 b	0.08 a
Renewal	1.53 c	1.02 c	0.07 a
F significance			
Rootstock (R)	NS	NS	NS
Promalin (P)	NS	NS	**
R $\times$ P	NS	NS	NS
Technique (T)	**	**	**
R $\times$ T	NS	NS	NS
P $\times$ T	NS	NS	NS
R $\times$ P $\times$ T	NS	NS	NS

^zMean separation within columns and variables by least significant difference at $P \leq 0.05$.

NS, ** Nonsignificant or significant at $P \leq 0.01$, respectively.

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