Branch Inducement in Apple Stoolbed Shoots by Summer Leaf Removal and Tipping

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Abstract. The ability of various leaf removal treatments or shoot tipping to induce lateral shoot development on current-season stoolbed shoots of MM.106 EMLA and M.26 EMLA apple (*Malus domestica* Borkh.) rootstocks was investigated. Removal of the five uppermost immature leaves or shoot tipping after every 20 to 25 cm of terminal growth produced more lateral budbreak than occurred on nontreated shoots. Shoot tipping resulted in the highest number of branches (≥ 5 cm) and greatest total branch length. Only tipping consistently induced lateral budbreak higher than 30 cm up the shoot. Removal of the 10 uppermost leaves and tipping resulted in the shortest terminal shoots. MM.106 shoots had more lateral budbreak, branches, and total branch length than did M.26 shoots.

Early branch development of young apple trees is essential for selecting properly spaced scaffold limbs and encouraging the early production required in high-density plantings. Trees that are well branched at planting will crop earlier and more heavily than poorly branched trees (Shepherd, 1979; Van Oosten, 1978). If a poorly branched tree is planted, development of an extensive branching framework the first year is imperative. Current recommendations for developing scaffold branches on central-leader trees include a dormant heading at planting and each year thereafter (Unrath and Obermiller, 1984). Dormant heading into 1-year-old wood frequently induces only the uppermost buds to develop into branches. Heading discourages early production by removing potential fruiting wood and by promoting vigorous shoot growth. The success of a high-density orchard depends on a tree structure that has a maximum proportion of less vigorous fruit-producing wood.

The use of techniques that induce branching on current-season growth may eliminate the need for a heading cut that removes a substantial portion of the central leader each year. Growth regulators have been used successfully to induce branching on current-season growth (Cody et al., 1985; Elfving, 1984; Wertheim, 1978), but have not been widely adopted. Timing, concentration, and applica-

tion method of chemical treatments, along with various environmental factors, interact to give extremely variable results, making it difficult to regulate the number and length of branches produced. Lateral shoots produced on current-season growth are often too short to develop into scaffold branches (Elfving, 1984). The use of certain growth regulators, such as Promalin [gibberellic acid (GA_{4+7}) + benzyladenine (BA); Abbott Laboratories, North Chicago, Ill.], may decrease flower bud production (Guttridge, 1962; Miller, 1986).

The drawbacks of dormant heading and the erratic results produced by chemical branching agents support the development of alternative methods of inducing branches. Branch inducement on current-season growth by shoot tipping or removal of immature, apical leaves is likely due to the removal of auxin sources (Wertheim, 1978). Branches induced by summer pruning are more numerous than those induced on shoots pruned in the dormant season (Maggs, 1965) or those not pruned (Mika et al., 1983). Summer tipping increases total and mean branch length (Myers and Ferree, 1983; Wertheim, 1978). Continuous removal of immature leaves can be effective (Barlow and Hancock, 1962; Popenoe and Barritt, 1988), but the effect of removing leaves at regular intervals is not clear. The objective of this study was to determine if periodic summer leaf removal or shoot tipping would induce branching on current-season growth throughout an entire growing season.

Materials and Methods

In Mar. 1993, 60 dormant 2-year-old shoots of MM.106 EMLA and M.26 EMLA apple rootstocks located in adjacent rows were selected randomly from a large population of upright stoolbed shoots in Raleigh, N.C. Selected shoots averaged 1.2 cm in diameter (measured 12 cm above soil line) and were 10 to 30 cm apart within each row. All nonselected shoots were removed. Each shoot was dor-

mant-headed at 20 to 25 cm above the soil line, and all remaining branches were removed. Only the most vigorous of the newly induced shoots below the heading cut was retained.

To accurately describe position along each terminal shoot, leaf notation similar to that of Barlow and Hancock (1960) was used. The first fully unfolded leaf (clearly separate from the terminal leaf cluster) was designated leaf +1. Leaves distal or proximal to this leaf were given negative or positive numbers, respectively, in increasing order. Nodes were given the same designation as the leaf at that position. After 20 to 25 cm (15 to 20 nodes) of new terminal growth, 12 shoots of each rootstock were assigned randomly to one of five treatments (Fig. 1): 1) control (nontreated); 2) removal of the most recent (first) fully expanded (mature) leaf and the four leaves immediately distal to it (leaves +6 to +2, inclusive); 3) removal of the first fully unfolded leaf and the four leaves immediately distal to it (leaves +1 to -4, inclusive); 4) removal of the first mature leaf and the nine leaves immediately distal to it (leaves +6 to -4, inclusive); 5) tipping above the first fully unfolded leaf (removal of shoot tip and leaves -1 to -4, inclusive).

Treatments were repeated after each additional 20 to 25 cm of new terminal growth. Leaf and node designations were based on the first treatment application and were retained throughout the entire season. New upright shoots arising between the selected shoots were removed. All branches were maintained in a horizontal position with clothespins or concrete weights. Stoolbeds were irrigated to maintain adequate soil moisture.

At the end of the growing season, current-season shoots were divided into four zones: shoot base through node +7; nodes +6 to +2 (inclusive); nodes +1 to -4 (inclusive); and node -5 to the shoot tip. Measurements of current-season growth included terminal shoot length; shoot diameter; and number of nodes, lateral budbreaks, and branches (≥ 5 cm); and length of each branch within each of the four zones. Data were subjected to analysis of variance procedures, and treatment means were separated using the least significant difference test ($P \leq 0.05$).

Results

Terminal growth of all M.26 shoots had slowed considerably by the first week in July, 3 weeks after the treatments were initially performed, and was not discernible by the end of July, as internodes had become exceedingly short. No additional treatments were performed on these shoots after the initial treatment date because terminal shoot growth was not adequate for a second treatment. Terminal growth of MM.106 shoots remained vigorous throughout the summer. Internode length, terminal shoot length, lateral budbreak, branching, and branch length of MM.106 shoots exceeded those of M.26 shoots (Tables 1 and 2).

With both rootstocks, tipping or removing leaves +6 to -4 resulted in the shortest terminal shoots (Table 1). Shoot diameter was not affected by leaf removal or tipping (data not

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Fig. 1. Diagram illustrating initial application of leaf removal and tipping treatments to current-season stoolbed shoots. Dotted line indicates approximate shoot height at time of treatment. Arrows indicate position of reference leaf (+1).

Table 1. Internode length and terminal shoot length of current-season M.26 EMLA and MM.106 EMLA stoolbed shoots following leaf removal or tipping every 20 to 25 cm of new terminal growth.^z

Treatment	Internode length (cm)			Terminal shoot length (cm)		
	M.26	MM.106	Mean	M.26	MM.106	Mean
Control (nontreated)	1.04	1.67	1.36 a ^y	57.4	111.5	84.5 a
Leaves +6 to +2 removed	1.03	1.66	1.34 ab	56.1	105.8	80.9 a
Leaves +1 to -4 removed	1.04	1.64	1.34 ab	56.8	101.8	79.3 a
Leaves +6 to -4 removed	1.01	1.64	1.32 ab	52.7	90.6	71.6 b
Tipped	0.97	1.64	1.30 b	44.8	94.6	69.7 b
Mean	1.02 b ^x	1.65 a		53.6 b	100.8 a	

^zData shown are means of 12 replications.

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

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

shown). There were few treatment differences in lateral budbreak or branching of M.26 shoots (Table 2). Removal of leaves +1 to -4 or tipping produced more lateral budbreak on MM.106 shoots than did the control, but tipping was the only treatment that increased branch count. Nearly 90% of the lateral buds induced to grow out by tipping developed into branches. In addition, tipping more than doubled total branch length on MM.106 shoots (Table 2) and increased mean branch length by 50% compared to the control.

Lateral budbreak and branching of both rootstocks up through node +7 were similar for all treatments (Table 2), indicating no treatment effect >10 to 15 cm below the shoot tip. Budbreak was similar at nodes +6 to +2 on both rootstocks. Tipping increased branching at nodes +6 to +2 on M.26 shoots, inducing about one-third of the buds to develop into

branches. In this same zone on MM.106 shoots, removing leaves +1 to -4 induced a similar number of branches as tipping. Removing leaves +6 to +2 on MM.106 shoots reduced branching in this zone compared to the control. Removing leaves +1 to -4 increased budbreak at nodes +1 to -4 on both rootstocks, inducing nearly three out of five buds to break. Removal of an additional five leaves resulted in a similar amount of budbreak as the control. Removing leaves +1 to -4 on MM.106 shoots induced more than twice the number of branches in this same zone as removing leaves +6 to +2 or leaves +6 to -4, neither of which was as effective as the control. Budbreak was very limited above node -4 on M.26 shoots. With MM.106 shoots, few budbreaks occurred above node -4 following the removal of leaves +1 to -4, but tipping induced branching along the entire shoot length.

This study indicates that the developmental stage of removed apical leaves influences lateral shoot development. Neither the removal of the 10 uppermost leaves nor the removal of unfolded, immature leaves below the terminal leaf cluster increased budbreak, whereas the removal of the uppermost five leaves did. Barlow and Hancock (1962) reported that the number of apical leaves removed was positively correlated with the amount of budbreak, but only leaves in the terminal cluster were removed. Mika (1971) showed that removal of fully mature leaves does not stimulate lateral budbreak.

The greater branching of MM.106 than M.26 shoots suggests that lateral shoot development and terminal shoot vigor are positively correlated. Trees on MM.106 are generally 50% larger than trees on M.26 (Ferree and Carlson, 1987; Young and Unrath, 1989). Despite similar diameter, the terminal growth rate of MM.106 shoots was much greater than that of M.26 shoots, evidenced by longer internodes along the entire shoot length. The development of many branches on nontreated MM.106 shoots up through node +2 (≈20 cm from the shoot base) was expected, since trees severely headed back frequently form numerous wide-angled branches on the vigorous new leader (Verner, 1945). Before the initial heading of 2-year-old shoots, most branching occurred at the base of 2-year-old wood.

There are several reports of greater sensitivity to branching treatments during periods of rapid growth (Greene and Miller, 1988; Larsen, 1979; Quinlan, 1978). In our study, leaf removal was effective only during the initial flush of spring growth. Removing leaves in the terminal leaf cluster may induce lateral shoot development by temporarily slowing terminal growth. Chemicals that reduce terminal growth rates can induce lateral budbreak (Larsen, 1979; Quinlan, 1978). The rate of terminal growth immediately following leaf removal may be important. More branches were produced, and discernible terminal growth resumed much sooner, following the removal of the uppermost five leaves compared with the removal of the uppermost 10 leaves.

Rootstock differences in branching within the first three zones (<30 cm from the shoot base) did not result from the early cessation of growth of M.26 shoots in midsummer. Growth of these shoots was moderately vigorous during a 3-week period following the initial treatment date, when any treatment effect likely would have been noticeable. The slowing of terminal growth of M.26 shoots was not caused by any of the treatments, since growth of nontreated shoots also was slowed. Reduction in terminal growth rate and dramatic shortening of internodes are often observed in low-vigor apple shoots with the onset of high summer temperatures, despite adequate soil moisture. Grochowska et al. (1984) associated this 'June effect' with a substantial reduction of root-produced gibberellins in the xylem and to high concentrations in the phloem.

Repeated tipping of vigorously growing

Table 2. Number of lateral budbreaks, branches (≥ 5 cm), and total branch length in zones of current-season M.26 EMLA and MM.106 EMLA stoolbed shoots following leaf removal or tipping every 20 to 25 cm of terminal growth.^z

Treatment	Shoot base to node +7			Node +6 to +2			Node +1 to -4			Node -5 to shoot tip			Total		
	M.26	MM.106	Mean	M.26	MM.106	Mean	M.26	MM.106	Mean	M.26	MM.106	Mean	M.26	MM.106	Mean
<i>No. lateral budbreaks</i>															
Control (nontreated)	3.7	4.0	3.8 a ^y	2.1	3.3	2.7 a	0.8	1.6	1.2 b	0.3 a/a ^x	0.4 bc/a	0.3	6.8 ab/b	9.3 c/a	8.1
Leaves +6 to +2 removed	3.3	5.1	4.2 a	1.8	3.1	2.4 a	0.6	0.8	0.7 bc	0.1 a/a	0.0 c/a	0.0	5.7 b/b	8.9 c/a	7.3
Leaves +1 to -4 removed	3.2	4.1	3.6 a	2.5	4.2	3.3 a	2.9	2.8	2.8 a	0.3 a/b	0.9 b/a	0.6	8.8 a/b	11.9 b/a	10.4
Leaves +6 to -4 removed	3.8	4.5	4.1 a	2.3	3.3	2.8 a	0.9	1.6	1.3 b	0.1 a/a	0.0 c/a	0.0	7.1 ab/a	9.3 c/a	8.2
Tipped	3.5	5.1	4.3 a	2.8	4.3	3.5 a	0.0	0.0	0.0 c	0.0 a/b	5.2 a/a	2.6	6.3 b/b	14.6 a/a	10.4
Mean	3.5 b ^w	4.6 a		2.3 b	3.6 a		1.1 a	1.3 a		0.1	1.3		6.9	10.8	
<i>No. branches (≥ 5 cm)</i>															
Control (nontreated)	1.0	2.7	1.8 a	0.3 b/b	2.8 bc/a	1.6	0.0 a/b	1.3 a/a	0.7	0.0 a/a	0.3 bc/a	0.2	1.3 a/b	7.2 bc/a	4.3
Leaves +6 to +2 removed	1.7	3.8	2.8 a	0.3 b/b	1.3 d/a	0.8	0.0 a/a	0.5 b/a	0.3	0.0 a/a	0.0 c/a	0.0	2.0 a/b	5.6 c/a	3.8
Leaves +1 to -4 removed	0.8	2.8	1.8 a	0.4 b/b	3.5 ab/a	2.0	0.3 a/b	1.9 a/a	1.1	0.0 a/b	0.9 b/a	0.5	1.5 a/b	9.1 b/a	5.3
Leaves +6 to -4 removed	1.5	3.9	2.7 a	0.8 b/b	2.2 c/a	1.5	0.0 a/a	0.6 b/a	0.3	0.0 a/a	0.0 c/a	0.0	2.3 a/b	6.7 c/a	4.5
Tipped	1.4	4.0	2.7 a	1.9 a/b	4.3 a/a	3.1	0.0 a/a	0.0 b/a	0.0	0.0 a/b	4.7 a/a	2.3	3.3 a/b	12.9 a/a	8.1
Mean	1.3 b	3.4 a		0.8	2.8		0.1	0.9		0.0	1.2		2.1	8.3	
<i>Total branch length (cm)</i>															
Control (nontreated)	8.0	30.2	19.1 a	2.3 b/b	29.2 bc/a	15.8	0.0	16.0	8.0 ab	0.0 a/a	2.3 b/a	1.2	10.3 b/b	77.8 b/a	44.0
Leaves +6 to +2 removed	20.7	44.2	32.5 a	4.2 b/a	9.3 d/a	6.8	0.0	3.9	2.0 bc	0.0 a/a	0.0 b/a	0.0	24.9 ab/b	90.3 b/a	57.6
Leaves +1 to -4 removed	12.8	43.1	27.9 a	5.2 b/b	42.3 b/a	23.8	3.3	19.3	11.3 a	0.0 a/a	6.7 b/a	3.3	21.2 ab/b	111.6 b/a	66.4
Leaves +6 to -4 removed	24.8	41.9	33.3 a	8.3 b/b	23.6 c/a	16.0	0.0	11.4	5.7 a-c	0.0 a/a	0.0 b/a	0.0	42.0 ab/b	107.5 b/a	74.8
Tipped	21.2	45.0	33.1 a	31.8 a/b	62.6 a/a	47.2	0.0	0.0	0.0 c	0.0 a/b	48.8 a/a	24.4	53.0 a/b	203.1 a/a	128.0
Mean	17.5 b	40.9 a		10.4	33.4		0.7 b	10.1 a		0.0	11.6		30.3	118.0	

^aData shown are means of 12 replications.^yMean separation within columns by LSD at $P \leq 0.05$.^xInteraction mean separation by LSD at $P \leq 0.05$, where first letter indicates separation within column and second letter indicates separation between adjacent columns.^wMean separation between columns by LSD at $P \leq 0.05$.

shoots proved to be the most effective treatment because branching was induced throughout the growing season and branch length was markedly increased. In addition, the devigoration likely resulting from periodic tipping every summer may be desirable in high-density plantings where controlling tree size is a major concern.

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