Table 2. Mean nutrient-element concn of the petiole combined from samples taken at the vegetative, bud, and flowering stages.

<table>
<thead>
<tr>
<th>Treatment</th>
<th>H₂O (wt %)</th>
<th>N (wt %)</th>
<th>P (wt %)</th>
<th>K (wt %)</th>
<th>Ca (wt %)</th>
<th>Mg (wt %)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low N</td>
<td>91.0a²</td>
<td>0.95a</td>
<td>0.35a</td>
<td>4.70a</td>
<td>1.77a</td>
<td>0.71a</td>
</tr>
<tr>
<td>Medium N</td>
<td>90.3b</td>
<td>1.17b</td>
<td>0.30b</td>
<td>3.41b</td>
<td>1.59b</td>
<td>0.70a</td>
</tr>
<tr>
<td>High N</td>
<td>89.8c</td>
<td>1.45c</td>
<td>0.25c</td>
<td>2.55c</td>
<td>1.55b</td>
<td>0.72a</td>
</tr>
<tr>
<td>Low P</td>
<td>90.1a</td>
<td>1.18a</td>
<td>0.16a</td>
<td>3.65a</td>
<td>1.61a</td>
<td>0.68a</td>
</tr>
<tr>
<td>Medium P</td>
<td>90.4b</td>
<td>1.18a</td>
<td>0.28b</td>
<td>3.47a</td>
<td>1.58a</td>
<td>0.71ab</td>
</tr>
<tr>
<td>High P</td>
<td>90.6c</td>
<td>1.21a</td>
<td>0.46c</td>
<td>3.55a</td>
<td>1.72b</td>
<td>0.73b</td>
</tr>
<tr>
<td>Low K</td>
<td>90.1a</td>
<td>1.25a</td>
<td>0.30a</td>
<td>2.90a</td>
<td>1.70a</td>
<td>0.80a</td>
</tr>
<tr>
<td>High K</td>
<td>90.6b</td>
<td>1.15b</td>
<td>0.30a</td>
<td>4.21b</td>
<td>1.57b</td>
<td>0.62b</td>
</tr>
</tbody>
</table>

²Mean separation in columns within the N, P, and K treatments by Dunnett’s multiple range test, 5% level.

vegetative stage results in high fruit-yielding plants but they produce a high percentage of undesirable smaller-sized fruits (Awada, M. and C. Long. The critical petiole phosphorus level of papaya, Hawaii Agr. Expt. Sta. Tech. Bul. 97. In press.). Hence, a petiole N range of 1.15 to 1.33%, which is associated with 90% of maximum petiole wt from the low and medium P plots is recommended for growers in Hawaii. This concn range is about the same as the one recommended for bearing plants (3, 4).

Literature Cited

Effects of Naphthaleneacetic Acid on Shoot Growth of Apple Trees¹

D. C. Elfving²
Department of Pomology, Cornell University, Ithaca, NY 14853
C. G. Forshey³
Hudson Valley Laboratory, Highland, NY 12528

Additional index words. Malus domestica, pruning, scoring

Abstract. Naphthaleneacetic acid (NAA) treatments were applied to pruned or unpruned dormant, vigorous, upright apple branches (Malus domestica Borkh.) Bud-break was delayed by NAA, but total inhibition of bud development required the presence of actively growing shoots above the treated area. NAA reduced growth where it was applied, but because of compensating growth increases from untreated branch sections, total growth was unchanged. Applied to 1-year-old whips immediately after planting, NAA reduced the quantity of undesirable growth, increased the growth of favorably positioned shoots, and improved the crotch angles of those shoots.

Early research showed that NAA applications could inhibit the growth of dormant vegetative buds of fruit trees, but had little effect on flower buds (9). Similar growth-inhibiting effects were demonstrated when NAA was applied to roses and potato tubers (5, 8). Little further work ensued and it is only recently that this growth-regulating property of NAA has been commercially exploited for controlling sprout growth from pruning cuts (10, 11). The effective inhibition of sprout growth suggested the possibility that NAA applied to the cut ends of shoots might eliminate the “witch’s brooms” that characteristically develop in response to mechanical hedging. Since apple trees often develop a similar undesirable cluster of vigorous, upright shoots near the heading cut during the first growing season, NAA might also be useful in training young trees.

The following studies were conducted to examine the effects of NAA treatments on shoot growth from both intact and pruned vigorous, upright apple branches, and from newly planted trees.

Materials and Methods

Vigorous, upright branches of previously unpruned and un-
trained 3-year-old 'Delicious' (Vance strain)/Malling Merton 106 trees were headed-back in early April, 1975, before growth began, or were left unpruned. Two heading-back treatments were employed: 2/3 of the previous season's terminal extension growth was removed, or all of that growth was removed just below the scar separating the 1- and 2-year-old branch sections. NAA in latex paint at 0%, 1/2%, 1% or 3% was painted on the cut ends of the shoots immediately after pruning. The experiment was a randomized complete-block design with single tree plots and 10 replications. All the branches on a tree received the same pruning-NAA treatment combination. Bud-break was monitored by counting and averaging the number of buds showing green tissue on 1- and 2-year-old branch sections of 5 branches/tree at various times after green tissue first appeared. Numbers and lengths of shoots originating from 1- and 2-year-old branch sections of 10 branches/tree were determined at various times during the growing season.

In a second experiment, vigorous, 10-year-old, bearing 'Spartan' trees received NAA and/or hedging treatments as follows: 1) unpruned, 2) simulated hedging with all upright shoots on the outside of the tree headed-back by hand at approximately the scar between 1- and 2-year-old wood, and 3) simulated hedging, as above, with the cut ends of the shoots coated with NAA 1% in latex paint immediately after pruning. The treatment units were whole trees in a randomized complete block design with 6 replications. All treatments were completed in late March before growth began. In late summer, treatment response was evaluated by counting and measuring all shoots to the base of 2-year-old wood on 20 representative branches/tree.

In a third experiment, vigorous, upright, 1-year-old branches which developed in 1974 from the trunk of 3-year-old 'McIntosh' trees were treated in late March, 1975, before growth began. NAA 1% in latex paint was applied to either the terminal or basal half of replicated branches. Where NAA was applied to the terminal half of the branch, the terminal bud was not covered. Half of the treated branches in each NAA treatment were then scored with a single, continuous knife cut through the phloem and around the branch. The score was located at the base of the NAA in the terminal-half treatment, or at the top of the NAA in the basal-half treatment. The 5 treatments, including an untreated check, were arranged in a randomized complete-block design, with single-branch plots and 15 replications. Numbers of 1975 shoots originating from each half of the 1-year-old branches and the length of each new shoot were determined at several times during the 1975 growing season.

On the basis of 1975 results, a tree training study was initiated in 1976. Vigorous, 1-year whips of 'Jonamac'/MM 106 and 'Empire'/MM 106 were headed-back to a height of 76 cm (30 inch) immediately after planting. Three growth zones were identified on the basis of the preferred structure of a young tree: Tip, midsection and base. The tip zone is the first 4 buds below the heading cut. Ideally, 1 strong shoot, slated to become the central leader, should arise from this zone. The midsection zone, from below the first 4 buds to a point about 41 cm (16 in) above the ground, is the region from which the first scaffold branches should arise. The base zone is from 41 cm to ground level. Growth in this zone is of little value because it must be removed to assure proper tree structure. NAA 1% in latex paint was applied to 1 or more of these zones immediately after planting as follows: Tip — the first bud below the heading cut was left untreated and a band of NAA-latex paint was applied around the trunk, starting below the first bud and covering the next 3 buds. Midsection — in the area below the uppermost 4 buds and above the basal 41 cm of trunk, 4 buds, evenly spaced around the trunk, were selected as desirable locations for scaffold branches. All other buds in this section were individually coated with NAA-latex paint, but the bark between buds was not covered. Base — the entire basal 41 cm of the trunk was coated with NAA-latex paint. A total of 8 individual and combination treatments were made including an untreated control. For each cultivar the experiment was set up in a randomized complete-block design with single-tree plots, replicated 12 times. In late summer, the shoots developing from each of the 3 zones were counted and measured. After leaf-fall the crotch angles of all the branches originating in the mid-section zone were measured with a protractor.

**Results**

NAA painted on the ends of pruned 'Delicious' branches delayed bud-break in 1-year-old branch sections roughly in proportion to concentration (Fig. 1, 2), but did not affect bud-break in the 2-year-old branch sections, even when applied directly to the 2-year-old wood. Growth from the unpruned and pruned 'Delicious' branches receiving no NAA (Fig. 3) behaved as reported previously (2). NAA did not overcome the invigorating effect of either heading-back treatment, but it did reduce the number of shoots and total shoot growth from 1-year-old wood to control levels. Reductions in growth from 1-year-old wood were associated with compensating increases in growth from 2-year-old wood.

Hedging increased the number of shoots, average shoot length, and total shoot growth of 'Spartan' trees (Table 1). NAA applied to the cut ends of the pruned branches had no effect on the response to hedging.

Application of NAA to the terminal half of vigorous 'McIntosh' branches substantially altered the distribution of growth, but did not affect total growth (Fig. 4). Inhibition of bud development on the terminal half by NAA stimulated more buds on the basal half to develop into shoots. Although the number of growing shoots was less than in the control, the total growth was not significantly different. NAA applied to the basal half of branches virtually eliminated growth from that section without affecting the number of shoots or amount of growth developing on the terminal half. Scoring intact shoots interrupts the downward movement of growth regulating materials and the upward movement of metabolites (6). Terminal shoot growth is reduced by such a treatment (6), and growth from the basal half develops as though the branch had been headed at the score (Forshey, unpublished). Scoring below the terminal NAA treatment in this experiment produced a similar response from the basal branch half. NAA applied to the basal half of the branch did not totally suppress the growth-inducing effects of a mid-shoot score; 1 or 2 vigorous shoots developed from buds just below the score (Fig. 5).

In the young trees, growth responses of 'Empire' were similar to those presented for 'Jonamac' (Table 2). The 4 treatments not including basal NAA responded much as has been suggested from 1975 results. NAA applied to tip and/or mid-section zones reduced growth in the treated zones, but increased growth in untreated zones offset these reductions. Redistribution of growth resulted primarily from changes in the numbers of shoots developing in each zone. The basal treatment, whether alone or in combination, radically altered the distribution of growth among zones and significantly reduced total growth. Treating other zones in conjunction with the base produced some shifts of growth between zones, but the dominant influence of the basal treatment on growth was unaltered.

Crotch angles of scaffold shoots were favorably influenced by NAA applications to the tip, but not to other zones (Table 3). Verner reported increased crotch angles in young 'Delicious' trees after treatment of heading cuts with indolebutyric acid (IBA), and pointed out the influence of distally-produced auxin supply on crotch angle (12, 13).

**Discussion**

NAA applied to the cut ends of headed-back shoots delayed
EFFECTS OF NAA ON BUD BREAK OF 'DELICIOUS' BRANCHES

1975

I unpruned ■ headed-back 2:3

Fig. 1. Effects of NAA concn (%) on bud-break in 1-year-old branch sections of vigorous, upright 'Delicious' branches on 4 dates in spring. Pruning and NAA treatments applied before growth began. Mean separations within dates by Duncan's multiple range test, 5% level.

the growth of vegetative buds, but complete inhibition of growth required: 1) application of NAA directly to the buds, and 2) the simultaneous presence of growing shoots above the treated area. When basally-treated branch halves were physiologically isolated from the terminal halves by scoring, 1 or 2 buds just below the score grew through the NAA and produced vigorous shoots. These shoots, in combination with NAA, suppressed further bud development from the remainder of the NAA-treated basal branch half. In fact, the number of shoots and the amount of growth from these physiologically isolated, NAA-treated basal branch halves were equal to those from NAA-treated terminal branch halves, in which the terminal buds were not treated with NAA. This suggests an interaction of NAA with growth regulators produced by growing shoots. Sprout control with NAA (10, 11) is probably successful because active shoot growth occurs above the treated pruning cuts. NAA would not be expected to control growth from heading-back cuts when the application is made to the cut ends. This would seem to limit the usefulness of NAA for control of the undesirable shoot growth that develops in response to hedging.

The importance of early physiological events in determining growth patterns is illustrated by the effects of scoring. Although a single knife cut would only serve as an effective girdle for a few weeks early in the growing season (13), the changes set in motion by that girdle had a substantial impact on numbers of shoots, total growth, and the site of that growth. In both experiments involving branch treatments, the final pattern of growth was clearly established by the time 20-25% of the

Fig. 2. Effects of NAA on shoot development as of May 21, 1975, from 1-year-old sections of upright 'Delicious' branches pruned and treated with NAA before growth began. From the left: a) 0% NAA; b) 1/2% NAA; c) 1% NAA; d) 3% NAA.
Fig. 3. Effects of pruning and NAA treatments on numbers of shoots and shoot growth developing on 1- and 2-year-old branch sections (1974 and 1973) of vigorous, upright 'Delicious' trees and on total growth from both branch sections. Pruning treatments are as follows: 1) unpruned control; 2) 2/3 of 1974 terminal extension growth removed; 3) all (3/3) of 1974 terminal extension growth removed. NAA treatments are as follows: a) 0% NAA; b) 1/2% NAA; c) 1% NAA; d) 3% NAA. Mean separations by Duncan's multiple range test, 5% level.

Fig. 4. Effects of NAA on shoot growth developing from basal and terminal halves of vigorous, upright 1-year-old 'McIntosh' branches. The numbers above each bar graph represent the average number of shoots originating from each branch half. NAA treatments are as follows: 1) control; 2) NAA (1%) applied to terminal branch half; 3) NAA (1%) applied to basal branch half. Scoring treatments are as follows: a) no score; b) scored. Mean separations within branch halves and growth totals by Duncan's multiple range test, 5% level.
Table 1. Effect of hedging and NAA treatments on shoot growth of vigorous ‘Spartan’ apple trees.

<table>
<thead>
<tr>
<th>Treatment</th>
<th>No. shoots</th>
<th>Total shoot growth (cm)</th>
<th>Mean shoot length (cm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Check</td>
<td>3.5a</td>
<td>56.6a</td>
<td>16.2a</td>
</tr>
<tr>
<td>Hedged</td>
<td>4.4b</td>
<td>106.5b</td>
<td>24.4b</td>
</tr>
<tr>
<td>NAA on hedging cuts</td>
<td>3.9ab</td>
<td>98.4b</td>
<td>25.2b</td>
</tr>
</tbody>
</table>

*Mean separation in columns by Duncan’s multiple range test, 5% level.

xTrees pruned and NAA (1% in latex paint) applied in late March before growth started.

yHedging cut made by hand at approximately the growth scar between 1 and 2 yr-old wood.

zHedged as in (y) above and all pruning cuts coated with NAA/latex paint.

In all cases, the NAA treatments had a much greater effect on the distribution of growth than on the total amount of growth. NAA did not nullify pruning-induced increases in total growth of vigorous branches, although the distribution of that growth was changed. NAA had a much greater effect on bud development from 1-year-old branch sections of pruned branches than from 2-year-old branch sections. The buds on 1-year-old wood are almost exclusively vegetative and thus may be more responsive to NAA-induced growth inhibition (9). For each reduction in shoot growth from 1-year-old wood, there was a compensating increase in growth from the 2-year-old section (Fig. 3). Increased vegetative growth from 2-year-old wood is associated with reduced fruitfulness (3), and is, therefore, an undesirable response. Elfving and Forshey (2) reported evidence for 2 mechanisms which influence the amount and distribution of growth from a branch. The data presented here indicate that NAA affects growth distribution largely by controlling the number of buds that develop into shoots, rather than by controlling the amount of growth those shoots make. NAA apparently cannot replace the growth-controlling influence of the tip of an unpruned branch.

These responses to NAA can be used to facilitate training of young trees. The most acceptable structure was obtained when the tip of newly-planted trees was treated with NAA (Fig. 6). The “witch’s broom” effect of heading-back was completely eliminated and replaced by improved growth of favorably positioned scaffold-candidate shoots with better crotch angles (Table 3). In nearly all cases, only 1 dominant shoot developed from the tip. In a few tip-treated trees, the uppermost bud failed to develop, but a lower bud, although treated with NAA, developed into a central leader shoot (Fig. 7). This again emphasizes the interaction of NAA and active shoot growth above. Trees receiving the tip treatment required little or no pruning to adjust tree structure. This approach is simpler and more effective than other chemical treatments that have been suggested to stimulate earlier scaffold branch development (7, 14, 15).

Table 2. Effects of individual and combination NAA treatments on zonal and total growth of newly-planted ‘Jonamac’ apple trees.

<table>
<thead>
<tr>
<th>NAA treatment</th>
<th>Tip</th>
<th>Mid-section</th>
<th>Base</th>
<th>Total tree</th>
</tr>
</thead>
<tbody>
<tr>
<td>Check</td>
<td>3.2c</td>
<td>2.4c</td>
<td>0.7b</td>
<td>6.3bc</td>
</tr>
<tr>
<td>Tip</td>
<td>1.1a</td>
<td>4.3d</td>
<td>1.6ed</td>
<td>6.9c</td>
</tr>
<tr>
<td>Mid-section</td>
<td>2.8bc</td>
<td>1.2b</td>
<td>1.2bc</td>
<td>5.1b</td>
</tr>
<tr>
<td>Base</td>
<td>2.2b</td>
<td>0.3a</td>
<td>0a</td>
<td>2.4a</td>
</tr>
<tr>
<td>Tip + mid-section</td>
<td>1.1a</td>
<td>2.4c</td>
<td>2.1d</td>
<td>5.6b</td>
</tr>
<tr>
<td>Tip + base</td>
<td>1.1a</td>
<td>0.4a</td>
<td>0.1a</td>
<td>1.6a</td>
</tr>
<tr>
<td>Mid-section + base</td>
<td>2.3b</td>
<td>0.2a</td>
<td>0.1a</td>
<td>2.6a</td>
</tr>
<tr>
<td>Tip + mid-section + base</td>
<td>1.3a</td>
<td>0.6a</td>
<td>0a</td>
<td>1.8a</td>
</tr>
</tbody>
</table>

*Mean separation in columns within variable by Duncan’s multiple range test, 5% level.

Fig. 5. Effects of scoring on shoot growth from NAA-treated basal branch halves. Note the development of strong shoots from NAA-treated buds just below the score (arrow).

Table 3. Effects of NAA applications to various zones of newly-planted apple trees on average crotch angle of all shoots arising in the mid-section zone.

<table>
<thead>
<tr>
<th>NAA treatment</th>
<th>Jonamac</th>
<th>Empire</th>
</tr>
</thead>
<tbody>
<tr>
<td>Check</td>
<td>40.6b</td>
<td>42.5b</td>
</tr>
<tr>
<td>Tip</td>
<td>43.0b</td>
<td>41.8b</td>
</tr>
<tr>
<td>Mid-section</td>
<td>42.4b</td>
<td>44.9b</td>
</tr>
<tr>
<td>Base</td>
<td>59.9a</td>
<td>59.0a</td>
</tr>
</tbody>
</table>

*Mean separation in columns by Duncan’s multiple range test, 5% level.
The mid-section bud spacing treatment proved to be ineffective and impractical. In a number of cases, buds chosen as desirable sites failed to develop even though they were not coated with NAA. The treatment was very time-consuming and required considerable judgment on the part of the applicator. The basal treatment was very effective in controlling growth from the base of the trunk, but its unfavorable effects on total growth make such a treatment unacceptable. The origin of the growth suppression is unclear, but it is interesting to note that the reduction in growth associated with the basal NAA came about primarily because of an overall failure of buds to develop into shoots. Newly planted trees have limited root systems and root development must proceed rapidly to support top growth. The large dose of NAA applied to the base of the trunk may have interfered with early root development.

A recent, extensive survey of cultural practices and orchard productivity in Washington indicated that 1 of 3 factors consistently associated with early bearing and high productivity was the early selection and training of scaffold branches (1). The NAA tip treatment of newly planted trees would appear to be an effective step in that direction.

**Literature Cited**


