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Modification of Branching Behavior in Apical-Dominant Apple Trees With Plant Growth Regulators and Their Residual Effects on Tree Growth After Transplanting

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Abstract

Nursery trees of apple hybrids NY73334-35, NY75413-30 and NY75414-1 were treated once or twice with the plant growth regulator (PGR) Accel or Promalin, alone or in combination, to induce branching. Regardless of the PGR used, or the rate and frequency of application, treated trees produced more shoots per tree than untreated control trees for all three hybrid selections. Medium [750 mg·L^{-1} N-(phenylmethyl)-1H-purine-6-amine (6 benzyladenine or BA)] or high rates (1000 mg·L^{-1} BA) of both compounds were more efficient in shoot induction than low rates (500 mg·L^{-1} BA). When comparable rates of both chemicals were applied, no differences in the number of lateral shoots, shoot length distribution, total tree extension growth and apical dominance among chemical treatments were noted. Regression analysis on rates of Accel and Promalin *vs.* total number of shoots demonstrated that Accel promoted a linear increase in this characteristic, whereas Promalin caused a parabolic effect on branching. The trees treated once or twice in the nursery at medium rates of either compound were transplanted into the orchard. One year after transplanting the trees exhibited a pronounced increase in the total number of shoots and their extension growth, and also considerable reduction in apical dominance. It is believed that those changes may facilitate canopy training, and thus accelerate the onset of bearing.

An important advantage of planting apple (*Malus* × *domestica* Borkh.) trees with lateral shoots (feathers) is the potential for early cropping. However, a number of commercially important apple cultivars lack the natural ability to induce feathers. Branching may be influenced by rootstock (33), propagation technique (11), cultural practices (4, 40) and/or environmental factors (36). However, the degree of branching in a given cultivar is primarily under genetic control (35). Recently there have been attempts using molecular biology techniques to transfer branch regulating gene(s) into newly bred apple cultivars (S. Brown and N. Weeden, Cornell University, personal communication).

Several methods to promote branching have been developed (27, 30, 32, 38, 40). Application of chemical branching agents has been shown to be one of the most efficient and predictable ways of inducing branching (35). Branching agents fall into three basic groups, namely auxin transport inhibitors, terminal bud inhibitors, and cytokinins [such as 6-benzyladenine (BA)] with or without gibberellin (GA) (primarily GA_{4+7}) additives. Cytokinins are used in the nursery industry worldwide. In contrast with branching agents from the first two groups, BA compounds have not basically shown any detrimental effects on treated nursery plants, but Miller and Eldridge (26) reported some phytotoxicity on young Promalin-treated orchard apple trees. It has been suggested that BA+GA may play a sequential role in overcoming apical dominance with the initiation of axillary buds by BA and their subsequent elongation by GA (2, 3). Recently, the PGR cyclanilide, which appears to interfere with auxin transport was shown to stimulate the formation of lateral shoots on current season's shoot growth in nursery- and orchard-grown apple and sweet cherry trees (7, 8).

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The main effect of application of a branching agent is to increase the number of lateral shoots on the treated branch (3, 10). Yet, the variation in tree growth habit may also result from changing such features as shoot elongation (39), crotch angle (13, 19, 22), size of leaf (21, 22) and development of root system (13, 21, 22, 23). Tree height and trunk diameter are usually not affected by application of branching agents (1, 39). It is commonly agreed that the net branching effect is associated with the type of chemical used, and rate and frequency of application. However, it is known that different cultivars, which are grown in the same environmental and cultural conditions, may differently respond to application of branching agents (6, 15, 18). In contrast with natural branching ability, this phenomenon may be termed *branching potential* that is essentially an index of responses to exogenously induced branching (16). For instance, the apple cultivars 'Liberty' and 'Paulared' are characterized by low ability to branch, but both have different branching potential, i.e. 'Liberty' branches readily when treated with BA-branching agents, whereas 'Paulared' does not (6, 15).

Besides the direct changes in nursery tree morphology induced by branching agents, carry-over effects may also result. Application of branching agents in the nursery (with no additional sprays in the orchard) usually contributes to increased cropping and return bloom in comparison with untreated trees (9, 40). Quinlan (34) reported that chemical treatment to improve branching of apple nursery trees of 'Spartan' and 'Cox Orange' resulted in better flowering and cropping in the early years. Johann (21) reported that during the first four years branching agent-treated trees produced ca. 15 kg more apples per tree than untreated trees. Tree quality is a result of the number, length, crotch angle, size and distribution pattern of lateral shoots, parent shoot height and diameter, and the distribution and expansion of the root system. If tree quality is to be considered as an important factor in orchard establishment, a young orchard tree should bear its first crop in the second or third year after planting; otherwise the advantage of quality is lost (29). Calculation of crop values indicates positive economic benefits resulting from planting feathered trees vs. whips (9, 14, 29). The objectives of this research were to determine the potential for improving branching habit of nursery trees of three apple hybrids from the Cornell-Geneva Fruit Tree Breeding Program and to establish protocols for chemical branching for these apple selections in the nursery before their release to commercial production, and to observe residual effects of the previous chemical treatments one year after transplanting these trees into the orchard.

Materials and Methods

Nursery experiment. This experiment was carried out in the nursery of the New York State Agricultural Experiment Station in Geneva NY, using apple trees in their first year after budding. The trees were apple hybrid selections with known resistance to powdery mildew (*Podosphaera leucotricha* [Ellis & Everth.] Kuntze), apple scab (*Venturia inaequalis* [Cooke] Wint.), and cedar apple rust (*Gymnosporangium juniperi-virginiana* Schwein), and coded as NY73334-35 ('Liberty' x 'Starking Delicious') on Malling 9, NY75413-30 ('Liberty x 'Starking Delicious') on Malling 26, and NY75414-1 ('Liberty' x 'Macspur,') on Malling 9 rootstock. The trees of each hybrid selection were planted in separate rows. Before treatment application, diameter of the parent shoot (tree trunk) at 5 cm above the bud union, and tree height were measured.

Treatments. The trees were treated with foliar sprays containing the proprietary mixture of Promalin and/or Accel (Abbott Laboratories, Chicago, Ill.) containing 1.8% BA + 1.8% GA_{4+7}, and 1.8% BA + 0.18% GA_{4+7}, respectively. A non-ionic wetting agent Buffer-X (Custom Agricultural Formulators, Fresno, Calif.) at 0.3% was added to each chemical spray. The chemical rates chosen for this experiment were based on the final concentration of BA in the spray tank. Control trees were sprayed with an aqueous solution of 0.3% Buffer-X at the same time as chemically treated trees. The treatments are explained in Table 1. The rates 250 + 250, 500 + 250 and 375 + 375, and 750 + 250 mg·L^{-1} BA are referred to in the text as "low", "medium" and "high", respectively. At the time of treatment application, the trees had no lateral branches, and tree height was ca. 80-100 cm. The sprays were directed at the uppermost 20-25 cm of parent shoots and applied to run-off. The trees were not pruned during the entire course of the study. All applicable cultural and plant protection practices were routine as for commercial fruit nurseries.

Data recording and analysis. A randomized complete block design with six single-tree replications was used for each apple hybrid examined. Upon harvest in the fall, trunk diameter, tree height, and the number and length of lateral shoots were recorded. Apical dominance was expressed as percent of parent shoot length in total tree extension growth, according to the method of Lee and Looney (25). The data were subjected to analysis of variance. Branching responses vs. rates of sequential application of both branching agents were subjected to regression analysis. All calculations were done in R (R Foundation for Statistical Computing, Vienna, Austria, 2006), and checked with SAS STAT software (SAS Institute Inc., Cary, NC, 2004).

Table 1. Proprietary spray treatments applied to nursery trees to induce lateral branching on three apple hybrid selections. All sprays applied dilute in aqueous solution with a hand-wand sprayer to run-off. Buffer-X included in all sprays at 0.3% (w/v).

Treatment	Promalin[z] (mg•L^{-1} BA)	Accel[z] (mg•L^{-1} BA)
1	0	0
2	250 + 250[y]	0
3	500 + 250[y]	0
4	750 + 250[y]	0
5	0	250 + 250[y]
6	0	500 + 250[y]
7	0	750 + 250[y]
8	250[x]	250[x]
9	250[x]	500[x]
10	250[w]	250[w]
11	375[w]	375[w]

[z] Promalin is a proprietary mixture of 1.8% (w/v) N-(phenylmethyl -1H-purine 6-amine and 1.8% (w/v) gibberellins A_{4+7}; Accel is a mixture of 1.8% (w/v) N-(phenylmethyl -1H-purine 6-amine and 0.18% (w/w) gibberellins A_{4+7}

[y] sequential sprays applied at the rate indicated (in mg•L^{-1}) with the first spray applied on 2 July, and the second spray applied on 16 July

[x] sequential spray applied at the rate indicated with the first spray (Accel) applied on 2 July, and the second spray (Promalin) applied on 16 July

[w] single spray applied at the rate indicated on 2 July with a mixture of Promalin and Accel

Orchard experiment. The experiment was conducted in the orchard of the New York State Agricultural Experiment Station in Geneva NY. The trees chosen for this experiment were those previously treated in the nursery with either Promalin (500 + 250) mg·L^{-1} BA [treatment 3], Accel (500 + 250) mg·L^{-1} BA [treatment 6], Accel + Promalin (500 + 250) mg·L^{-1} BA [treatment 9], Accel at 375 + Promalin 375 mg·L^{-1} BA combined in one spray [treatment 11], and untreated control trees [treatment 1] (see Table 1). In the autumn after harvest, the trees were directly transplanted into the orchard. In the spring, the tree leader was cut back to ca. 100 cm above the soil line. The trees were trained to a central leader canopy by branch bending techniques with minimal pruning. No chemical branching agents were applied. The orchard floor consisted of herbicide strips maintained with glyphosate [N-(phosphonomethyl)glycine] and/or 2,4-D (2,4-dichlorophenoxyacetic acid) and mowed sod consisting of perennial rye (*Lolium perenne* L.), red fescue (*Festuca rubra* L.) and Kentucky blue grass (*Poa pratensis* L.) in the interrows. Cultural and plant protection practices were routine as for young non-bearing apple commercial orchards.

Data recording and analysis. A split-plot design with five blocks each of three main plots (hybrids), and five subplots (nursery chemical treatment) each containing one tree was used. Upon completion of tree growth in the orchard, the following data were recorded for each tree: trunk diameter, tree height, the number and length of lateral shoots $\leq$ 5 cm

Table 2. Statistical differences between control (unsprayed trees) and the means of all treatments sprayed with Promalin and/or Accel plant growth regulators for three apple hybrid selections in the nursery.

Characteristic	Apple hybrid		
	NY73334 – 35	NY75413 – 30	NY75414 – 1
Trunk diameter increment (cm)	-0.02 ns[z]	-0.01 ns	0.10 ns
Tree height increment (cm)	3.7 ns	4.6 ns	3.1 ns
Total tree extension growth (cm)[y]	-78.1 **	-59.4 ***	-25.0 ***
Apical dominance (%)[x]	29.2 ***	33.0 ***	20.5 ***
No. lateral shoots 0-5 cm	-0.8 *	-3.0 ***	-5.5 ***
No. lateral shoots 5-10 cm	-1.4 ***	-2.1 ***	-1.0 ***
No. lateral shoots 10-20 cm	-1.4 ***	-1.4 ***	-0.03 ns
Total no. lateral shoots	-2.0 ***	-7.4 ***	-7.2 ***

[z] differences marked with *, ** , *** are significant at P= 0.05, P= 0.01 and P= 0.001, respectively; ns=not significant.
[y] length of parent shoot (tree leader) included.
[x] parent shoot length expressed as percent of total tree extension growth according to the method of Lee and Looney (25).

(spurs), > 5-30 cm, and > 30 cm. Some of the recorded data were used to calculate annual increment of trunk cross-sectional area, total number of lateral shoots, total extension shoot growth and % of apical dominance. All data were subjected to analysis of variance and mean separation was by LSD with $\alpha = 0.05$.

Results

Nursery experiment. All three of the apple selections used in this study exhibited a strong apical dominant growth pattern (Fig. 1). Treatment with Promalin and/or Accel at rates ranging from 250 $mg \cdot L^{-1}$ BA to 750 $mg \cdot L^{-1}$ BA had a significant effect on most of the growth characteristics measured except tree height, trunk diameter, and the number of 10-20 cm laterals for NY75414-1 (Table 2).

Effect on lateral shoot distribution. The detailed data on shoot length distribution are not shown. However, chemically treated trees of NY75413-30 and NY75414-1 produced significantly more spurs than control trees. No such differences were noted in hybrid NY73334-35. Treated trees of all three hybrid apple selections produced twice as many of 5-10 cm laterals as untreated trees. Yet NY75414-1 trees treated with low rates of either Promalin or Accel, or a combined Accel + Promalin treatment, did not differ in this respect from the controls. The trees of apple hybrid selections NY73334-35 and NY75413-30 induced a similar number of both 5-10 cm and 20-30 cm long shoots, whereas NY75414-1 did not produce 10-20 cm shoots.

Total number of shoots. Regardless of the type of chemical used, its concentration and frequency of application, treated trees of NY73334-35, NY75413-30, and NY75414-1 produced on average 10.6, 7.3, 7.5 vs. 1.2, 0.0, 0.1 shoots/tree for the controls, respectively (Table 3). Medium and high rates of Promalin promoted significantly more laterals than did the low rates. No significant differences in the total number of shoots induced by different Accel rates were observed, except for Accel that was sequentially applied at 250 $mg \cdot L^{-1}$ BA (Table 1, treatment 5) to NY75414-1 trees. No significant difference occurred in the number of laterals between Promalin and Accel applied at medium and high rates (Table 3). No significant differences in the total number of shoots generated by medium rates of the chemicals used in different manner were noted except for one single spray containing Accel plus Promalin, each at 375 $mg \cdot L^{-1}$ BA (Table 1, treatment 11) to NY75413-30 trees (Table 3, Fig. 2). Despite a similar total number of shoots induced by medium or high rates of both compounds, there was a great

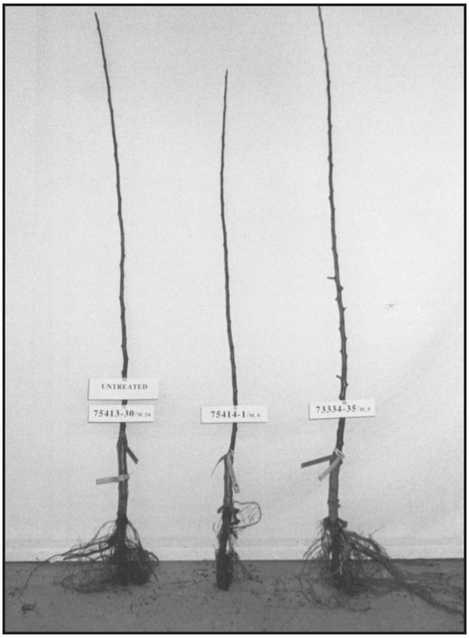

Figure 1. Untreated apple nursery trees of NY 75413-30 (left), NY 75414-1 (middle) and NY 73334-35 (right).

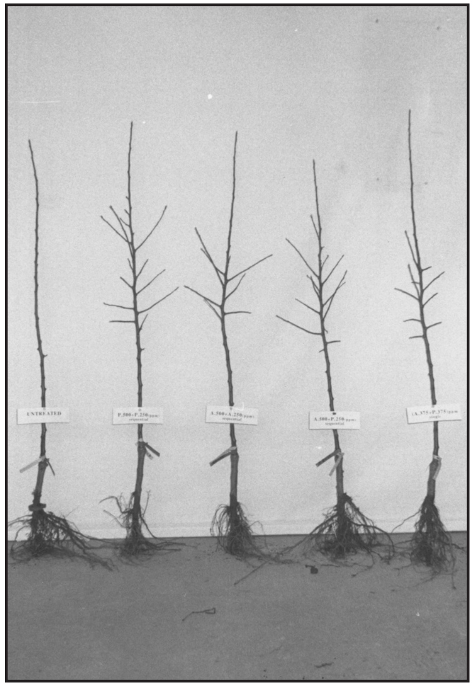

Figure 2. Chemically treated apple nursery trees of NY 73334-35 at a comparable rate of 750 mg•L^{-1} BA. From left to right: untreated control, (P. 500 + P. 250) sequential spray, (A. 500 + A. 250) sequential spray, (A. 500 + P. 250) sequential spray, (A. 375 + P. 375) single spray, where P. = Promalin and A. = Accel.

difference in shoot quality (length) among the hybrid trees. Most shoots produced by apple hybrid selection NY75413-30 and/or NY75414-1 were not suitable for tree training. In NY75414-1 trees, the applied range of both chemicals was not sufficient to stimulate adequate feathering. These results coupled with field observations of mature tree form indicate the apple hybrid NY75414-1 is very upright, suggesting that it can be genetically characterized as possessing a more apical dominant growth pattern than the other two apple hybrid selections. The comparison of chemical treatments for different shoot length categories expressed by P (>F) values indicates that the responsiveness to applied treatments, as measured by total number of shoots, was greatest in apple hybrid selection trees NY75414-1 [P <0.0001], then in NY75413-30 [P = 0.0015], and then in NY73334-35 [P = 0.0513].

Regression analysis for the rates of sequential application of either Accel or Promalin vs.

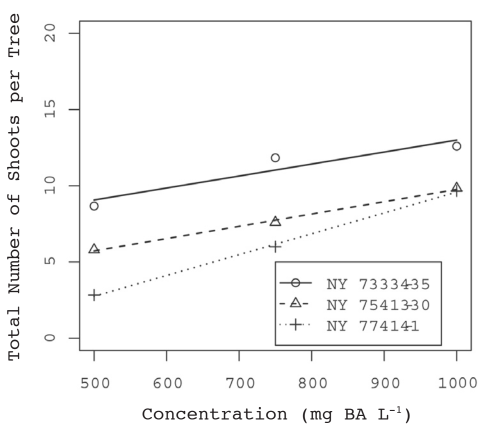

Figure 3. Branching responses of apple nursery trees as influenced by Accel treatments.

Table 3. Total number of lateral shoots produced on nursery trees of three hybrid apple selections following sequential spray treatments with Promalin and/or Accel plant growth regulators.

Treatment rate (mg•L^{-1} BA)	Apple hybrids[z]		
	NY73334 – 35	NY75413 – 30	NY75414 – 1
1. Control	1.2 d[v]	0.0 d	0.1 d
Promalin[y]			
2. 250 + 250	6.4 bc	3.5 c	4.4 bc
3. 500 + 250	13.2 a	10.1 a	10.1 a
4. 750 + 250	13.8 a	10.5 a	8.2 a
Accel[y]			
5. 250 + 250	7.8 abc	8.0 a	2.2 c
6. 500 + 250	11.4 ab	8.6 a	8.0 a
7. 750 + 250	11.7 ab	10.4 a	9.9 a
Accel + Promalin			
8. 250 + 250[x]	4.7 cd	3.7 c	4.5 b
9. 500 + 250[x]	12.9 ab	7.5 ab	9.7 a
10. (250 + 250)[w]	12.0 ab	6.9 abc	7.3 ab
11. (375 + 375)[w]	11.8 ab	4.0 bc	10.8 a

[z] before ANOVA, square root transformations were used to stabilize variances. The data are shown in back-transformed values
[y] two separate chemical applications
[x] two separate chemical applications with the first being Accel
[w] one combined chemical application
[v] mean separation within columns by least significant difference test, α= 0.05. Interaction of hybrid x treatment was not significant

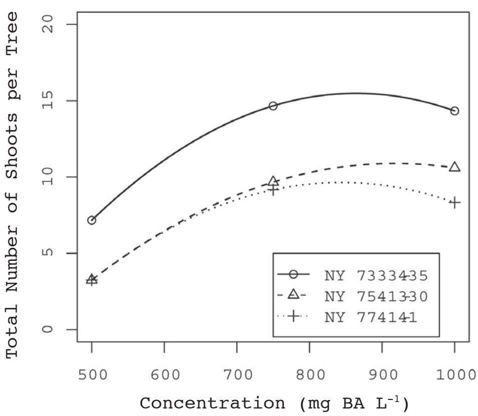

Figure 4. Branching responses of apple nursery trees as influenced by Promalin treatments.

branching responses demonstrated that Accel promoted a linear increase in total number of shoots within the range of rates applied. No clear-cut maxima for total number of shoots were observed: linear models were adequate in the range of Accel rates used (Table 4, Fig. 3). Application of Promalin showed a parabolic effect on branching with the maximum total number of shoots within the range of the rates used. Responses were fitted by quadratic models, and maximum total number of shoots for the trees of hybrids NY3334-35, NY75413-30 and NY75414-1 were predicted at Promalin rates of 864, 917 and 844 mg·L^{-1}BA, respectively (Table 4, Fig. 4).

Total tree extension growth and apical dominance. In most instances medium and high rates produced significantly greater values of total extension growth in comparison with low rates. Low chemical rates and the controls did not differ significantly except in treatments 5 and in NY75413-30 trees (Table 5). The magnitude of apical dominance was inversely related to total extension growth (Tables 5 and 6). Irrespective of type of plant materials used, type of chemical compound

Table 4. Coefficients (with standard errors in parentheses) for the regression of the total number of shoots on concentration of the chemical branching agents.

Branching agent	Apple hybrid	b_0	b_1	b_{11} (x 10^{-5})	r^2
Promalin[z]	NY73334-35	- 31.333 (19.79)	0.1083 (0.058)	- 6.267 (3.892)	0.58
	NY75413–30	- 26.030 (11.13)	0.0805 (0.031)	- 4.387 (2.031)	0.67
	NY75414–1	- 28.833 (7.54)	0.0912 (0.021)	- 5.400 (1.365)	0.73
Accel[y]	NY73334-35	5.0430 (2.06)	0.0080 (0.003)		0.37
	NY75413–30	1.6800 (2.33)	0.0081 (0.003)		0.35
	NY75414–1	- 4.0833 (2.18)	0.0137 (0.003)		0.60

[z] Regression equation: $y = b_0 + b_1 x + b_{11} x^2$, where x is concentration of branching agent in mg•L-1 BA
[y] Regression equation: $y = b_0 + b_1 x$, where x is concentration of branching agent in mg•L-1 BA

Table 5. Total tree extension growth (cm) produced on nursery trees of three hybrid apple selections following sequential spray treatments with Promalin and/or Accel plant growth regulators.

Treatment rate (mg•L-1 BA)	Apple hybrid NY73334 – 35	NY75413 – 30	NY75414 – 1
1. Control	147.8 d[w]	110.0 e	104.5 f
Promalin [z]			
2. 250 + 250	189.6 bcd	130.1 de	106.5 f
3. 500 + 250	279.3 a	196.1 ab	144.1 abc
4. 750 + 250	279.8 a	204.5 a	124.8 de
Accel [z]			
5. 250 + 250	177.6 cd	154.1 cd	110.8 ef
6. 500 + 250	255.8 ab	171.0 bc	127.6 cde
7. 750 + 250	245.2 ab	207.8 a	155.5 a
Accel + Promalin			
8. 250 + 250[y]	193.2 bcd	134.6 de	111.1 ef
9. 500 + 250[y]	250.4 ab	166.5 bc	133.9 bcd
10. (250 + 250)[x]	196.3 bcd	144.7 cd	121.5 def
11. (375 + 375)[x]	237.3 abc	159.1 cd	148.6 ab

[z] two separate chemical applications
[y] two separate chemical applications with the first being Accel
[x] one combined chemical application
[w] mean separation within columns by least significant difference test, α= 0.05. Interaction of hybrid x treatment was not significant

and frequency of application, medium and high rates significantly reduced apical dominance compared with the controls.

Orchard experiment. The data recorded one year after transplanting the trees into the orchard did not show any significant differences in the number of spurs (P = 0.483), tree height (P = 0.217) and the increment of tree trunk cross-sectional area (P = 0.126) between chemically treated trees and the controls. There were no differences in these characteristics among the chemical treatments. Regardless of treatment, observations on shoot distribution indicated some significant differences between the trees in the number of shoots ≤ 30 cm. The number of these shoots

Table 6. Apical dominance (%) in nursery trees of three hybrid apple selections following sequential spray treatments with Promalin and/or Accel plant growth regulators. Apical dominance was calculated according to the method of Lee and Looney (25).

Treatment rate (mg•L^{-1} BA)	Apple hybrid		
	NY73334 – 35	NY75413 – 30	NY75414 – 1
1. Control	87.0 a[w]	100.0 a	97.9 a
Promalin [z]			
2. 250 + 250	70.6 abc	88.8 ab	92.4 ab
3. 500 + 250	46.8 de	56.4 fg	71. 8 ef
4. 750 + 250	42.7 e	50.2 g	71.9 ef
Accel [z]			
5. 250 + 250	72.2 abc	71.1 de	91.6 ab
6. 500 + 250	48.1 de	61.9 efg	75.7 de
7. 750 + 250	45.6 de	51.9 g	64.8 f
Accel + Promalin			
8. 250 + 250[y]	73.2 ab	84.9 bc	87.9 bc
9. 500 + 250[y]	48.0 de	65.9 def	73.2 def
10. (250 + 250)[x]	61.1 bcd	76.7 bcd	81.3 cd
11. (375 + 375)[x]	54.8 cde	75.3 cd	68.1 ef

[z] two separate chemical applications
[y] two separate chemical applications with the first being Accel
[x] one combined chemical application
[w] mean separation within columns by least significant difference test, α= 0.05. Interaction of hybrid x treatment was not significant

expressed as overall mean was 2.5, 4.4 and 3.2 (LSD = 1.40) for apple hybrid selections NY73334-35, NY75413-30 and NY75414-1, respectively. All chemically treated trees of NY75414-1 were characterized by a significantly higher number of shoots ≤ 30 and shoots longer than 30 cm in comparison with control trees (data not shown).

Total number of shoots. NY75413-30 trees were characterized by having significantly more lateral shoots than NY73334-35 or NY75414-1 trees as expressed by the overall mean value of total number of shoots (Table 7). However, the comparison of the hybrid controls indicates differences in this characteristic between both NY73334-35 and NY75413-30 vs. NY75414-1 (Table 7). Application of chemical branching agents to nursery trees caused a significant residual effect on total shoot number since the mean values for each treatment were significantly higher than that of the control (Table 7, and Figures 5 and 6). In all trees, there were no significant differences in total number of shoots among chemical treatments. Total number of shoots for all chemical treatments in NY75414-1 and NY75413-30 trees [except for trees from nursery treatment 11 (Tables 1 and 7)] significantly differed from their respective controls. No differences between chemical treatments and the control in NY73334-35 trees were found (Table 7).

Total extension growth. The differences in total extension growth assessed by the overall cultivar and control means indicate that NY75413-30 trees produced significantly greater total extension growth than NY75414-1 trees (Table 8). However, there were no significant differences in this respect between NY73334-35 and NY75413-30 or between NY73334-35 and NY75414-1 trees (Table 8). No differences between the treatments in either NY73334-35 or NY75413-30 trees were found except some in NY73334-35 trees [nursery

Figure 5. Apple tree of NY 75414-1 treated in the nursery with Promalin 500 + Promalin 250 mg•L^{-1} BA sequential spray, one year after transplanting into the orchard.

treatment 3 vs. nursery treatment 1 (control) (Tables 1 and 8)]. In NY75414-1 trees, total extension growth for all chemical treatments was significantly greater than the control. Comparison of treatment means indicates lack of differences among the chemical treatments. Yet all chemical treatments assessed the same way produced significantly more total extension growth than control trees (Table 8).

Apical dominance. The NY75414-1 trees exhibited the most distinct apical growth habit compared to other hybrids, as shown by the control means. Each of the chemical treatments applied to NY75414-1 trees significantly reduced apical dominance in comparison with the control trees (Table 9). This was not the case in either NY73334-35 or NY75413-30 trees except in those from nursery treatment 3 (Tables 1 and 9). No significant differences in the reduction of apical dominance between the hybrids within each of the chemical treatments or between the overall chemical treatment means were found (Table 9). However, all chemical treatments significantly suppressed apical dominance in comparison with control trees, as shown by the overall treatment means (Table 9).

Discussion

The primary impact of the chemicals used in these studies was significant changes in syllepsis and its components, i.e. shoot length distribution, extension growth and apical dominance. Other features like parent shoot height and diameter were less affected by the chemical application. All chemical treatments stimulated an increase in the total shoot number which was generally rate-dependent. Both chemicals were similarly efficient in promoting axillary outgrowth. Accel, which contains benzyladenine and GA_{4+7}, applied as a spray, was reported to be ineffective for induction of axillary shoots in chrysanthemum plants (31). The content of BA in Promalin and Accel is the same, whereas they contain

Figure 6. Apple tree of NY 75414-1 untreated in the nursery, one year after transplanting into the orchard.

Table 7. Residual effects of chemical treatment of nursery trees of three hybrid apple selections on the total number of lateral shoots one year after transplanting. Shoot counts are given per tree with no spurs included.

Apple hybrid	Treatment[z]					Hybrid mean
	$P_1 + P_2$	$A_1 + A_2$	$A_1 + P_2$	$(A_3 + P_3)\ x\ 1$	Control	
NY 73334-35	8.2	8.2	6.7	8.2	6.2	7.5
NY 75413-30	10.3	10.3	11.3	8.8	6.2	9.4
NY 77414-1	9.8	7.4	8.0	8.7	2.4	7.3
Treatment mean	9.4	8.6	8.7	8.6	5.0	

[z] chemical treatments done in the nursery (in mg•L^{-1} BA): P_1 - Promalin at 500; P_2 - Promalin at 250; P_3 - Promalin at 375; A_1 - Accel at 500; A_2 - Accel at 250; A_3 - Accel at 375 (treatment details are given in Table 1). LSD $_{0.05}$: cultivar means = 1.54; treatment means = 1.84; between treatments at the same level = 3.17, and for different cultivars = 3.14

Table 8. Residual effects of chemical treatment of nursery trees of three hybrid apple selections on total tree extension growth (cm) one year after transplanting.

Apple hybrid	Treatment[z]					Hybrid mean
	$P_1 + P_2$	$A_1 + A_2$	$A_1 + P_2$	$(A_3 + P_3)\ x\ 1$	Control	
NY 73334-35	366	354	322	361	271	335
NY 75413-30	402	373	355	393	348	374
NY 77414-1	334	310	309	374	143	294
Treatment mean	367	346	329	376	254	

[z] chemical treatments done in the nursery (in mg•L^{-1} BA): P_1 - Promalin at 500; P_2 - Promalin at 250; P_3 - Promalin at 375; A_1 - Accel at 500; A_2 - Accel at 250; A_3 - Accel at 375 (treatment details are given in Table 1). LSD $_{0.05}$: cultivar means = 44.3; treatment means = 54.6; between treatments at the same level = 94.6, and for different cultivars = 93.1

1.8% and 0.18% of GA_{4+7}, respectively. Since in most cases no significant differences in examined tree characteristics were observed to be influenced by medium and high rates of both compounds, it is likely that the main factor responsible for changing parameters of growth characteristics was BA. It seems then, that GA_{4+7} was of minor importance in affecting tree syllepsis, in contrast to the supposition of Cody et al. (3). Basak et al. (1) reported that Paturyl, containing 10% BA, and Promalin (BA+GA_{4+7}) often have shown similar effectiveness in lateral-shoot promotion. Jacyna (17) reported no differences in tree vegetative characteristics when maiden trees of ‘Rubin’ apple were sprayed with 750 mg·L^{-1} BA of either Promalin, Accel, Paturyl or Arbolin (BA+GA_3).

It is not clear why in this experiment Promalin showed a parabolic effect on branching while Accel brought about a linear increase in the total shoot number. One of the likely reasons seems to be a specific response of a particular hybrid or the apparent synergism between BA and GA resulting from the different content of GA in the chemicals used. Greene and Miller (10) reported that when BA was applied in increasing rates to young ‘Starkrimson’ apple trees, a linear increase in the number of shoots associated with a reduction in shoot length was observed. Koen et al. (24) found that Promalin applied to young ‘Red Delicious’ apple trees promoted an increase in the number of shoots expressed by a quadratic regression. It is likely that the addition of a surfactant such as Buffer X might have contributed to the increase in the number of induced shoots. Edgerton (5) and Unrath

Table 9. Residual effects of chemical treatment of nursery trees of three hybrid apple selections on apical dominance (%) in trees on year after transplanting.

Apple hybrid	Treatment[z]					Hybrid mean
	$P_1 + P_2$	$A_1 + A_2$	$A_1 + P_2$	$(A_3 + P_3)\ x\ 1$	Control	
NY 73334-35	31.0[y]	33.1	34.4	31.9	40.3	34.2
NY 75413-30	31.7	30.6	33.4	30.2	34.7	32.1
NY 77414-1	34.6	36.5	37.1	31.4	57.6	40.7
Treatment mean	32.4	33.4	35.0	31.2	44.2	

[z] chemical treatments done in the nursery (in mg•L^{-1} BA): P_1 - Promalin at 500; P_2 - Promalin at 250; P_3 - Promalin at 375; A_1 - Accel at 500; A_2 - Accel at 250; A_3 - Accel at 375 (treatment details are given in Table 1). $LSD_{0.05}$: cultivar means = 4.56; treatment means = 4.99; between treatments at the same level = 8.65, and for different cultivars = 8.71

[y] apical dominance calculation: parent shoot length expressed as a percent of total tree extension growth according to the method of Lee and Looney (25)

and Shaltout (37) reported the increase in the number of lateral shoots on apple seedlings and young orchard apple trees treated with BA supplemented with Buffer X, respectively.

It is believed that multiple applications of BA are more efficient in inducing branching than a single application (12, 39). However, a single application of combined low rates of Accel and Promalin promoted more shoots than that of separate low-rate applications. It is possible that this might have been caused through rapid suppression of apical dominance by the single spray at double the concentration of branching agent than the first spray of low-rate sequential application. Quantitatively, apical dominance inversely reflects tree branching behavior. In this study, the applications of branching agents resulted in a measurable increase in the total shoot number, thus enhancing shoot extension growth and simultaneously reducing apical dominance. However, in some instances the quality of feathers induced did not match the quality of planting materials required for establishing modern orchards. Therefore, it seems to be reasonable in difficult-to-branch cultivars to simultaneously apply chemical branching agents coupled with removal of the top 5 to 6 leaves (27). Early leaf deblading and BA are synergistic in stimulating lateral shoot growth thus reducing apical dominance and correlative inhibition by growing leaves.

Residual effects of chemical treatment by comparable BA rates exhibited by orchard trees were very evident when compared with untreated trees. Despite different amounts of gibberellins contained in spray materials and the number of applications, residual effects expressed by overall treatment means for total number of shoots, shoot extension growth and % of apical dominance did not differ from each other for all chemical treatments. Orchard trees of apple hybrid NY75414-1 demonstrated relatively higher values in the above mentioned characteristics than either NY73334-35 or NY75413-30 trees when comparing chemical treatments vs. control. It is possible that different amounts of residual BA from the chemicals used might have been stored in the plant's tissues bringing about carry-over effects. Pronounced branching potential (16) exhibited by NY73334-35 and NY75413-30 trees in the first year after budding coupled with apparent depletion of exogenous BA may have contributed to low responsiveness after transplanting compared to NY75414-1 trees. Considerable changes in correlative inhibition associated with a reduction of apical dominance occur in transplanted one-year-old trees during the transition over the winter chilling period (20). In addition, some possible reserve of exogenous BA from the nursery treatment might contribute to satisfactory performance of NY75414-1 trees in the orchard. These hypotheses may explain why the most apical-dominant NY75414-1 trees responded more to the applied treatment after transplanting than the other hybrids.

This research suggests that application of chemical branching agents containing BA to nursery trees with no additional sprays after transplanting will enhance branching in several apple selections that show strong apical dominance during the onset of their life. The fact that branching is increased may suggest improved ease in training and earlier bearing (22, 28, 29, 34).

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