Use of Plant Growth Regulators for Feathering and Flower Suppression of Apple Nursery Trees

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Abstract. The use of highly feathered trees can make high-density apple plantings more profitable through enhanced precocity and increased early yield. Currently, nurseries are asked to provide highly feathered trees with wide branch crotch angles. The use of plant growth regulators (PGRs) can play a key role when it comes to branch induction; however, dose and timing both need to be tested to enhance branching without compromising other tree quality attributes. Over the last 4 years, we have conducted studies of the use of MaxCel® (6-benzyladenine) and Promalin® (a mixture of 1.8% 6-benzyladenine and 1.8% GA₄₊₇) in comparison with Tiberon™ SC (cycilanilide) at several nurseries in NY, WA, DE, Ontario (Canada), and Chile. The best results were obtained with four applications of MaxCel® or Promalin® (400 mg·L⁻¹) beginning when leader growth reached 70 cm above the soil line and reapplied at 10–14 days intervals. Promalin® was a slightly less effective branching agent than MaxCel®. On the other hand, Promalin® stimulated leader growth resulting in improved final tree height, whereas MaxCel® induced the widest branch angles. Overall, we observed good response and quality ratings with ‘Cameo’, ‘Cripps Pink’, ‘Enterprise’, ‘Fuji’, ‘Ambrosia’, ‘Crimson Crisp’, ‘Gingergold’, and ‘Granny Smith’, whereas less quality ratings were observed on ‘Ambrosia’, ‘Cortland’, ‘Goldrush’, ‘Honeycrisp’, and ‘Suncrisp’. Response with ‘Gala’ varied depending on the temperature range. Multiple sprays of Gibberellins (GA₄₊₇, or GA₃) at 250 mg·L⁻¹ applied to nursery trees in the late summer inhibited flower bud development and flowering in the orchard the next year. This reduces the risk of fire blight infection in newly planted trees.

The adoption of high-density apple orchards during the last several decades has resulted in a significant improvement in precocity, cumulative yield, and fruit quality. However, as planting density is increased, the

additional benefit in yield is smaller and smaller with each additional tree (Robinson, 2008; Robinson et al., 2007). Therefore, high early yields are needed to pay back the initial investment. With the use of highly feathered

trees, significant yield can be achieved in the 2nd and 3rd years after planting, which is an essential asset to help pay for increased tree numbers and establishment costs (Robinson and Stiles, 1995). As the benefits of highly feathered trees were discovered, it became necessary to develop nursery management techniques to stimulate lateral branch development. Therefore, besides large trunk caliper, nurseries are asked to provide trees with a relatively high number of short lateral branches (feathers) with wide crotch angles (Van den Berg, 2003; Weis, 2004; Wertheim and Webster, 2003). In the 1970s, leaf removal and pinching were commonly used to induce branching on nursery trees (Wertheim, 1978). In the United States, the number of feathers on grown nursery trees has improved significantly in the last decade. Before 2009, most nurseries used a single spray of Promalin® (benzyladenine + GA₄₊₇; Valent BioSciences Corp., Libertyville, IL) combined with leaf removal to obtain trees with three-to-five feathers. In the spring of 2009, a new branching chemical, Tiberon™ SC (cycilanilide, Bayer Environmental Sciences, Research Triangle Park, NC), was registered and was used commercially in the United States, improving the quality of apple nursery trees (Elfving and Visser, 2005, 2006b). In 2012, Tiberon™ SC was withdrawn from the market. European nurseries have been using 6-benzyladenine in the form of MaxCel® (Valent BioSciences Corp./Exilis (Fine Agrochemicals, Worcester, UK) or 10% BA Paturyl (Reanal, Budapest, Hungary) to induce branching (Basak et al., 1992). MaxCel®, a cytokinin plant growth regulator that is already labeled for several uses on apples, was registered for chemical branching of nursery apple trees in the United States in 2013.

Most of the published branching studies were done many years ago on varieties that are no longer grown (Basak et al., 1992; Cody et al., 1985; Forshey, 1982; Jaumien et al., 1993; Miller and Eldridge, 1986). Other studies reported notching (Greene and Autio, 1994) or a combination of notching plus hormone sprays (Greene and Miller, 1988; McCartney and Obermiller, 2015) as a technique to increase branching. In 2010, we evaluated the use of Tiberon™ SC on ‘Macoun’ trees in New York and found Tiberon™ SC to significantly reduce tree height and caliper, resulting in poor tree architecture under Eastern climatic conditions (Miranda Sazo and Robinson, 2011). To further study the use of MaxCel® and Promalin® in comparison with Tiberon™ SC, we have conducted 10 experiments at several nurseries in NY, WA, DE, Ontario (Canada), and Chile over the last 4 years.

Nursery-produced apple trees of many varieties bloom prolifically when subsequently planted in commercial orchards. Once trees are moved from the nursery to the orchard, new spring planted trees bloom later than established orchards when temperatures are warmer. These trees are at higher risk of blossom fire blight (*Erwinia amylovora* Burrill) if left unprotected or with fewer

streptomycin sprays (Vanneste, 2000). Hence, an apple tree that doesn't flower in the 1st year after planting may be a good strategy for fire blight control. Although many studies have reported the use of hormone sprays to reduce flower induction and improve biennial bearing (Greene, 2000; Jonkers, 1979; McCartney and Li, 1998; Unrath and Whitworth, 1991), there is a dearth of studies that focus on flower inhibition for nursery trees. A second objective of our study was to determine if gibberellin sprays in the nursery could inhibit flower bud formation thus reducing flowering the following season in the orchard to minimize the risk of fire blight.

Materials and Methods

Branching induction experiments

PGR application and design. All plant growth regulator treatments were applied with manually operated Solo (425; Solo, Newport News, VA) and Shindaiwa (SP415; Shindaiwa, Lake Zurich, IL) backpack sprayers with a single nozzle directed over the leader tip of each tree, calibrated to apply 4 mL of solution at each application (Table 1). On the first application date, the central leader shoot tips for each budded scion were ≈ 70 cm above the soil. Tree height is a good criterion for branching induction through PGR applications (Elfving and Visser, 2006a, 2006b). Control trees were unsprayed.

In November (USA & Canada), or in July (Chile), trees were measured in the nursery for: 1) trunk diameter (measured 13 cm above bud union), 2) length of central leader above-ground level to tip, 3) total number of feathers (any lateral shoot longer than 10 cm), 4) distance from the ground level to each of the induced feathers, 5) length of each feather, and 6) crotch angle of each feather (90° = upright, 0° = flat). In experiment 10, tree quality (1 = poor, 5 = excellent) was subjectively assessed, taking into account the overall tree height, number of feathers, and their angle. Excellent quality trees had a tree height of 180–200 cm, and 12–15 wide-angle feathers, whereas poor quality trees were short in height and with no

feathers at all. Every experiment used a separate randomized complete block design for each cultivar with four replications (experiments 1, 3, and 5–9), five replications (experiment 2 and 4) or 10 replications (experiment 10), distributed down a row with each experimental unit being a section of five trees (experiments 1–5, 7, 9) or 10 trees (experiments 6, 8, and 10).

Experiment 1: Cyclanilide, Benzyladenine (BA), and BA plus GA₄₊₇ on 'Macoun'. A field experiment was conducted in 2012 near Ellendale, DE, where we compared the effect of summer applications of cyclanilide (Tiberon™ SC; Bayer Environmental Science, Montvale, NJ), BA (MaxCel®; Valent BioSciences Corp.), and BA plus GA₄₊₇ (Promalin®, a mixture of 1.8% BA and 1.8% GA₄₊₇; Valent BioSciences Corp.) on branching. Cyclanilide was applied as a foliar spray twice at 50 mg·L⁻¹; whereas BA (at 500 and 1000 mg·L⁻¹) and BA plus GA₄₊₇ (at 500 mg·L⁻¹) were sprayed up to five times; all sprays were applied 2 weeks apart to standard fall budded nursery trees of 'Macoun' on 'Malling M.9T337'. All the treatments included the nonionic surfactant Regulaid® (Kalo Inc., Overland Park, KS) at 0.125% (v/v).

Experiment 2: Cyclanilide, BA, and BA plus GA₄₊₇ on 'Ambrosia'. A field experiment was conducted in 2012 in Niagara, (Ontario) Canada, where we compared the effect of summer applications of cyclanilide (Tiberon™ SC), BA (MaxCel®), and BA plus GA₄₊₇ (Promalin®) on branching. Cyclanilide was applied as a foliar spray twice at 50 mg·L⁻¹; whereas BA and BA plus GA₄₊₇ (at 500 and 1000 mg·L⁻¹) were sprayed up to four times; all sprays were applied 2 weeks apart to standard fall budded nursery trees of 'Ambrosia' on 'Budagovsky 9'. All the treatments included the nonionic surfactant Regulaid® at 0.125% (v/v).

Experiment 3: Cyclanilide, BA, and BA plus GA₄₊₇ on 'Fuji' and 'Gala'. An experiment was conducted in 2012 at Quincy, WA, where we compared the number of BA or BA plus GA₄₊₇ sprays in comparison with one spray of cyclanilide on branching on apple nursery trees. Proprietary formulations of cyclanilide (Tiberon™ SC), BA (MaxCel®), and BA plus GA₄₊₇ (Promalin®) were used in the trial. Cyclanilide was sprayed a single time at 100 mg·L⁻¹ whereas BA or BA plus GA₄₊₇ were applied at 500 and 1000 mg·L⁻¹ either two, three, four, or five times, 2 weeks apart to standard fall budded nursery trees of 'Fuji'/'M.9Nic9' and 'Gala'/'M.9Nic9'. All the treatments included Regulaid® at 0.125% (v/v) as a surfactant.

Experiment 4: BA and BA plus GA₄₊₇ on 'Fuji', 'Gala', and 'Granny Smith'. An experiment was conducted in the spring of 2012 at a nursery located near Santiago, Chile, to determine the effect of BA plus GA₄₊₇ (Promalin®) and BA (Cylex®; Valent BioSciences) on branching on three apple cultivars. BA plus GA₄₊₇ at one rate (800 mg·L⁻¹) and BA at three rates (500, 750, and 1000 mg·L⁻¹) were applied one, two, three, four, or five times 2 weeks apart to standard fall budded nursery trees of 'Fuji'/'M.9T337',

'Gala'/'M.9T337', and 'Granny Smith'/'M.9T337'. All the treatments included Regulaid® at 0.125% (v/v) as a surfactant.

Experiment 5: Cyclanilide, BA, and BA plus GA₄₊₇ on 'Golden Delicious'. A field experiment was conducted in 2012 near Ellendale, DE, comparing the effect of summer sprays of cyclanilide (Tiberon™ SC), BA (MaxCel®), and BA plus GA₄₊₇ (Promalin®) on branching on 'Golden Delicious'/'M.9T337'. Cyclanilide was sprayed one time at 100 mg·L⁻¹, or two times at 50 mg·L⁻¹; whereas BA (at 500 and 1000 mg·L⁻¹) and BA plus GA₄₊₇ (500 mg·L⁻¹) were sprayed either two, four, or five times, 2 weeks apart. All the treatments included Regulaid® at 0.125% (v/v) as a surfactant.

Experiment 6: Cyclanilide, BA, and BA plus GA₄₊₇ on 'Fuji'. A field experiment was conducted in 2013 at Ellendale, DE, where we compared the effect of summer sprays of cyclanilide (Tiberon™ SC), BA (MaxCel®), and BA plus GA₄₊₇ (Promalin®) on branching on 'Fuji'/'M.9T337'. The experiment was designed to evaluate the effect of additional surfactant Regulaid® to the BA treatments. Cyclanilide was sprayed two times at 50 mg·L⁻¹; BA was sprayed two to four times at 300, 400, and 500 mg·L⁻¹; and BA plus GA₄₊₇ was sprayed four times at 500 mg·L⁻¹. All treatments were sprayed at 10-d intervals. Treatments with four sprays of MaxCel® at 300, 400, and 500 mg·L⁻¹ were sprayed with and without Regulaid® at 0.125% (v/v) as a surfactant.

Experiment 7: BA and BA plus GA₄₊₇ on 'Macoun'. An experiment was conducted in 2013 near Ellendale, DE, to determine the effect of BA (MaxCel®) and BA plus GA₄₊₇ (Promalin®) on branching of 'Macoun' apple nursery trees. Three rates of BA and BA plus GA₄₊₇ (300, 400 or 500 mg·L⁻¹) with and without Regulaid® were applied four times at 10-d intervals to standard fall budded nursery trees of 'Macoun'/'M.9T337'. Regulaid® was added at 0.125% (v/v).

Experiment 8: Cyclanilide, BA, and BA plus GA₄₊₇ on 'Fuji' and 'Gala'. An experiment was conducted in 2013 at Quincy, WA, where we compared the number of BA or BA plus GA₄₊₇ sprays in comparison with one spray of cyclanilide on branching on apple nursery trees. Proprietary formulations of cyclanilide (Tiberon™ SC), BA (MaxCel®), and BA plus GA₄₊₇ (Promalin®) were used in the trial. Cyclanilide was sprayed a single time at 100 mg·L⁻¹, whereas BA or BA plus GA₄₊₇ were applied at 500 and 750 mg·L⁻¹ either one, two, three, or four times, 2 weeks apart to standard fall budded nursery trees of 'Fuji'/'M.9T337' and 'Gala'/'M.9T337'. All the treatments included Regulaid® at 0.125% (v/v) as a surfactant.

Experiment 9: BA and BA plus GA₄₊₇ on 'Fuji'. An experiment was conducted in 2014 near Ellendale, DE, to determine the effect of the number of BA and BA plus GA₄₊₇ sprays on branching of 'Fuji' apple nursery trees. Two application rates (400 and 500 mg·L⁻¹) for both BA plus GA₄₊₇ (Promalin®) and BA (MaxCel®) were applied four or five times 2 weeks apart to standard fall budded nursery

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Table 1. List of experiment number, year, location, variety, treatments [MaxCel[®], Promalin[®], Tiberon[™] SC, and Cylex[®] rates are in mg·L⁻¹; Regulaid[®] at 0.125% (v/v)], and timing within sprays performed for the different branching induction trials.

Expt. #	Yr	Location	Variety	Treatments	Timing between sprays
1	2012	Ellendale, DE	Macoun	MaxCel1000 5× + Regulaid MaxCel500 5× + Regulaid Promalin500 5× + Regulaid Tiberon50 2× + Regulaid Untreated	2 weeks apart
2	2012	Niagara, ON, Canada	Ambrosia	MaxCel1000 2× + Regulaid MaxCel1000 4× + Regulaid MaxCel500 2× + Regulaid MaxCel500 4× + Regulaid Promalin500 2× + Regulaid Promalin500 4× + Regulaid Tiberon50 2× + Regulaid Untreated	2 weeks apart
3	2012	Quincy, WA	Fuji Gala	MaxCel500 2× + Regulaid MaxCel500 3× + Regulaid MaxCel500 4× + Regulaid MaxCel500 5× + Regulaid MaxCel1000 2× + Regulaid MaxCel1000 3× + Regulaid MaxCel1000 4× + Regulaid MaxCel1000 5× + Regulaid Promalin500 2× + Regulaid Promalin500 3× + Regulaid Promalin500 4× + Regulaid Promalin500 5× + Regulaid Tiberon100 1× + Regulaid Untreated	2 weeks apart
4	2012	Santiago de Chile, Chile	Fuji Gala Granny Smith	Promalin800 1× + Regulaid Promalin800 2× + Regulaid Promalin800 3× + Regulaid Promalin800 4× + Regulaid Promalin800 5× + Regulaid Cylex500 1× + Regulaid Cylex500 2× + Regulaid Cylex500 3× + Regulaid Cylex500 4× + Regulaid Cylex500 5× + Regulaid Cylex750 1× + Regulaid Cylex750 2× + Regulaid Cylex750 3× + Regulaid Cylex750 4× + Regulaid Cylex750 5× + Regulaid Cylex1000 1× + Regulaid Cylex1000 2× + Regulaid Cylex1000 3× + Regulaid Cylex1000 4× + Regulaid Cylex1000 5× + Regulaid Untreated	2 weeks apart
5	2012	Ellendale, DE	Golden Delicious	MaxCel1000 2× + Regulaid MaxCel1000 4× + Regulaid MaxCel1000 5× + Regulaid MaxCel500 2× + Regulaid MaxCel500 4× + Regulaid MaxCel500 5× + Regulaid Promalin500 2× + Regulaid Promalin500 4× + Regulaid Tiberon100 1× + Regulaid Tiberon50 2× + Regulaid Untreated	2 weeks apart
6	2013	Ellendale, DE	Fuji	MaxCel300 4× MaxCel300 4× + Regulaid MaxCel400 3× MaxCel400 4× MaxCel400 4× + Regulaid MaxCel500 2× MaxCel500 3× MaxCel500 4× MaxCel500 4× + Regulaid Promalin500 4× Tiberon50 2× Untreated	10-d intervals
7	2013	Ellendale, DE	Macoun	MaxCel300 4× MaxCel300 4× + Regulaid	10-d intervals

(Continued on next page)

Table 1. (Continued) List of experiment number, year, location, variety, treatments [MaxCel[®], Promalin[®], Tiberon[™] SC, and Cylex[®] rates are in mg·L⁻¹; Regulaid[®] at 0.125% (v/v)], and timing within sprays performed for the different branching induction trials.

Expt. #	Yr	Location	Variety	Treatments	Timing between sprays
8	2013	Quincy, WA	Fuji Gala	MaxCel400 4×	2 weeks apart
				MaxCel400 4× + Regulaid	
				MaxCel500 4×	
				Promalin400 4× + Regulaid	
				Promalin500 4×	
				Untreated	
				MaxCel500 1× + Regulaid	
				MaxCel500 2× + Regulaid	
				MaxCel500 3× + Regulaid	
				MaxCel500 4× + Regulaid	
				MaxCel750 1× + Regulaid	
				MaxCel750 2× + Regulaid	
				MaxCel750 3× + Regulaid	
				MaxCel750 4× + Regulaid	
				Promalin500 4× + Regulaid	
9	2014	Ellendale, DE	Fuji	Promalin750 4× + Regulaid	2 weeks apart
				Tiberon100 1× + Regulaid	
				Untreated	
				MaxCel400 4×	
				MaxCel400 5×	
				MaxCel500 4×	
				MaxCel500 5×	
				Promalin400 4×	
				Promalin400 5×	
				Promalin500 4×	
10	2014 2015	Ellendale, DE	Aceymac Ambrosia Cameo Cortland Crimson Crisp Cripps Pink Empire Enterprise Fuji Gala Gingergold Goldrush Granny Smith Honeycrisp Macoun Suncrisp	Promalin500 5×	2 weeks apart
				Untreated	
				MaxCel400 4×	
				MaxCel400 5×	
				MaxCel500 4×	
				MaxCel500 5×	
				Promalin400 4× + Regulaid	
				Promalin400 5× + Regulaid	
				Promalin500 4× + Regulaid	
				Promalin500 5× + Regulaid	
				Untreated	
				Untreated	
				Untreated	
				Untreated	
				Untreated	
				Untreated	
				Untreated	

trees of ‘Daybreak Fuji’/‘M.9T337’. All the Promalin[®] applications included Regulaid[®] at 0.125% (v/v) as a surfactant.

Experiment 10: BA and BA plus GA₄₊₇ on a range of varieties. Two trials were conducted in 2014 and 2015 near Ellendale, DE, to determine the effect of BA (MaxCel[®]) and BA plus GA₄₊₇ (Promalin[®]) sprays on branching of a range of varieties. For both years all Promalin[®] treatments included Regulaid[®] at 0.125% (v/v) as a surfactant, whereas MaxCel[®] treatments did not include any surfactant. In 2014, MaxCel[®] at 400 mg·L⁻¹ and Promalin[®] at 400 and 500 mg·L⁻¹; and in 2015, MaxCel[®] at 400 and 500 mg·L⁻¹ and Promalin[®] at 500 mg·L⁻¹ were applied five times 2 weeks apart to standard fall budded nursery trees of ‘Aceymac’/‘M.9T337’, ‘Ambrosia’/‘M.9T337’, ‘Cameo’/‘M.9T337’, ‘Crimson Crisp’/‘M.9T337’, ‘Cripps Pink’/‘M.9T337’, ‘Empire’/‘M.9T337’, ‘Enterprise’/‘M.9T337’, ‘Aztec Fuji’/‘M.9T337’, ‘Ultima Gala’/‘M.9T337’, ‘Gingergold’/‘M.9T337’, ‘Goldrush’/‘M.9T337’, ‘Granny Smith’/‘M.9T337’, ‘Honeycrisp’/‘M.9T337’, ‘Honeycrisp Premier’/‘M.9T337’, ‘Macoun’/‘M.9T337’, and ‘Royal Court - Cortland’/‘M.9T337’. In

2015, MaxCel[®] at 200, 300, and 400 mg·L⁻¹ only with no surfactant was applied five times 2 weeks apart for ‘Suncrisp’/‘M.9T337’.

Flower inhibition experiment

Experiment 11: Inhibition of flowering. An experiment was conducted in Ephrata, WA, in the late summer of 2013 to inhibit the formation of flower buds in the nursery, which would reduce flowering in the first year in the orchard. GA₃ at two rates (100 and 250 mg·L⁻¹) and GA₄₊₇ at 250 mg·L⁻¹ were sprayed two, three, or four times to ‘Pink Lady’/‘M.9T337’ and ‘Gala’/‘M.9T337’ apple trees every 14 d, starting on 15 July.

The trees were dug in Nov. 2013 and kept in commercial cold storage through the winter; then planted at Geneva, NY (‘Gala’), Payson, UT (‘Gala’), and Mills River, NC (‘Pink Lady’), in the spring of 2014. At full bloom the number of flower clusters per tree was counted.

Weather data

Daily climatic variables such as maximum temperature (Max, °C), minimum temperature (Min, °C), and relative humidity (RH, %) were obtained from the closest automatic weather

station for Quincy, WA, in 2012–13 (Experiments 3 and 8), Chile 2012 (Experiment 4), Ellendale, DE, 2014 (Experiment 9), Geneva, NY, 2014 (Experiment 11), and Payson, UT, 2014 (Experiment 11) (Fig. 1).

Data analysis

Each site/experiment was analyzed individually. Response variables for both branching induction and flower inhibition experiments were modeled using linear mixed effect models. Mixed models including treatment as fixed factor and block as a random factor were built to separate treatment effects. For all the models, when the main effect (treatment) was significant, comparisons among treatments were made by Tukey’s honest significant difference test at *P* values ≤0.05. Residual analysis was performed to ensure that model assumptions were met. Data were analyzed using the JMP statistical software package (Version 12; SAS Institute Inc., Cary, NC).

Results

Experiment 1: Cyclanilide, BA, and BA plus GA₄₊₇ on ‘Macoun’ in 2012 in DE. Smaller trunk cross sectional area (TCSA)

Fig. 1. Average daily maximum and minimum temperature (°C) and relative humidity (RH, %) for Santiago de Chile 2012 (Experiment 4), Quincy, WA, 2012–13 (Experiments 3 and 8), and Ellendale, DE, 2014 (Experiment 9). Bottom chart represents average daily minimum temperature (°C) for Geneva, NY, and Payson, UT, in 2014 (Experiment 11).

values were observed on Tiberon™ SC sprayed-trees, whereas no significant differences were observed among MaxCel® or Promalin® sprays or the untreated control (Table 2). Final height and height increase was lower on Tiberon™ SC sprayed-trees, higher on Promalin®, with

no differences between MaxCel® sprayed-trees and control trees. Phytotoxicity was very low with all the treatments except trees sprayed with Tiberon™ SC which had higher amounts of phytotoxicity. On those trees, high phytotoxicity was observed on the growing tips, along the leader where there was

twisting, and some thickening or swelling of the tissues.

The untreated trees had the fewest number of branches per tree (2.3 branches per tree), followed by the Tiberon™ SC-sprayed (5.6) treatments and then both MaxCel® and Promalin® treatments (>8.9) with higher

number of feathers originating farther up the tree. Both MaxCel® and Promalin® also induced wider branch angles, and increasing the dose significantly reduced the shoot angle (flatter) as well. Shorter lateral shoots were observed on the treatments that had greater shoot number.

Experiment 2: Cyclanilide, BA, and BA plus GA₄₊₇ on 'Ambrosia' in 2012 in Ontario. No significant differences were observed regarding TCSA on 'Ambrosia' trees (Table 3). The highest TCSA increase was observed with two applications of Promalin® at 500 mg·L⁻¹, whereas the lowest was observed when applying four sprays of MaxCel® at 1000 mg·L⁻¹. Tree height and height increase were greatest on untreated and Promalin® sprayed-trees, whereas they were reduced when increasing the dose and number of sprays of MaxCel®. More shoots were observed when applying MaxCel® at 1000 mg·L⁻¹, followed by MaxCel® at 500 mg·L⁻¹, Promalin® at 500 mg·L⁻¹, Tiberon™ SC, and lastly the untreated trees. Untreated trees had longer shoots at a lower average height. Narrower crotch angles were observed when Tiberon™ SC was applied.

Experiment 3: Cyclanilide, BA, and BA plus GA₄₊₇ on 'Fuji' and 'Gala' in 2012 in WA. No significant differences were observed in TCSA on either 'Fuji' or 'Gala' trees among the different treatments in this study (Table 4).

On 'Fuji', even though no significant differences in tree height were observed among the different treatments, there was a tendency for reduced tree height with increasing dose and number of MaxCel® sprays. Number of shoots was significantly

increased up to four times more with increasing rate and the number of sprays (MaxCel® 1000 mg·L⁻¹ four to five sprays and Promalin® 500 mg·L⁻¹ five sprays). Average shoot height tended to be higher on untreated trees, followed by Promalin® sprayed-trees, and then MaxCel® and Tiberon™ SC with the lowest average shoot height. Compared with the control, lateral shoot length was only increased with either MaxCel® sprayed-trees or Promalin® sprayed-trees three times. On 'Gala', unsprayed trees had similar height as the ones sprayed with Promalin®, whereas trees sprayed with MaxCel® four to five times were shorter. There was a tendency to increase the number of lateral shoots when increasing the number of sprays of MaxCel®, but with 'Gala', no treatment was significantly different from the untreated control. No significant differences were observed regarding the height or length of the feathers among untreated and PGR sprayed-trees with 'Gala'.

Experiment 4: BA and BA plus GA₄₊₇ on 'Fuji', 'Gala', and 'Granny Smith' in 2012 in Chile. Leader growth followed a sigmoidal curve throughout the season, with the greatest growth rate on the date of the first application (Fig. 2). Higher growth rates were observed for 'Fuji', followed with similar values by 'Gala' and 'Granny Smith'. About 3–4 weeks after the first application, growth rate was higher on Promalin® sprayed-trees than the control, whereas a slight decrease in growth rate compared with the control was observed when Cylex® was applied.

Both Cylex® and Promalin® induced significant greater numbers of feathers in all

varieties than the untreated controls which had an average slightly more than three feathers per tree (Fig. 3). With 'Fuji' and 'Granny Smith', the best treatments produced slightly more than 13 feathers, whereas with 'Gala', the best treatments produced about 10–12 feathers. With Cylex®, a double spray produced an intermediate feathering response in 'Fuji' and 'Granny Smith' and less feathering response in 'Gala'. The greatest number of feathers with Cylex® was obtained with four sprays of 750 mg·L⁻¹ for 'Granny Smith', 'Fuji', and 'Gala'. With Promalin®, four sprays of 800 mg·L⁻¹ gave the greatest number of feathers for 'Fuji', 'Gala', and 'Granny Smith'. No significant differences among treatments were observed within the same number of applications. A fifth spray of Promalin® at 800 mg·L⁻¹ or Cylex® either at 500, 750, or 1000 mg·L⁻¹ did not increase the number of feathers, indicating that only four sprays were needed for maximum branching.

Feather length of untreated trees was greatest for 'Fuji', followed by 'Gala' and 'Granny Smith' (Fig. 3). Promalin® sprays increased the length of feathers of all cultivars. Feather length had a slight negative correlation with the number of applications of Cylex®. The greatest reduction in feather length was produced for 'Gala' with five sprays of Cylex® at 750 mg·L⁻¹.

Experiment 5: Cyclanilide, BA, and BA plus GA₄₊₇ on 'Golden Delicious' in 2012 in DE. No differences in TCSA were observed, whereas tree height was significantly reduced when applying Tiberon™ SC (Table 5). Doubling MaxCel® dose to 1000 mg·L⁻¹ tended to reduce tree height when compared with either

Table 2. Effects of various plant growth regulator treatments sprayed two or five times (2×, 5×) at 50, 500, or 1000 mg·L⁻¹ on 'Macoun' apple trees in Ellendale, DE, in 2012 (Experiment 1). All the treatments included Regulaid® at 0.125% (v/v) as a surfactant. Shoot height from ground is the distance from the ground level to each of the induced feathers.

Treatment	TCSA (cm ²)	TCSA increase (cm ²)	Ht (cm)	Ht increase (cm)	Phytotoxicity (1 = none, 10 = severe)	Shoot number	Shoot ht from ground (cm)	Shoot angle (degrees)	Shoot length (cm)
MaxCel1000 5×	2.3 ab	1.5 ab	163 bc	61 b	0.2 b	10 a	41 b	43 c	8 b
MaxCel500 5×	2.4 a	1.6 ab	169 b	64 b	0.0 b	9 a	43 ab	48 b	8 b
Promalin500 5×	2.5 a	1.7 ab	178 a	77 a	0.0 b	9 a	43 a	49 b	8 b
Tiberon50 2×	2.1 b	1.3 b	152 d	52 c	1.3 a	6 b	35 c	54 a	15 a
Untreated	2.2 ab	1.5 ab	160 c	59 b	0.0 b	2 c	36 c	57 a	14 a
P	0.0085	0.0095	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001

Means within a column followed by different letters denotes significant differences among treatments (Tukey's honestly significant difference, $P \leq 0.05$). TCSA = trunk cross sectional area.

Table 3. Effects of various plant growth regulator treatments sprayed two or four times (2×, 4×) at 50, 500, or 1000 mg·L⁻¹ on 'Ambrosia' apple trees in Ontario, Canada, in 2012 (Experiment 2). All the treatments included Regulaid® at 0.125% (v/v) as a surfactant. Shoot height from ground is the distance from the ground level to each of the induced feathers.

Treatment	TCSA (cm ²)	TCSA increase (cm ²)	Ht (cm)	Ht increase (cm)	Shoot number	Shoot ht from ground (cm)	Shoot angle (degrees)	Shoot length (cm)
MaxCel1000 2×	1.19	1.0 ab	106 de	37 d	6 a	63 a	36 cd	14 c
MaxCel1000 4×	1.16	0.9 b	103 e	34 d	5 a	61 a	35 d	14 c
MaxCel500 2×	1.27	1.0 ab	113 bc	43 bc	4 b	66 a	42 b	14 c
MaxCel500 4×	1.22	1.0 ab	109 cd	45 b	3 b	60 a	42 bc	14 c
Promalin500 2×	1.30	1.1 a	120 a	51 a	1 c	64 a	43 bc	18 bc
Promalin500 4×	1.21	1.0 ab	118 ab	51 a	1 c	62 a	45 b	20 b
Tiberon50 2×	1.25	1.0 ab	108 cde	39 cd	1 c	61 a	53 a	14 c
Untreated	1.29	1.1 ab	121 a	54 a	0 c	41 b	49 ab	29 a
P	NS	0.0297	<0.0001	<0.0001	<0.0001	0.0002	<0.0001	<0.0001

Means within a column followed by different letters denotes significant differences among treatments (Tukey's honestly significant difference, $P \leq 0.05$). TCSA = trunk cross sectional area; NS = nonsignificant at $P \leq 0.05$.

Table 4. Effects of MaxCel® (Max), Promalin® (Prom), or Tiberon™ SC (Tib) treated two to five times (2× to 5×) at 100, 500, or 1000 mg·L⁻¹ on 'Fuji' and 'Gala' apple trees in the nursery at Quincy, WA, in 2012 (Experiment 3). All the treatments included Regulaid® at 0.125% (v/v) as a surfactant. Shoot height from ground is the distance from the ground level to each of the induced feathery.

Variety	Treatment	TCSA (cm ²)	Ht (cm)	Shoot number	Shoot ht from ground (cm)	Shoot length (cm)
Fuji	Max500 2×	1.5	175 ab	8 fg	84 ef	41 abc
	Max500 3×	1.5	184 a	10 def	85 def	44 ab
	Max500 4×	1.5	178 ab	14 bcd	95 bcd	37 abc
	Max500 5×	1.5	172 b	16 bc	95 bcd	38 abc
	Max1000 2×	1.5	175 ab	10 ef	80 f	42 abc
	Max1000 3×	1.5	175 ab	12 de	80 f	43 ab
	Max1000 4×	1.5	178 ab	17 ab	90 cdef	38 abc
	Max1000 5×	1.5	171 b	20 a	91 cde	34 bc
	Prom500 2×	1.5	178 ab	7 fg	97 bc	42 abc
	Prom500 3×	1.6	174 ab	9 ef	94 bcde	46 a
	Prom500 4×	1.6	185 a	13 cd	103 b	36 bc
	Prom500 5×	1.5	178 ab	17 abc	102 b	35 bc
	Tib100 1×	1.6	183 a	9 ef	84 ef	42 abc
	Untreated	1.5	180 ab	5 g	119 a	33 c
	P	NS	<0.0001	<0.0001	<0.0001	<0.0001
Gala	Max500 2×	1.4	183 bcd	15 abc	85 a	34 bcdef
	Max500 3×	1.6	187 abcd	15 abc	81 ab	34 abcde
	Max500 4×	1.4	181 cd	15 abc	80 ab	30 cdef
	Max500 5×	1.5	183 bcd	17 a	83 a	31 bcdef
	Max1000 2×	1.5	183 bcd	14 abc	80 ab	30 def
	Max1000 3×	1.5	186 abcd	15 abc	82 ab	29 ef
	Max1000 4×	1.5	179 d	16 a	81 ab	28 f
	Max1000 5×	1.5	181 cd	16 ab	80 ab	31 bcdef
	Prom500 2×	1.5	194 a	13 bc	80 ab	35 abcd
	Prom500 3×	1.5	195 a	12 c	77 b	35 abcd
	Prom500 4×	1.5	190 abc	14 abc	85 a	40 a
	Prom500 5×	1.6	192 ab	13 abc	84 a	36 abc
	Tib100 1×	1.5	183 bcd	15 abc	83 a	36 ab
	Untreated	1.5	196 a	14 abc	81 ab	33 bcdef
	P	NS	<0.0001	<0.0001	<0.0001	<0.0001

Means within a column followed by different letters denote significant differences among treatments (Tukey's honestly significant difference, $P \leq 0.05$). TCSA = trunk cross sectional area; NS = nonsignificant at $P \leq 0.05$.

Fig. 2. Effects of plant growth regulator treatments at 500, 750, 800, or 1000 mg·L⁻¹ sprayed from two to five times (2× to 5×) on leader growth rate (cm per day) on 'Fuji', 'Gala', and 'Granny Smith' in the nursery at Chile in 2012 (Experiment 4). All the treatments included Regulaid® at 0.125% (v/v) as a surfactant. Vertical bars indicate least significant difference (LSD) at $P < 0.05$.

MaxCel® or Promalin® at 500 mg·L⁻¹. MaxCel® at higher rates (1000 mg·L⁻¹) and Tiberon™ SC had the highest phytotoxicity values. Tiberon™ SC did not increase lateral shoot number, whereas increased number of shoots were observed when spraying either MaxCel® five times at 500 mg·L⁻¹ or four times at 1000 mg·L⁻¹. Average shoot height from the ground was higher on trees sprayed four to five times with either

MaxCel® or Promalin®. Narrowest branch angles were observed on untreated and Tiberon™ SC sprayed-trees, whereas higher rates of MaxCel® (1000 mg·L⁻¹) induced wider shoot angles. Shoots were longer on control and Tiberon™ SC sprayed-trees.

Experiment 6: Cyclanilide, BA, and BA plus GA₄₊₇ on 'Fuji' in 2013 in DE. TCSA was unaffected when applying MaxCel® and Promalin® (at ≤500 mg·L⁻¹), or Tiberon™

SC (at 50 mg·L⁻¹) on 'Fuji' trees (Table 6). For the same dose, taller trees were observed when spraying Promalin® compared with MaxCel®; however, no significant differences were observed when MaxCel® was reduced below 500 mg·L⁻¹. Higher number of shoots was observed when applying MaxCel® at 400–500 mg·L⁻¹ four times, or at 300 mg·L⁻¹ plus a surfactant. All the treatments significantly increased the number of shoots compared with the control, and the average shoot height was also increased when three or more sprays were done. However, crotch angle was only reduced when applying MaxCel® four times at 300–400 mg·L⁻¹ and a surfactant. This MaxCel® treatment also induced the shortest lateral shoots of any treatment.

Experiment 7: BA and BA plus GA₄₊₇ on 'Macoun' in 2013 in DE. Promalin® at 400 mg·L⁻¹ and MaxCel® at 300 mg·L⁻¹, both with a surfactant were the only two treatments that significantly increased tree height, whereas no differences were observed regarding TCSA among treatments (Table 7). On average, control trees of 'Macoun' had no lateral shoots at all, whereas all the PGR treatments increased lateral shoot number significantly. Higher number of shoots was observed when spraying MaxCel® at 400–500 mg·L⁻¹, or Promalin® at 400 mg·L⁻¹ plus a surfactant. Average shoot height of the leader was increased with MaxCel® at 300 mg·L⁻¹, and Promalin® at 400 mg·L⁻¹ plus a surfactant. Untreated trees had the narrowest lateral branch angles, followed by the ones sprayed with Promalin®, and then those sprayed MaxCel® which had the widest angles. All the different treatments had considerably shorter lateral shoots compared with the control.

Experiment 8: Cyclanilide, BA, and BA plus GA₄₊₇ on 'Fuji' and 'Gala' in 2013 in WA. No significant differences among treatments were observed in TCSA of 'Fuji' (Table 8). Tree height was reduced by MaxCel® when sprayed more than two times, but not by Promalin®. As the number of sprays of MaxCel® increased greater negative effect on tree height. The untreated control trees had only one feather per tree, whereas trees treated

Fig. 3. Effects of plant growth regulator treatments at 500, 750, 800, or 1000 mg·L⁻¹ on number and length of feathers on 'Fuji', 'Gala', and 'Granny Smith' in the nursery at Chile in 2012 (Experiment 4). All the treatments included Regulaid® at 0.125% (v/v) as a surfactant. Vertical bars indicate least significant difference (LSD) at $P < 0.05$.

Table 5. Effects of various plant growth regulator treatments treated one to five times (1× to 5×) at 50, 100, 500, or 1000 mg·L⁻¹ on 'Golden Delicious' apple trees in Ellendale, DE, in 2012 (Experiment 5). All the treatments included Regulaid® at 0.125% (v/v) as a surfactant. Shoot height from ground is the distance from the ground level to each of the induced feathers.

Treatment	TCSA (cm ²)	Ht (cm)	Phytotoxicity (1 = none, 10 = severe)	Shoot number	Shoot ht from ground (cm)	Shoot angle (degrees)	Shoot length (cm)
MaxCel1000 2×	2.0 a	69 def	2.0 b	7 c	37 c	42 de	15 def
MaxCel1000 4×	1.8 a	69 def	3.1 a	10 ab	39 abc	42 de	13 f
MaxCel1000 5×	2.1 a	68 def	3.0 a	9 b	38 bc	40 e	15 ef
MaxCel500 2×	2.2 a	70 cde	1.0 de	7 c	37 cd	48 c	17 cde
MaxCel500 4×	2.2 a	73 abc	1.0 de	9 b	40 ab	47 c	14 f
MaxCel500 5×	2.1 a	74 ab	1.3 cd	11 a	41 a	49 bc	13 f
Promalin500 2×	2.0 a	72 abc	0.3 f	7 cd	36 cd	50 bc	18 cd
Promalin500 4×	1.9 a	75 a	0.8 e	9 b	40 ab	46 cd	14 f
Tiberon100 1×	2.1 a	68 ef	1.5 c	6 cde	38 bc	53 ab	21 ab
Tiberon50 2×	1.9 a	66 f	1.4 cd	5 de	37 c	53 ab	18 bc
Untreated	2.2 a	71 bcd	0.0 f	5 e	34 d	56 a	22 a
P	0.0061	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001

Means within a column followed by different letters denote significant differences among treatments (Tukey's honestly significant difference, $P \leq 0.05$). TCSA = trunk cross sectional area.

Table 6. Effects of various plant growth regulator treatments sprayed two to four times (2× to 4×) at 50, 300, 400, or 500 mg·L⁻¹ on 'Fuji' apple trees in Ellendale, DE, in 2013 (Experiment 6). Treatments with four sprays of MaxCel® at 300, 400 and 500 mg·L⁻¹ were sprayed with and without Regulaid® (Reg) at 0.125% (v/v) as a surfactant. Shoot height from ground is the distance from the ground level to each of the induced feathery.

Treatment	TCSA (cm ²)	Ht (cm)	Shoot number	Shoot ht from ground (cm)	Shoot angle (degrees)	Shoot length (cm)
MaxCel300 4×	1.7	173 abc	11 de	104 ab	67 abcde	28 cd
MaxCel300 + Reg 4×	1.9	177 ab	16 abc	108 a	62 e	25 d
MaxCel400 3×	1.7	170 abc	15 bc	97 bc	69 abc	29 cd
MaxCel400 4×	1.7	172 abc	16 abc	100 bc	70 ab	30 cd
MaxCel400 + Reg 4×	1.8	176 ab	19 a	105 ab	62 de	24 d
MaxCel500 2×	1.6	167 bc	13 cd	87 de	67 abcde	32 c
MaxCel500 3×	1.7	165 c	15 bcd	95 cd	67 abcd	30 cd
MaxCel500 4×	1.6	170 abc	17 ab	99 bc	66 bcde	29 cd
MaxCel500 + Reg 4×	1.7	169 bc	19 a	99 bc	65 cde	26 cd
Promalin500 4×	1.7	180 a	14 bcd	100 abc	66 abcde	27 cd
Tiberon50 2×	1.7	171 abc	8 e	86 e	71 a	44 b
Untreated	1.7	171 abc	3 f	82 e	68 abc	51 a
P	NS	0.0002	<0.0001	<0.0001	<0.0001	<0.0001

Means within a column followed by different letters denote significant differences among treatments (Tukey's honestly significant difference, $P \leq 0.05$). TCSA = trunk cross sectional area; NS = nonsignificant at $P \leq 0.05$.

Table 7. Effects of various plant growth regulator treatments sprayed four times (4×) at 300, 400, or 500 mg·L⁻¹ on 'Macoun' apple trees in Ellendale, DE, in 2013 (Experiment 7). Rates of 300 and 400 mg·L⁻¹ were applied with and without the surfactant Regulaid® (Reg) at 0.125% (v/v). Shoot height from ground is the distance from the ground level to each of the induced feathery.

Treatment	TCSA (cm ²)	Ht (cm)	Shoot number	Shoot ht from ground (cm)	Shoot angle (degrees)	Shoot length (cm)
MaxCel300 4×	1.8	157 bc	5 c	96 a	50 bc	19 b
MaxCel300 + Reg 4×	1.8	161 ab	10 b	89 ab	50 bc	18 b
MaxCel400 4×	1.9	156 bc	12 ab	88 bc	48 c	20 b
MaxCel400 + Reg 4×	1.7	156 bc	10 b	88 bc	48 c	20 b
MaxCel500 4×	1.7	153 bc	13 a	85 bc	43 d	19 b
Promalin400 4×	1.8	155 bc	6 c	86 bc	53 b	22 b
Promalin400 + Reg 4×	1.9	171 a	11 ab	96 a	51 b	20 b
Promalin500 4×	1.8	159 bc	6 c	81 c	53 b	25 b
Untreated	1.7	150 c	0 d	78 bc	59 a	46 a
P	NS	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001

Means within a column followed by different letters denote significant differences among treatments (Tukey's honestly significant difference, $P \leq 0.05$). TCSA = trunk cross sectional area; NS = nonsignificant at $P \leq 0.05$.

with either MaxCel®, Promalin®, or Tiberon™ SC had from two to six feathery. Increasing the rate of MaxCel® from 500 to 750 mg·L⁻¹ did not induce significantly more feathery. Promalin® was only tested with four applications, and no significant differences were observed regarding the number of shoots for the two tested rates (500 and 750 mg·L⁻¹). A single spray of Tiberon™ SC induced the same number of feathery as four sprays of MaxCel® or Promalin®. The average length of feathery was decreased by sprays of MaxCel®, Promalin®, or Tiberon™ SC. Shoot height was higher on untreated trees and when spraying four times with the higher rates of either MaxCel® or Promalin®. Tiberon™ SC applications induced the narrowest branch angles compared with untreated control trees, or Promalin®, or MaxCel® treated trees.

No differences between the control and the rest of treatments were observed in TCSA of 'Gala'. Tree height of 'Gala' was reduced by high rates of MaxCel®, and as the number of sprays increased the negative effect on tree height was greater. No significant differences regarding shoot number were observed for 'Gala'. The average length of feathery was unaffected by MaxCel®, Promalin®, or Tiberon™ SC. Shoot height was higher than the untreated control when trees were sprayed one time with Tiberon™ SC or with MaxCel® and Promalin® when sprayed more than two times.

Experiment 9: BA and BA plus GA₄₊₇ on 'Fuji' in 2014 in DE. Increasing the Promalin® dose from 400 to 500 mg·L⁻¹ slightly increased the TCSA of treated trees compared with the untreated control trees (Table 9). Similarly to previous experiments, Promalin® increased tree height compared with MaxCel® sprays. Higher quality ratings were observed when using the highest doses (500 mg·L⁻¹) and number of sprays (Five sprays) for both MaxCel® and Promalin®, whereas phytotoxicity was almost nonexistent across all the treatments. Higher doses and number of sprays also induced more lateral shoots, and similar numbers were observed when applying either MaxCel® four times at 500 mg·L⁻¹, or five times at 400 mg·L⁻¹. Similar responses were observed regarding Promalin® and the average shoot height. MaxCel® induced wider shoot angles compared with Promalin®, with more upright shoots observed on the control trees. No significant differences were observed regarding shoot length when comparing MaxCel® vs. Promalin® sprays. Longer shoots were observed on untreated trees.

Experiment 10: BA and BA plus GA₄₊₇ on a Range of Varieties in 2014–15 in DE. In 2014, 'Cripps Pink', 'Enterprise', and 'Fuji' had the highest tree quality ratings when sprayed with either Promalin® or MaxCel® (Fig. 4). 'Ambrosia', 'Crimson Crisp', and 'Gala' had the next highest quality ratings, whereas 'Cortland', 'Aceymac', 'Goldrush',

'Honeycrisp', and 'Suncrisp' had the least branching response to Promalin® or MaxCel®.

In 2015, 'Aceymac', 'Enterprise', and 'Gingergold' had the highest tree quality ratings when sprayed with either Promalin® or MaxCel®. 'Cameo', 'Crimson Crisp', 'Fuji', 'Gala', and 'Granny Smith' had lower quality ratings, followed by 'Cripps Pink', 'Suncrisp', and 'Macoun'. 'Ambrosia', 'Cortland', 'Goldrush', and 'Honeycrisp' had the lowest ratings.

For both years, there were no significant differences in tree quality between those treated with Promalin® or MaxCel® when averaged over all the varieties (data not shown).

Experiment 11: Inhibition of flowering in 2013 in NY, UT, and NC. Application of gibberellins in the late summer during the nursery year reduced flowering in both 'Gala' and 'Pink Lady' the following year in the orchard (Table 10). Untreated 'Gala' trees produced about five flower clusters per tree, whereas 'Pink Lady' produced about 18 flower clusters/tree. The low rate of GA₃ (100 mg·L⁻¹) reduced flowering of the 'Gala' trees planted at NY, but not the 'Gala' trees planted at Utah. The highest rates of GA₃ or GA₄₊₇ were the most effective treatments and essentially eliminated flowering in 'Gala'. With 'Pink Lady', the highest rate of GA₃ was better than the lowest, but did not totally eliminate flowering. Increasing the number of sprays also resulted in reduced flowering

Table 8. Effects of MaxCel® (Max), Promalin® (Prom), or Tiberon™ SC (Tib) sprayed one to four times (1× to 4×) at 100, 500, or 750 mg·L⁻¹ on ‘Fuji’ and ‘Gala’ apple trees in the nursery at Washington State in 2013 (Experiment 8). All the treatments included Regulaid® at 0.125% (v/v) as a surfactant. Shoot height from ground is the distance from the ground level to each of the induced feathery.

Variety	Treatment	TCSA (cm ²)	Ht (cm)	Shoot number	Shoot ht from ground (cm)	Shoot length (cm)	Shoot angle (degrees)
Fuji	Max500 1×	2.1	165 abc	2 bc	80 bc	43 b	—
	Max500 2×	2.0	163 abc	3 abc	78 c	36 bcd	—
	Max500 3×	2.0	160 c	4 ab	80 bc	37 bcd	—
	Max500 4×	2.2	158 c	4 abc	83 abc	41 bc	—
	Max750 1×	2.1	169 ab	3 bc	79 c	41 bc	—
	Max750 2×	2.1	162 abc	4 ab	77 c	33 cd	—
	Max750 3×	2.1	161 bc	5 ab	80 bc	35 bcd	59 b
	Max750 4×	2.0	158 c	3 abc	79 bc	35 bcd	—
	Prom500 4×	2.2	171 a	4 abc	89 ab	42 bc	—
	Prom750 4×	2.2	170 ab	6 a	85 abc	31 d	61 b
	Tib100 1×	2.0	165 abc	6 a	79 bc	37 bcd	73 a
	Untreated	2.2	171 a	1 c	91 a	53 a	60 b
	<i>P</i>	NS	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
Gala	Max500 1×	1.5 b	171 ab	4	64 c	36 a	—
	Max500 2×	1.7 ab	171 ab	5	66 c	34 a	—
	Max500 3×	1.7 ab	172 ab	6	68 abc	42 a	—
	Max500 4×	1.8 ab	170 ab	6	73 abc	36 a	—
	Max750 1×	1.7 ab	169 ab	4	67 c	38 a	—
	Max750 2×	1.7 ab	176 a	6	68 bc	37 a	—
	Max750 3×	1.7 ab	167 b	6	68 abc	35 a	—
	Max750 4×	1.8 ab	166 b	5	71 abc	39 a	—
	Prom500 4×	1.9 a	174 ab	6	71 abc	38 a	—
	Prom750 4×	1.8 ab	173 ab	6	77 a	35 a	—
	Tib100 1×	1.8 ab	176 a	7	76 ab	35 a	—
	Untreated	1.7 ab	172 ab	4	66 c	41 a	—
	<i>P</i>	0.0135	0.0009	NS	<0.0001	0.0079	—

Means within a column followed by different letters denote significant differences among treatments (Tukey’s honestly significant difference, $P \leq 0.05$). TCSA = trunk cross sectional area; NS = nonsignificant at $P \leq 0.05$.

Table 9. Effects of various plant growth regulator treatments treated either four or five times (4×, 5×) at 400 or 500 mg·L⁻¹ on ‘Fuji’ apple trees in Ellendale, DE, in 2014 (Experiment 9). All the Promalin® applications included Regulaid® at 0.125% (v/v) as a surfactant. Shoot height from ground is the distance from the ground level to each of the induced feathery.

Treatment	TCSA (cm ²)	Ht (cm)	Phytotoxicity (1 = none, 10 = severe)	Overall rating (1 = poor, 5 = excellent)	Shoot number	Shoot ht from ground (cm)	Shoot angle (degrees)	Shoot length (cm)
MaxCel400 4×	2.1 ab	182 d	1.0 b	3.0 ab	13 bc	103 ab	65 bc	36 b
MaxCel400 5×	2.2 a	187 bcd	1.3 a	3.2 a	16 a	106 ab	65 bc	33 b
MaxCel500 4×	2.1 ab	184 cd	1.1 b	3.3 a	17 a	106 ab	63 c	31 b
MaxCel500 5×	2.1 ab	185 cd	1.0 b	3.5 a	15 ab	104 ab	64 c	33 b
Promalin400 4×	1.8 b	189 abc	1.0 b	2.4 bc	12 c	97 b	69 b	30 b
Promalin400 5×	2.1 ab	195 a	1.0 b	2.4 c	12 c	111 a	68 b	34 b
Promalin500 4×	2.2 a	192 ab	1.1 b	3.1	14 abc	101 ab	68 bc	34 b
Promalin500 5×	2.0 ab	190 abc	1.1 ab	3.4 a	15 ab	110 a	65 bc	28 b
Untreated	1.9 b	188 bc	1.0 b	1.4 d	5 d	97 b	73 a	49 a
<i>P</i>	0.0002	<0.0001	0.0003	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001

Means within a column followed by different letters denote significant differences among treatments (Tukey’s honestly significant difference, $P \leq 0.05$). TCSA = trunk cross sectional area.

the next year. Four sprays of GA₄₊₇ at 250 mg·L⁻¹ was the best treatment for both varieties.

Discussion

Cyclanilide, BA, and BA + GA₄₊₇ were effective in inducing branching on several varieties in our experiments. Branching increase by BA + GA₄₊₇ has been reported on ‘Jonica’ and ‘Sampion’ apple varieties by Kaplan (2010); and on ‘Liberty’ x ‘Starking Delicious’, and ‘Liberty’ x ‘Macspur’ hybrids by Jacyna and Barnard (2008). On the other hand, other authors (Hrotko et al., 2000) found increased feathering on ‘Idared’ and ‘Egri piros’ by spraying BA. Among the three PGRs tested here, cyclanilide induced the least amount of branching, and it also reduced final caliper and tree height, resulting in poor tree architecture. This effect was dose

dependent and the negative effects on tree growth were more evident on ‘Macoun’, ‘Gala’, ‘Granny Smith’, and ‘Golden Delicious’, than on ‘Fuji’. Negative effects were also observed on ‘Macoun’, ‘Fuji’, ‘Acemy-mac’, and ‘Empire’ in a previous experiment in NY (Miranda Sazo and Robinson, 2011). Conversely, Elfving and Visser (2005) did not observe leader growth differences either on ‘Fuji’, ‘Cameo’, or ‘Scarletspur Delicious’ when spraying cyclanilide in Washington State. Most likely, this was due to greater shoot growth rate in Washington State than under Eastern US climatic conditions. An influence of temperature on branching response has been reported by the nurserymen in Italy, where they observe better results when BA sprays are followed by a 3 h period of at least 18 °C (65 °F) (Leo Forcher, personal communication). In our study ‘Gala’ was tested in WA, DE, and

Chile. Although no more feathers were observed in WA when spraying either Max-Cel® or Promalin®, higher quality trees were observed when spraying both products in DE, whereas in Chile only Promalin® gave more feathers on ‘Gala’. Higher temperatures and lower RH were observed in Quincy, WA, compared with Ellendale, DE, whereas in Santiago Chile (December) weather was in between DE and WA. The lowest RH and highest temperatures observed in WA may result in quicker drying of the PGR solution, hindering its uptake and activity. On the other hand, the highest RH observed in DE might have allowed longer drying time resulting in more uptake of the PGR, resulting in the better response we observed.

Both BA and Promalin® induced greater number of branches than cyclanilide in our studies and had smaller negative effect on final tree height. Tree height was reduced

Fig. 4. Effects of four or five applications of either MaxCel® or Promalin® on the overall tree quality of 17 apple varieties in Ellendale, DE, in 2014 and 2015 (Experiment 10). Tree quality (1 = poor, 5 = excellent) was subjectively assessed, taking into account overall tree height, number of feathers, and their angle. Excellent quality trees had a tree height of 180–200 cm and 12–15 wide-angle feathers, whereas poor quality trees were short in height and with no feathers at all. All the Promalin® applications included Regulaid® at 0.125% (v/v) as a surfactant. Bars with different letters denote significant differences among varieties (Tukey's honestly significant difference, $P \leq 0.05$).

Table 10. Effects of gibberellin treatment in the nursery on flowering of 'Gala' and 'Pink Lady' apple trees the next year in the orchard (Experiment 11).

Treatment	Gala (NY)	Gala (UT)	Pink lady (NC)
Untreated Control	4.5 a	5.6 a	17.5 ab
100 mg·L ⁻¹ GA ₃ 2×	1.2 bc	5.0 ab	17.0 abc
100 mg·L ⁻¹ GA ₃ 3×	0.6 c	4.5 ab	17.7 a
100 mg·L ⁻¹ GA ₃ 4×	0.5 c	7.3 a	14.2 cd
250 mg·L ⁻¹ GA ₃ 2×	2.2 b	6.1 a	13.7 d
250 mg·L ⁻¹ GA ₃ 3×	2.3 b	5.6 a	14.8 bcd
250 mg·L ⁻¹ GA ₃ 4×	0.7 c	1.5 bc	11.9 d
250 mg·L ⁻¹ GA ₄₊₇ 3×	0.0 c	0.5 c	12.7 d

Means within a column followed by different letters denote significant differences among treatments (Tukey's honestly significant difference, $P \leq 0.05$).

when using MaxCel® compared with Promalin®. Similar tree height decreases were reported by Palmer et al., (2011) when spraying the cytokinins, thidiazuron and benzyladenine, on pear trees. Similar to our results, Jacyna and Barnard (2008) observed greater leader growth on different apple hybrids when spraying Promalin® at 250–750 mg·L⁻¹.

Higher rates of BA were tested in our first experiments (1–5), but we did not see significant differences regarding lateral shoot number when comparing 500 mg·L⁻¹ vs. 1000

mg·L⁻¹ on 'Macoun', 'Fuji', 'Gala', 'Granny Smith', and 'Golden Delicious'. Hence, lower rates and more sprays were assessed in subsequent experiments (6–10). Higher number of shoots was observed when using MaxCel® at 400–500 mg·L⁻¹, or 300 mg·L⁻¹ plus a surfactant. However, adding a surfactant to MaxCel® caused significant phytotoxicity in previous studies (Robinson et al., 2014). This may be explained because the MaxCel® formulation already contains proprietary surfactants (Gregory Clarke, personal

communication). With the exception of the 1000 mg·L⁻¹ rate (2× label), we did not observe significant phytotoxicity when using Promalin®; still, when using a surfactant Miller and Eldridge (1986) reported some phytotoxicity on 'Delicious' trees when applying it at 300–500 mg·L⁻¹ rates. However, Miller and Eldridge (1986) reported identical responses when a much lower surfactant rate was also used together with Promalin®.

Compared with untreated trees, sprays of either BA or Promalin® increased the number of feathers by three-to-four times and reduced their crotch angle (flatter branches). Conversely, Keever et al. (1993) reported a crotch angle increase when spraying either BA or Promalin® on 'Bradford' pear trees. In our study, the widest shoots were observed when spraying MaxCel® compared with Promalin®. A study done by Elfving and Visser (2005) on 'Scarletspur Delicious' trees reported a branch angle increase (more upright) when cyclanilide plus Promalin® were sprayed together, compared with single sprays of cyclanilide.

Significant variety effects were observed in our study, for instance with 'Fuji' we induced an average of 16 branches compared with 14 for 'Gala', and 10 for 'Golden Delicious' or 'Macoun'. Overall, we observed good response and quality ratings on 'Cameo', 'Cripps Pink', 'Enterprise', 'Fuji', 'Ambrosia', 'Crimson Crisp', 'Gingergold', 'Gala', and 'Granny Smith' when spraying five times either Promalin® or MaxCel® at 400–500 mg·L⁻¹. On the other hand, varieties such as 'Ambrosia', 'Cortland', 'Goldrush', 'Honeycrisp', and 'Suncrisp' had the lowest ratings. Because we know of no published branching studies for such varieties, it is difficult to contrast our observations. The less branching induced on 'Honeycrisp' could be explained because of its weak growing habit. On the other hand, even though 'Ambrosia', 'Cortland', 'Goldrush', and 'Suncrisp' have less vigor than 'Fuji', their poor response to branching sprays might be explained by a strong apical dominance. In addition, 'Suncrisp' was observed to be very rate dependent, being more responsive at lower rates and more subject to phytotoxicity (data not shown).

Four sprays of GA₃ or three of GA₄₊₇ at 250 mg·L⁻¹ essentially eliminated flowering in 'Gala', whereas it was not quite enough on 'Pink Lady'. Davis (2002) observed that GA₄₊₇ more effectively suppressed flowering than GA₃ on 'Ramey York' in Blacksburg, Virginia. However, we cannot support that because multiple rates and spray times for GA₄₊₇ were not examined in our study. For the same treatments, there were far fewer flowers on 'Gala' in NY compared with UT. Trees were dug in Nov. 2013 and kept all together in cold storage during winter before planting them in spring at the different locations. Therefore, differences within locations must be explained by flower damage due to low spring temperatures, which were considerably lower in NY than in UT (Fig. 1). Flower induction in apple occurs in early summer (Ferree and Warrington, 2003), thus,

because flower bud initiation occurred when trees from both locations were under the same conditions, lower temperatures could cause some damage to floral buds in NY, rather than being a different gibberellin response to temperature.

To enhance branching on nursery trees, the best results were obtained with four applications at 2-week intervals of either MaxCel® or Promalin® at 400 mg·L⁻¹. Promalin® was slightly less effective branching agent than MaxCel®, but its effect could be improved by adding Regulaid® as a surfactant at 0.125% (v/v). On the other hand, Promalin® stimulated leader growth rate resulting in improved final tree height, whereas MaxCel® induced the widest branch angles. Sprays could be increased up to five times on varieties less prone to branching such as 'Macoun' and 'Golden Delicious'.

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