Influence of prohexadione calcium (Apogee®) on shoot growth of non-bearing mature apple trees in two different growing regions

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Privé, J.-P., Cline, J. and Fava, E. 2006. **Influence of prohexadione calcium (Apogee®) on shoot growth of non-bearing mature apple trees in two different growing regions.** Can. J. Plant Sci. **86**: 227–233. Orchard experiments were conducted on mature non-bearing apple (*Malus* × *domestica* Borkh.) trees to determine the efficacy of prohexadione-calcium (PC), formulated as Apogee® [27.5% PC + 56.1% $(NH_4)_2$ SO_4 +16.4% other proprietary additives] for shoot growth control on six cultivars grown in Ontario (ON) and one grown in New Brunswick (NB), Canada. Seasonal patterns of extension shoot growth among cultivars in both locations were also compared. Results indicate that PC applications are most effective at the beginning of the season, when relative growth rates were greatest in eastern Canada. Four applications of PC failed to significantly reduce shoot growth more than two applications in either location. However, the level of control might have been more effective in ON if treatment applications were initiated earlier in the season. Although tree vigor and shoot growth differed between cultivars and locations, PC significantly and consistently reduced shoot growth and relative shoot growth rates for all cultivars at both locations. Empire shoots treated with PC were approximately 33 and 37% shorter at the end of the season in NB and ON, respectively.

Key words: Calcium 3-oxido-5-oxo-4-propionylcyclohex-3-enecarboxylate, anti-giberellin, plant growth regulator, relative growth rate, *Malus*

Privé, J.-P., Cline, J. et Fava, E. 2006. **Influence de la prohexadione calcique (Apogee®) sur la croissance des pousses de pommier mature non en production dans deux régions**. Can. J. Plant Sci. **86**: 227–233. Les auteurs ont effectué des expériences au verger sur des pommiers matures non en production (*Malus* × *domestica* Borkh.) en vue d'établir dans quelle mesure la prohexadione calcique (PC), en l'occurrence le produit Apogee® (27,5 % PC + 56,1 % $(NH_4)_2SO_4$ + 16,4 % autres additifs exclusifs), permet de contrôler la croissance des pousses de sept variétés, soit six cultivées en Ontario (ON) et une autre au Nouveau-Brunswick (NB), au Canada. Les auteurs ont aussi comparé les variations saisonnières de la croissance des pousses d'extension pour ces cultivars, aux deux endroits. Les résultats indiquent que les applications de PC sont plus efficaces en début de saison, quand le taux de croissance relatif est le plus élevé, dans l'est du Canada. Quatre applications de PC n'ont pas permis de réduire la croissance des pousses significativement plus que l'ont fait deux applications à l'un et à l'autre endroit. Il se peut néanmoins que les applications aient été plus efficaces en Ontario, car elles ont été effectuées plus tôt dans la saison. Bien que la vigueur des arbres et la croissance des pousses diffèrent d'un cultivar et d'un lieu à l'autre, la PC a toujours réduit significativement la croissance des pousses et le taux de croissance relatif de ces dernières pour l'ensemble des cultivars aux deux endroits. Les pousses de pommier Empire traitées à la PC étaient plus courtes d'environ 33 % et 37 % à la fin de la saison au Nouveau-Brunswick et en Ontario, respectivement.

Mots clés: 3-oxydo-5-oxo-4-propionylcyclohex-3-ènecarboxylate de calcium, anti-giberrelline, régulateur de croissance, taux de croissance relatif, *Malus*

A delicate balance exists between vegetative and reproductive growth in apple trees. Frequently, management mistakes, biennial bearing, or abnormal weather conditions disrupt this balance, resulting in poor fruit set and excessive vegetative growth. Vigorous shoot growth can negatively influence tree productivity, fruit quality, pest control, and consequently profit (Forshey et al. 1992). From the standpoint of light alone, vigorous shoot growth and consequently shading affect the two essential properties required from a canopy for optimum orchard productivity: the concurrent capacity for high light interception and good distribution throughout the canopy (Corelli Grappadelli 2003). Previous studies by Privé and Stewart (2002) have shown that PC can increase light interception to the inner canopies of fully grown apple trees and thus enhance flower bud formation and possibly yield.

Pruning is one of the most expensive and time-consuming management practices in apple production (Felland 1998), particularly when trees are vigorous. Reducing tree growth reduces pruning costs (Forshey et al. 1992). A number of techniques are used to reduce growth, such as chemical con-

Abbreviations: **GA**, gibberellin; **GDD**, growing-degree day; **PC**, prohexadione-calcium; **RGR**, relative growth rates; **TCSA,** trunk cross-sectional area; **WAFB**, weeks after full bloom trol (Ethephon®), aggressive pruning, and root pruning, with varying degrees of success (Autio and Greene 1994). Ethephon® can be used to control tree growth but it may overthin the crop load if applied at the time and concentrations that most effectively control growth. It can also stimulate pre-harvest drop, and hasten ripening (Autio and Greene 1994). Aggressive pruning reduces tree size initially, but ultimately stimulates even more vigorous shoots the next growing season, resulting in reduced flower bud formation, fruit set, fruit quality and yield (Alderman and Auchter 1916; Pearson 1895). Root pruning reduces vigorous vegetative growth, but it also reduces fruit size and anchoring stability (Schupp and Ferree 1988).

Another option for controlling vegetative shoot growth is to apply a gibberellin (GA) biosynthesis inhibitor. These inhibitors can retard growth and improve plant productivity and/or performance (Rademacher 1991). Paclobutrazol, a gibberellin biosynthesis inhibitor, was used successfully on fruit trees to control vegetative growth, but the adverse effects on fruit quality factors such as size and pedicel length are unsustainable (Privé et al. 1989). Cyclohexanetriones are a new class of gibberellin biosynthesis inhibitors (Rademacher et al. 1992). Of these, prohexadione-calcium (PC) appears to be particularly effective, and has potential for improving the productivity of apple trees while reducing the requirement for pruning (Greene 1999).

Regalis® (Europe) and Apogee® (North America) are two formulations of PC that are commercially registered and available. Both Regalis® and Apogee® are sold as wettable granular formulations with 10% PC and 27.5% PC, respectively (Rademacher and Kober 2003). In Canada, Apogee® received registration in 2005 to reduce the vegetative growth of apples in the year of application. BASF, the developers of this product, indicate that it may serve, in part, as a pruning replacement by substantially reducing the internode shoot length without affecting the number of leaves per shoot or fruit size. Thus, the vegetative/reproductive balance of the tree is regulated. Other reported benefits include increased red color of apples, improved spray coverage and reduced disease pressure (Greene and Autio 2000). Rademacher and Kober (2003) also note that PC can improve fruit set.

Prohexadione-calcium reduces terminal growth by inhibiting the synthesis of gibberellins. By reducing the levels of growth-active GAs, shoot growth is regulated. The active component in the formulation is the free acid prohexadione, which is very unstable on its own. Therefore, a calcium salt is used to stabilize the acid. The acid, becomes liberated when prohexadione-calcium is mixed in the aqueous spray solution (Rademacher and Kober 2003). This acid blocks the enzymes involved in the biosynthesis of GAs in the pathway between GA_{20} to GA_1 (Nakayama et al. 1992). The dioxygenase, GA_{20}-3β-hydroxylase, is the most important target enzyme as it is the primary catalyst for the conversion of inactive GA_{20} into the highly active GA_1 (Rademacher and Kober 2003).

The material exhibits favorable ecotoxicological features as it has low mammalian toxicity, is not persistent in the environment, and has little or no carry-over residual activity. Once applied, PC requires between 10 and 14 d to become physiologically active. It degrades within the trees in a few weeks, so multiple applications may be necessary to maintain growth control throughout the entire season. The commercial interest in PC will stem from its ability to reduce or eliminate the need for dormant and/or summer pruning to regulate the vegetative and reproductive balance of the tree combined with its favorable ecotoxicological features.

Patterns of terminal extension growth and fruit set characteristics differ among apple cultivars and producing regions. The response to PC is therefore likely dependent upon the seasonal pattern and extent of shoot growth, which is influenced by genetic (cultivar, rootstock), cultural (tree age and health, summer/dormant pruning, fertilization, etc.) and environmental (seasonal temperatures, available moisture, hours of sunlight, etc.) factors.

Several studies on the efficacy of Apogee® on *Malus* and *Pyrus* have been reported in the United States (Greene 1999), however the results of these studies are specific to different growing conditions and cultivars than those common in ON and NB. Furthermore, the Canadian Pest Management Regulatory Agency (PMRA) requires efficacy data on the performance of Apogee® on the end use crops before considering the registration of this product for use in Canada. Preliminary results by Privé et al. (2004) showed promise for shoot control, therefore, a more elaborate orchard study was conducted in ON and NB to determine the efficacy of Apogee® as it relates to apple tree shoot growth in commercial non-bearing mature Empire apple orchards. A concurrent study also examined the efficacy of Apogee® on shoot growth for six nonbearing apple cultivars in ON.

MATERIALS AND METHODS

An orchard experiment was initiated in the spring of 2001 to determine the efficacy of PC on the vegetative growth control of six commercial apple cultivars grown in Ontario and one apple cultivar grown in New Brunswick. An additional objective of the trial in Ontario was to compare the seasonal patterns of extension shoot growth of six cultivars that differ in growth habit and vigor.

At both sites, three rates of PC were used: water only (control), two sprays of 125 mg L^{-1} PC (low rate) and four sprays of 125 mg L^{-1} PC (high rate) applied using a commercial air-blast sprayer. In ON, the sprays were applied at 1× tree row volume (TRV), while in New Brunswick, 3.7× TRV was used for the first application and subsequent applications were made at 2.4× TRV, due to machinery constraints. Previous studies in Bouctouche had shown little effect of PC applied at concentrations ranging from 1× to 7× on shoot growth suppression (Privé and Stewart 2002). All PC sprays in ON contained 125 mg L^{-1} ammonium sulfate and 0.125% Regulaid (Kalo Labs, USA) surfactant as well as 0.1% of a silicone-based defoamer (Fighter F, Loveland Industries, USA). In NB, all sprays included 0.125% surfactant (Agral 90) and 0.045% defoamer (Fighter F). Full bloom occurred on May 10 and Jun. 05 in ON and NB, respectively. Shoot growth, measured with a ruler from 100 shoots, at the time of the first PC treatments averaged 3 cm (May 17) in ON and 4 cm (Jun. 11) in NB. In order to maximize vegetative shoot growth, trees were de-fruited during fruit set (ca. 8–10 mm) using a combination of 1500 mg L^{-1} carbaryl (Sevin XLR, Bayer Inc) followed by hand removal.

Shoot Growth and Relative Growth Rates

The lengths of seven randomly selected and tagged shoots on each tree were measured at weekly intervals beginning on May 15 and Jun. 08, in ON and NB, respectively, and continuing until the end of August (Aug. 29, ON and Aug. 28, NB) when terminal buds were set and shoot growth had ceased. At the end of the growing season in NB, the number of nodes from each of the seven tagged shoots per tree was counted and the internode length of each shoot was calculated by dividing shoot length by number of nodes.

To examine the effect of climate on the physiological response of Empire trees treated with PC, Empire shoots from both NB and ON were measured during the growing season as mentioned above, and plotted on three different scales: calendar, growing-degree day (GDD, base 5°C) and weeks after full bloom (WAFB). This was done to determine whether the growth response of 'Empire' shoots in the two environments could be better explained by a physiological parameter based on temperature (GDD_5) or a phenological parameter based on calendar date (WAFB). Because the trees in NB were not grafted to the same rootstocks in ON (Ottawa 3/MM.111 vs. M.9) direct comparisons between the two sites are not permissible. Nonetheless, from what we know about the wide range of adaptability of PC with apple cultivars of differing vigor (Privé and Fava 2001), some insight from these experiments can be useful. Since the growing seasons vary greatly between NB and ON, relative growth rates were also calculated based on the number of WAFB. Relative growth rates (RGR) were calculated (Hunt 1982) on a weekly basis starting at full bloom as follows: L_2-L_1/T_2-T_1, where L_2 and L_1 are mean shoot length (cm) at measured times T_2 and T_1, respectively. Day was used as the time unit for this analysis.

Trunk Cross-sectional Area

Trunk circumference was measured at the beginning and end of the growing season at 30 cm and 20 cm above the graft union in ON and NB, respectively. These measurements were then converted to trunk cross-sectional area (TCSA) and used to assess tree vigor. Measurements were taken in the fall of 2000 and 2001. Data were normalized by examining the increase in trunk girth (TCSA 2001 – TCSA 2000).

Statistical Analysis

The orchard in ON consisted of six apple cultivars on M.9 rootstocks, planted in 1994 in a randomized block fashion with three individual tree replications at a spacing of 4.5 m × 2.5 m (888 trees ha^{-1}). The experiment was conducted at the Simcoe Campus of the University of Guelph, Simcoe, Ontario (42°15′N, 80°16′W). The trial was designed as a split-plot with PC rate as the main plot and cultivars as the split plot. The cultivars were Vista Bella, Thome Empire, Redspur Delicious, Crispin, Reinders Golden Delicious, and Northern Spy.

In NB, the trial was conducted in St-Antoine (46°26′N, 64°46′W) at the Uris Williams & Sons orchard using Thome Empire scions grafted to O.3 interstems and MM.111 rootstocks. The trees were planted in 1986 at a spacing of 2.5 m × 6.5 m (615 trees ha^{-1}). The trial was a completely randomized design, consisting of three individual tree replications for each of the three PC treatments.

Analysis of variance was conducted by the MIXED procedure of SAS (Version 8.12. SAS Institute, Inc., Cary, NC) with treatments treated as fixed while blocks were treated as random variables.

Due to the differences in cultivar/rootstock combinations between NB and ON, all variables measured at each site were analyzed by site. Mean separation was by protected least significant difference at $P = 0.05$. In NB, the RGR was log transformed to normalize the variance associated with this variable whereas this was not necessary for the ON data.

RESULTS AND DISCUSSION

Cultivar Differences

Significant differences in shoot growth ($P = 0.001$, Table 1) were found among the various cultivars from bloom until harvest. On Aug. 29, after terminal bud set, the most vigorous cultivar in ON was Empire followed by Crispin, Golden Delicious, Vista Bella, Northern Spy and Red Delicious (Table 1). Red Delicious had an average shoot length of 13.7 cm, which was much shorter than the average shoot length of 25.9 cm for Empire. Growth of Redspur Delicious was significantly less than the other cultivars in ON because of its spur type growth habit, but was comparable to that of the control-treated Empire trees in NB (Fig. 1). One of the main differences between the two sites was the vigor of the Empire trees. Although direct shoot growth comparisons between the Empire trees grown in NB and ON cannot be made because of their different rootstock combinations, relative differences with respect to PC treatments can be examined within sites.

PC Differences

Although tree vigor and shoot growth differed between cultivars and locations, PC significantly and consistently reduced shoot growth and RGR across all cultivars and locations, i.e., no cultivar by PC treatment interactions were found (Table 1). This supports previous studies that PC provided similar shoot growth suppression to Golden Russet, McIntosh and Cortland (Privé and Stewart 2002; Privé et al. 2004).

In both ON and NB, PC applications had the greatest effect at the beginning of the growing season when shoot RGR was reduced by ca. 62 and 67%, respectively, compared with the control trees. In ON, the greatest reduction in shoot growth ($P = 0.01$) occurred from 5 to 6 WAFB, when treated shoots were growing at an approximate rate of 0.3 cm d^{-1}, whereas control shoots were growing at an approximate rate of 0.8 cm d^{-1}. Smaller, but statistically significant reductions in shoot RGR were also found during the first 4 WAFB in ON. In NB,

Table 1. Main effects of PC and cultivar on mean shoot length (cm) per tree in Ontario in 2001

	May 17	May 24	May 31	Jun. 07	Jun. 15	Jun. 21	Jun. 28	Jul. 4	Jul. 18	Jul. 30	Aug. 29
Rate of PC (mg L^{-1})^z											
Untreated control	3.0	6.5	9.6	13.1	19.4	22.6	24.2	25.0	26.7	28.7	28.0
2 × 125 mg L^{-1}	3.4	6.5	8.7	10.6	13.5	14.4	15.2	15.7	17.0	18.6	18.0
4 × 125 mg L^{-1}	3.8	6.8	9.2	11.5	14.4	15.6	16.1	16.5	17.3	19.0	19.3
Significance	NS	NS	NS	*	**	**	**	**	**	***	**
LSD (P = 0.05)	0.56	0.74	0.9	1.0	1.5	1.8	2.3	2.3	2.5	2.7	3.0
Cultivar											
Redspur Delicious	1.18	2.11	3.2	4.1	6.6	7.9	9.4	10.6	11.7	13.0	13.7
Thome Empire	2.39	5.43	8.4	11.6	16.9	19.6	21.0	21.5	23.1	25.7	25.9
Reinders Golden Delicious	3.89	7.78	10.3	12.9	16.8	18.6	19.9	20.5	20.9	23.6	23.0
Crispin	5.42	9.47	12.6	15.5	19.7	21.7	22.8	23.3	24.4	26.6	25.6
Northern Spy	3.14	6.27	8.8	12.0	15.9	17.7	18.3	19.1	20.5	21.4	20.3
Vista Bella	4.34	8.56	11.6	14.3	18.8	19.7	19.7	20.5	21.2	22.4	22.2
Significance	***	***	***	***	***	***	***	***	***	***	***
LSD (*P* = 0.05)	0.789	1.05	1.2	1.4	2.1	2.5	3.2	3.2	3.6	3.8	4.2
Interaction (PC × Cultivar)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

^{z}Treatments applied on 5/16/01, 5/31/01, 6/18/01 and 6/28/01.

*, **, *** and **** indicate statistical significance at $P = 0.10$, $P = 0.05$, $P = 0.01$ and $P = 0.001$, respectively. NS, non significant. Seven shoots per rep with $n = 3$.

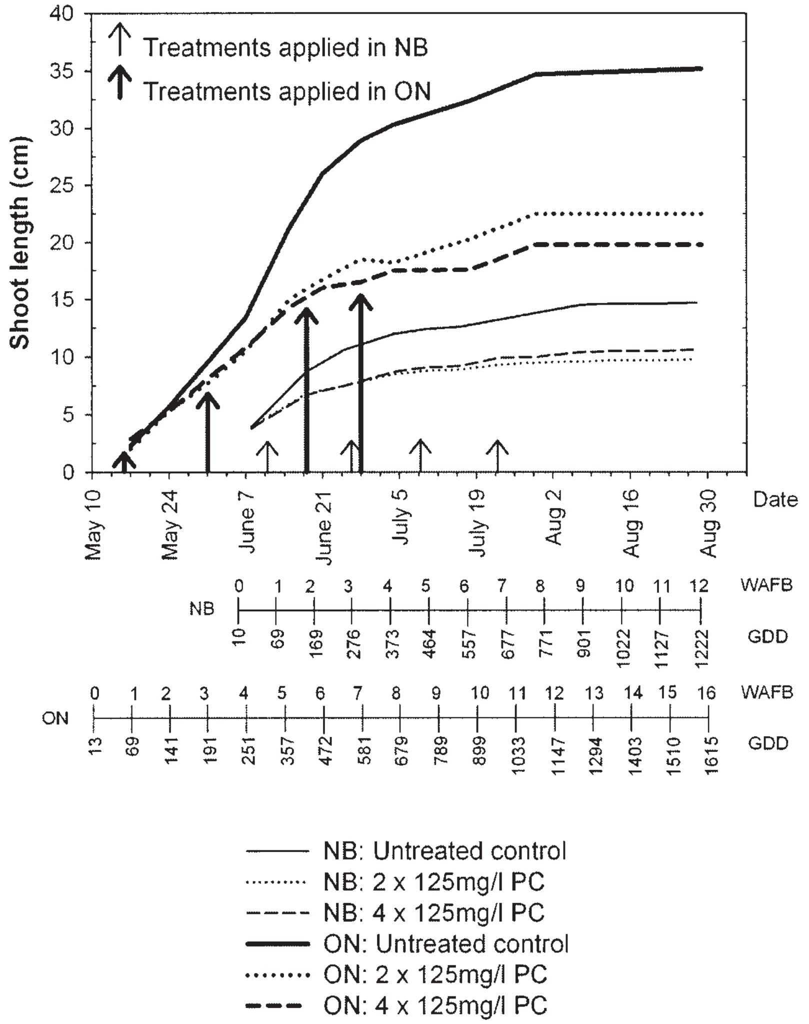

Fig. 1. Growth of Empire extension shoots from trees treated with prohexadione-calcium (PC) in New Brunswick and Ontario.

significant growth control was achieved very early in the season, i.e., within the first 3 WAFB, but with the greatest magnitude of growth control occurring between 2 and 3 WAFB. During this period, PC treated shoots were growing at an approximate rate of 0.1 cm d^{-1}, while control shoots were growing at a threefold increase of 0.3 cm d^{-1}. Significant differences were also found in the period from 7 to 9 WAFB; however, shoots had nearly ceased growing at this point with only 0.1 cm d^{-1} of growth. Although not as sensitive to change as RGR, the actual shoot growth was also a good indicator of shoot suppression by PC and could also be used as a diagnostic indicator of response (Fig. 1). Visual differences were evident from the field trials and the statistical analyses supported these findings. Significant differences in shoot growth were found in ON at 5 WAFB (4 wk after the first PC application, ca. Jun. 13) and 3 WAFB (2 wk after the first PC application, ca. Jun. 25) in NB (Fig. 1). Significant reductions in shoot growth for PC treated trees continued to the end of the growing season, where 33 and 37% reduction was obtained in NB and ON, respectively. The number of nodes per shoot did not differ significantly among PC treatments so the reduction in shoot growth by PC was caused mostly by reduced internode lengths (control = 1.0 cm; 2 × 125 = 0.7 cm; 4 × 125 = 0.7, cm, $P = 0.14$) similar to the findings by Privé and Stewart (2002). Unfortunately, leaf area measurements were not measured, but would have proved useful to the explanation of increased light interception to the inner canopy of the tree as reported by Privé and Stewart (2002). TCSA, a parameter often used to indicate tree vigor, was also not significantly reduced by the PC treatments at the $P = 0.05$ level (control = 8.5 cm^2; 2 × 125 = 4.9 cm^2; 4 × 125 = 4.5 cm^2, $P = 0.11$) but some debate could be made (at a higher P value) that it may/can reduce vigor during the growing season.

Rademacher and Kober (2003) suggest that shoot growth reduction with PC should range from 40 to 60% and that it may be necessary to increase the concentration and/or the number of applications when fruit set is light. As a consequence of defruiting the Empire trees in this experiment, two to four applications were anticipated. However, no significant difference in shoot growth control of trees treated with two or four applications of 125 mg L^{-1} of PC was observed at either location. The expected result might have been achieved had the sprays been applied at more frequent intervals early in the season. However, sufficient leaf surface area is required at the first spray for uptake of prohexadione. Therefore, the optimum stage for the initial treatment occurs when plants have two to five fully developed leaves per shoot. This stage corresponds to new shoots being 2–5 cm in length (roughly petal fall) (Rademacher and Kober 2003). The first application was made at this stage at both sites when shoots were approximately 3 cm in ON and 4 cm in NB. Thus, if greater shoot control is warranted, more frequent applications and/or higher concentrations during the first weeks after bloom may be required. However, this may not be entirely effective, since Greene and Autio (2000) reported that there is a 10 to 14 d lag between PC application and effective growth control. In the present study, most of the reduction in shoot growth occurred within 2 and 4 wk following the first application in NB and ON, respectively. Environmental conditions in NB (warmer temperatures and high humidity in June) most likely favored PC uptake (Rademacher, personal communication 2002) compared with the May applications in ON. With applications at 2-wk intervals, the third and fourth treatments were made after the period of greatest shoot growth at both sites and did not provide additional shoot suppression. At 3 WAFB, growth in NB had already begun to level off, while in ON, most of the sharp increase in shoot growth had yet to occur. This was most likely due to the more progressive increase of GDD_5, as well as the greater tree vigor in ON.

To examine the physiological and phenological differences in shoot growth response to PC, Empire shoot growth was more closely analyzed by calendar date, WAFB and GDD_5 (Fig. 1). The seasonal pattern of shoot growth was curvilinear over the season at both sites. Full bloom in NB occurred nearly 4 wk later than in ON (Jun. 05 vs. May 10) yet terminal buds were set by the end of August at both locations. Since the GDD_5 were calculated from the full bloom date, ON had a longer growing season and finished with approximately 400 more degree days than NB. Interestingly, at 1 WAFB, both ON and NB had accumulated 69 GDD_5 and their shoots had similar RGRs for this period (Table 2). However, by 4 WAFB, the climate in NB had accumulated 122 GDD_5 more than in ON because of the time of year (June to July in NB vs. May to June in ON). This would explain why the RGR, on a WAFB basis, peaked much earlier in NB than in ON.

GDD_5 and WAFB gave very similar shoot response curves to the PC treatments suggesting that either variable could be used for comparative shoot growth studies. However, upon closer examination of shoot RGR, it seems that GDD_5 may be a better indicator than WAFB. Although PC treatments were made consistent to tree phenology in both NB and ON (i.e., applications made at similar WAFB), the timings did differ in accumulated GDD_5. In general, other than the first application at 65 GDD_5, the remaining three sprays were applied in NB when more heat units had accumulated (NB: 276, 450 and 670 vs. ON: 200, 422, 581 GDD_5). This may be one reason why the shoot RGR was suppressed sooner in NB (at 3 WAFB) than in ON (at 7 WAFB). Also, the increased vigor of the ON trees is known to reduce the shoot suppression effectiveness of PC (Rademacher and Kober 2003).

SUMMARY

These data support the literature, that PC applications are most effective at the beginning of the season, when growth rates are greatest (Bubán et al. 2003; Rademacher and Kober 2003). They also suggest that PC can be a management option for growers wanting to control excessive shoot growth in non-fruiting trees. Although PC is commonly used on bearing trees to reduce vigor and shading in orchards with excessive growth, the response on bearing trees would be similar in percent control, but shoot growth would be less due to the sink strength of the fruit (Rademacher and Kober 2003). The consistent response of PC on reducing shoot growth for numerous cultivars sug-

Table 2. Relative growth rates for vegetative shoots of Thome Empire apple trees grown in ON and NB and treated with various rates of PC

	Relative growth rate (cm d^{-1})													
WAFB[z]	1–2	2–3	3–4	4–5	5–6	6–7	7–8	8–9	8–10	9–10	10–11	10–12	11–12	12–16
Ontario														
Rate of PC (mg L^{-1})[y]	trt[x]		trt[x]		trt[x]		trt[x]							
Untreated control	0.49	0.55	0.56	0.99	0.78	0.41	0.20		0.11			0.24		0.02
2 × 125 mg L^{-1}	0.47	0.34	0.40	0.56	0.28	0.26	0.14		0.15			0.18		0.00
4 × 125 mg L^{-1}	0.35	0.40	0.38	0.44	0.27	0.07	0.00		0.01			0.18		0.01
Significance	*	*	**	*	****	NS	NS		NS			NS		NS
LSD ($P = 0.05$)	0.087	0.078	0.036	0.100	0.002	0.280	0.206		0.500			0.619		0.855
New Brunswick														
Rate of PC (mg L^{-1})[y]	trt[x]		trt[x]	trt[x]		trt[x]								
Untreated control	0.48	0.28	0.16	0.06	0.04	0.08	0.08	0.09		0.02	0.01		0.00	
2 × 125 mg L^{-1}	0.28	0.09	0.11	0.06	0.01	0.06	0.02	0.02		0.01	0.00		0.02	
4 × 125 mg L^{-1}	0.29	0.11	0.13	0.07	0.02	0.09	0.02	0.03		0.00	0.00		0.02	
Significance	*	***	NS	NS	NS	NS	**	***		NS	NS		***	
LSD ($P = 0.05$)	0.099	0.009	0.344	0.679	0.116	0.534	0.027	0.004		0.326	0.422		0.011	

[z] WAFB = weeks after full bloom; full bloom occurred on 5/10/01 in ON and 06/05/01 in NB.

[y] Treatments applied on 5/16/01, 5/31/01, 6/18/01, 6/28/01 in ON and 06/11/01, 06/26/01, 07/09/01 and 07/23/01 in NB.

[x] trt indicates that PC sprays were applied during this period.

*, **, *** and **** indicate statistical significance at $P = 0.10$, $P = 0.05$, $P = 0.01$ and $P = 0001$, respectively; NS, non significant. Seven shoots per rep with $P = 3$.

gests that this product is very versatile and will likely have a large window of opportunity for Canadian apple growers. Although this study has shown that PC can suppress shoot growth (by 33–37%), it remains to be seen whether PC can reduce it to the extent of eliminating or significantly reducing the labor-intensive practice of shoot pruning, thus providing an economical incentive to the grower.

A strategy worth considering to improve the efficacy of PC for very vigorous trees would be to spray on a weekly basis beginning immediately near petal fall (the point at which extension shoot growth begins) and to continue these treatments until the rate of growth lessens. However, the crop load potential of the tree is unknown at this time and so the rates and timings of future PC applications may need to be adjusted according to crop load activity. The 10 to 14 d lag between PC applications does, however, allow decisions to be made at a later date as shoot growth continues elongation. Concurrently, the potential advantage of improved growth control would need to be balanced with the added application costs and other demands in the orchard at this time of the year.

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