Performance of prohexadione-calcium on shoot growth and fruit quality of apple — Effect of spray surfactants

J. A. Cline[1,4], C. G. Embree[2], J. Hebb[2], and D. S. Nichols[3]

[1]University of Guelph, Department of Plant Agriculture, Horticultural Experiment Station, Simcoe, Ontario, Canada N3Y 4N5; [2]Agriculture and Agri-Food Canada, Atlantic Food and Horticulture Research Centre, Kentville, Nova Scotia, Canada B4N 1J5; and [3]Nova Scotia Fruit Growers' Association, 32 Main St., Kentville, Nova Scotia, Canada B4N 1J5. Received 23 May 2007, accepted 7 August 2007.

Cline, J. A., Embree, C. G., Hebb, J. and Nichols, D. S. 2008. **Performance of prohexadione-calcium on shoot growth and fruit quality of apple — Effect of spray surfactants**. Can. J. Plant Sci. **88**: 165–174. Vegetative growth control of apples (*Malus × domestica* Borkh.) is necessary to maintain a balance between growth and cropping. Pruning is a labour-intensive management practice to achieve this and intrinsically stimulates new growth. Prohexadione-calcium (PC) is a plant bioregulator that effectively regulates the shoot extension growth of apples and other tree fruits. Previous research has demonstrated that its efficacy can vary based on the use of spray surfactants and adjuvants. This study investigated the efficacy of two rates of Apogee™, the commercial form of PC, used in combination with the spray surfactants Sylgard 309 and LI 700, on extension shoot growth and yield parameters.

Experiments were conducted in Ontario on Empire and Nova Scotia on Royal Court™ Cortland apples. Treatments of 0, 75 or 125 mg L^{-1} PC, with and without either 0.5% (vol/vol.) LI 700 surfactant or 0.05% (vol/vol) Sylgard 309 surfactant were applied to Empire trees, and 75 or 125 mg L^{-1} PC, with or without 0.5% (vol/vol) LI 700, were applied to Royal Court™ trees. An untreated control treatment was also included for comparison purposes. A total of two sprays were applied to the Empire trees and a total of three sprays were applied to the Royal Court™ trees. PC significantly decreased the vegetative growth of Empire and Royal Court™ trees by approximately 18 to 44%, respectively, and the efficacy of PC was enhanced when combined with either Sylgard 309 or LI 700 surfactant. No additional benefit in vegetative growth control was gained when using Apogee™ at rates of 125 mg L^{-1} PC, relative to 75 mg L^{-1} PC. The rate of Apogee™ did not influence the number of fruit or yield per tree or mean fruit size of either cultivar. For Empire, LI 700 and Sylgard 309 significantly reduced the number of fruit per tree, resulting in lower yields and crop densities. In addition, higher mean fruit weights, and a greater distribution of fruit in the larger size categories were observed for LI 700. Fruit from Royal Court trees treated with the highest rate of Apogee™ had higher crop densities, poorer coloured fruit, and a higher percentage of fruit less than 60 mm in diameter. These data provide support for the use of alternative surfactants with Apogee™ other than those listed on the US and Canadian product labels.

Key words: Apogee™, Empire, Cortland, Regalis, calcium 3-oxido-5-oxo-4-propionylcyclohex-3-enecarboxylate, surfactant

Cline, J. A., Embree, C. G., Hebb, J. et Nichols, D. S. 2008. **Effets de la prohexadione-calcium sur la croissance et la qualité des fruits du pommier — Incidence de la pulvérisation de surfactifs**. Can. J. Plant Sci. **88**: 165–174. Pour préserver l'équilibre entre la croissance de l'arbre et la production de pommes, il est impérieux de réguler la croissance végétative du pommier (*Malus ×domestica* Borkh.). L'élagage est une technique de gestion laborieuse qui permet d'y parvenir et stimule naturellement l'apparition de pousses. La prohexanione-calcium est un biorégulateur végétal qui contrôle l'expansion des pousses sur le pommier et d'autres arbres fruitiers. Des recherches antérieures ont néanmoins montré que son efficacité varie selon qu'on s'en sert sous la forme de surfactif à pulvériser ou d'adjuvant. La présente étude devait établir l'efficacité de deux taux d'Apogee^{MC}, version commerciale du PC, employée avec les surfactifs Sylgard 309 et LI 700, sur l'extension des nouvelles pousses et les paramètres du rendement. Les expériences se sont déroulées en Ontario sur des pommiers Empire et en Nouvelle-Écosse sur des pommiers Cortland Royal Court^{MC}. Les auteurs ont appliqué 0, 75 ou 125 mg de PC par litre avec ou sans surfactif LI 700 à 0,05% (vol/vol) ou Sylgard 309 à 0,05% (vol/vol) sur les pommiers Empire, et 75 ou 125 mg de PC par litre, avec ou sans LI 700 à 0,05% (vol/vol) sur les pommiers Royal Court^{MC}. Aux fins de comparaison, les auteurs ont inclus un témoin non traité. Ils ont pulvérisé les pommiers Empire à deux reprises et les Royal Court^{MC} trois fois. La PC ralentit sensiblement la croissance végétative des pommiers Empire et Royal Court^{MC}, soit d'environ 18 à 44%, respectivement; et les surfactifs Sylgard 309 ou LI 700 en accroissent l'efficacité. L'utilisation d'Apogee^{MC} avec 125 mg de PC par litre plutôt que 75 mg n'ajoute rien de plus. Le dosage d'Apogee^{MC} n'exerce aucune influence sur le nombre de fruits, le rendement par arbre ni le calibre moyen des fruits des deux cultivars. Dans le cas du pommier Empire, le LI 700 et le Sylgard 309 diminuent de façon appréciable le nombre de fruits par arbre, ce qui diminue le rendement et la densité des fruits. On observe aussi un poids moyen plus élevé des fruits et une meilleure répartition des pommes de plus gros calibre avec LI 700. Les pommiers Royal Court traités avec le taux le plus élevé d'Apogee^{MC} ont

[4]*To whom correspondence should be addressed (e-mail: jcline@uoguelph.ca)*

Abbreviations: **AMS**, ammonium sulphate; **PC**, prohexadione-calcium; **TRV**, tree row volume

donné une production plus dense de fruits moins colorés et une plus grande proportion de pommes de moins de 60 mm de diamètre. Ces données confirment l'utilité d'autres surfactifs que ceux énumérés sur l'étiquette des produits américains et canadiens avec Apogee[MC].

Mots clés: Apogee[MC], Empire, Cortland, Regalis, calcium 3-oxido-5-oxo-4-propionylcyclohex-3-enecarboxylate, surfactif

Managing the vegetative growth of apple (*Malus* × *domestica* Borkh.) trees by summer and dormant pruning is a very labour-intensive practice, yet essential to sustain orchard productivity and optimize fruit quality. In the early 1990s, a new class of growth retardants, the acylcyclohexanediones, was developed (Rademacher et al. 1998) and subsequently investigated for the potential to reduce vegetative growth of many plant species. Their mode of action is the inhibition of either 2∃-hydroxylase (Griggs et al., 1991) or 3∃-hydroxylase (Nakayama et al. 1992), which regulates the biosynthesis of active gibberellins, for example the hydroxylation of GA_{20} to GA_1 (Bomben et al. 1998). One chemical in this class, prohexadione-calcium (BAS125W or Apogee™), was recently registered in the United States and Canada for use on apples (Cline 2006). Registration is also currently being pursued in Europe for use on small grains, apples and pears (Evans et al. 1997, 1999).

Since its commercialization, several studies have demonstrated the season-long effectiveness that Apogee™ has provided for regulating apple tree extension growth ranging from 20 to 60% (Unrath 1999; Miller 2002; Dayatilake et al. 2005). However, spray timing in relation to phenology, spray concentration, the number of applications per season, seasonal pattern of tree growth, cultivar response and climate (short-season Maritime) are important factors that influence its efficacy (Unrath 1999). Recent reports (Schupp et al. 2003; Byers et al. 2004a) indicate that the presence and type of surfactant in the spray solution can also affect the efficacy of PC. The product label in the United States of America recommends the use of a standard spray surfactant, such as the non-ionic surfactant Regulaid (polyoxyethylene-polypropoxy-propal, alkyl 2-ethoxethanol, and dihydroxy propane; Kalo Inc, Overland Park, KS) to improve leaf coverage and maintain compound efficacy (BASF 2004). Byers et al. (2004a) found that when using spray water high in calcium salts, the growth suppression of Apogee was greatest with a combination of the non-ionic surfactant LI 700 and Choice [a commercial water conditioner containing ammonium sulphate (AMS), Loveland Industries, Greeley, CO] or the organosilicone surfactant Silwet L-77. Because of the interaction of Apogee with minerals found in hard water, AMS is recommended with Apogee™ if the source of spray water is high in calcium carbonate (“hard water”), or if calcium-containing fertilizers are added to the spray solution (BASF 2004; Cline 2006). While the formulated Apogee™ product already contains an unspecified amount of AMS, additional AMS may be required in some instances (G. Thomas, personal communication, BASF Chesapeake City, MD) where the product can become inactive in the presence of mineral salts, particularly Ca^{2+} ions.

Since Regulaid is not a registered agricultural surfactant for legal use in Canada, an alternative surfactant(s) to use with Apogee™ is required. ‘Sylgard 309’ (Dow Corning Canada Inc., Mississauga, ON), which contains 2-(hydroxypropyl)- heptamethyl-trisiloxane, and LI 700, which contains phosphatidylcholine, methylacetic acid and alkyl polyoxyethylene ether, are two Canadian registered non-ionic surfactants that have been effective with other plant growth regulators. A third surfactant, Agral 90 (nonylphenoxy polyethyoxyethanol surfactant, Syngenta Crop Protection Canada, Guelph, ON), is also available and has been shown to be effective with Apogee. While the Canadian product label for Apogee™ (BASF 2007) recommends the use of Agral 90 in instances where uptake of prohexadione-calcium could be reduced (drought, low humidity, hot temperatures), there are no reports in the literature on the individual effects of the Sylgard 309 or LI 700. The objective of this research was, therefore, to quantify the efficacy of Apogee™ at two rates, on two cultivars in two climatic regions, in the absence and presence of Sylgard 309 and LI 700.

MATERIALS AND METHODS

Experiment 1 – Simcoe, Ontario

A 10-yr-old research orchard of Empire/M.9 EMLA located at the University of Guelph, Simcoe Campus (42°51′40″N Lat. and 80°16′8″W Long), planted at a spacing of 2 m × 4.5 m (1111 trees ha^{-1}) was used for this study. Trees were trickle irrigated and trained to a slender spindle training system with a 2-m wooden support post adjacent to each tree. No chemical or hand thinning was conducted in the orchard to fully evaluate the effect of PC on fruit set and crop density. Apart from thinning, standard cultural and pest management practices for Ontario were used (Anonymous 2003).

Treatments were applied using a commercial air blast sprayer (GB Irrorazione Diserbo, Model Laser P7, Italy) to both sides of single tree plots at 1379 kPa, 750 L· ha^{-1}, which equated to tree row volume (TRV) pesticide dilute (Sutton and Unrath 1988). To minimize treatment interference caused by spray drift, experimental units were separated by at least one guard tree. A random complete block (RCBD) with six replications and seven treatments was used. Treatments were: (1) untreated control; (2) 75 mg L^{-1} prohexadione calcium (PC) (Apogee™ formulation containing 27.5% PC); (3) 75 mg L^{-1} PC plus 0.5% (vol/vol) LI 700; (4) 75 mg L^{-1} PC plus 0.5% (vol/vol) Sylgard 309 surfactant; (5) 125 mg L^{-1} PC; (6) 125 mg L^{-1} PC plus 0.5% (vol/vol) LI 700, and; (7) 125 mg L^{-1} PC plus 0.5% (vol/vol) Sylgard 309 surfactant. Ammonium sulphate (AMS) was included at a rate of 454 mg L^{-1} in all the PC treatments to maintain compound activity. Sprays were applied on May 20 and re-applied on Jun. 10, 2003, for a total of two applications. The average extension shoot length during the first application was approximately 2.5 cm.

Tree trunk circumference 30 cm above the soil line was measured and recorded to calculate trunk cross-sectional area. The length of new growth (current growing season) on five randomly selected extension shoots (selected randomly on each date) was measured on Jun. 05, Jun. 19, Jul. 03, Jul. 17, Aug. 05, and Aug. 25 (terminal bud set).

The total number and weight of fruit were recorded at harvest (Oct. 03) and a sample of approximately 100 fruits (1 bushel) was placed in cold storage for subsequent grading. Later in the autumn, fruit were graded into 11 commercial weight categories (<63 g, 64–81 g, 82–100 g, 101–24 g, 125–142 g, 143–161 g, 162–179 g, 180–197 g, 198–222 g, 223–240 g, 241–258 g), which represented fruit diameters ranging from 57.2 to 88.9 mm in 3.2 mm increments.

Experiment 2 – Canard, Nova Scotia

A 3-yr-old commercial block of Royal Court™/M.26 planted in Canard, Nova Scotia (lat. 45°7′57″N and 64°26′8″W) at a spacing of 2.5 m × 4.5 m (888 trees ha^{-1}) was used for this study. Trees were not irrigated and were trained to a vertical-axis central leader orchard system with a 3-m support post adjacent to each tree. Standard cultural and pest management practices for the region were used (Craig 2003). No chemical or hand thinning was conducted in the orchard, since the trees were in their third leaf and one objective of the experiment was to ascertain the effect of PC on fruit set.

Spray treatments were applied for 15 seconds per tree using a hand gun applicator set at 2000 kPa water pressure for delivery of 3370 L ha^{-1} TRV pesticide dilute (Sutton and Unrath 1988). To minimize treatment interference caused by spray drift, experimental units were separated by at least one guard tree. A randomized complete block with four replications, five treatments, and three trees per experimental unit was used as the experimental design. On May 20, 2003 trees were selected on the basis of uniform number of blossom clusters per tree and then grouped into four similar vigour classes based on trunk cross-sectional area (30 cm above the soil line). Each of the following five treatments was randomly assigned to one set of trees in each vigour group (replication). Treatments consisted of: (1) untreated control; (2) 75 mg L^{-1} prohexadione calcium (PC) (Apogee™ formulation containing 27.5% PC); (3) 75 mg L^{-1} PC plus 0.5% (vol/vol) LI 700; (4) 125 mg L^{-1} PC, and; (5) 125 mg L^{-1} PC plus 0.5% (vol/vol) LI 700. Ammonium sulphate (454 mg L^{-1}) was included in all treatments containing PC. Sprays were applied on Jun. 11 and re-applied at 14-d intervals on Jun. 25, and Jul. 09, for a total of three applications. The average extension shoot length at time of the first application was approximately 5 cm.

The trunk circumference 30 cm above the soil line was measured at the end of the growing season. Ten shoots were randomly selected and tagged from the canopies of the trees in the plots of each treatment (three shoots per outside tree and four from the tree at the centre of the plot) and measured on Jun. 10, Jul. 02, and Jul. 29, 2003 (terminal bud set). Initial and final crop density was determined on Jun. 28 and Jul. 28, respectively, by counting the total number of viable fruit per tree and dividing by truck cross-sectional area. All fruit were harvested and recorded on Sep. 27 2003 from each plot. The fruit was sorted into four categories based on fruit diameter: culls (<60.3 mm), small (60.3 to 63.5 mm), medium (63.5 to 69.9 mm) and large (>69.9 mm). Furthermore, fruit were assigned a colour rating of No. 1 (>70% red colour), No. 2 (50%–70% red colour), No. 3 (30%–50% red colour) or No. 4 (<30% red colour). Mean fruit size was determined from the total weight divided by the number of fruit in the sample.

Statistical Analyses

All data from both experiments were subjected to analysis of variance using SAS PROC GLM procedure (SAS Institute, Inc., Cary, NC). Data sets from each location were analysed separately due to confounding effects between both sites (cultivars, growing conditions, etc.). Mean separation using Protected Fisher's Least Significance Difference was used to separate treatment means ($P = 0.05$). Percent data were arc-sine transformed prior to analysis to correct for unequal variance. Means of non-transformed data are reported in tables. Orthogonal single-degree-of-freedom contrasts were used to make pre-planned comparisons of rates of Apogee™ and surfactants.

RESULTS

Experiment 1 – Simcoe, Ontario

Apogee™ reduced shoot extension growth in comparison with the untreated trees, but not significantly until approximately 7 wk after the first applications were made (Table 1) and only when a spray surfactant was used with Apogee™. This difference in growth was maintained until terminal bud set on Aug. 25. Applications of PC at 125 mg L^{-1} did not provide any additional growth control in comparison with applications at 75 mg L^{-1}. At both rates of PC, the inclusion of either Sylgard 309 or LI 700 significantly reduced shoot

Table 1. The influence of Apogee in combination with or without Sylgard 309 and LI-700 surfactants on shoot growth, tree growth, and yield parameters of ‘Empire’/M.9 trees. University of Guelph, Simcoe, Ontario, 2003

			Mean shoot length[y]											
Treatment	Apogee (mg L^{-1})[z]	Surfactant (% vol/vol)	06 Jun (cm)	19 Jun (cm)	03 Jul (cm)	17 Jul (cm)	05 Aug (cm)	25 Aug (cm)	TCSA fall 2003 (cm^2)	Total number fruit per tree	Yield (kg.$tree^{-1}$)	Yield efficiency (kg.cm^{-2})	Crop density (#.cm^{-2})	Mean fruit weight (g)
1	0	–	9.0	21.3	28.7	33.4	33.0	34.2	23.2	280	33.3	1.52	12.9	121.0
2	75	–	8.7	18.9	26.7	29.7	28.9	29.1	20.8	195	25.5	1.25	9.6	131.4
3	75	0.5 LI-700	7.9	18.9	24.1	25.8	26.9	27.8	25.9	175	24.3	0.98	7.1	139.0
4	75	0.05 Sylgard 309	8.4	20.0	26.3	26.9	27.1	28.3	30.2	210	28.2	0.90	6.4	138.3
5	125	–	8.8	21.9	27.9	27.1	29.3	30.5	23.2	265	34.7	1.56	12.1	134.6
6	125	0.5 LI-700	9.5	18.1	22.1	23.2	22.8	24.4	25.9	161	22.1	0.90	6.6	137.7
7	125	0.05 Sylgard 309	9.1	18.4	22.7	23.4	23.3	26.1	23.6	189	24.0	1.06	8.4	128.1
	Significance		NS	NS	*	**	**	*	NS	*	NS	*	*	NS
	P value		0.823	0.200	0.024	0.0089	0.0015	0.0470	0.2246	0.0734	0.1082	0.0549	0.0403	0.1539
	Contrasts (*P* value)													
	Effect of rate of PC-(2 vs 5)		0.9512	0.0957	0.5868	0.3842	0.8665	0.6676	0.4931	0.1288	0.0836	0.2556	0.3043	0.6687
	Effect of Li-700 (3+6 vs 1)		0.7110	0.0615	0.0040	0.0005	0.0002	0.0036	0.3359	0.0054	0.0237	0.0135	0.0047	0.0079
	Effect of Sylgard 309 (4+7 vs 1)		0.8039	0.1647	0.0296	0.0012	0.0004	0.0124	0.2124	0.0427	0.1061	0.0247	0.0113	0.0601
	Effect of surfactants (4+7 vs 3+6)		0.8875	0.5611	0.3538	0.7233	0.8289	0.5975	0.6964	0.3241	0.4203	0.8341	0.7574	0.3182

[z]Sprays applied at full bloom (2003 May 20) and at full bloom plus 14 d (2003 Jun. 10).
[y]Average of 10 random extension shoots per tree.
***, **, *, indicates statistical significance at $P = 0.001$, $P = 0.01$, and $P = 0.05$, respectively; NS, non significant.

Table 2. The influence of Apogee in combination with or without Sylgard 309 and LI-700 surfactants on the commercial grade out of fruit[z] from 'Empire'/M.9 trees. University of Guelph, Simcoe, Ontario, 2003

			Minimum fruit size (mm) in each category									
			57.2	63.5	66.7	69.9	73.0	76.2	79.4	82.6	85.7	88.9
			Commercial countsize category									
Treatment	Apogee (mg L^{-1})[y]	Surfactant (% vol/vol)	198	163	150	145	141	138	125	113	100	88
1	0	–	3.1	12.6	34.2	26.6	12.4	8.0	2.5	0.3	0.0	0.0
2	75	–	1.4	8.9	27.3	25.2	22.4	10.2	3.4	0.6	0.4	0.4
3	75	0.5 LI-700	1.5	5.2	17.9	30.3	25.5	11.5	5.0	1.9	0.5	0.5
4	75	0.05 Sylgard 309	1.8	9.6	21.6	22.9	18.5	14.1	6.9	3.6	0.7	0.2
5	125	–	0.9	7.8	26.1	24.9	20.0	10.1	6.0	3.0	0.7	0.2
6	125	0.5 LI-700	2.4	6.2	21.0	25.5	18.6	13.5	8.2	2.6	0.2	1.4
7	125	0.05 Sylgard 309	2.5	6.5	31.5	28.7	17.0	8.9	2.8	1.2	0.2	0.2
	Significance		NS	NS	NS	NS	*	NS	NS	NS	NS	NS
	P value		0.2557	0.4682	0.0770	0.3553	0.0467	0.6636	0.1743	0.1284	0.1215	0.6935
	Contrasts (*P* value)											
	Effect of rate of PC- (2 vs 5)		0.628	0.789	0.848	0.938	0.542	0.981	0.309	0.079	0.631	0.545
	Effect of Li-700 (3+6 vs 1)		0.150	0.034	0.005	0.648	0.005	0.182	0.053	0.095	0.184	0.023
	Effect of Sylgard 309 (4+7 vs 1)		0.240	0.160	0.131	0.782	0.124	0.308	0.274	0.077	0.453	0.294
	Effect of surfactants (4+7 vs 3+6)		0.759	0.376	0.093	0.380	0.111	0.713	0.302	0.870	0.489	0.128

[z]Grading values are percent based on number of fruit in each category (not weight).
[y]Sprays applied at full bloom (2003 May 20) and at full bloom plus 14 d (2003 Jun. 103).
***, **, *, indicates statistical significance at $P = 0.001$, $P = 0.01$, and $P = 0.05$, respectively; NS, non significant.

growth by 8.5% and 12.4% at terminal bud set, respectively. Apogee™ treatments, averaged over all the rates, reduced shoot growth by approximately 20% by the end of the growing season. Apogee™ at a rate of 125 mg L^{-1} plus either Sylgard 309 or LI 700 surfactant reduced shoot growth the most ($P = 0.047$). Tree growth, as represented by trunk cross-sectional area, was similar for all treatments. As a result of a reduction in the total number of fruit per tree on trees treated with Apogee™ plus either Sylgard 309 or LI 700, yield efficiency and crop density were significantly lower for these treatments as well.

Neither Apogee™ rate or the inclusion of a surfactant had a marked influence on fruit size distribution (Table 2). Contrast analysis indicated that there were significantly fewer fruit in 163, 150, 141, and 88 count-size categories from trees treated with LI 700 in comparison with untreated trees. This effect was independent of the rate of Apogee™.

Experiment 2 – Canard, Nova Scotia

Apogee™ significantly ($P = 0.047$) reduced shoot extension growth of Royal Court™ on Jul. 02, which coincided with 6 wk after the first application of Apogee™ (Table 3). Contrast analysis of PC vs. untreated control treatments revealed that PC on average, reduced shoot growth by 23 and 36% by Jul. 02 and Jul. 29 (terminal bud set), respectively. Applications of PC at 125 mg L^{-1} did not provide any additional growth control in comparison with a rate of 75 mg L^{-1}. There did appear to be a slight improvement in growth control (11 to 18% for the 75 mg L^{-1} and 125 mg L^{-1} rates of PC, respectively) when LI 700 was included as a spray surfactant, however, this effect was just shy of statistically significant ($P = 0.0578$). Tree growth, expressed as trunk cross-sectional area, was similar for all treatments, as was the number of fruit per tree, yield per tree, and mean fruit weight. There was, however, a significant ($P = 0.04$) increase in crop density at the highest rate of PC in comparison with the untreated control and low rate of PC treatments, despite any measurable effect on fruit set (data not shown).

Based on fruit colour grading data, fruit from trees treated with the highest rate of PC (125 mg L^{-1}) had fewer fruit in the No.1, No.2 and marketable colour categories (Table 4). Contrast analysis indicated a slight improvement in colour with the use of LI 700, but this only occurred in the No.2 colour category. In terms of the effect of PC on fruit size distribution, Apogee™ increased the percentage of unmarketable small fruit (culls), and this effect increased significantly with increasing rates of PC. This effect was likely an indirect effect of the higher crop densities observed on trees treated with PC. Overall, the percentage of total marketable fruit was similar for all treatments.

Table 3. The influence of Apogee in combination with or without LI-700 surfactant on shoot growth and yield of 'Royal Court'/M.26. Canard, Nova Scotia, 2003

Treatment	Apogee rate[z] (mg L^{-1})	Surfactant (% vol/vol)	Mean shoot length (cm)[y] 10 Jun	02 Jul	29 Jul	TCSA fall 2003 (cm^2)	Total number of fruit/tree[x]	Yield per tree (kg)	Crop density (no. cm^{-2})	Mean fruit weight (g)
1	0	–	3.9	23.3	32.9	7.5	108	19.0	14.0	180.5
2	75	–	4.2	18.5	23.4	7.5	108	18.5	15.9	173.1
3	75	0.5 % LI-700	4.7	17.9	20.8	7.3	103	14.3	15.7	174.3
4	125	–	4.7	19.6	22.4	7.2	97	13.7	16.5	175.5
5	125	0.5% LI-700	4.0	15.7	18.2	7.3	137	22.3	19.7	164.2
	Significance[w]		NS	*	**	NS	NS	NS	NS	NS
	P value		0.436	0.047	0.003	0.829	0.201	0.521	0.111	0.385
	Contrasts (*P* value)									
	Effect of LI-700-(3+5 vs 2+4)		0.4376	0.1314	0.0578	0.6987	0.0839	0.4632	0.0888	0.3238
	Effect of Rate of PC (2+3 vs 4+5)		0.4150	0.6227	0.2199	0.3794	0.1770	0.5621	0.0396	0.4303
	Effect of Apogee (1 vs 2+3+4+5)		0.1765	0.0095	0.0005	0.7272	0.9537	0.6263	0.3272	0.2140

[z]Three sprays applied on Jun. 11, Jun. 25 and Jul. 09.
[y]The average length of 10 randomly selected tagged extension shoots per tree.
[x]TCSA refers to trunk cross-sectional area.
[w]The fruit was harvested from each plot on 2003 Sep. 25.
***, **, *, indicates statistical significance at $P = 0.001$, $P = 0.01$, and $P = 0.05$, respectively; NS, non significant.

Table 4. The influence of Apogee in combination with or without LI-700 surfactant on commercial gradeout and marketable yield of 'Royal Court'/M.26. Canard, Nova Scotia, 2003

				Grading by colour (%)					Grading by size (%)					
Treatment	Apogee rate[z] (mg L^{-1})	Surfactant (% vol/vol)	Mean fruit weight (g)	No. 1[y]	No.2[x]	No.3[w]	No.4[v]	Fruit with marketable colour[u]	< 60.3 mm- Cull	60.3 mm min (small)	63.5 mm min (med)	>69.9 mm min (large)	Fruit with marketable size[t]	Total marketable fruit[s]
1	0	–	181	64.1	25.1	5.9	0.0	95.1	5.1	33.9	43.4	17.9	61.2	61.2
2	75	–	173	68.5	18.3	4.4	0.0	91.2	8.9	29.1	48.7	13.4	62.1	62.1
3	75	0.5 LI-700	174	67.2	20.8	3.8	0.3	91.9	7.8	36.1	43.2	13.0	56.1	55.8
4	125	–	176	58.4	20.2	9.9	2.1	88.5	9.3	33.5	44.3	12.7	57.1	55.3
5	125	0.5 LI-700	164	49.9	26.6	9.1	0.4	85.6	15.4	37.5	38.5	9.9	48.5	48.3
	Significance		NS	NS	NS	NS	NS	*	*	NS	NS	NS	NS	NS
	P value		0.3566	0.118	0.030	0.470	0.579	0.032	0.007	0.884	0.455	0.720	0.560	0.605
	Contrasts (*P* value)													
	Effect of LI-700-(3+5 vs 2+4)		0.4376	0.324	0.026	0.976	0.588	0.649	0.196	0.351	0.137	0.810	0.294	0.366
	Effect of Rate of PC (2+3 vs 4+5)		0.4150	0.019	0.044	0.081	0.306	0.047	0.043	0.639	0.234	0.769	0.367	0.332
	Effect of Apogee (1 vs 2+3+4+5)		0.1765	0.618	0.080	0.862	0.579	0.014	0.009	0.946	0.952	0.217	0.391	0.384

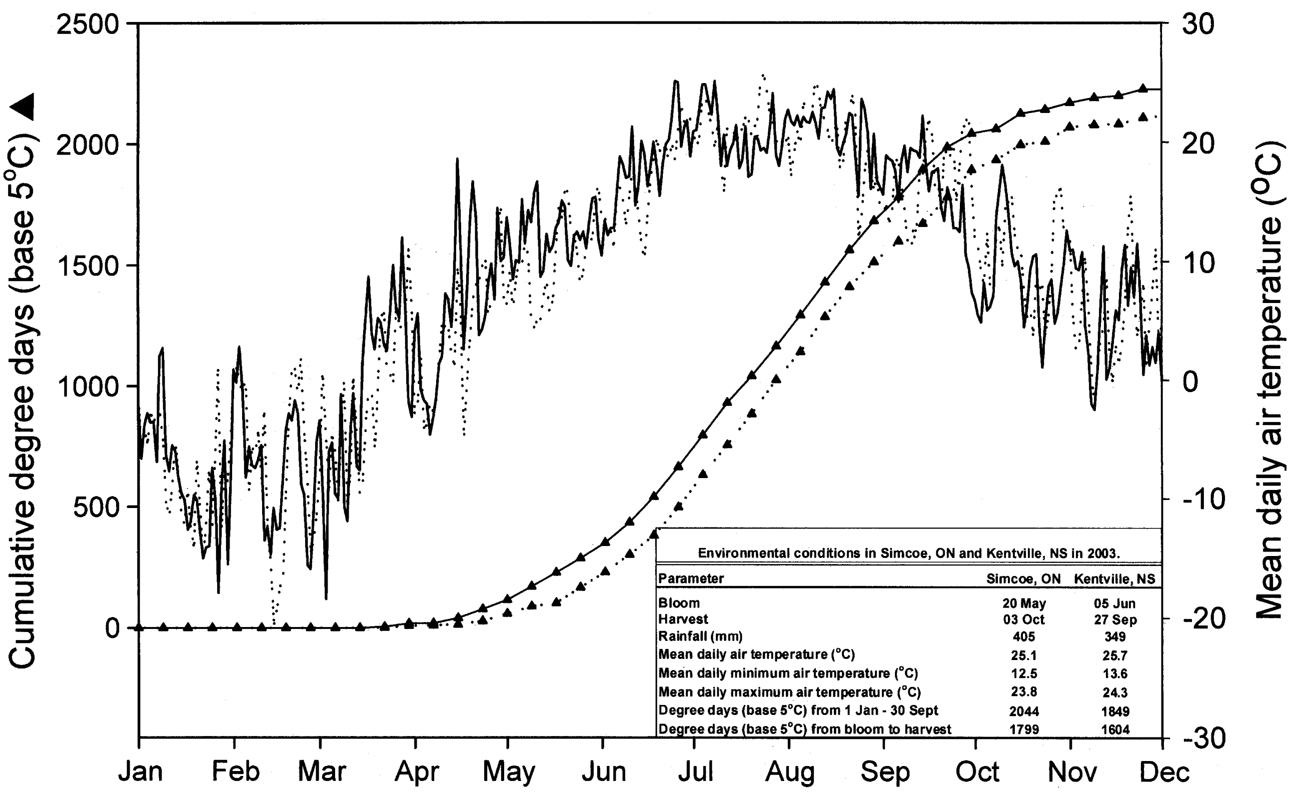
[z]Apogee.
[y]Fruit with surface colour >70% red, irrespective of size.
[x]Fruit with surface colour between 50 and 70% red, irrespective of size.
[w]Fruit with surface colour between 30 and 50% red, irrespective of size.
[v]Fruit with surface colour <30% red, irrespective of size.
[u]Fruit with Colour Grades No. 1, No. 2, No. 3.
[t]Fruit >2.5" (64 mm) (120, 100, and 80 count size).
[s]Fruit with surface colour >33% and fruit size >2.5″
***, **, *, indicates statistical significance at $P = 0.001$, $P = 0.01$, and $P = 0.05$, respectively; NS, non significant.

DISCUSSION

These studies indicate that proxhexadione-calcium (Apogee™ formulation) can significantly decrease the vegetative shoot extension growth of Empire and Royal Court™ trees by approximately 18 to 44%, respectively, and that the efficacy of PC is enhanced when combined with either Sylgard 309 or LI 700 surfactant. While an overall average total shoot length of 34 and 33 cm for Empire and Royal Court™ may seem insufficient to warrant the use of a growth regulator compound, these numbers represent an average shoot extension growth and therefore many shoots were indeed longer and some shorter than the means presented. In Ontario, summer pruning of Empire is often conducted to enhance fruit colour, even when shoot growth of this weak-growing spur-type cultivar is comparable to the levels observed in the present studies.

The growth response of apple trees to Apogee™ has been extremely consistent after nearly a decade of research in Simcoe (Cline and Norton 2006). Therefore, in the present study the authors maintain that the differences in growth rates between the two cultivars are more likely associated with genetic and cultural influences (including soil properties) than climactic influence between the two locations. This is supported from environmental data obtained from Kentville, NS (Environment Canada 2007) and Simcoe, ON (University of Guelph weather station); these data indicate rainfall, mean daily air temperatures, mean daily minimum and maximum temperatures from bloom until harvest were quite similar in 2003 for each location (Fig. 1). While the degree days from Jan. 01 to harvest or from bloom until harvest were lower for Kentville, NS, in comparison with Simcoe, ON, (Fig. 1-inset) most of this difference was associated with warmer temperatures in Simcoe between mid August and harvest – well after the period of terminal bud set, which coincides with the cessation of shoot extension growth.

While the overall shoot extension growth of ~35 cm in the untreated control trees may not seemingly justify the use of Apogee™ in the particular cultivars and year of this study, one must consider that this is an average value and that many shoots would indeed have been longer than 35 cm, warranting at the least, summer pruning. Second, this growth was limited by the atypically heavy crop densities that resulted from the testing of PC on fruit set. Overall, the reduction in growth in the present studies, based on the rates used, is consistent with the magnitude (percent) in growth suppression observed in other studies on Delicious (Greene 1996; Byers and Yoder 1999; Unrath 1999), Fuji (Byers and Yoder 1999; Byers et al. 2004b; Unrath



Environmental conditions in Simcoe, ON and Kentville, NS in 2003.

Parameter	Simcoe, ON	Kentville, NS
Bloom	20 May	05 Jun
Harvest	03 Oct	27 Sep
Rainfall (mm)	405	349
Mean daily air temperature (°C)	25.1	25.7
Mean daily minimum air temperature (°C)	12.5	13.6
Mean daily maximum air temperature (°C)	23.8	24.3
Degree days (base 5°C) from 1 Jan - 30 Sept	2044	1849
Degree days (base 5°C) from bloom to harvest	1799	1604

Fig. 1. Mean daily air temperatures, calculated cumulative degree days (△) and various phenological and climatic parameters (table inset) for Simcoe, Ontario (——) and Kentville, Nova Scotia (......) in 2003. The bloom and harvest dates for Simcoe and Kentville (inset) are for Empire and Royal Court, respectively (Kentville Data Source: Environment Canada 2007).

1999), Gala (Byers and Yoder 1999), Golden Delicious (Yoder et al. 1999), Rubin (Porebski et al. 2006) and McIntosh (Greene 1996; Privé et al. 2004) apple trees. Based on these data, Sylgard 309 and LI 700 appear to be suitable non-ionic surfactants for use with Apogee™. Furthermore, these results fail to demonstrate any additional benefit in vegetative growth control when using Apogee™ at rates of 125 mg L^{-1} PC, in contrast to 75 mg L^{-1} PC. PC led to a reduction (up to 50%) in the crop density of Empire, and this effect was exacerbated by the addition of a surfactant. A reduction in crop density has been observed previously on Empire when PC was used in combination with water high in mineral salts (Schupp et al. 2003). The opposite was observed in the Royal Court™ where Apogee™ increased fruit set, consist with the results of others (Byers et al. 2004b; Greene, 1999; Unrath, 1999). Some studies have demonstrated little or no effect of Apogee™ on fruit set (Byers and Yoder 1999; Costa et al. 2001). Despite the reduction in crop density on Empire in the present study, PC treated trees were not over thinned and would have required minimal chemical or follow-up hand thinning in a commercial orchard. The negative effects of Apogee™ on fruit size of Royal Court™ are likely a direct result of the increased fruit set and crop density found in PC-treated trees. Additional chemical or hand thinning can be used commercially to overcome this effect (Byers et al. 2004b; Basak and Krzewinska 2006). In previous studies with Apogee™, reduced shoot extension growth has resulted in improved light penetration within the top of the tree canopy (Privé et al. 2004, 2006; Cline, unpublished data) and improved fruit colour (Cline, unpublished data). In the present study, however, a slight but significant reduction (~10%) in the percentage of fruit with marketable colour was observed in fruit from trees treated with PC. This response is likely because of the tip bearing nature of the Royal Court™ cultivar combined with shortened internodes of fruiting branches caused by PC, which consequently would result in a more compact tree with greater shading within the lower portions of the canopy.

Although Schupp et al. (2003) and Byers et al. (2004a) report that the formulated Apogee™ product can cause sporadic fruit cracking of Empire under certain unspecified environmental conditions in the northeastern production areas of the United States, no negative effect of PC on cracking of either cultivar in either climate and for any rate was observed in the present study (data not presented).

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