Prohexadione-calcium Decreases Fall Runners and Advances Branch Crowns of ‘Chandler’ Strawberry in a Cold-climate Annual Production System

Brent L. Black[1]
U.S. Department of Agriculture, Agricultural Research Service, Henry A. Wallace Beltsville Agricultural Research Center, Fruit Laboratory, Building 010A, 10300 Baltimore Avenue, Beltsville, MD 20705-2350

Additional index words. *Fragaria ×ananassa*, plant growth regulator, GA, gibberellin synthesis inhibitor

Abstract. **Balancing vegetative growth with fruiting is a primary concern in strawberry (*Fragaria ×ananassa* Duch.) production. Where nursery plant selection and preconditioning are inadequate for runner control, additional approaches are needed. The gibberellin biosynthesis inhibitor prohexadione-Ca (commercial formulation Apogee) was tested over two seasons for suppressing fall runners of ‘Chandler’ plug plants in a cold-climate annual hill production system. Prohexadione-Ca was applied as a foliar spray at active ingredient concentrations ranging from 60 to 480 mg·L^{-1} , either as a single application 1 week after planting, or repeated at 3-week intervals. The lowest rate resulted in inadequate runner control, with some runners producing malformed daughter plants. Higher rates resulted in 57% to 93% reductions in fall runner numbers, with a concomitant increase in fall branch crown formation. There were no effects of the prohexadione-Ca treatments on plant morphology the following spring, and no adverse effects on fruit characteristics or yield. Chemical names used: prohexadione-calcium, calcium 3-oxido-4-propionyl-5-oxo-3-cyclohexene-carboxylate.**

The balance between vegetative (branch crowns, stolons) and generative (flowers, fruit) growth of strawberry is of critical concern to plant breeders, propagators, and fruit producers (Darrow, 1929). Cultural practices and systems in the nursery and fruiting field have been devised to promote either vegetative or generative growth, by exploiting components of the seasonal growth cycle. In the annual hill production system, nursery transplants are planted close-spaced and stolons or runners are prevented or removed to promote fruit production on large multi-crown plants (Galletta and Bringhurst, 1989). In this system as practiced in regions of concentrated production, vegetative growth is effectively regulated by environmental conditions in the nursery and fruiting field. These conditions are controlled by selecting nursery location based on latitude and altitude, carefully orchestrating the time of digging in the nursery, the amount of chilling of the bare-root nursery plants, and the date of transplanting to the fruiting field.

Adapting this production system to other geographic regions with very different climatic conditions requires the use of different nursery plant types, and additional refinement of cultural practices to regulate vegetative growth (Fiola et al., 1995). In the colder maritime and piedmont climates of the mid-Atlantic United States, the most commonly practiced adaptation of this system involves planting fresh-dug field plants or rooted plug plants of the June-bearing cultivar Chandler in late summer or early fall, depending on type and availability of nursery plants and on local climatic conditions (Poling, 1993). ‘Chandler’ has a relatively high propensity for runnering that can be exacerbated by early planting. However, later planting may result in inadequate plant establishment, insufficient branch crown formation and poor flower bud initiation, resulting in reduced yields (Fiola et al., 1995). In climates with variable fall weather conditions, optimum planting date has proven difficult to predict. Additional approaches are needed for more consistent regulation of vegetative growth.

Plant growth regulators have been used widely in tree fruit production to regulate vegetative and reproductive growth, improve fruit size and quality, and alter harvest date and postharvest properties (reviewed by Petracek et al., 2003). A number of growth regulators have been tested for regulating vegetative growth in strawberry. Published studies have indicated that runnering can be increased with applications of gibberellins (GA) (Kender et al., 1971; Tehranifar and Battey, 1997), cytokinins (Biain de Elizalde and Guitman, 1979; Hasse et al., 1989; Pritts et al., 1986; Waithaka and Dana, 1978) or combinations of these (Kender et al., 1971; Waithaka and Dana, 1978). As a result, a wide range of growth inhibitors targeting GA biosynthesis or response have been tested for suppression of runners (Archbold 1986, 1989; Bish et al., 1996; Deyton et al., 1991; Hasse et al., 1989; Ibrahim and Mohamed, 1993; McArthur and Eaton, 1987). Of these, the most consistently effective has been the strong biosynthesis inhibitor paclobutrazol (Archbold, 1989; Bish et al., 1996; Deyton et al., 1991). However, this compound has yet to be registered for use on fruit crops, perhaps due to long residual activity in the plant (Archbold, 1989; Greene, 1986), and a half-life in the soil of several months (Rademacher, 2000). In contrast, prohexadione-Ca (P-Ca) is a short-acting synthesis inhibitor with a half-life in the soil of <7 d (Evans et al., 1999), that has now been registered for use on bearing apple trees. Due to the transitory response of apple to P-Ca, sustained growth inhibition requires repeat applications at 2- to 3-week intervals (Unrath, 1999).

Reekie and Hicklenton (2002) conducted controlled-environment studies to test the activity of P-Ca on dormant cold-stored ‘Camarosa’ and ‘Sweet Charlie’ strawberry plants. They noted reductions in runner number and length, indicating the potential of this material for runner control in the fruiting field. The first objective of the present work was to test the efficacy of post-transplant applications of P-Ca for reducing runnering of summer-planted annual hill strawberry. Timing and rate of application, and single or multiple applications of P-Ca were compared to untreated control plants. Since the present recommendations are to control vegetative

Received for publication 16 Dec. 2003. Accepted for publication 3 Feb. 2004. The author gratefully acknowledges student intern Michele Sumi for technical assistance, Davon Crest Farms for supplying strawberry plug plants, and BASF Corp. for providing prohexadione-Ca. Mention of a trademark, proprietary product, or vendor does not constitute a guarantee or warranty of the product by the U.S. Dept. of Agriculture and does not imply its approval to the exclusion of other products or vendors that may be suitable.
[1]E-mail blackb@ba.ars.usda.gov.

growth by later planting, the second objective of the study was to compare P-Ca treatments to later planting dates.

Materials and Methods

2001–02 Experiment. In Aug. 2001, a planting site was prepared with raised beds, subsurface drip irrigation, and black plastic mulch as described previously (Black et al., 2002). Beds were divided into 1.2-m-long plots and assigned to one of four replications and 15 treatments (Table 1). Plots were arranged in a randomized complete-block design, with blocking by location in the field. Plug transplants of 'Chandler' strawberry were obtained from a commercial nursery in Hurlock, Md., and the control and P-Ca treatments were transplanted to the field on 29 Aug. 2001. Plants were placed in an offset double-row arrangement spaced 30 cm within and between rows, resulting in six plants per plot with a 60-cm buffer between plots. Cultural practices were as described previously (Black et al., 2002).

A commercially available formulation of P-Ca (27.5% active ingredient, Apogee) was provided by BASF Corp. (Research Triangle Park, N.C.). Solutions of 60, 120, or 240 $mg \cdot L^{-1}$ (active ingredient) were applied 8 d after planting (6 Sept. 2001) to treatments 3, 4, and 5, respectively (Table 1). Treatments 6, 7, and 8 were also treated on 6 Sept. with 60, 120, or 240 $mg \cdot L^{-1}$ applications, and received two repeat applications at ≈3-week intervals (6 Sept., 28 Sept., 22 Oct.). A series of late applications were made 3 weeks after planting (18 Sept.) to treatments 9, 10, and 11. P-Ca solutions were applied as foliar sprays to drip point, using a pressurized garden sprayer. Runners were left on the plant for the control treatment. For a second nonchemical treatment, runners were removed by hand several times during September (–R). To compare the effect of planting date (treatments 12 to 15, Table 1), additional nursery plants were obtained and transplanted to the field at 2- to 3-week intervals (14 Sept., 27 Sept., 9 Oct., 29 Oct.). During the week of 17 Oct., runners were counted and removed for all treatments, and runner length, petiole length, crown number, and leaf number were recorded. All plots were mulched with straw in mid-December, and straw mulch was removed from the beds in mid-March. On 14 May 2002, peduncle lengths were measured and flowers per truss and trusses per crown were counted. From 15 May to 10 June, ripe fruit was harvested from each plot twice weekly, and total fruit weight and the weight of 10 randomly selected fruit were determined. To determine whether there were any treatment differences in crown number during the fruiting season, total crowns were again counted in early July.

2002–03 Experiment. For the second study, the effects of P-Ca and planting date were compared on both 'Chandler' and 'Allstar'. Plugs were propagated in a commercial nursery and the planting field was prepared as described above. Beds were divided into 96 plots, with plots assigned to one of four replications, two cultivars, and 12 growth regulator/planting date treatments (Table 1), arranged in a randomized complete-block design. Control, –R, and P-Ca treatments for both cultivars were planted on 28 Aug.

Table 1. Treatments from 2 years of field experiments testing prohexadione-Ca (P-Ca) and planting date. Listed are planting dates, rate, and application date of P-Ca.

No.	Description	Planting date	P-Ca rate ($mg \cdot L^{-1}$)	Application date
2001–02				
1	Control	29 Aug.		
2	Runners removed (-R)	29 Aug.		
3	P-Ca Single early	29 Aug.	60	6 Sept.
4	Single early	29 Aug.	120	6 Sept.
5	Single early	29 Aug.	240	6 Sept.
6	Multiple	29 Aug.	60	6 Sept., 28 Sept., 22 Oct.
7	Multiple	29 Aug.	120	6 Sept., 28 Sept., 22 Oct.
8	Multiple	29 Aug.	240	6 Sept., 28 Sept., 22 Oct.
9	Single late	29 Aug.	60	18 Sept.
10	Single late	29 Aug.	120	18 Sept.
11	Single late	29 Aug.	240	18 Sept.
12	2nd Planting	14 Sept.		
13	3rd Planting	27 Sept.		
14	4th Planting	9 Oct.		
15	5th Planting	29 Oct.		
2002–03				
1	Control	28 Aug.		
2	Runners removed (-R)	28 Aug.		
3	P-Ca Single	28 Aug.	120	3 Sept.
4	Single	28 Aug.	240	3 Sept.
5	Single	28 Aug.	480	3 Sept.
6	Multiple	28 Aug.	120	3 Sept., 24 Sept., 16 Oct.
7	Multiple	28 Aug.	240	3 Sept., 24 Sept., 16 Oct.
8	Multiple	28 Aug.	480	3 Sept., 24 Sept., 16 Oct.
9	2nd Planting	4 Sept.		
10	3rd Planting	11 Sept.		
11	4th Planting	18 Sept.		
12	5th Planting	25 Sept.		

2002. To compare planting dates, additional nursery plants were obtained and transplanted at weekly intervals (4 Sept., 11 Sept., 18 Sept., 25 Sept; treatments 9 to 12). Replicate plots of 'Chandler' and 'Allstar' received foliar applications of 120, 240, or 480 mg·L^{-1} P-Ca on 3 Sept. (Treatments 3 to 5, Table 1). Additional treatments received foliar applications of P-Ca at 120, 240, or 480 mg·L^{-1} (Treatments 6 to 8) repeated at 3-week intervals as weather permitted (3 Sept., 24 Sept., 16 Oct.).

To compare fall growth among treatments, runners, leaves and crowns were counted, and petiole and runner lengths determined during the week of 21 Oct. 2002. Total number of branch crowns was again counted in the spring, prior to harvest (8 May 2003). Ripe fruit was harvested twice weekly from 27 May to 23 June, marketable fruit was separated from culls, and weights recorded to determine total yield, marketable yield, and average weight of marketable fruit.

Treatment comparisons were made using the GLM procedure of the SAS program package. Comparison of individual treatments were made using PDIFF option of the LSMEANS statement. Trends with P-Ca concentration and planting date were tested using orthogonal contrast statements. In the case of P-Ca concentrations, orthogonal polynomials were used for unequally spaced treatments (Gill, 1978).

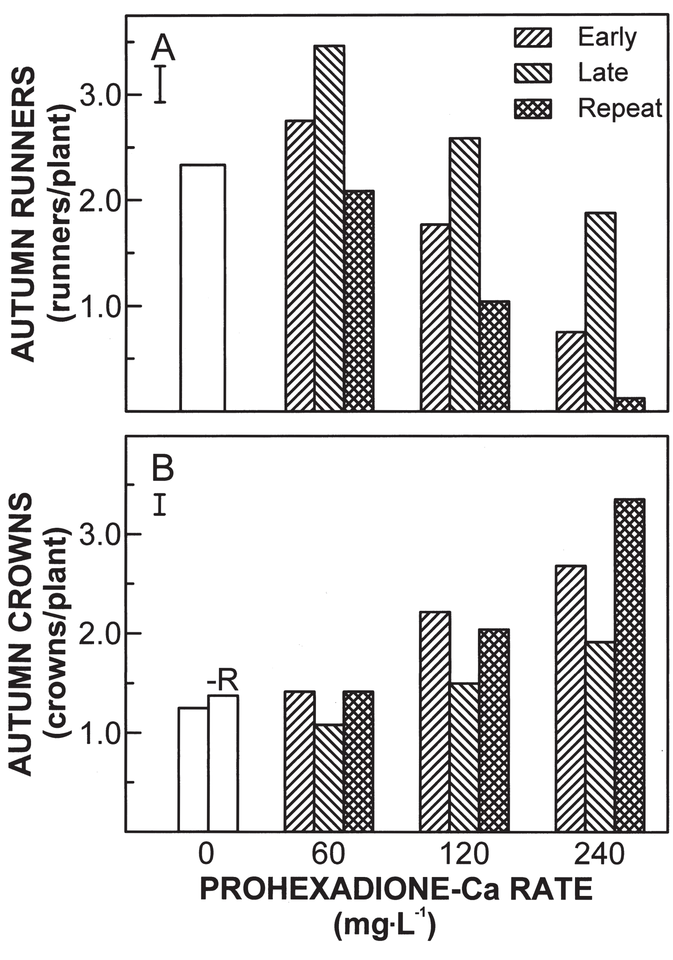

Fig. 1. The effect of posttransplant foliar applications of prohexadione-Ca on fall runner number (**A**) and branch crown number (**B**) of 'Chandler' strawberry. Counts were taken on 17 Oct. 2001. Prohexadione-Ca treatments are compared to a control treatment with no runner removal through mid-October and to periodic hand removal of runners (–R). Standard errors are shown as vertical bars in upper left corner of the histograms.

Results and Discussion

2001–02 Experiment. Applications of P-Ca at rates of 120 and 240 mg·L^{-1} in Fall 2001 resulted in significant reduction in fall runners when applied either singly at 8 d after planting, or at 8 d after planting and repeated at 3-week intervals (Fig. 1A.). Runner number decreased linearly with P-Ca concentration ($P < 0.001$). The single application 8 d after planting was more effective at fall runner suppression than was the single application 20 d after planting ($P = 0.023$) for all concentrations of P-Ca, while repeat applications were more effective than single applications at either timing ($P = 0.020$). Repeat applications at 240 mg·L^{-1} resulted in an average of 0.125 runners per plant, compared to 2.33 runners per plant for the control treatment. P-Ca-treated plants also showed significant increase in the number of branch crowns apparent by mid-October (Fig. 1B), showing a linear increase in crown numbers with P-Ca concentration ($P < 0.001$). This increase was inversely proportional to fall runner number, with the 240 mg·L^{-1} repeat application having 3.35 crowns per plant on 17 Oct. compared to 1.28 and 1.35 crowns per plant for control and hand runner removal, respectively. A delay of two or more weeks in planting resulted in minimal runners, but also resulted in a complete lack of branch crown formation through mid-October (data not shown).

The 60 mg·L^{-1} rate of P-Ca did not reduce runner number in either single or repeat applications, and the late application may have increased runner number (Fig. 1). Runners on plants receiving the 60 mg·L^{-1} rate were reduced in length, and many of the runner tips were malformed. Due to the shortened runner length, daughter plants remained on the plastic mulch, and therefore did not root down. Despite the lack of an independent root system, these runner tips had large crowns, with some instances of crown branching (Fig. 2). How a low rate P-Ca treatment results in increased run-

Fig. 2. Runner tip from a 'Chandler' plant treated with a foliar application of 60 mg·L^{-1} prohexadione-Ca 8 d after transplanting. Note the lack of a root system, the large primary crown on the right, and the smaller branch crown on the left.

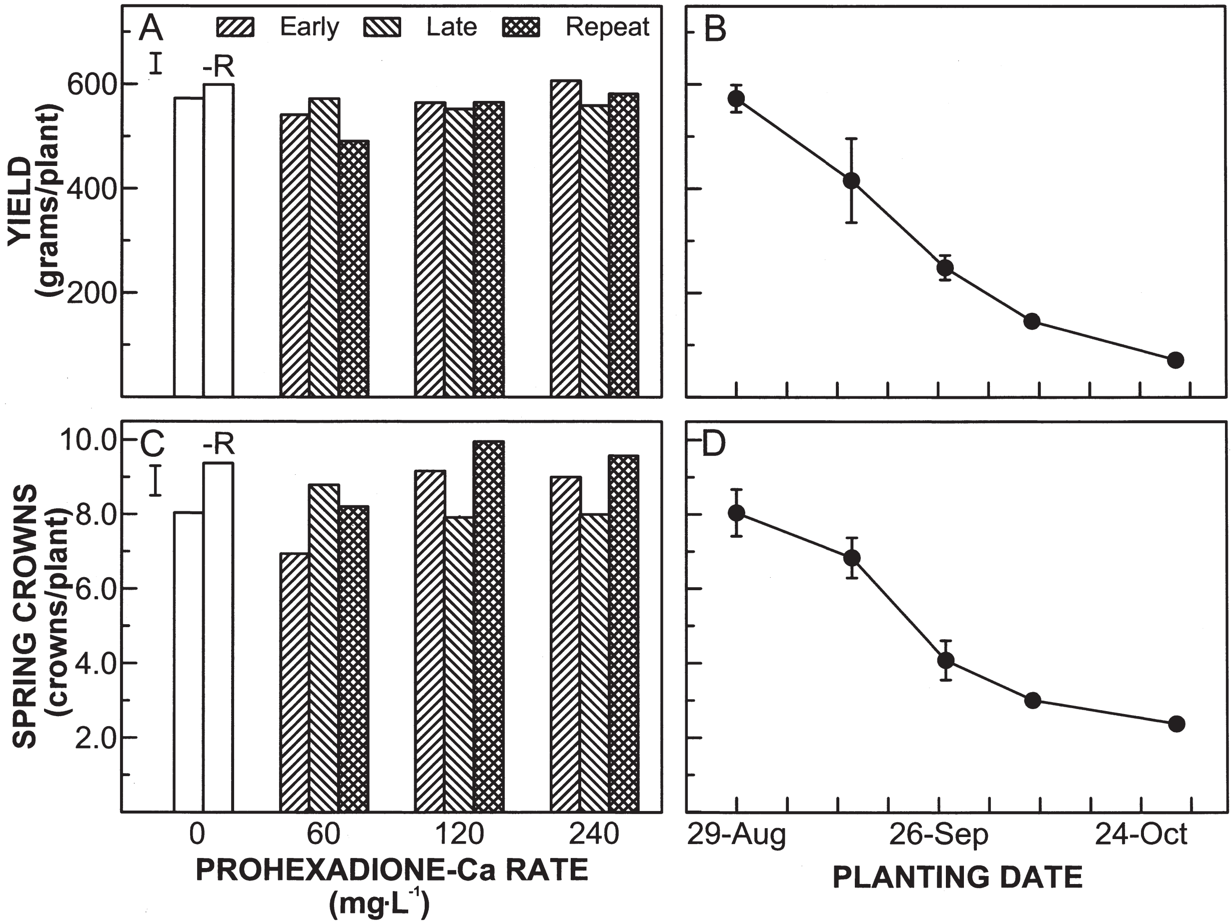

Fig. 3. The effect of planting date, and posttransplant foliar applications of prohexadione-Ca on yield (**A** and **B**) and spring crown numbers (**C** and **D**) of 'Chandler' strawberry, 2002 harvest. Prohexadione-Ca treatments are compared to a control with no runner removal through mid-October and with periodic hand removal of runners (–R). Crowns were counted after harvest in July. Standard errors are shown as vertical bars in upper left corner of the histograms.

ners, while higher rates reduce runner number is puzzling. Reekie and Hicklenton (2002) found increased root growth of transplants treated with P-Ca. The lowest rate may have stimulated transplant establishment without suppressing runners, resulting in a net increase in runner number relative to the control.

All P-Ca treated plants showed a general alteration in fall growth, with a more compact growth habit due to shortened petioles. The 240 mg·L^{-1} applications resulted in an average petiole length of 4.7 cm for repeat applications, and 5.8 cm for single early application, compared to 8.1 cm for the control. However, total plant growth did not appear to be reduced by P-Ca as there were no significant differences in leaf number in mid-October (data not shown). Straw mulch was applied in mid-December and removed in mid-March for winter cold protection, however, Winter 2001–02 was unusually mild.

Measurements taken after full bloom indicated no differences in inflorescence number, flowers per inflorescence, or peduncle length due to P-Ca treatment (data not shown). The first fruit harvest occurred on 15 May 2002, with twice-weekly harvests until 10 June. There were no differences in harvest season, as determined by first harvest and peak harvest dates (data not shown). Total yields were similar among treatments planted on 29 Aug. 2001, except for the low rate P-Ca treatment where repeat applications resulted in yields significantly lower ($P < 0.05$) than that of hand removal of runners (Fig. 3A). Yield decreased dramatically with later planting date, where a 2-week delay resulted in a 30% reduction in total yield (Fig. 3B). There were no significant differences in fruit size among any treatments, with the exception of the later planting dates. Fruit size at the first harvest was 18.7 g for the control treatment, compared to 20.2 and 22.1 g for the 27 Sept. and 9 Oct. planting dates, respectively ($P < 0.01$). However this increased size resulted from yield reductions of 56% and 75% compared to the control (Fig. 3B). A postharvest count showed a high number of branch crowns compared to counts from the previous fall, with similar crown numbers among control, hand runner removal, and P-Ca treatments (Fig. 3C). The difference in crown number from October to July suggests that crown development continued during the mild fall and winter. Among treatments planted 29 Aug., only the single early application of P-Ca differed significantly, with fewer crowns ($P < 0.05$). Crown number also decreased linearly with later planting date ($P < 0.001$), and treatment differences in crown number were proportional to differences in yield (Fig. 3B and D). Repeat applications of the higher rates of P-Ca, and hand removal of runners resulted in the highest number of branch crowns.

2002–03 'Chandler'. A second study was initiated in Aug. 2002, in which single or multiple applications of P-Ca were made at three concentrations (120, 240, and 480 mg·L^{-1}). Because the 60 mg·L^{-1} treatment did not reduce total runner number and resulted in malformed runners, this concentration was not repeated in the second study. It was also apparent from the first experiment that 240 mg·L^{-1} did not exceed the optimum dose, and a higher concentration treatment was included. Runner counts taken in mid-October indicated that maximum runner suppression resulted from the 240 mg·L^{-1} treatment where repeat applications resulted in 0.21 runners per plant, compared to 3.12 for the control treatment (Fig. 4A). Fall crown numbers were significantly increased by all P-Ca treatments (Fig. 4B). Among single application treatments, 240 mg·L^{-1} had significantly more branch crowns by mid-October than did the 120 or 480 mg·L^{-1} applications. For the repeat applications, crown number increased with P-Ca concentration.

Straw was applied in mid-Dec. 2002 and removed in Mar. 2003 for winter cold protection. Winter temperatures were below normal, and snowfall reached record high levels. Crown counts of 'Chandler' taken just before harvest indicated much less late crown development than for the previous season. With the exception of repeat applications at 480 mg·L^{-1}, all P-Ca treatments resulted in increased crown numbers relative to the control treatment (Fig. 5A). It is interesting to note that among P-Ca treatments, the repeated high-rate treatment had the highest number of crowns in October at 2.81 crowns per plant, but the lowest crown number the following spring with 3.71. Spring crown number was lower in later planting dates (Fig. 5B), with a 4-week delay in planting reducing spring crowns from 3.8 to 2.6 crowns per plant. As with the previous experiment, leaf petioles were shortened by P-Ca treatment. However, fall leaf number was not reduced, suggesting no general inhibition of plant growth.

During the fall and winter, a neighboring forest was cleared for a construction project resulting in increased deer pressure. As a result, there was noticeable deer damage within the plots despite extensive electric fencing. In addition, Spring 2003 was characterized by frequent rain and high humidity. Despite a regular fungicide application program, much of the 2003 crop was lost to fruit rot. Repeat applications of 120 mg·L^{-1} P-Ca gave the highest yields at 128 g/plant, but this was 23% of the yields from the previous season (data not shown). By comparison, yields for the control treatment were 35 g/plant, or a 94% reduction from the previous year. Clearly, it is impossible to draw meaningful conclusions from the 2003 harvest data.

2002–03 'Allstar'. The cultivar Allstar is less prolific in runner production than 'Chandler', but has been one of the most promising eastern genotypes for cold-climate annual hill production (Black et al., 2002). Treatments described above for 2002–03 'Chandler' were also applied to 'Allstar'. Very few fall runners were produced among any of the treatments, with less than 0.1 runners per plant for the control treatment (data not shown). P-Ca treatment either had no effect on branch crown development, or reduced fall branch crown number (Fig. 6A). In the case of the highest rate of P-Ca, the reduced crown numbers carried through to spring (Fig. 6C). This reduction in crown numbers was likely the result of a general inhibition of plant growth, as evidenced by a significant reduction in total leaf number (data not shown).

Taken together, results from the two studies presented here indicate that P-Ca can effectively reduce fall runnering in 'Chandler', with repeat applications of 240 mg·L^{-1} resulting in the greatest reduction in runner number. To affect a similar reduction in runners by delayed planting, a 2-week delay would have been sufficient in the 2001 planting season, while a 4-week delay would have been required in 2002 (Fig. 4A inset). Despite the mild fall and winter conditions in 2001–02, a 2-week delay resulted in a significant reduction in total yield ($P < 0.001$). Although the 2002–03 season did not produce reliable yield data, a 4-week delay in planting significantly reduced crown number for both cultivars (Figs. 5 and 6).

A comparison of fall and spring crown numbers suggests that P-Ca treatment advanced branch crown development in 'Chandler'.

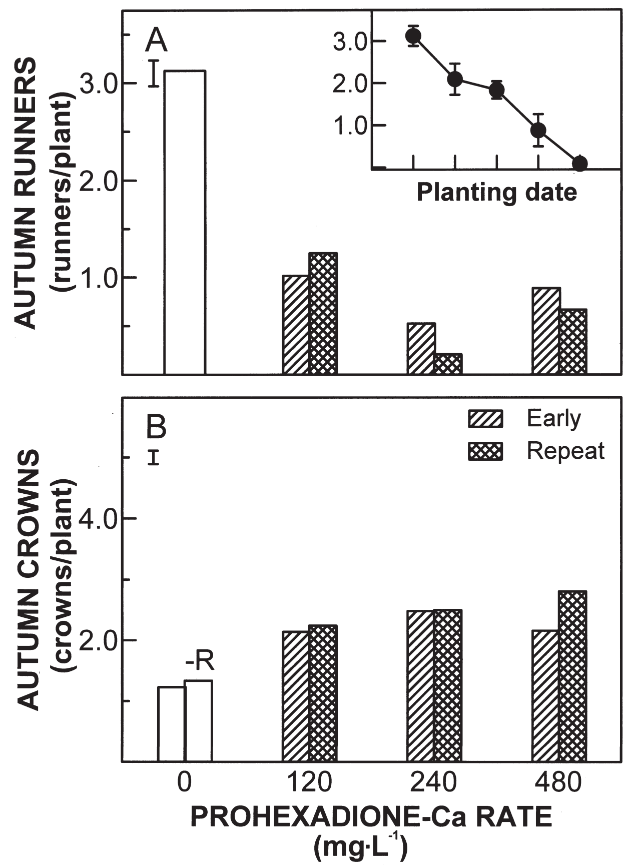

Fig. 4. The effect of posttransplant foliar applications of prohexadione-Ca on fall runner (**A**) and branch crown numbers (**B**) of 'Chandler' strawberry. Counts were taken the week of 21 Oct. 2002. Prohexadione-Ca treatments are compared to a control treatment with no runner removal through mid-October and with periodic hand removal of runners (–R). The inset graph shows the effect of planting date on fall runner number. Planting dates were at weekly intervals from 28 Aug. to 25 Sept. Standard errors are shown as vertical bars in the upper left corner of the histograms.

The transition from runner production to branch crown formation is thought to be the result of shorter day lengths and cooler temperatures (Darnell and Hancock, 1996). In northern climates, there are fewer fall days with conditions conducive to crown formation. Under these conditions, preventing runnering of early-planted material and advancing fall crown formation may be equally desirable outcomes.

According to recommendations for annual hill production in North Carolina (Poling, 1993), five crowns per plant is considered optimal for large, high-quality fruit, and for target yields of 450 g/plant. Further, eight to ten crowns per plant is considered excessive, resulting in reduced fruit size and a dense canopy where fruit rot is more prevalent. Excluding the 60 mg·L^{-1} P-Ca treatments, all treatments planted in late Aug. 2001 produced 8 to 10 crowns by the end of harvest, and between 550 and 610 g of fruit per plant. The 14 Sept. 2001 planting date resulted in no appreciable fall runnering and a postharvest crown count nearest to the proposed ideal. However, yields for this treatment were 250 g/plant or 45% below the 450-g target. By contrast, the only 'Chandler' treatments that exceeded 4 crowns/plant in the 2002–03 season were planted in late August with runner control either by hand removal or P-Ca treatment. These two seasons represent opposite extremes in weather conditions, and the results presented here illustrate the point that regulating plant growth through planting date alone has limited potential in a climate with variable fall conditions. Ad-

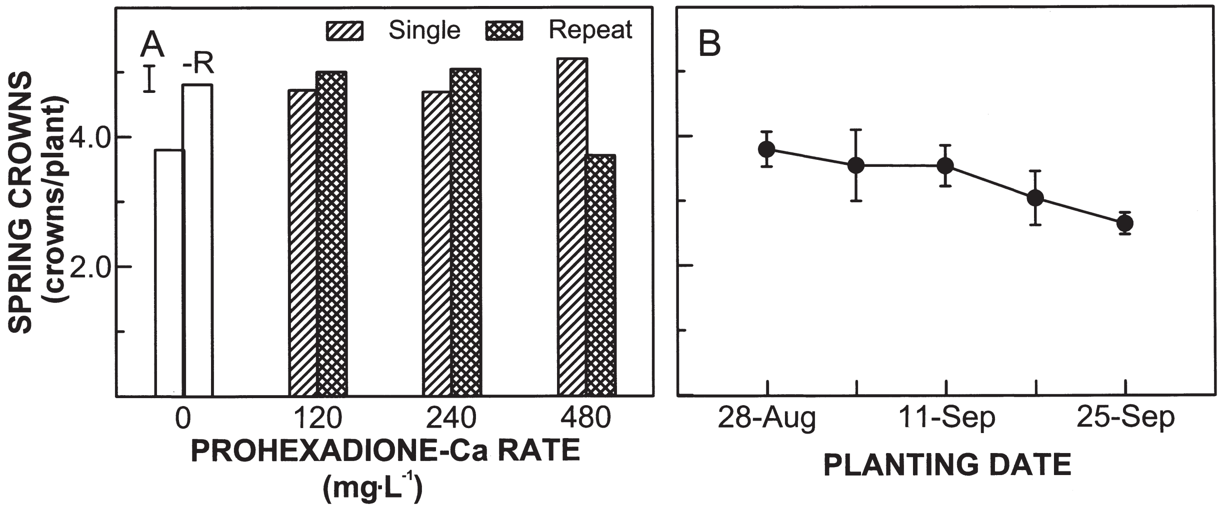

Fig. 5. The effect of posttransplant foliar applications of prohexadione-Ca (**A**) and planting date (**B**) on spring crown numbers of 'Chandler' strawberry in 2003. Crown counts were taken in mid May before fruit harvest. Prohexadione-Ca treatments are compared to a control with no runner removal through mid-October and with periodic hand removal of runners (–R). Standard errors are shown as vertical bars in the upper left corner of the histograms.

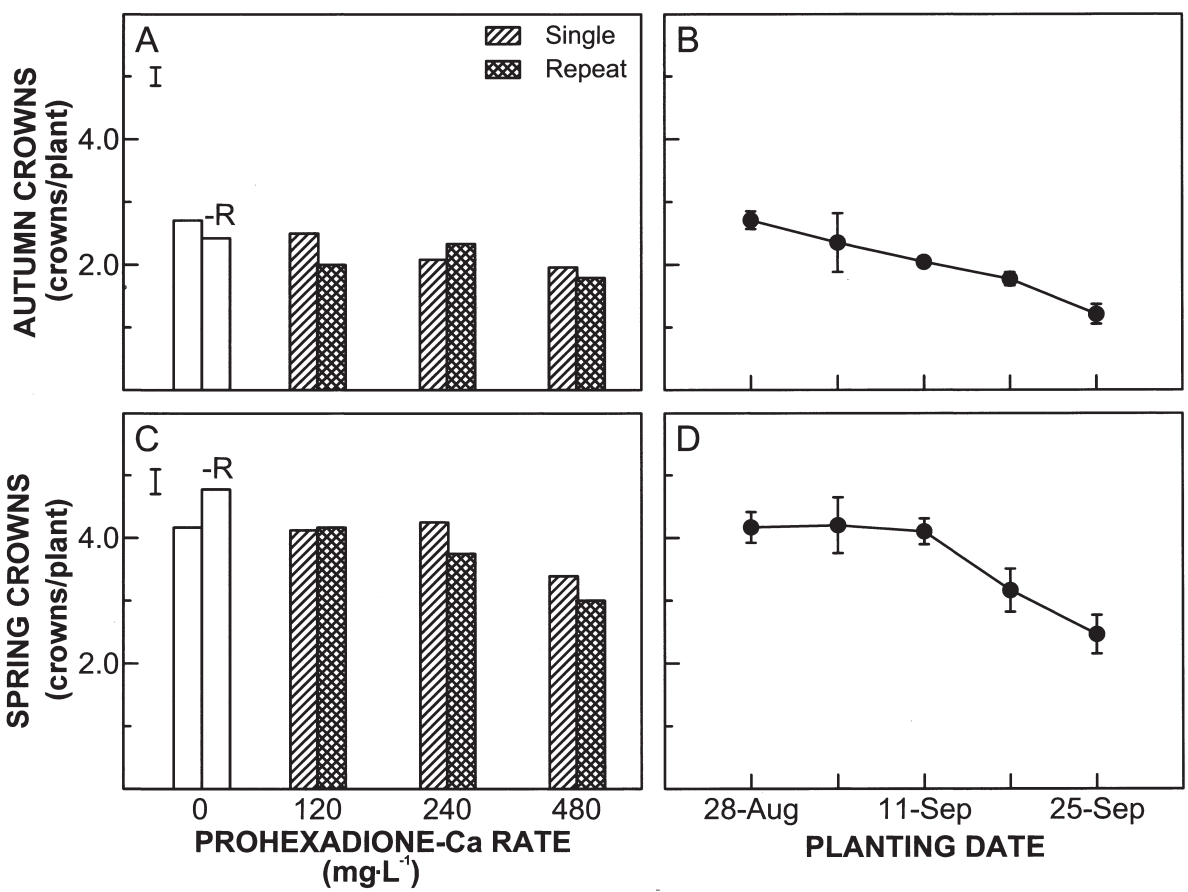

Fig. 6. The effect of posttransplant foliar applications of prohexadione-Ca and planting date, on fall (**A** and **B**) and spring (**C** and **D**) crown numbers of 'Allstar'. Crown counts were taken in October 2002 and May 2003. Prohexadione-Ca treatments are compared to a control with no runner removal through mid-October and with periodic hand removal of runners (–R).

ditional management tools are needed in climates where fall and spring weather conditions are not consistent. Floating row covers are often used in cold-climate annual hill production to increase crown development and advance bloom in the spring. Consistent vegetative control may be best accomplished with a combination of management practices including nursery plant conditioning, proper planting date, row cover management and application of a growth regulator such as P-Ca.

The P-Ca effects of reduced runner number, shortened petioles, and increased crown branching, were not unexpected. There have been a number of reports of similar response to the GA biosynthesis inhibitor paclobutrazol (Braun and Garth, 1986; Deyton et al., 1991; McArthur and Eaton, 1987; Stang and Weis, 1984). However, other GA biosynthesis inhibitors have shown mixed results. Archbold (1986) found some runner suppression with flurprimidol, but this activity was weaker than the response found with paclobutrazol, while ancymidol had no activity. Similarly, mepiquat (Duval, 2003) was found to have weak or no runner-suppressive activity, while reports of chlormequat activity have been mixed (Guttridge et al., 1966, McArthur and Eaton, 1987) and daminozide was reported to increase runners (Ibrahim and Mohamed, 1993). The effectiveness of a GA inhibitor for a specific horticultural application is not only influenced by biochemical activity, but also plant sensitivity, uptake, translocation and persistence (Rademacher, 2000). The 2002–03 study illustrates cultivar differences in sensitivity, in that P-Ca did not appear to affect ‘Chandler’ plant growth as indexed by fall leaf number, but resulted in reduced leaf number of ‘Allstar’.

A short-acting growth regulator effective at runner suppression would have applications beyond that of plug transplants in cold-climate annual hill production. Properly timed applications in matted row development could reduce plant number and increase plant size (Weidman and Stang, 1983), effectively producing a spaced matted row (Galletta and Bringhurst, 1989) with a greater potential for high yields and large fruit size. The author conducted a preliminary test of P-Ca for regulating plant density of a first-year matted row planting of ‘Northeaster’, but response was negligible and may have resulted from incorrect time of application, or lack of cultivar sensitivity to P-Ca (unpublished data). Runner suppression is also an important component of ribbon row management, and the use of GA biosynthesis inhibitors has been proposed for this system (Archbold, 1989). Runnering can also be problematic in the winter production system used in Florida (Bish et al., 1996). However, there is no temporal separation between runnering and fruiting in the winter production system, and early results indicate that posttransplant applications of P-Ca may delay fruiting (Duval, 2003).

Chemical suppression of strawberry runners would be a useful management tool in a number of production systems. However, with the wide range of conditions among production systems, the number of cultivars used in different production systems, and the potential differences in cultivar response to P-Ca, commercializing P-Ca for strawberry runner suppression may require optimized rate and timing for each production system and cultivar.

Literature Cited

Archbold, D.D. 1986. Control of strawberry plant growth and runner production by flurprimidol. Adv. Strawberry Prod. 5:28–30.

Archbold, D.D. 1989. Integrating paclobutrazol, GA_3, and plant density in ribbon row strawberry production, and sustained effects of the growth regulators. Acta Hort. 239:289–292.

Biain de Elizalde, M.M. and M.R. Guitman. 1979. Vegetative propagation in everbearing strawberry as influenced by a morphactin, GA_3, and BA. J. Amer. Soc. Hort. Sci. 104:162–164.

Bish, E.B., D.J. Cantliffe, and C.K. Chandler. 1996. Strawberry plug transplants: Regulation of growth and production. Proc. Fla. State Hort. Soc. 109:160–164.

Black, B.L., J.M. Enns, and S.C. Hokanson. 2002. A comparison of temperate-climate strawberry production systems using eastern genotypes. HortTechnology 12:670–675.

Braun, J.W. and J.K.L. Garth. 1986. Strawberry vegetative and fruit growth response to paclobutrazol. J. Amer. Soc. Hort. Sci. 111:364–367.

Darnell, R.L. and J.F. Hancock. 1996. Balancing vegetative and reproductive growth in strawberry. Proc. N. Amer. Strawberry Conf. 4:144–150.

Darrow, G.M. 1929. Development of runners and runner plants in the strawberry. USDA Tech. Bul. 122:1–28.

Deyton, D.E., C.E. Sams, and J.C. Cummins. 1991. Strawberry growth and photosynthesis responses to paclobutrazol. HortScience 26:1178–1180.

Duval, J. 2003. Effect of prohexadione-Ca and mepiquat chloride on stolon production and yield of Florida-grown strawberry (*Fragaria ×ananassa* Duch.). HortScience 38:701–702 (abstr.).

Evans, J.R., R.R. Evans, C.L. Regusci, and W. Rademacher. 1999. Mode of action, metabolism, and uptake of BAS 125W, Prohexadione-calcium. HortScience 34:1200–1201.

Fiola, J.A., R.J. Lengyen, and D.A. Reichert. 1995. Planting density and date affect productivity and profitability of ‘Chandler’, ‘Tribute’, and ‘Tristar’ in strawberry plasticulture. Adv. Strawberry Res. 14:49–52.

Galletta, G.J. and R.S. Bringhurst. 1989. Strawberry management, p. 83–156. In: G.J. Galletta and D.G. Himelrick (eds.). Small fruit crop management. Prentice Hall, Englewood Cliffs, N.J.

Gill, J.L. 1978. Design and analysis of experiments in the animal and medical sciences, 1st ed. Iowa State Univ. Press, Ames.

Greene, D.W. 1986. Effect of paclobutrazol and analogs on growth, yield, fruit quality, and storage potential of ‘Delicious’ apples. J. Amer. Soc. Hort. Sci. 111:328–332.

Guttridge, C., H.M. Anderson, and W.S. Stewart. 1966. The control of strawberry runners in the field with CCC. Expt. Hort. 15:92–95.

Hasse, L., M.P. Pritts, and M. Eames-Sheavly. 1989. Growth regulators affect vegetative and reproductive growth in a dayneutral and junebearing strawberry cultivar. Adv. Strawberry Prod. 8:45–50.

Ibrahim, I.E. and A.I. Mohamed. 1993. Effect of alar and nitrogen fertilizer treatments on growth, yield and quality of strawberry. Acta Hort. 345:29–36.

Kender, W.J., S. Carpenter, and J.W. Braun. 1971. Runner formation in everbearing strawberry as influenced by growth-promoting and inhibiting substances. Ann. Bot. 35:1045–1052.

McArthur, D.A.J. and G.W. Eaton. 1987. Effect of fertilizer, paclobutrazol, and chlormequat on strawberry. J. Amer. Soc. Hort. Sci. 112:241–246.

Petracek, P.D., F.P. Silverman, and D.W. Greene. 2003. A history of commercial plant growth regulators in apple production. HortScience 38:937–942.

Poling, E.B. 1993. Strawberry plasticulture in North Carolina. II. Preplant, planting, and postplant considerations for growing ‘Chandler’ strawberry on black plastic mulch. HortTechnology 3:383–393.

Pritts, M.P., G.S. Posner, and K.A. Worden. 1986. Effects of 6-BA application on growth and development in ‘Tristar’, a strong day-neutral strawberry. HortScience 21:1421–1423.

Rademacher, W. 2000. Growth retardants: Effects on gibberellin biosynthesis and other metabolic pathways. Annu. Rev. Plant Physiol. Plant Mol. Biol. 51:501–531.

Reekie, J.Y.-C. and P.R. Hicklenton. 2002. Strawberry growth response to prohexadione-calcium. Proc. N. Amer. Strawberry Conf. 5:147–152.

Stang, E.J. and G.G. Weis. 1984. Influence of paclobutrazol plant growth regulator on strawberry plant growth, fruiting, and runner suppression. HortScience 19:643–645.

Tehranifar, A. and N.H. Battey. 1997. Comparison of the effects of GA_3 and chilling on vegetative vigour and fruit set in strawberry. Acta Hort. 439:627–631.

Unrath, C.R. 1999. Prohexadione-Ca: A promising chemical for controlling vegetative growth of apples. HortScience 34:1197–1200.

Waithaka, K. and M.N. Dana. 1978. Effects of growth substances on strawberry growth. J. Amer. Soc. Hort. Sci. 103:627–628.

Weidman, R.W. and E.J. Stang. 1983. Effects of gibberellins (GA_{4+7}), 6-benzyladenine (6-BA) and promalin (GA_{4+7} + 6-BA) plant growth regulators on plant growth, branch crown and flower development in ‘Scott’ and ‘Raritan’ strawberries. Adv. Strawberry Prod. 2:15–17.