Vegetative Growth and Flowering of Primocane Raspberry ‘Ariadne’ as Affected by Prohexadione–calcium Treatments

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Additional index words. growth control, ProCa, *Rubus idaeus*

Abstract. Maintaining an appropriate balance between vegetative and generative growth is a prerequisite for profitable raspberry (*Rubus idaeus* L.) production. The objective of our study was to test the effect of prohexadione–calcium (ProCa) on vegetative growth and flowering of primocane fruiting red raspberry ‘Ariadne’ in greenhouse conditions. ProCa was applied either once or twice in a concentration of 100 ppm or 200 ppm. Double applications of ProCa reduced cane height by 33 cm (100 ppm) or by 46 cm (200 ppm). Growth reduction was the result of shortening of the internodes, because total node number in plants was unaffected. Furthermore, cane diameter was reduced in plants treated with 200 ppm ProCa. ProCa treatments reduced the total aboveground dry weight by 32% to 55% but did not affect the allocation of dry weight into different plant parts. All ProCa treatments reduced the number of flowers by 22% to 42%. In conclusion, ProCa proved effective in controlling vegetative growth of red raspberry. However, because the number of flowers was reduced, ProCa cannot be recommended for growth regulation of primocane fruiting raspberry without further studies.

Red raspberry (*Rubus idaeus*) has a relatively low harvest index, i.e., the relationship of harvestable crop to vegetative growth. When cultured in plastic tunnels or greenhouses, cane growth of raspberry plants is even more vigorous than in the field, and methods to control growth would be useful. The effect of traditional chemical growth retardants on raspberry has been reported in a few papers (Braun and Garth, 1984, 1986; Crandall and Garth, 1981; Ghora et al., 2000; Goulart, 1989; McGregor, 1987). However, their use is limited in fruit production.

Prohexadione–calcium (ProCa) is a gibberellin biosynthesis inhibitor, a fast degrading compound that has no negative effect on animals or soil micro-organisms (Evans et al., 1999). ProCa reduces levels of GA₁ because it blocks the last steps of gibberellin biosynthesis, thus preventing the formation of active gibberellin, which causes accumulation of its immediate inactive precursors GA₁₉ and GA₂₀. As ProCa degrades, the accumulated precursors are converted into active gibberellin and growth restarts. ProCa has been reported to reduce vegetative growth in many cultivated fruit species (Lo Giudice et al., 2003; Owens and Stover, 1999; Reekie and Hicklenton, 2001; Southwick et al., 2004). Reduction in vegetative growth is mainly the result of shortening of internodes (Medjdoub et al., 2004, 2005). ProCa reduces vegetative growth and advances terminal bud

set in apple trees (*Malus ×domestica* Borkh.), thus reducing the need for pruning without affecting the crop in the next year (Byers et al., 2004; Greene, 1999; Guak et al., 2001; Medjdoub et al., 2004, 2005; Owens and Stover, 1999). Furthermore, increases in fruit set in the year of application have been reported for apple (Glenn and Miller, 2005) and pear (*Pyrus communis* L.) (Smit et al., 2005). Consequently, decrease in return bloom, more likely resulting from increased fruit set, has been reported for some pear cultivars (Smit et al., 2005; Sugar et al., 2004), whereas in others, ProCa had no effect on return bloom (Southwick et al., 2004). However, in grapevine (*Vitis vinifera* L.), prebloom applications resulted in substantial crop loss, although they were most effective in growth reduction (Lo Giudice et al., 2003). The influence of ProCa seems to be species- and cultivar-dependent.

Because ProCa has proved effective in growth control of many fruit species, it might be applicable to control growth in raspberry cultivars as well. The aim of our study was to examine the effects of ProCa on growth and flowering in primocane fruiting red raspberry ‘Ariadne’.

Materials and Methods

Primocane fruiting red raspberry ‘Ariadne’ plants propagated from root cuttings were received in 10-cm pots from a commercial nursery (Marja-Suomen Taimituotanto, Suonenjoki, Finland). On 24 June 2003, they were planted in 3-L pots in a peat-based potting mixture (Kekkilä Ruukutusseos,

NPK 11-4-21; Kekkilä, Tuusula, Finland) and pruned to a single cane per pot. Plants were grown outdoors on a sand bed during summer and drip-irrigated with 0.2% compound fertilizer solution (Puutarhan täyslannos, Kemira, NPK 14-5-21; Kemira GrowHow, Harjavalta, Finland). They were moved into a dark, cold storage (1 °C) on 17 Oct. After 45 d, plants were pruned to soil level and transferred into a cold storage with temperature of 5 °C for 14 d. On 15 Dec., when plants had accumulated a total of 1416 chilling hours, they were placed into a greenhouse compartment (18 °C, 16-h photoperiod, 60% relative humidity). Light was provided with HPS lamps (OSRAM PlantaStar 400 W; Osram, Munchen, Germany) with a photon flux density of 225 $\mu\text{mol}\cdot\text{m}^{-2}\cdot\text{s}^{-1}$. Plants were drip-irrigated with 0.1% compound fertilizer solution (Kekkilä Turve-Superex, NPK 12-5-27; Kekkilä, Tuusula, Finland).

On 9 Jan. 2004, when the plants had two to five fully expanded leaves, 45 plants were randomly assigned into three treatments and sprayed to drip-off with 0 (control), 100, or 200 ppm of ProCa [BAS 125 10 W (BASF, Ludwigshafen, Germany), a.i. 10% w/w ProCa] dissolved in water with 0.05% Tween 20 as a surfactant. There were 15 single plant replications per treatment. For eight plants per treatment, ProCa applications were repeated with the same concentrations 4 weeks later. Plant height, node number, cane diameter (3 cm above soil level), and the number of flowers were recorded weekly for 10 weeks until 19 Mar. At the end of the experiment, plants were harvested and partitioned into a main cane, leaves on a main cane, fruiting laterals (a stem and flowers), leaves on fruiting laterals, and vegetative branches. Vegetative branches were vigorous lateral shoots that originated from buds in the basal part of a cane and clearly differed in their growth habit from the other lateral shoots. Dry weights of these plant parts were determined by measuring oven dry weights (70 °C for 2 d).

The experiment was set up in a completely randomized design. Before data analysis, one replicate of plants that received a double treatment was arbitrarily selected and removed. Thus, there were seven single plant replicates per treatment. An analysis of variance was performed to test the significance of ProCa treatments on plant growth by using GLM procedure of SAS (SAS Institute Inc., Cary, NC). Where appropriate, treatment means were separated using Dunnett’s test.

Results

In the beginning of the experiment, the average cane height was 25.9 cm, cane diameter 4.1 mm, and node number 3.8. Ten weeks later, at the end of the experiment, canes that were treated twice with ProCa were 29% to 41% shorter than the untreated control canes (Table 1). Cane diameter was reduced in plants treated with 200 ppm ProCa either once or twice. The average total node number in canes was between 18.7 and 20.6 and unaffected by the treatment.

Received for publication 22 Dec. 2008. Accepted for publication 24 Jan. 2009.

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Table 1. The effect of different prohexadione–calcium (ProCa) treatments (single application or two applications in 4-week intervals) on growth parameters of primocane raspberry ‘Ariadne’ measured 10 weeks after the first application.^z

ProCa concn (ppm)	Cane ht (cm)	Cane diam (mm) ^y	Cane dry wt (g)	Node number	Internode length (cm) ^x	Flower number	Total dry wt (g)
0 (control)	118	7.9	11.5	20.6	5.2	89	57.9
100	96	7.5	8.2	19.3	4.3*	62*	39.3*
200	92	7.0*	7.4*	20.3	3.8*	52*	30.0*
0 + 0 (control)	113	7.1	9.3	20.6	5.2	78	51.0
100 + 100	80*	6.4	5.4*	19.3	3.3*	61*	26.7*
200 + 200	67*	6.2*	4.0*	18.7	2.7*	56*	22.9*
P value in analysis of variance	<0.001	<0.001	<0.001	NS	<0.001	<0.001	<0.001

^aMeans marked with an asterisk are different from a corresponding control at $P \leq 0.05$ by Dunnett’s test ($n = 7$).

^yMeasured 3 cm above the soil level.

^zInternodes that developed after the treatments were initiated.

The average length of the internodes formed after the applications was reduced by all ProCa treatments (Table 1). For 3 weeks after the first ProCa application, new internodes in the treated plants were shorter than in the controls (data not shown). The effect of the second ProCa treatment was observed for 2 weeks after the application. Seven weeks after the first application, the new internodes in the plants that received a single application were 7.5 cm (100 ppm) and 7.3 cm (200 ppm) on an average compared with 4.0 and 3.3 cm in control treatments ($P = 0.045$). However, the treated plants did not differ significantly from the controls by Dunnett’s test. Treatments also affected growth cessation; 7 weeks after the initiation of the treatments, only two of the seven plants treated twice with 200 ppm ProCa were producing new nodes, whereas of the plants treated once, five were actively growing.

All ProCa treatments reduced the total number of flowers in plants (Table 1). Furthermore, the total aboveground plant dry weight was reduced by all ProCa treatments (Table 1). Dry weight of a main cane was reduced in plants treated twice with ProCa and by a single application of 200 ppm ProCa. Treating the plants twice with 200 ppm ProCa reduced the dry weight of the leaves on a main cane and dry weight of fruiting laterals (data not shown). The dry weight of vegetative branches was reduced by treating the plants once with 200 ppm ProCa and by both double applications. The allocation of dry weight into different plant parts (percentage of total aboveground dry weight accumulation) was unaffected by the treatments. On average, 20% of the aboveground dry weight was allocated into a main cane, 32% into the leaves on a main cane, 18% into the fruiting laterals, 6% into the leaves on fruiting laterals, and 25% into the vegetative branches.

Discussion

ProCa reduced vegetative growth of primocane raspberry ‘Ariadne’ as has been reported for a few other fruit species (Lo Giudice et al., 2003; Owens and Stover, 1999; Reekie and Hicklenton, 2001; Southwick et al., 2004). Cane height was reduced by 33 cm and 46 cm in the plants treated twice with 100 ppm and 200 ppm ProCa, respectively. Thus, ProCa treatment might reduce the trellising requirement of primocane rasp-

berries. Growth reduction was the result of shortening of the internodes, because total node number in plants was unaffected. Cane diameter was reduced by treating the plants either once or twice with 200 ppm ProCa.

ProCa affected the length of the internodes formed during the first 3 weeks after the application. Four weeks after the treatment, the effect had disappeared indicating that ProCa rapidly breaks down in a plant. Therefore, several applications during the growing season are needed for effective growth control. The extent of growth control is dependent on both timing and number of applications (Medjdoub et al., 2004, 2005). In strawberry (*Fragaria xananassa* Duch.), the effect of one ProCa application lasts for ≈ 3 weeks and repeated applications are needed to effectively control plant height (Reekie and Hicklenton, 2001). For apple, application should be made 0 to 12 d after full bloom; later in the season, the effect is weaker, possibly as a result of high concentrations of GA₁ already accumulated in the shoot tissues (Medjdoub et al., 2005). Two applications in 6- to 8-week intervals were needed to avoid regrowth of the shoots (Medjdoub et al., 2004). In another experiment, three applications at 2-week intervals beginning at petal fall reduced terminal shoot growth by 59% (Glenn and Miller, 2005). For raspberry, ProCa applications at 3-week intervals might be recommended.

Seven weeks after ProCa treatments were initiated, raspberry plants that received a single application produced longer internodes than the control plants. The differences were not significant by Dunnett’s test, probably because a few plants had already stopped producing new internodes, so variation was high. Also in strawberry, increased growth above the control level occurred 9 weeks after ProCa application (Reekie and Hicklenton, 2001). ProCa blocks the last steps in gibberellin biosynthesis pathways, which leads to accumulation of immediate precursors of active gibberellin (Evans et al., 1999). When ProCa breaks down, the accumulated precursors are converted into active gibberellin, and growth rate may even exceed the normal growth as a result of excess amount of active gibberellin available in a plant. The second treatment was needed to suppress growth after breakdown of ProCa in raspberry.

Because the number of flowers was reduced in all ProCa-treated plants by 22% to 42%, altered GA levels in the plant have

apparently interfered with floral induction. Second treatment did not further suppress flowering, possibly because at that time, flower initiation was completed. Detailed knowledge on the role of distinct GAs on flower induction in raspberry is lacking. However, Vasilakakis et al. (1979) reported that increased GA levels in the shoot tip were associated with flower induction in primocane fruiting raspberry. In apple tree, in which GAs have been implicated in flower inhibition, ProCa application increased flowering by 20% (Owens and Stover, 1999). In primocane raspberries, vegetative and generative growth are coincident. However, in florican raspberries, vegetative growth and floral induction are temporally separated, which may facilitate manipulation of vegetative growth without affecting flower induction. Apparently, timing of ProCa application is extremely crucial and requires careful examination.

Total aboveground dry weight of raspberry plants was drastically reduced by ProCa treatments: 32% to 48% by single applications and 48% to 55% by double applications. However, the allocation of dry weight into different aboveground plant parts was unaffected. ProCa did not alter allocation of total nonstructural carbohydrates in apple trees either (Guak et al., 2001). However, in strawberry, ProCa-treated plants allocated more dry weight to roots and proportionally less to shoots (Reekie et al., 2005).

In conclusion, ProCa reduced cane growth and internode length in primocane fruiting raspberry ‘Ariadne’. Treatment with 200 ppm ProCa twice in 4-week intervals caused the most effective reduction in vegetative growth. However, the number of flowers was drastically reduced in all ProCa-treated plants. Therefore, ProCa cannot be recommended for growth regulation of primocane fruiting raspberry without further studies.

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