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# Prohexadione calcium controls shoot growth of pear trees under mild winter conditions

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## ABSTRACT

The aim of this study was to evaluate the effects of prohexadione calcium (ProCa) on vegetative growth and yield of 'Carrick', 'Packham's Triumph' and 'William's' pear trees. The trial was performed at the experimental orchards of the Federal University of Pelotas, Capão do Leão, RS, Brazil (31° 52' 00" S; 52° 21' 24" W), during the growing seasons of 2011/12 and 2012/13. Treatments were applied to single-tree replications in a randomized complete block design with four replications as follows: Control (unsprayed), ProCa (ProCa - 750 g $ha^{-1}$ i.a.). The ProCa was split in four (187.5 g $ha^{-1}$ a.i. each) or three timings (250 g $ha^{-1}$ a.i. each) applications in the 2011/12 and 2012/13 growing seasons, respectively. The assessed parameters were: one-year-old shoot length, number of nodes per shoot, average internode length per shoot, trunk cross sectional area (TCSA) increment, pruning weight, number of fruit per tree, average fruit weight, yield per tree and return bloom. The application of ProCa at 750 g ha-1 a.i. satisfactorily controlled shoot growth through the reduction of internode length of 'Carrick', 'Packham's Triumph' and 'William's' pears. Besides, return bloom was not negatively affected by ProCa. Therefore, this plant growth regulator is a potential management tool to reduce shoot growth and the need for pruning in pear orchards.

**Keywords**: Pyrus communis L.; return bloom; pruning weight; vegetative growth; vigor.

## INTRODUCTION

Pear is the leading fruit type imported into Brazil both in quantity and in value. According to the Food and Agriculture Organization of the United Nations (FAO, 2014), the imported pears in 2010 amounted to approximately 190,000 metric tons, representing about 90% of domestic consumption, while in 2009 it was nearly 160,000 metric tons, which amounts to an 18.75% increase. The value of the imported pears in 2010 was US$ 189 million. This scenario is due to various factors amongst which one of the most important is the excessive vegetative growth of the main cultivars (Pasa et al., 2011).

Excessive vegetative growth is a major concern in a pear orchard as it is negatively correlated with yield efficiency, (Pasa et al., 2012) probably due to the competition with fruit growth (Forshey and Elfving, 1989) in the early stages of fruit development when shoot and fruit growth is maximal. This competition might result in fewer fruit cells and therefore decreasing the chance of reaching acceptable fruit size and yield. Besides, excessive vigor leads to overcrowding and reduced light penetration (Sharma et al., 2009) and distribution (Einhorn et al., 2012), which potentially decrease fruit quality, yield and hinders pest control. In addition, pruning costs are increased by excessive shoot growth (Glenn and Miller, 2005).

The majority of pear orchards in Brazil are grafted to Pyrus rootstocks, which usually induce excessive vegetative growth, delaying their cropping and decreasing yield. Since size-controlling rootstocks are not currently available for pears (Elkins et al., 2012), to the extent that they are for apples (Elfving et al., 2003), pear growers rely mainly on winter and summer pruning to control vegetative growth. However, winter pruning usually induces excessive vegetative growth during the early season and therefore overcrowding the canopy. Besides, as mentioned before, pruning is an important component of production costs. In this way, the development of new tools, such as plant growth regulators, to control vegetative growth (Lafer, 2008) is very important to increase productivity and profitability of pear orchards in Brazil.

ProCa is currently registered in Brazil for vegetative growth control in apple under the trade name Viviful® (Ihara Chemical Industry Co., Ltd). The most obvious effect caused by ProCa, is reduced one-year-old shoot length through reduced biosynthesis of the plant hormone gibberellin (GA), which regulates cell elongation. This is achieved by ProCa blocking of 2-oxoglutaric acid-dependent dioxygenases involved in the biosynthesis of GAs, mainly the GA20-3ß-hydroxylase, which catalyzes the conversion of inactive $GA_{20}$ into highly active GA1 (Rademacher and Kober, 2003). The biological half-life of ProCa in plants is in the range of 10 to 14 days (Rademacher et al., 2004). Furthermore, this compound has very favorable toxicological and eco-toxicological features, a low propensity for crop residues and no health risk for user or consumer (Spinelli et al., 2010).

Previous studies have demonstrated that ProCa controls shoot growth of different pear (Elfving et al., 2003; Smit et al., 2005; Asín et al., 2007; Hawerroth et al., 2012; Einhorn et al., 2014; Pasa and Einhorn, 2014) and apple (Duyvelshoff and Cline, 2013) cultivars with varied influences on other horticultural traits. Sugar et al. (2004) reported smaller fruit size of ‘William’s’, but not ‘Bosc’, and ‘Red Anjou’ in the year of ProCa application, while ‘D’Anjou’ fruit size was affected in just one trial; ‘Bosc’ return bloom and yields were markedly reduced the year following application, but ‘William’s’ and ‘D’Anjou’ were not similarly affected. The aim of this study was to evaluate the effects of ProCa on vegetative growth and yield of ‘Carrick’, ‘Packham’s Triumph’ and ‘William’s’ pear trees.

## MATERIAL AND METHODS

The experiment was performed at the experimental orchards of the Federal University of Pelotas located in the city of Capão do Leão, RS, Brazil (31° 52’ 00" S; 52° 21’ 24" W; Altitude: 48m.), during the growing seasons of 2011/12 and 2012/13. The orchard is planted in a Eutrophic Yellow Argissol soil type. The accumulation of temperatures lower than 7.2 °C, from May to August, were 440 h in the 2011 season, and 368 h in the 2012 season (Data not shown). Climatic conditions during the trial is shown in table 1.

Research plots were established in a seven year-old pear orchard of the cultivars Carrick, Packham’s Triumph and William’s pear trees grafted to Pyrus calleryana, at 1.5 x 5 m spacing (1333 trees $ha^{-1}$). Trees were trained to a central leader system using a three-wires fixed to cement poles. The cultural management was according to standard commercial practices and similar for all treatments: fertilization based on soil analysis, shoot bending, pest and disease management, weed control, and drip irrigation. At the end of the winter of 2011 and 2012, at the stage of green tip, trees were sprayed with hydrogen cyanamide (0.3%) mixed with mineral oil (3%) to normalize budburst and flowering.

**Table 1.** Weather conditions of the experimental field located at the municipality of Capão do Leão, in the state of Rio Grande do Sul, Brazil[(1)].

| Month | Monthly Average of Minimum Temperatures (ºC) | Monthly Average of Maximum Temperatures (ºC) | Monthly Rainfall (mm) |
|---|---|---|---|
| | ----------2011---------- | | |
| May | 11.1 | 21.0 | 118.3 |
| June | 8.7 | 17.7 | 116.2 |
| July | 7.5 | 16.2 | 71.0 |
| August | 9.2 | 17.0 | 114.2 |
| September | 10.1 | 20.0 | 75.1 |
| October | 13.5 | 22.1 | 75.9 |
| November | 15.1 | 25.3 | 60.3 |
| December | 16.2 | 26.0 | 53.7 |
| | ----------2012---------- | | |
| January | 17.9 | 28.4 | 73.6 |
| February | 20.2 | 29.8 | 171.9 |
| March | 16.6 | 28.1 | 49.0 |
| April | 12.8 | 23.7 | 52.4 |
| May | 12.2 | 23.9 | 5.1 |
| June | 7.3 | 19.5 | 78.0 |
| July | 5.6 | 16.8 | 138.5 |
| August | 12.6 | 22.9 | 128.3 |
| September | 12.3 | 21.3 | 115.3 |
| October | 15.9 | 23.6 | 106.5 |
| November | 16.6 | 27.0 | 52.1 |
| December | 18.7 | 29.3 | 133.4 |
| | ----------2013---------- | | |
| January | 17.5 | 27.5 | 110.9 |
| February | 19.1 | 28.0 | 177.3 |
| March | 15.2 | 25.8 | 27.6 |
| April | 13.8 | 24.5 | 147.4 |
| May | 10.5 | 20.6 | 84.1 |
| June | 8.0 | 18.4 | 75.8 |
| July | 7.2 | 17.8 | 56.6 |
| August | 7.0 | 17.1 | 95.3 |
| September | 11.5 | 21.1 | 133.7 |

[(1)] Data obtained from the weather station located at the municipality of Pelotas (Estação Agroclimatológica de Pelotas), in the state of Rio Grande do Sul, Brazil.

Treatments were applied to single-tree replications in a randomized complete block design with four replications per treatment as follows: 1) Control (unsprayed), 2) ProCa - 750 g a.i. ha-1. As source of ProCa the commercial product Viviful® (27.5% a.i; Ihara Chemical Industry Co., Ltd) was used. The application was split in four (187.5 g a.i. $ha^{-1}$ each) or three applications (250 g a.i. $ha^{-1}$ each) in the 2011/12 and 2012/13 growing seasons, respectively. The first application was performed when current year shoots were an average 10 cm long while the second, and third were made 30 and 60 days after the first application (DAFA), respectively; the fourth application in 2011 was made 120 DAFA. ProCa applications were performed using a hand-gun backpack sprayer, using a spraying volume of 1000 L $ha^{-1}$. The application water pH was ~6.95. Trees were sprayed during the morning, with temperature ranging from 20 to 25 °C, relative humidity of 85-95% and wind speed not exceeding 7 km $h^{-1}$.

Twelve one-year-old shoots of even length were selected, tagged and measured at the time of the first application and then at weekly intervals until the cessation of shoot growth. Node number was also counted on these shoots at the end of the growing season. From these data internode length (cm) was calculated. TCSA ($cm^2$) increment was calculated subtracting the TCSA of the current season from the previous season. The TCSA was calculated through the following formula: TCSA= $\pi.r^2$, where $\pi$ = 3.1416 and r= d/2, where d= trunk diameter, measured at 5 cm above graft union at the start of the trial and the following fall of each year. Trees were summer pruned every year in January and pruning weight of each tree was recorded (kg).

The fruit of all cultivars were harvested in the period between 15 Jan and 15 Feb, based on fruit firmness (~60 Newton). All fruits of each tree were counted and weighed. From these data, yield per tree and average fruit weight were calculated. Return bloom was calculated as a percentage of bloom from the previous season, based on the total number of flower clusters on each tree, which were counted at the inception of the experiment (2011) and then in the year following application.

Data were analyzed for statistical significance, by means of F test. Duncan's test was used to compare treatments when analysis of variance showed significant differences among means.

## RESULTS AND DISCUSSION

Average one-year old shoot length of 'Carrick', 'Packham's Triumph' and 'William's' pear trees was significantly reduced relative to the control trees on all assessment dates starting when shoots were about 10 cm long in both growing seasons (Figure 1). In the 2011/12 growing season the greatest shoot length reduction was observed 60 DAFA where ProCa treated shoots of 'Carrick' (Figure 1A), 'Packham's Triumph' (Figure 1B) and 'William's' (Figure 1C) pears were 40.1%, 27.6% and 44.6% shorter than control shoots, respectively. After that, both ProCa treated and control shoots did not grow further therefore any second flush of growth occurred. In the 2011/12 growing season, the fourth application did not yield any further shoot growth reduction since even control shoots had stopped growing. The ProCa dose (750 g a.i. $ha^{-1}$) in the 2012/13 season was split in only three applications, i.e 250 g a.i. $ha^{-1}$ each. The fourth ProCa application was therefore not necessary once shoot length was reduced with three applications in all cultivars. In fact, shoot length reduction in comparison to the control was even higher than in the 2011/12 growing season, probably because the ProCa dose was higher per application, since it was split in only three applications. By the end of the 2012/13 growing season ProCa treated shoots were 56.1%, 42.1% and 54.6% shorter than control shoots for 'Carrick' (Figure 1D), 'Packham's Triumph' (Figure 1E), and 'William's' (Figure 1F), respectively.

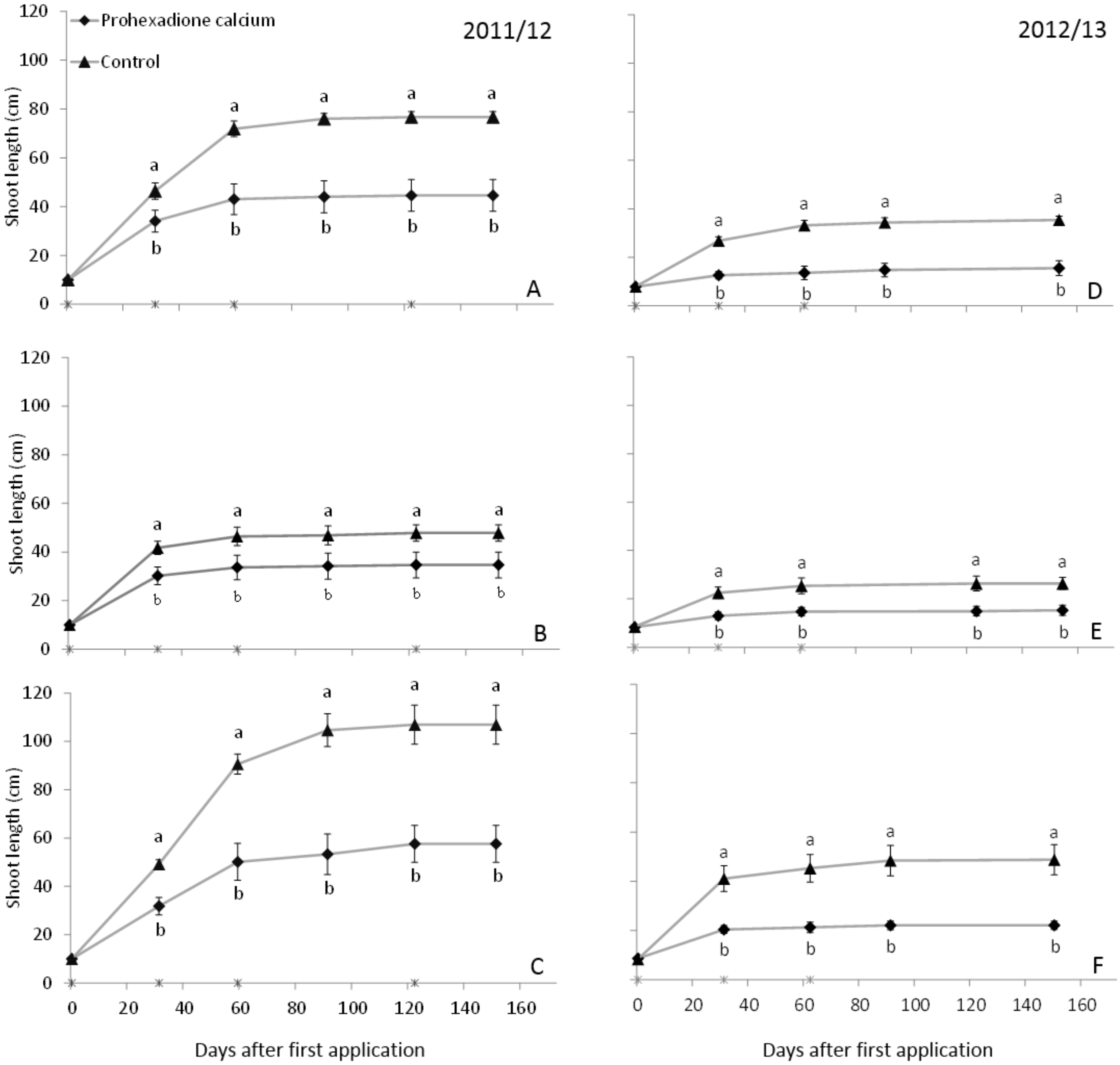


**Figure 1.** Shoot length of 'Carrick', 'Packham's Triumph' and 'William's' pear trees treated with prohexadione calcium (ProCa) in the 2011/12 (A, B and C, respectively) and 2012/13 (D, E and F, respectively) growing seasons. Different letters within each assessment date indicate significant differences by Duncan's test ($p < 0.05$). Asterisk in the bottom of the graph denote time of ProCa application and bars the standard error of the means.

The above results show that ProCa was effective in shoot growth control of the pear cultivars investigated. Similar results were found by Smit et al. (2005), which observed reduced shoot growth up to 50% in 'Packham's Triumph', 'Golden Russet Bosc', 'Early Bon Chretien' and 'Rosemarie' with ProCa concentrations ranging from 50 mg $L^{-1}$ a.i. to 250 mg $L^{-1}$ a.i. Similar results were also observed by Hawerroth et al. (2012), who obtained shoot growth reduction in 'Hosui' pear trees grafted to vigorous rootstocks by application of 600 g $ha^{-1}$ a.i., split in two applications (first when shoots were ~5-10 cm long and the second 30 DAFA). Even though single applications of ProCa control shoot growth of some cultivars (Smit et al., 2005), split applications, such as used in the present study, are preferred since this would enable the relatively short-lived ProCa to control flushes of shoot growth, which may occur later in the season (Rademacher et al., 2004). Additionally, ProCa translocation in-planta is acropetal (Evans et al., 1999), so its activity should be limited to tissues that have come in direct contact with the compound, as shown in 'D'Anjou' pears (Pasa and Einhorn, 2014). So, ProCa is a potential tool to control shoot growth of for targeted areas of canopy with high vigor.

The number of nodes in 2011/12 was reduced in ProCa treated 'William's' shoots. In 2012/13, ProCa treated 'Carrick' and 'Packham's Triumph' trees had fewer nodes per one-year-old shoot compared to control trees (Table 2). The internodes of ProCa treated trees of all cultivars were shorter than those of control trees in both growing seasons (Table 2). Therefore, both the reduction in the internode length and number of nodes was responsible for the reduction in shoot growth (Figure 1). Similar results were observed by Einhorn et al. (2014) in 'D'Anjou' pears in response to application of ProCa 250 mg $L^{-1}$. The reduction in internode length is the most obvious effect caused by ProCa due to reduction in the biosynthesis of GA, which regulates internode elongation. This is achieved by ProCa blocking the conversion of inactive $GA_{20}$ into highly active GA1 (Rademacher and Kober, 2003). The reduction of the number of nodes is possibly also an effect of GA biosynthesis blocking, since node formation is dependent on the rate of shoot growth (Jackson, 2003), which is reduced by ProCa application (Pasa and Einhorn, 2014). The reduction in the internode length as a response to ProCa application was also observed in 'Smoothee Golden Delicious' apple (Medjdoub and Blanco, 2004).

**Table 2.** Trunk cross sectional area (TCSA) increment, number of nodes, average internode length and pruning weight of 'Carrick', 'Packham's Triumph' and 'William's' pear trees treated with prohexadione calcium (ProCa) in the 2011/12 and 2012/13 growing seasons.

| Treatment | TCSA increment ($cm^2$) | | Number of nodes | | Average Internode length (cm) | | Pruning weight (kg) | |
|---|---|---|---|---|---|---|---|---|
| | 2011/12 | 2012/13 | 2011/12 | 2012/13 | 2011/12 | 2012/13 | 2011/12 | 2012/13 |
| | | | | 'Carrick' | | | | |
| Control | 15.0 | 14.7 | 19.9 | 13.9 a* | 3.9 a | 2.5 a | 2.9 | 0.8 |
| PCa | 11.6 | 11.8 | 15.6 | 8.6 b | 2.8 b | 1.9 b | 2.6 | 0.6 |
| *P > F* | 0.99 | 0.42 | 0.07 | <0.01 | <0.01 | 0.02 | 0.94 | 0.79 |
| CV (%) | 29.3 | 28.4 | 6.2 | 4.9 | 9.2 | 12.1 | 32.9 | 35.7 |
| | | | | 'Packham's Triumph' | | | | |
| Control | 14.2 | 9.7 | 16.6 | 15.5 a | 2.9 a | 1.7 a | 3.0 | 2.3 a |
| PCa | 13.6 | 6.8 | 15.7 | 11.0 b | 2.2 b | 1.4 b | 2.6 | 1.0 b |
| *P > F* | 0.90 | 0.41 | 0.60 | 0.05 | <0.01 | 0.01 | 0.55 | 0.03 |
| CV (%) | 28.6 | 32.4 | 7.7 | 6.9 | 6.3 | 6.0 | 32.3 | 27.5 |
| | | | | 'William's' | | | | |
| Control | 26.5 | 12.7 a | 31.1 a | 17.1 | 3.4 a | 2.8 a | 7.4 a | 6.9 a |
| PCa | 21.2 | 5.8 b | 22.7 b | 14.4 | 2.5 b | 1.6 b | 5.2 b | 4.2 b |
| *P > F* | 0.33 | 0.02 | 0.02 | 0.3 | <0.01 | 0.02 | <0.01 | 0.05 |
| CV (%) | 27.4 | 24.9 | 4.4 | 9.8 | 6.7 | 16.9 | 17.9 | 22.4 |

*Different letters in the column indicate significant differences by Duncan's test (p < 0.05).

Even though there was an overall trend towards a smaller TCSA increment on ProCa treated trees it was only significant in 2012/13 in ‘William’s’ trees (Table 2), as was found in apple by Medjdoub and Blanco (2004). The fact that trunk growth was little affected indicates that the reduction in shoot growth was not too severe to the point of completely stopping tree growth. In such case yield might be impaired by a lack of carbohydrates to supply fruit and flower bud formation.

Pruning weight of ProCa treated ‘William’s’ pears was significantly lower in both 2011/12 and 2012/13 growing seasons and only in 2012/13 in the case of ‘Packham’s Triumph’ (Table 2). The fact that pruning weight was only reduced by ProCa in ‘William’s’ in both growing seasons is probably due to its higher vigor associated with a strong water shoot growth. Thus at the time of pruning water shoots were removed from control trees but in ProCa treated trees some were left unpruned as they were not too long. Similarly, the pruning weight of ‘D’Anjou’ and ‘William’s’ pears treated with ProCa was reduced in comparison to control trees, and this reduction was correlated to the amount of ProCa applied (Elfving et al., 2003). In ‘Hosui’ pears, pruning weight was also reduced as ProCa dose increased (Hawerroth et al., 2012). The reduction in pruning weight associated with ProCa indicates a potential decrease in the need for pruning, which is an important component, approximately 14%, of production cost in pear orchards (Seavert et al. 2005).

The reduction in shoot growth and pruning weight resulted in a decreased canopy density. This implies an improved spray penetration into the canopy when applying fungicides and insecticides (Rademacher and Kober, 2003). In such a situation, diseases and pest would be better controlled so fewer applications would be necessary, thus reducing spraying costs as well as potential environmental damage.

Yield and fruit number per tree did not differ between treatments for all cultivars, except ‘Packham’s Triumph’ in 2011/12, where ProCa treated trees were more productive and had a higher number of fruits than control trees. No differences were found in average fruit weight in the evaluated cultivars (Table 3). The overall absence of yield increase associated with ProCa in this study agrees with the results found for ‘Shinseiki’ (Hawerroth et al., 2011) and ‘Blanquilla’ (Asín et al., 2007). The higher yield of ProCa treated ‘Packham’s Triumph’ in 2011/12 was therefore due to more fruit rather than bigger fruit, although it has to be borne in mind that fruit number on ‘Packham’s Triumph’ was very low in 2011/12. The low production of all cultivars in this season, but mainly ‘Packham’s Triumph’, is probably due to alternate bearing effect, since the production in the previous season and 2012/2013 was greater. This cultivar is also susceptible to bud abortion, as observed in the field. Another possible reason for the low yield of all cultivars in this season is the climatic conditions observed during flowering. Accordingly to the monthly climatic data (Table 1), these conditions were basically similar, but in 2011 the average of minimum temperatures in September was 10.1°C and the maximum 20°C, while in 2012 these temperatures were greater (12.3°C and 21.3°C, respectively). The optimum temperatures for pollination and fertilization ranges from 20°C to 25°C. Then, in 2011, the average of maximum temperatures during flowering (September) was in the lower limit of the optimum range, which may have negatively affected the pollination and fertilization, thus reducing the yield.

The increase in the number of fruit as a response to ProCa has been reported for some pear cultivars, but it seems to be cultivar dependent and varies with years (Smit et al., 2005; Asín et al., 2007) making it difficult to determine if this is really a direct ProCa effect. However, usually higher number of fruit will be associated with a decrease in the average fruit size (Sugar et al., 2004; Einhorn et al., 2014). Therefore, the average fruit weight was not affected by ProCa because in general the number of fruit did not differ between treatments. Varying results for yield among ProCa studies indicates that several factors

contribute to this effect. Cultivar, rootstock/scion combinations, crop load and hormonal balance would all be expected to interact with dose and timing of ProCa relative to the environmental conditions prior, during and after applications (Stover and Greene, 2005).

**Table 3**. Number of fruits, average fruit weight, production per tree and return bloom of 'Carrick', 'Packham's Triumph' and 'William's' pear trees treated with prohexadione calcium (ProCa) in the 2011/12 and 2012/13 growing seasons.

| Treatment | Number of fruits | | Average fruit weight (g) | | Yield per tree (kg) | | Return bloom (%) | |
|---|---|---|---|---|---|---|---|---|
| | 2011/12 | 2012/13 | 2011/12 | 2012/13 | 2011/12 | 2012/13 | 2011/12 | 2012/13 |
| | | | | 'Carrick' | | | | |
| Control | 25.5 | 14.0 | 145.6 | 171.1 | 3.8 | 2.4 | 107.1 | 266.0 |
| PCa | 35.0 | 20.0 | 136.5 | 174.1 | 5.1 | 3.1 | 146.8 | 305.2 |
| *P > F* | 0.57 | 0.88 | 0.56 | 0.56 | 0.69 | 0.73 | 0.32 | 0.79 |
| CV (%) | 22.4 | 26.1 | 14.1 | 3.8 | 31.4 | 36.8 | 27.4 | 36.6 |
| | | | | 'Packham's Triumph' | | | | |
| Control | 1.3 b* | 30.5 | 99.5 | 121.9 | 0.1 b | 3.9 | 130.3 b | 28.3 |
| PCa | 6.0 a | 53.5 | 100.0 | 123.2 | 0.6 a | 6.6 | 221.5 a | 56.1 |
| *P > F* | <0.01 | 0.32 | 0.94 | 0.89 | <0.01 | 0.40 | 0.01 | 0.18 |
| CV (%) | 8.9 | 23.8 | 8.8 | 9.1 | 29.3 | 34.7 | 13.6 | 23.4 |
| | | | | 'William's' | | | | |
| Control | 15.7 | 18.7 | 115.1 | 104.7 | 1.8 | 2.2 | 112.4 | 35.91 |
| PCa | 26.7 | 18.0 | 108.7 | 111.3 | 2.8 | 2.2 | 121.4 | 62.6 |
| *P > F* | 0.32 | 0.76 | 0.45 | 0.33 | 0.31 | 0.91 | 0.93 | 0.11 |
| CV (%) | 26.7 | 17.1 | 9.5 | 7.5 | 33.7 | 24.9 | 28.6 | 34.1 |

*Different letters in the column indicate significant differences by Duncan's test ($p < 0.05$).

The increase in the number of fruit as a response to ProCa has been reported for some pear cultivars, but it seems to be cultivar dependent and varies with years (Smit et al., 2005; Asín et al., 2007) making it difficult to determine if this is really a direct ProCa effect. However, usually higher number of fruit will be associated with a decrease in the average fruit size (Sugar et al., 2004; Einhorn et al., 2014). Therefore, the average fruit weight was not affected by ProCa because in general the number of fruit did not differ between treatments. Varying results for yield among ProCa studies indicates that several factors contribute to this effect. Cultivar, rootstock/scion combinations, crop load and hormonal balance would all be expected to interact with dose and timing of ProCa relative to the environmental conditions prior, during and after applications (Stover and Greene, 2005).

Return bloom was not affected by ProCa in either growing season, except 'Packham's Triumph' in 2012/13 where ProCa treatment increased return bloom (Table 3). Similar results were observed in 'Blanquilla' (AsÍn et al., 2007), 'Abbé Fétel' and 'William's' pear (Costa et al., 2004) where ProCa did not reduce return bloom. On the other hand, Sugar et al. (2004) found that in 'William's', 'D'Anjou' and 'Bosc' return bloom was reduced the year following ProCa application, as did Smit et al. (2005) in ‘Forelle’ and ‘Packham’s Triumph’, and Einhorn et al. (2014) for ‘D’Anjou’. These different responses of pear trees following ProCa application seems to be cultivar and rate dependent (Rademacher et al., 2004). However, further studies are necessary in order to elucidate the actual effect of ProCa over return bloom in pear.

**CONCLUSIONS**

1- Shoot growth and average internode length of ‘Carrick’, ‘Packham’s Triumph’ and ‘William’s’ pear trees were reduced by application of ProCa at 750 g. ha$^{-1}$ a.i. split over three or four applications.
2- Return bloom of the investigated cultivars was not negatively affected by ProCa.
3- Yield and fruit size are little affected by ProCa.

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**REFERENCES**

Asín A, Alegre S, Montserrat R (2007). Effect of paclobutrazol, prohexadione-Ca, deficit irrigation, summer pruning and root pruning on shoot growth, yield, and return bloom, in a ‘Blanquilla’ pear orchard. Scientia Horticulturae, 113:142-148.

Costa G, Sabatini E, Spinelli F, Andreotti C, Spada G, Mazzini F (2004). Prohexadione–Ca controls vegetative growth and cropping performance in pear. Acta Horticulturae, 653:127-132.

Duyvelshoff C, Cline JA (2013) Ethephon and prohexadione-calcium influence the flowering, early yield, and vegetative growth of young ‘Northern Spy’ apple trees. Scientia Horticulturae, 151:128–134.

Einhorn TC, Pasa MS and Turner J (2014). D’Anjou pear shoot growth and return bloom, but not fruit size, are reduced by prohexadione-calcium. HortScience, 49:180-187.

Einhorn T, Turner J and Laraway D (2012). Effect of Reflective Fabric on Yield of Mature ‘d’Anjou’ Pear Trees. HortScience, 47:1580–1585.

Elfving DC, Lombardini L, McFerson JR, Drake SR, Faubion DF, Auvil T et al (2003). Effects of directed applications of prohexadione-calcium to tops of mature pear trees on shoot growth, light penetration, pruning and fruit quality. Journal of the American Pomological Society, 57:45-57.

Elkins R, Bell R, Einhorn T (2012) Needs assessment for future US pear rootstock research directions based on the current state of pear production and rootstock research. Journal of the American Pomological Society, 66:153–163.

Evans, JR, Evans, RR, Regusci, CL, Rademacher, W 1999 Mode of action, metabolism, and uptake of BAS 125W, prohexadione-calcium. HortScience, 34:1200–1201.

ESTAÇÃO AGROCLIMATOLÓGICA DE PELOTAS (Capão do Leão). Boletim Agroclimatológico. 2015. Available from: <http://www.cpact.embrapa.br/agromet/estacao/boletim.php>. Access in: 31 may 2016.

FAO. FAOSTAT: Trade. Available on: < http://faostat.fao.org/site/535/default.aspx#ancor > Access in: 2nd Jul. 2014.

Forshey CG, Elfving DC (1989) The relationship between vegetative growth and fruiting in apple trees. Horticultural Reviews, 11:229–287.

Glenn DM, Miller S (2005) Effects of apogee on growth and whole canopy photosynthesis in spur ‘Delicious’ apple trees. HortScience, 40:397-400.

Hawerroth FJ, Herter FG, Fachinello JC, Petri JL, Prezotto ME, Hass LB et al. (2011) Aumento da produção de pereira asiática pelo uso de fitorreguladores. Ciência Rural, 41:1750-1754.

Hawerroth FJ, Petri JL, Fachinello JC, Herter FG, Prezotto ME, Hass LB et al (2012). Redução da poda hibernal e aumento da produção de pereiras ‘Hosui’ pelo uso de prohexadiona cálcio. Pesquisa Agropecuária Brasileira, 47:939-947.

Jackson, JE (2003). Biology of apples and pears. Cambridge, 501p.

Lafer G (2008) Effects of different bioregulator applications on fruit set, yield and fruit quality of 'Williams' pears. Acta Horticulturae, 800:183‑188.

Medjdoub RM, Blanco JVA (2004) Prohexadione calcium inhibits vegetative growth of 'Smoothee Golden Delicious' apple trees. Scientia Horticulturae, 101:243-253.

Pasa, MS, Einhorn, TC (2014) Heading cuts and prohexadione-calcium affect the growth and development of 'd'Anjou' pear shoots in a high-density orchard. Scientia Horticulturae, 168:267-271.

Pasa MS, Fachinello JC, Schmitz JD, Souza ALK, Franceschi E (2012) Desenvolvimento, produtividade e qualidade de peras sobre porta-enxertos de marmeleiro e Pyrus calleryana. Revista Brasileira de Fruticultura, 34:873-880.

Pasa MS, Fachinello JC, Schmitz JD, Souza ALK, Herter FG (2011) Hábito de frutificação e produção de pereiras sobre diferentes porta-enxertos. Pesquisa Agropecuária Brasileira, 46:998-1005.

Rademacher W, Kober R (2003) Efficient use of prohexadione-Ca in pome fruits. European Journal of Horticultural Science, 68:101-107.

Rademacher W, Saarloos KV, Porte JAG, Forcades FR, Senechal Y, Andreotti C et al (2004). Impact of prohexadione-Ca on the vegetative and reproductive performance of apple and pear trees. European Journal of Horticultural Science, 69:221-228.

Seavert CF, Moore J, Castagnoli S (2005) The Economic costs and returns of producing pears in Hood River, Oregon, USA. Acta Horticulturae, 671:421-427.

Sharma S, Rehalia AS, Sharma SD (2009) Vegetative growth restriction in pome and stone fruits - a review. Agricultural Reviews, 30:13-23.

Smit M, Meintjes JJ, Jacobs G, Stassen PJC, Theron KI (2005) Shoot growth control of pear trees (Pyrus communis L.) with prohexadione-calcium. Scientia Horticulturae, 106:515-529.

Spinelli F, Rademacher W, Sabatini E, Costa G (2010) Reduction of scab incidence (Venturia inaequalis) in apple with prohexadione-Ca and trinexapac-ethyl, two growth regulating acylcyclohexanediones. Crop Protection, 29:691-698.

Stover, EW, Greene, DW (2005) Environmental effects on the performance of foliar applied plant growth regulators: a review focusing on tree fruits. HortTechnology, 15:214-221.

Sugar D, Elfving DC, Mielke EA (2004) Effects of prohexadione-calcium on fruit size and return bloom in pear. HortScience, 39:1305-1308.