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PROHEXADIONA CÁLCIO NO CONTROLE DO CRESCIMENTO VEGETATIVO DE PEREIRAS

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PROHEXADIONA CÁLCIO NO CONTROLE DO CRESCIMENTO VEGETATIVO DE PEREIRAS

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RESUMO

PASA, MATEUS DA SILVEIRA. **Prohexadiona cálcio no controle do crescimento vegetativo de pereiras.** 2014. 138f. Tese (Doutorado) – Programa de Pós-Graduação em Agronomia. Universidade Federal de Pelotas.

O excesso de crescimento vegetativo é uma das principais preocupações dos produtores de pera porque resulta em sérios efeitos negativos no pomar, como alto custo de poda, sombreamento da parte interna da copa, baixa qualidade de frutas e dificuldade no manejo de pragas e doenças. A utilização de fitorreguladores [e.g. Prohexadiona cálcio (PCa)] é uma das alternativas mais promissoras para manejar o crescimento vegetativo de pereiras. PCa reduz o crescimento de ramos através do bloqueio da biossíntese do hormônio vegetal giberelina, a qual regula o crescimento longitudinal dos ramos. O objetivo do presente estudo foi, portanto, de avaliar as respostas produtivas e vegetativas de várias cultivares de pereira em função da PCa. Três experimentos foram conduzidos: Experimento 1) PCa foi aplicado em pereiras ‘d’Anjou’ localizadas em regiões de baixa e alta altitude do Hood River Valley, Oregon, USA, para determinar a sua efetividade no manejo do crescimento vegetativo excessivo em diferentes condições climáticas, com doses de PCa variando de 125 a 250 mg $L^{-1.}$ O fitorregulador Etefon também foi aplicado (150 e 300 mg L^{-1}) como uma tentativa de melhorar a diferenciação floral; Experimento 2) PCa foi seletivamente aplicado em ramos despontados no período de dormência (1/3 removido) e não podados em um pomar em alta densidade de pereiras ‘d’Anjou’ em Oregon, USA. Ambos os conjuntos de ramos foram tratados com 250 mg $^{L-1}$ i.a. P-Ca, o qual foi aplicado uma ou duas vezes; Experimento 3) PCa foi aplicado em pereiras ‘Carrick’, ‘Packham’s’ e ‘William’s’ no campo experimental da Universidade Federal de Pelotas, RS, Brasil. As plantas foram tratadas com 750 g ha^{-1} a.i. PCa, o qual foi parcelado em quatro (187,5 g ha-1 i.a. cada) e três vezes (250 g ha^{-1} i.a. cada) nas safras de 2011 e 2012, respectivamente. Os resultados mais importantes são apresentados separadamente para cada experimento. Experimento 1) P-Ca foi eficiente na redução do crescimento de ramos nos diferentes locais e em diferentes safras. Em uma das safras, também foi observado aumento na frutificação efetiva e produtividade. No entanto, a consistente redução no retorno da floração, que resultou em menores retornos de produtividade, a qual não foi relatada anteriormente para ‘d’Anjou’, neutraliza esses benefícios. Etefon mostrou potencial para melhorar os efeitos do PCa no retorno da floração e produção, mas isso requer estudos adicionais. Experimento 2) No final da estação de crescimento, o comprimento dos ramos não despontados foi reduzido em 28% e 41%, quando tratados com PCa uma e duas vezes, respectivamente, enquanto que os ramos despontados foram 37% menores (tratados apenas uma vez com PCa) do que o controle. O número de entrenós e comprimento médio dos entrenós foram significativamente reduzidos nos ramos tratados com PCa, independentemente do tipo de poda, conferindo uma maior densidade de entrenós em relação aos ramos controle. Esses resultados mostram que o PCa é uma potente ferramenta para o manejo preciso do vigor das plantas em pomares conduzidos em alta densidade através do tratamento seletivo de áreas com vigor excessivo. Experimento 3) A aplicação de PCa na dose de 750 g. ha^{-1} i.a. controla satisfatoriamente o crescimento de ramos das pereiras 'Carrick', 'Packham's' e 'William's', através da redução no comprimento médio dos entrenós. Além disso, foi observado que o retorno da floração não é negativamente afetado pela aplicação do PCa. Dessa forma, esse fitorregulador é uma ferramenta de manejo promissora para reduzir o crescimento de ramos e a necessidade de poda de pomares de pereira.

Palavras chave: *Pyrus communis* L., controle de vigor, reguladores de crescimento de plantas, crescimento de ramos, economia de trabalho.

ABSTRACT

PASA, MATEUS DA SILVEIRA. **Prohexadione calcium on vegetative growth control of pear.** 2014. 138p. Thesis (Doctorate) – Graduate Program in Agronomy. Federal University of Pelotas, Pelotas.

Excessive vegetative growth is a major concern among pear growers because it results in serious negative effects in the orchard, such as increased pruning costs, shading of the inner parts of the canopy, poor fruit quality and difficult pest control. The use of plant growth regulators [e.g. Prohexadione calcium (PCa)] is one of the most promising techniques currently available to manage vegetative growth in pears. PCa reduces shoot growth by blocking the biosynthesis of the plant hormone gibberellin, which regulates longitudinal shoot growth. The aim of this study was, therefore, to evaluate the productive and vegetative responses of various pear cultivars to PCa. Three trials were carried out: Trial 1) PCa was applied to ‘d’Anjou’ pear trees in the lower and upper Hood River Valley, Oregon, USA to determine its effectiveness for managing the excessive vigor of ‘d’Anjou’ under different growing climates, with PCa rates ranging from 125 to 250 mg $L^{-1.}$ Ethephon was also applied (150 and 300 mg L^{-1}) as an attempt to improve flower bud differentiation; Trial 2) PCa was selectively applied to dormant-headed (1/3rd removed) and unpruned shoots in a high-density ‘d’Anjou’ pear orchard in Oregon, USA. Both sets of shoots were treated with 250 mg L-1 P-Ca in either a single or double application; Trial 3) PCa was applied to ‘Carrick’, ‘Packham’s’ and ‘William’s’ pear in the experimental field of Federal University of Pelotas, RS, Brazil. Trees were treated with 750 g ha-1 i.a. PCa, which was split in four (187.5 g ha-1 a.i. each) and three timings (250 g ha-1 a.i. each) in the 2011 and 2012 growing seasons, respectively. The most important results are presented separated for each trial. Trial 1) P-Ca was effective for reducing shoot elongation at multiple sites over several growing seasons. In one case, the added benefits of increased fruit set and yield were also observed. However, the consistent reduction in return bloom and its translation to lower return yields, not previously documented for ‘d’Anjou’, counteracts these benefits. Ethephon showed potential to ameliorate the activity of P-Ca on return bloom and production but it requires further investigation. Trial 2) At the end of the season, unpruned shoot length was decreased by 28% and 41% for shoots treated with P-Ca once and twice, respectively, while headed shoots were 37% shorter than their controls (treated only once). The number of nodes and average internode length were significantly reduced for P-Ca-treated shoots, irrespective of pruning level, conferring a higher node density relative to control shoots. These results implicate P-Ca as a powerful tool for precision-management of tree vigor in intensive pear plantings via selective treatment to areas of high vigor. Trial 3) The application of PCa at 750 g. ha-1 a.i satisfactorily controls shoot growth through the reduction of internode length of ‘Carrick’, ‘Packham’s’ and ‘William’s’ pears. Besides, it was observed that return bloom is not negatively affected by PCa. So, this plant growth regulator is a promissing management tool to reduce shoot growth and the need for pruning in pear orchards.

Keywords: *Pyrus communis* L., vigor control, plant growth regulators, shoot growth, labor saving.

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INTRODUÇÃO GERAL

A pera é a fruta responsável pelo maior montante de importações do Brasil, tanto em quantidade quanto em valor. Segundo dados da FAO (2013), em 2010 o volume importado dessa fruta foi de aproximadamente 190 mil Mega gramas (Mg), representando cerca de 90 % do consumo interno, sendo que em 2009 o volume de peras importadas foi de aproximadamente 160 mil Mg, significando 18,75 % de acréscimo no período. O valor dessas importações representou, em 2010, US$ 189 milhões. Dentre os principais fatores condicionantes desse cenário destacam-se a comoa falta de conhecimento sobre as melhores combinações entre cultivares copa e porta-enxerto, desconhecimento sobre o hábito de frutificação dessas combinações, pouca formação de gemas florais e o excesso de crescimento vegetativo nas principais cultivares (PASA et al., 2011).

O excesso de crescimento vegetativo resulta em competição com o crescimento das frutas (FORSHEY e ELFVING, 1989) principalmente nos estágios iniciais do desenvolvimento, quando ocorre o máximo crescimento de ramos e frutas (ELFVING et al., 2002). Essa competição pode resultar em menor número de células nos frutas, e assim, reduzindo o potencial de alcançar adequado tamanho e produtividade. Além disso, o excesso de crescimento vegetativo conduz ao sombreamento, redução na penetração (SHARMA et al., 2009) e distribuição (EINHORN et al., 2012) da luz incidente na copa e, dessa forma, prejudicando a formação de gemas floríferas em pereiras (WAGENMAKERS, 1989).

O crescimento vegetativo em excesso também diminui a qualidade dos frutas, produtividade e dificulta o controle de pragas e doenças (MILLER, 1995). A necessidade de poda em pereiras é diretamente relacionada com o crescimento vegetativo. Sendo assim, quando maior for o vigor de uma planta, maior será a necessidade de poda, esta que é um importante componente dos custos de um pomar, contribuindo com aproximadamente 14% dos custos variáveis totais em pomares de pereiras (SEAVERT et al., 2005). Além disso, em pomares modernos de pereiras, ou seja, em alta densidade, o controle de crescimento é essencial para evitar a alternância de produção e manter as plantas em um porte que permita o manejo cultural (COSTA, 2002).

No intuito de controlar o crescimento vegetativo em pereiras, destaca-se a utlização de fitorreguladores inibidores da síntese de giberelinas, as quais estão diretamente relacionadas com o elongamento de ramos (OWENS e STOVER, 1999). Dentre esses fitorreguladores, destaca-se a proexadiona cálcio (PCa) (3-oxido-4-propionyl-5-oxo-3-cyclohexene-carboxylate), o qual é um inibidor da síntese de giberelinas, mais especificamente através da redução dos níveis de GA1 causando a acumulação do seu precursor GA20 (RADEMACHER, 2000), de baixa toxicidade e persistência limitada (OWENS e STOVER, 1999).

Dessa forma, vários trabalhos vêm sendo realizados no intuito de verificar a eficácia do PCa no controle de crescimento vegetativo. Em trabalhos realizados com aplicações de PCa em macieira (MEDJDOUB e BLANCO, 2003), cerejeiras (ELFVING et al., 2003) e pereiras (SMIT et al., 2005; ASÍN e VILARDELL, 2006; LAFER, 2008; HAWERROTH et al, 2011) foi observado que o PCa é eficiente na redução do crescimento vegetativo. Porém, em alguns casos, a aplicação de PCa tem resultado em redução no retorno da floração (SUGAR et al., 2004) quando utilizadas altas dosagens (RADEMACHER, 2004). Esses resultados parecem estar relacionados ao maior *fruit set* observado em resposta à aplicação de PCa (SMIT et al., 2005) e à cultivar utilizada (SUGAR et al., 2004).

O objetivo desse estudo foi de avaliar a influência do fitorregulador prohexadiona cálcio no crescimento vegetativo e produção de pereiras européias.

PROJETO DE PESQUISA

1. Título**: Fitorreguladores estratégia para controlar o crescimento vegetativo e produção de peras, na Região Sul do Brasil**

2**. Introdução e Justificativa**

A pereira pertence à família *Rosaceae*, subfamília *Pomoideae* e gênero *Pyrus*. Compreende mais de 20 espécies, todas nativas da Europa e da Ásia, sendo as mais importantes pertencentes às espécies: *Pyrus communis (*Européias)*, P. pyrifolia (*Japonesa*), P. bretschneideri* (Chinesa) e híbridos entre *P.* communis e *P. pyrifolia* (NAKASU e FAORO, 2003).

A pereira é cultivada em muitos países o que torna a pêra uma fruta de grande aceitação e importância nos mercados internacionais (FIORAVANÇO, 2007). Em 2009, os principais produtores foram China, que produziu aproximadamente 14 milhões de Megagramas (Mg) (84,67 %), seguida dos Estados Unidos 850 mil Mg (5 %), Itália 830 mil Mg (4,89 %), Argentina 520 mil Mg (3,06 %) e Espanha 400 mil Mg (2,4 %) (FAO, 2011). O Brasil ainda possui uma produção insignificante neste cenário, com 17 mil Mg (0,08 %), ocupando a 48º posição no ranking mundial de produção em 2007 (FAO, 2009).

A pêra é a fruta fresca responsável pelo maior montante de importações do Brasil, tanto em quantidade quanto em valor. Segundo dados da FAO (2011), de 2001 a 2005, foram importadas, em média, 90 mil Mg, sendo que em 2008 o volume de peras importadas foi de aproximadamente 140 mil Mg (IBRAF, 2009), o que significou um aumento de 55 % nas importações da fruta. O valor dessas importações representou, em 2008, US$ 120 milhões. No Brasil, a produção de peras é de aproximadamente 17.000 Mg, sendo os principais estados produtores, em ordem decrescente, Rio Grande do Sul, com uma produção de 8.431 Mg (56,75

%), Paraná 3.667 Mg (24,68 %), São Paulo 1.541 Mg (10,37 %), Minas Gerais 841 Mg (5,66 %) e Santa Catarina 376 Mg (2, 53 %) (IBGE, 2009). A partir dos dados acima apresentados verifica-se que o Brasil importa aproximadamente 90 % das peras consumida no país.

Considerando o que foi anteriormente discutido, é possível constatar que a cultura da pereira representa uma importante oportunidade de mercado. Porém, ainda existem alguns entraves que impossibilitam produções economicamente satisfatórias, como a falta de conhecimento sobre a melhor combinação entre cultivares copa e porta-enxertos (SIMONETTO e GRELLMANN, 1999; LEITE et al., 2001); problemas com o abortamento floral, este que segundo Arruda e Camelatto (1999), é um dos principais problemas verificados nos pomares de pereira do Brasil, sendo que em determinados anos, dependendo do cultivar, atinge de 30% a 100% das gemas florais (NAKASU e LEITE, 1992); pouca formação de estruturas de produção em algumas cultivares (PASA, 2011) e problemas relacionados ao excesso de crescimento vegetativo das principais cultivares copa com conseqüente redução da produção. Esse efeito antagônico do excesso de crescimento vegetativo na produção de pereiras foi observado por Pasa (2011) que, em estudos de desempenho com as cultivares Carrick, Packham's e William's sobre diferentes porta-enxertos, concluiu que a eficiência produtiva dessas cultivares, em geral, é inversamente proporcional ao vigor induzido pelos porta-enxertos.

Verifica-se assim, que o insucesso da cultura da pereira no Brasil é devido a vários problemas. No entanto, possíveis soluções já foram apontadas por trabalhos de pesquisa. Na questão relativa ao abortamento floral, várias hipóteses têm sido formuladas para explicar esse fenômeno, tanto no Brasil como em outros países, tais como: insuficiência de frio hibernal, flutuações de temperatura no inverno, doenças (NAKASU et al, 1995) e problemas nutricionais. No entanto, segundo Faoro (2001), até o momento não existe uma definição concreta para as causas e o controle desse problema e provavelmente ele só será sanado pelo melhoramento genético, com a obtenção de cultivares adaptadas às condições do sul do Brasil. Isto é parcialmente confirmado por Rodrigues (2006) que, em trabalho sobre balanço de carboidratos em gemas florais de dois genótipos de pereira sob condições de inverno ameno, concluiu que o genótipo mais adaptado teve um nível de açúcares totais na matéria seca maior no período pré-brotação do que aquela menos adaptada, sofrendo um menor abortamento floral.

Com relação à compatibilidade de porta-enxertos com cultivares (cv.) copa, Francescatto (2009), trabalhando com diferentes combinações copa x porta-enxerto de pereiras européias na região Sul do Brasil, indicou alguns porta-enxertos compatíveis com as cultivares Carrick, Packham's Triumph e William's. Em trabalhos posteriores, Pasa (2011) verificou que algumas dessas combinações obtiveram produções satisfatórias e, dessa forma, podem vir a serem cultivadas em escala comercial por produtores. No entanto, é necessário acompanhar o desempenho de cada uma dessas combinações nos anos sucessivos, e em maior escala, no intuito de confirmar a regularidade do seu desempenho produtivo. Fato importante a ser observado é que, dos porta-enxertos disponíveis, poucos reduzem o vigor de maneira satisfatória. Para Costa (2002), além de porta-enxertos ananizantes outras ferramentas são necessárias para controle do crescimento vegetativo e produção.

O adequado manejo do crescimento vegetativo é o maior interesse na produção de frutas. Em pomares jovens o manejo do excessivo crescimento vegetativo dos ramos é essencial para antecipação do florescimento e frutificação (RADEMACHER, 2004). Por outro lado, o controle de crescimento em pomares adultos é necessário para prevenir o excesso de ramos no interior da copa e o excesso de sombreamento, no intuito de criar condições para que ocorra a correta frutificação e produção de frutas de alta qualidade (BASAK, 2004). De acordo com Costa (2002), em pomares modernos de pereiras, ou seja, em alta densidade, o controle de crescimento é essencial para evitar alternância de produção e manter as plantas em um porte que permita o manejo cultural. Além disso, em nível mundial, produtores objetivam um retorno de investimento em curto prazo e economia de trabalho. Estes objetivos podem ser obtidos reduzindo o tamanho das plantas e aumentando a densidade de plantio, mas para tal, as plantas de pereira devem ser pouco vigorosas (WERTHEIM, 2002). O controle do crescimento vegetativo também é importante porque a copa de plantas frutíferas deve ser suficientemente aberta para permitir a melhor penetração de luz nas partes internas desta, melhorando a qualidade das frutas (RADEMACHER, 2004). Além disso, o excesso de crescimento vegetativo exerce efeito negativo sobre a produtividade e controle de doenças (MILLER; TWORKOSKI, 2003). Logo, é importante a utilização de práticas que controlem o crescimento vegetativo, como a utilização de porta enxertos e/ou fitorreguladores que reduzam o vigor da cultivar (cv.) copa (LAFER, 2008). Grande parte dos fitorreguladores utilizados para controle de vigor na cultura da macieira e pereira são inibidores, em algum ponto da rota, da síntese de giberelinas.

As Giberelinas estão associadas com o elongamento de ramos (OWENS e STOVER, 1999). O prohexadione de cálcio (Pro-Ca) (3-oxido-4-propionyl-5-oxo-3-cyclohexene-carboxylate) é um inibidor da síntese de giberelinas de baixa toxicidade e persistência limitada, sendo metabolizado de 6 a 7 semanas após a aplicação (OWENS e STOVER, 1999). Dessa forma, vários trabalhos vêm sendo realizados no intuito de verificar a eficácia do Pro-Ca no controle de crescimento vegetativo de macieiras. Em trabalhos realizados com aplicações de Pro-Ca em macieira (MEDJDOUB e BLANCO, 2003) e pereiras (SMIT et al, 2005; ASÍN e VILARDELL, 2006; LAFER, 2008) foi observado que o Pro-Ca é eficiente na redução do crescimento vegetativo. Esse efeito traz benefícios tanto no manejo do pomar, com redução na utilização da mão-de-obra, quanto na produção, pela redução da competição entre crescimento de ramos e formação de frutos.

No Brasil, grande parte dos pomares de pereiras são implantados sobre porta-enxerto originários de sementes ou de estacas, como por exemplo *P. calleryana*. Este porta-enxerto reconhecidamente induz vigor excessivo nas plantas enxertadas (LORETI, 1994; PASA et al., 2011) e induz pouca formação de estruturas de produção nas plantas enxertadas (PASA et al., 2011). No entanto, esse porta-enxerto é compatível com grande parte das cultivares de pereira e mostrou-se adaptado ás condições edafoclimáticas da Região Sul do Brasil (PASA et al., 2011). De acordo com Rademacher (2004), o adequado balanço entre crescimento vegetativo e formação de frutos pode ser alcançada através do emprego de redutores de crescimento. Dessa forma, a utilização de alguma estratégia para controlar o vigor induzido por *P. calleryana*, como por exemplo, a aplicação de Pro-Ca, poderia reduzir o vigor das plantas enxertadas, melhorando a relação entre crescimento vegetativo e produtivo, e assim, possibilitando a obtenção de produções satisfatórias. Adicionalmente, uma hipótese seria que, após a obtenção de um ou dois anos com produções regulares dessa cvs. sobre *P. calleryana*, o uso de fitorreguladores para controle do crescimento seria em menor proporção ou até mesmo desnecessário. Esse efeito seria decorrente da adequada partição dos fotoassimilados entre frutos e ramos em crescimento.

A obtenção de regularidade de produção é uma maneira de garantir o controle de crescimento vegetativo (VANTHOURNOUT et al., 2008). Essa regularidade é função de como o pomar é manejado nos primeiros anos de implantação. De acordo com Owens e Stover (1999), em pomares jovens de macieiras, a obtenção de produções precoces e consistentes dependem de um adequado manejo do pomar para que ocorra o balanço entre crescimento vegetativo e reprodutivo. De acordo com Jackson (2003), isso é controlado pelo genótipo, clima e manejo cultural. Dentre as práticas de manejo cultural em pereiras para melhorar a produção de pereiras, o arqueamento de ramos é uma das mais efetivas.

Em pereiras japonesas, o arqueamento de ramos diminuiu a concentração de AIA em gemas laterais, mas incrementou a de citocinina (ITO et al., 2004). De acordo com esse autor, essas mudanças hormonais podem melhorar o desenvolvimento floral. Além do arqueamento de ramos, a aplicação de fitorreguladores é uma prática utilizada para estimular brotações laterais, sejam elas vegetativas ou produtivas. Keever et al. (1993), avaliaram o efeito de aplicações da citocinina Benziladenina (BA) e Promalina® (GA_4+GA_7 + 6-BA) sobre o ângulo e número de ramos na pereira ornamental 'Bradford', e concluíram que houve incremento no ângulo dos ramos formados, assim como no número de ramos, porém sem incrementos significativos no comprimento médio destes.

Os resultados anteriormente discutidos, tanto de arqueamento quanto de fitorreguladores, podem ser explicados pelo controle que estas práticas exercem sobre a dominância apical. De acordo com Taiz e Zeiger (2004) este fenômeno é definido como a inibição das gemas laterais (axilares) pela gema apical, sendo regulado pelas auxinas. No entanto, se a relação entre auxinas/citocininas for reduzida, os efeitos da dominância apical se tornam mais fracos, permitindo o desenvolvimento de gemas laterais. A aplicação direta de citocininas às gemas axilares estimula o crescimento dessas gemas em muitas espécies, suprimindo o efeito inibitório do ápice caulinar (TAIZ e ZEIGER, 2004).

Dessa forma, a aplicação de fitorreguladores, como por exemplo, a Promalina® (GA_4+GA_7 + 6-BA), em pomares jovens de pereiras pode ser uma importante ferramenta para obtenção de produções regulares. Essa hipótese baseia-se no fato de que esse fitorregulador possa estimular maior brotação lateral inicial, com melhores (maiores) ângulos, além de reduzir o crescimento de ramos. A maior brotação lateral, aliada aos maiores ângulos formados (tanto por ação da Promalina® quanto pelo arqueamento), seria um impeditivo para o crescimento vegetativo exagerado, já que haveria uma menor relação auxinas/citocininas nos ramos em crescimento e uma melhor distribuição dos nutrientes, fotoassimilados, além de outros fatores importantes no desenvolvimento de órgãos de frutificação. De acordo com Jackson (2003) dentre os fatores que controlam a formação de gemas em pomáceas podem estar envolvidos o balanço hormonal, disponibilidade de nutrientes, especialmente carboidratos, e a interação entre estes. Além destes, Webster (2002) acrescenta outros fatores que podem influenciar na formação de gemas florais, como a idade da planta, poda e condução dos ramos, manipulação do crescimento radicular, uso de fitorreguladores, fatores climáticos do local de cultivo e escolha da cultivar copa e porta-enxerto.

3. **Objetivos**

3.1 **Objetivo Geral**

Avaliar a influência de fitorreguladores sobre o crescimento, produção e qualidade de frutas de pereiras, na região Sul do Brasil.

3.2 **Objetivos específicos**

- Avaliar a eficácia do fitorregulador Prohexadione de Cálcio no controle do desenvolvimento vegetativo e no incremento da produção das pereiras ‘Carrick’, ‘Packham’s’, William’s e ‘Seleta’.
- Avaliar a influência do fitorregulador Promalin® no desenvolvimento vegetativo inicial e produção das pereiras ‘Rocha’ e ‘Santa Maria’.
- Avaliar a qualidade das frutas obtidas das plantas tratadas como os fitorreguladores Prohexadione de Cálcio e Promalin®.

4. **Material e Métodos**

Os experimentos serão realizados em condições de campo no período de março de 2011 a março de 2014, na Faculdade de Agronomia Eliseu Maciel (FAEM) - Centro Agropecuário da Palma de propriedade da Universidade Federal de Pelotas – UFPel, localizada no município de Capão do Leão/RS (Latitude 31º 52’ 00" S; Longitude 52º 21’ 24" W Greenwich; Altitude: 13,24 m.); e na Embrapa Clima Temperado de Pelotas - R.S., onde a altitude média é de 224 m e as coordenadas geográficas são 52°21’ 42 Oeste e 31°52’ Sul.

O solo do campo experimental é classificado como Argissolo Amarelo Eutrófico Típico (Severo, 1999). O acúmulo médio de temperaturas inferiores a 7,2 ºC na região de Pelotas é de 400 horas (NAKASU e FAORO, 2003). Segundo as normais climatológicas da Estação Agroclimatológica de Pelotas (Capão do Leão), a precipitação média anual é 1367 mm, a temperatura mínima e máxima anual é de -3 ºC e 39,6ºC, respectivamente, e a temperatura média anual 17,8º C.

A seguir serão descritas as características das cultivares utilizadas nos experimentos.

4.1. **Material vegetal**

4.1.1 **Carrick**

Oriunda do Cruzamento entre as cultivares Seckel x Garber, obtida nos EUA. A planta é grande, vigorosa e produtiva. A plena floração ocorre, em geral, na segunda semana de setembro. A fruta é de tamanho médio a grande, forma oblongo-piriforme, epiderme bronzeada com manchas avermelhadas. A polpa é branco-amarelada, medianamente macia, moderadamente suculenta, doce, com pouca acidez, leve aroma e adstringente. A qualidade é média. A colheita ocorre em fins de janeiro. É suscetível à entomosporiose. (Nakasu & Faoro, 2003).

4.1.2 **Packham’s Triumph**

É de origem australiana, obtida de cruzamento entre ‘Uvedale St. Germain’(Bell) x William’s. Planta vigorosa e semi-expansiva. Floresce entre a última semana de setembro e meados de outubro. A fruta é de tamanho médio a grande, de formato piriforme e com contorno irregular, de epiderme delgada de cor amarelo-esverdeada e com *russeting* de intensidade média A polpa é creme, muito firme, fina, suculenta, doce, de aroma moderado e muito boa qualidade. Amadurece na segunda quinzena de fevereiro e suporta cerca de 3 a 5 meses de armazenagem. É suscetível à entomosporiose (*Entomosporium mespeli*) e à sarna (*Venturia sp*.), (Nakasu & Faoro, 2003).

4.1.3 **William's Bon Chrétiens**

Tipo européia, originada na Inglaterra em 1917, de progênie desconhecida. É a mais cultivada nos Estados Unidos, tanto para consumo in natura quanto para industrialização. A planta tem tamanho e vigor médios, é de crescimento ereto e moderadamente resistente à entomosporiose. Floresce em meados de outubro. Produz frutas de tamanho médio a grande, piriforme, de epiderme variando de verde a amarela. A polpa é branca, fina, firme, manteigosa, aromática, com epiderme delicada, delgada, lisa e de ótima qualidade. Amadurece na primeira quinzena de fevereiro e suporta cerca de três a quatro meses de armazenagem (Nakasu & Faoro, 2003).

4.1.4 **Seleta**

Resultante do cruzamento de 'Hood' x 'Packham's Triumph', realizado no IAC. Apresenta fruto de tamanho médio (180-200 g) e formato oblongo-piriforme; a película é fina e lisa com coloração verde-clara; a polpa é delicada com sabor doce acidulado. A produção é precoce (dezembro a janeiro). Vem se comportando bem em condições de inverno com pouco frio. O pólen é estéril (Nakasu & Faoro, 2003).

4.1.5 **Rocha**

Variedade portuguesa obtida casualmente de semente em 1836 no Conselho de Sintra. Variedade medianamente exigente em frio no período de inverno. Tem tendência para produzir frutos partenocárpicos (característica da variedade), estes que são predominantemente de calibres médios, caracterizando-se por uma carepa típica, dispersa pela epiderme, concentrada especialmente em redor do pedúnculo e na fossa apical (ANP, 2011).

As plantas da pereira Rocha caracterizam-se por serem medianamente exigentes em frio, necessitando de 550 horas de frio Invernal abaixo de 7º C, vigor médio, porte ereto, necessidade de polinizadoras (ANP, 2011).

Os frutos são de formato variável, sendo predominantes as formas redonda ovada, redonda piriforme, piriforme ovada e oblonga piriforme. Apresenta superfície lisa, a cor da epiderme é amarela e/ou verde-claro, por vezes existe uma mancha tenuamente\rosada do lado exposto ao sol. O peso médio dos frutos é de 130g. A polpa é de cor branca, macia-fundente, granulosa, doce, não ácida, sumarenta, com muito suco e de perfume ligeiramente acentuado (ANP, 2011).

4.1.6 **Santa Maria**

Essa cultivar tem origem na Itália e é originada do cruzamento entre William’s x Coscia. Difundida em 1951. As plantas dessa cultivar apresentam elevado vigor e são muito produtivas. Além disso, possuem boa afinidade de enxertia com marmeleiros (BELLINI e NATARELLI, 2007).

Os frutos possuem tamanho médio a grande, formato piriforme ou piriforme-truncado. A casca é de coloração amarelo claro e pode ser levemente avermelhada pelo efeito da insolação. A polpa possui elevada consistência e resistência ao armazenamento. O sabor dos frutos dessa cultivar é discreto (BELLINI e NATARELLI, 2007).

4.2 **Metodologia**

4.2.1 **Experimento 1**

Este experimento será constituído de um pomar de pereira formado pelas cutlivares Carrick, Packham’s, William’s e Seleta, todas enxertadas em *P. calleryana.* O experimento será instalado em um pomar de sete anos, plantado em média densidade, com espaçamento constante, 1,5 m entre plantas e 5 m entre filas, totalizando 1333 plantas.ha^{-1}. As plantas estão tutoradas através de uma estrutura composta de arame, com três fios em cada linha de plantio e conduzidas em forma de líder central. Os tratos culturais serão semelhantes para todos os tratamentos: adubação baseada em análise de solo, crescimento de ramos do ano e produtividade esperada; arqueamento de ramos; tratamentos fitossanitários quando necessários, controle de plantas daninhas e irrigação por gotejamento.

O delineamento experimental utilizado será de casualização por blocos, sendo constituído de quatro blocos, ou seja, quatro repetições. Foi escolhido este delineamento para isolar efeitos de diferenças de nível no terreno. A unidade experimental será considerada uma planta. Como serão utilizados dois níveis para o fator de tratamento fitorregulador (com e sem), cada bloco será constituído de oito plantas (duas de cada cultivar). Logo o experimento constituirá um fatorial 4 x 2, ou seja, quatro cultivares e dois níveis de fitorregulador (com e sem).

A aplicação do fitorregulador será realizada através de aspersão com pulverizador costal, com um volume médio de 1000 L ha^{-1}. Os níveis para o fator prohexadione de cálcio serão: 1) controle (sem aplicação) e 2) prohexadione cálcio a 550 g ha^{-1}. Como fonte de prohexadione de cálcio será utilizado o produto comercial Viviful®, contendo 27,5% de ingrediente ativo (i.a). A aplicação de prohexadione cálcio será parceladas em três épocas. A primeira aplicação será realizada quando as brotações apresentarem em média 10 cm, sendo a segunda e a terceira aplicação, realizadas aos 30 e 60 dias após a primeira aplicação.

4.2.1.1 **Variáveis a serem analisadas**

a) Crescimento de ramos – serão selecionados 10 ramos novos representativos (de crescimento do ano) por unidade experimental (uma planta) que serão medidos no momento da primeira aplicação e após em intervalos de 15 dias, até o final do crescimento vegetativo. Será expressa em centímetros (cm).

b) Comprimento médio dos entrenós – nos ramos selecionados para a variável anterior, será realizada contagem do número gemas. Então, através da relação entre o comprimento médio dos ramos e no número de gemas, ter-se-á o comprimento médio de entrenós, expresso em cm.

c) Diâmetro do tronco – o diâmetro do tronco a 20 cm do nível do solo será mensurado, com auxílio de um paquímetro digital, no momento da primeira aplicação e após em intervalos mensais, até o final do crescimento vegetativo. Expresso em milímetros (mm).

d) Volume de copa – calculado através da fórmula $VC = (\pi \times E \times L \times h)/3$, em que: E= espessura da planta (m), L = largura da planta (m), h= altura da planta a partir da inserção dos primeiros ramos (m). Essa medida será realizada no final do ciclo produtivo. Expressa em metros cúbicos (m^{-3}).

e) Massa fresca de poda – no momento da poda de inverno, será aferida a massa total de ramos retirados de cada planta, será expressa em gramas por planta ($Kg.planta^{-1}$).

f) Número de ramos podados – por ocasião da poda serão contados o número total de ramos podados.

g) Massa média de ramos podados – obtida pela relação entre as duas variáveis anteriormente citadas. Expressa em gramas por ramo ($g.ramo^{-1}$).

h) Comprimento médio dos ramos podados – será aferido o comprimento de cada ramo podado (cm) e então será feita uma média dessas medidas.

i) Contagem do número de gemas reprodutivas - previamente a primeira aplicação, ainda no período de dormência (inverno), será realizada contagem do número total de gemas reprodutivas cada planta.

j) Frutificação efetiva: no momento da floração será feita a contagem do número total de cachos florais de cada planta, e antes do raleio, será feita a apuração no número total das frutas remanescentes, para a obtenção do 'fruit-set', este que será expresso em percentagem.

l) Número total de cachos florais por planta – realizada através da contagem do número total de cachos florais por planta.

m) Retorno da floração – estimar-se-á pela contagem do número total de cachos florais de cada planta na floração seguinte a aplicação.

n) Crescimento das frutas: serão selecionados para esta análise 10 frutos/unidade experimental, nos quais serão realizadas medidas de comprimento e diâmetro dos frutos a cada 30 dias até a colheita.

o) Produção por planta – na ocasião da colheita os frutos serão colhidos e sua massa será auferida e expressa em quilogramas por planta ($Kg.planta^{-1}$).

p) Eficiência produtiva – calculada pela relação entre a produção por planta (Kg) e o volume de copa (m^{-3}). Expressa em $Kg.m^{-3}$

q) Número de frutas por planta – na colheita, será feita a contagem do número total de frutas por planta ($frutos.planta^{-1}$).

No momento da colheita será realizada uma amostragem de 10 frutas representativas por repetição (planta). Essas amostras ficaram na câmara fria (0 ± 1 °C e UR de 90%) durante trinta dias, para então serem realizadas as seguintes análises físico-químicas.

r) Sólidos solúveis (SS) – mensurado através da técnica não destrutiva por espectroscopia Vis/NIR, utilizando o equipamento NIR-Case (SACMI). Expresso em graus brix (º brix).

s) Firmeza da polpa ($kgf.cm^{-2}$) – idem 4.2.1.1.r

4.2.2 **Experimento 2**

Este experimento será constituído de um pomar de pereira formado pelas cultivares de pereira 'Rocha' e 'Santa Maria', ambas enxertadas sobre o marmeleiro

‘Adams’. O pomar foi implantado no inverno de 2010 e, dessa forma, terá um ano de idade no momento da instalação do experimento.

Ambas as cultivares foram implantadas em duas densidades de plantio: 0,5 m e 1 m entre plantas com 5 m entre linhas, totalizando 4000 e 2000 plantas.ha^{-1}, respectivamente. Em virtude das condições em que o pomar foi implantado (com as duas cultivares separadas), o experimento será dividido em dois sub-experimentos semelhantes, diferindo apenas a cultivar: ‘Rocha’ e ‘Santa Maria’.

As plantas serão tutoradas através de uma estrutura composta de arame, com três fios em cada linha de plantio e conduzidas em forma de líder central. Os tratos culturais serão semelhantes para todos os experimentos: adubação baseada em análise de solo, crescimento de ramos do ano e produtividade esperada; arqueamento de ramos; tratamentos fitossanitários quando necessários, controle de plantas daninhas e irrigação por gotejamento.

O delineamento experimental utilizado será de casualização por blocos, sendo constituído de quatro blocos (4 repetições). Foi escolhido este delineamento para isolar efeitos de diferenças de nível no terreno. Dada a divisão dos experimentos de acordo com as cultivares, os fatores a serem considerados para cada sub-experimento serão: Espaçamento entre plantas – 0,5 m e 1,0 m (2 níveis) e; Doses de Promalin® ($GA_{4,7}$ + 6BA) – controle (sem fitorregulador), 400, 800 e 1200 mg i.a L^{-1} (4 níveis). Logo, o experimento constituirá um fatorial 4 x 2, ou seja, quatro níveis de fitorregulador e dois de espaçamentos. Cada repetição será constituída de 2 plantas (unidade experimental).

A aplicação do fitorregulador será realizada através de aspersão com pulverizador costal. A aplicação será realizada em duas etapas: a primeira quando os brotos novos tiverem em média 6 cm e a segunda quinze dias após a primeira. Por ocasião da aplicação, o limite de volume aplicado será o ponto de escorrimento. Os níveis para o fator Promalin® serão: 1) controle (sem aplicação); 2) Promalin® 400 mg i.a L^{-1}; 3) 3) Promalin® 800 mg i.a L^{-1}; e 4) Promalin® 1200 mg i.a L^{-1}.

4.2.2.1 **Variáveis a serem analisadas**

a) Crescimento de ramos – idem 4.2.1.1.a

b) Número de ramos laterais formados no “líder” – será realizada contagem dos novos ramos laterais formados a partir do tronco principal, após a aplicação do fitorregulador. Serão considerados aqueles ramos com comprimento ≥ 2 cm.

c) Número de ramos laterais formados de acordo com a idade do ramo – durante o período no qual o experimento será conduzido, será feita contagem dos novos ramos formados sobre ramificações laterais de um, dois e três anos. Serão considerados aqueles ramos com comprimento ≥ 2 cm. Tanto nessa variável, quanto para a variável “b” os ramos contados serão separados em função de possuírem ou não gema terminal florífera.

d) Número total de ramos laterais – será contabilizado pela soma dos valores obtidos na variável “b” ,“c” e da contagem prévia que será realizada antes da implantação do experimento.

e) Diâmetro do tronco – idem 4.2.1.1.c

f) Volume de copa – idem 4.2.1.1.d

g) Massa fresca de poda – no momento da poda de inverno, será aferida a massa total de ramos retirados de cada planta, será expressa em gramas por planta ($Kg.planta^{-1}$).

h) Número de ramos podados – idem 4.2.1.1.f

i) Contagem do número de gemas reprodutivas formadas sobre ramos de um ano – no inverno seguinte a aplicação, será realizada contagem das gemas reprodutivas formadas sobre aqueles ramos que se formaram após a aplicação do fitorregulador.

j) Contagem do número total de gemas reprodutivas – idem 4.2.1.1.i

l) Frutificação efetiva: idem 4.2.1.1.j

m) Número total de cachos florais por planta – idem 4.2.1.1.l

n) Retorno da floração – idem 4.2.1.1.m

o) Crescimento das frutas: idem 4.2.1.1.n

p) Produção por planta – idem 4.2.1.1.o

q) Eficiência produtiva – idem 4.2.1.1.p

r) Número de frutas por planta – idem 4.2.1.1.q

s) Número e tipificação de estruturas produtivas: será realizada contagem e tipificação das estruturas produtivas de cada tratamento, segundo a classificação proposta por Pasa (2011). Desta forma a classificação de tais estruturas será a seguinte:

- Dardos – estrutura de 0,5 a 10 cm, que tem em sua porção apical uma gema vegetativa.

- Lamburdas – estrutura de 0,5 a 10 cm, que tem em sua porção apical uma gema florífera.

- Brindila vegetativa – estrutura de crescimento de ano, ou seja, que se originou no último ciclo vegetativo, de 10 a 30 cm, que apresenta em sua porção apical uma gema vegetativa.

- Brindila florífera – estrutura de ano, ou seja, que se originou no último ciclo vegetativo, de 10 a 30 cm, que apresenta em sua porção apical uma gema florífera.

- Bolsa – estrutura globosa formada devido ao acúmulo de carboidratos na porção apical de uma estrutura produtiva que produziu um fruto no último ciclo produtivo.

No momento da colheita será realizada uma amostragem de 10 frutos representativos por repetição (unidade experimental). Essas amostras ficaram na câmara fria (0 ± 1 °C e UR de 90%) por trinta dias, para então serem realizadas as seguintes análises físico-químicas.

t) Sólidos solúveis totais (SST) – idem 4.2.1.1.r

u) Firmeza da polpa – idem 4.2.1.1.r

4.2.3 **Experimento 3**

Esse experimento será implantado em um pomar localizado na Embrapa Clima Temperado e será constituído de plantas da pereira cultivar Carrick com 17 anos de idade. As plantas estão dispostas em espaçamento de 3 m entre plantas e 5 m entre linhas, totalizando 666 plantas há$^{-1}$.

As plantas estão conduzidas no sistema de “vaso”. Os tratos culturais serão semelhantes para todos tratamentos: adubação baseada em análise de solo, crescimento de ramos do ano e produtividade esperada; arqueamento de ramos; tratamentos fitossanitários quando necessários e controle de plantas daninhas.

O delineamento experimental utilizado será de casualização por blocos, sendo constituído de quatro blocos (4 repetições). As plantas constituintes de cada bloco serão agrupadas de acordo com a similaridade do diâmetro de tronco e avaliação visual, de forma que cada bloco seja o mais uniforme possível. O fator de tratamento será diferentes doses de Promalin® – controle (sem fitorregulador), 400, 800 e 1200 mg i.a L^{-1} (4 níveis). Cada repetição será constituída de uma planta (unidade experimental).

A aplicação do fitorregulador será realizada através de aspersão com pulverizador costal. A aplicação será realizada em duas etapas: a primeira quando os brotos novos tiverem em média 6 cm e a segunda quinze dias após a primeira. Por ocasião da aplicação, o limite de volume aplicado será o ponto de escorrimento. Os níveis para o fator Promalin® serão: 1) controle (sem aplicação); 2) Promalin® 400 mg i.a L^{-1}; 3) 2) Promalin® 800 mg i.a L^{-1}; e 2) Promalin® 1200 mg i.a L^{-1}.

4.2.3.1 **Variáveis a serem analisadas**

a) Crescimento de ramos – idem 4.2.1.1.a

b) Número de ramos laterais formados nas ramificações principais – será realizada contagem dos novos ramos laterais formados a partir das ramificações principais, no final do ciclo vegetativo seguinte a aplicação do fitorregulador. Serão considerados aqueles ramos com comprimento ≥ 2 cm.

c) Número de ramos laterais formados sobre ramos de um ano– durante o período no qual o experimento será conduzido, será feita contagem dos novos ramos formados sobre ramificações laterais de um ano. Serão considerados aqueles ramos com comprimento ≥ 2 cm. Tanto essa variável, quanto para a variável "b" os ramos contados serão separados em função de possuírem ou não gema terminal florífera.

d) Número de ramos laterais total – será contabilizado pela soma dos valores obtidos na variável "b" e "c", acrescidos do valor obtido na contagem de ramos laterais que será realizada previamente a instalação do experimento.

e) Diâmetro do tronco – idem 4.2.1.1.c

f) Massa fresca de poda – no momento da poda de inverno, será aferida a massa total de ramos retirados de cada planta, será expressa em gramas por planta ($Kg.planta^{-1}$).

g) Número de ramos podados – idem 4.2.1.1.f

h) Contagem do número total de gemas reprodutivas - idem 4.2.1.1.i

i) Frutificação efetiva: idem 4.2.1.1.j

j) Número total de cachos florais por planta idem 4.2.1.1.l

l) Retorno da floração – idem 4.2.1.1.m

m) Crescimento das frutas: idem 4.2.1.1.n

n) Produção por planta – idem 4.2.1.1.o

o) Eficiência produtiva – idem 4.2.1.1.p

p) Número de frutas por planta – idem 4.2.1.1.a

No momento da colheita será realizada amostragem de 10 frutos representativos por repetição (planta). Essas amostras ficaram na câmara fria (0 ± 1 °C e UR de 90%) por trinta dias, para então serem realizadas as seguintes análises físico-químicas.

q) Sólidos solúveis totais (SST) – idem 4.2.1.1.r

r) Firmeza da polpa – idem 4.2.1.1.r

5. **Orçamento**

Tabela 1. Despesas com materiais de consumo e permanentes, decorrentes de 3 anos.

5.1. Consumo				
Materiais	Und.	Qtd.	Custo unitário (R$)	Custo total (R$)
Dormex	Lt	3	60.00	180.00
Uréia	sc	6	41.50	249.00
Superfosfato simples	sc	6	40.00	240.00
Cloreto de potássio	sc	6	89.00	534.00
Cálcareo	ton	5	60.00	300.00
Fitorreguladores	L	6	250.00	1500.00
Fungicidas	-	-	-	1200.00
Inseticidas	-	-	-	600.00
Formicida	-	-	-	40.00
Herbicida (Paraquat)	-	-	-	600.00
Tesoura de poda	Un.	2	135.00	270.00
Serrote de poda	Un	1	90.00	200.00
Enxada	Un.	2	12.00	24.00
Fita de arqueamento	rolo	4	20.00	80
Subtotal				**6017.00**
5.2. Equipamentos e materiais permanentes				
Conjunto de Irrigação	Un.	1	4.000.00	4000.00
Paquímetro digital 150mm resolução 0,1mm	Un.	1	200.00	200.00
Refratômetro palette-style sugar, cat. Nº P-02940-58 resol. 0,1%, acuração 0,2%	Un.	1	998.00	998.00
Multi-processador	Un.	1	228.00	228.00
Subtotal				**5426.00**
5.3. Serviços de terceiros				
Manutenção de máquinas agrícolas	Un.	--	---	4000.00
Passagem aérea para congresso	Un.	1	3000.00	3000.00
Manutenção de área experimental	Un.	1	1500.00	1500.00
Subtotal				**8500.00**
Total				**19943.00**
Imprevistos (10%)				1994.30
TOTAL				**21937.30**

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7. Cronograma de Atividades

ATIVIDADES / ANO	2011										2012												2013												2014		
	M	A	M	J	J	A	S	O	N	D	J	F	M	A	M	J	J	A	S	O	N	D	J	F	M	A	M	J	J	A	S	O	N	D	J	F	M
Revisão bibliográfica	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Seleção das plantas			X	X	X	X																															
Avaliações preliminares				X	X	X																															
Instalação dos experimentos						X	X	X										X	X	X										X	X	X					
Avaliações vegetativas						X	X	X	X	X	X	X						X	X	X	X	X	X	X						X	X	X	X	X			
Avaliações reprodutivas						X	X	X	X	X	X	X	X	X				X	X	X	X	X	X	X	X	X				X	X	X	X	X	X	X	
Condução e poda					X	X				X	X						X	X				X	X						X	X				X			
Tratamento para Superação de dormência						X	X											X	X											X	X						
Acomp. fitossanitários e adubações	X	X		X			X	X	X	X	X	X	X	X	X		X		X	X	X	X	X	X	X	X	X		X		X	X	X	X			
Tabulação dos dados e análise estatística											X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X		
Redação do trabalho																	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X			
Defesa da tese																																					X

RELATÓRIO DE TRABALHO

Experimento desenvolvido no Brasil: O início dos trabalhos ocorreu em março de 2011, com o preparo e condução das plantas para coleta de dados conforme cada variável de estudo. As atividades realizadas na cultura foram análise de solo, adubação (N P K); aplicação de fungicidas para controle da sarna (*Venturia inaequalis*) e entomosporiose (*Entomosporiun maculatum*) com os fungicidas Cobre Atar, Score, Manzate, Captan, Cercobim, de acordo com as dosagens recomendadas para a cultura; aplicação de herbicida (glifosato) associado a óleo mineral na linha de plantio, abaixo da copa da cultura para controle de invasoras; roçada mecânica nas entre-linhas da cultura; poda de limpeza e frutificação; aplicação dos inseticidas Malathion e Sumithion, para o controle do pulgão e outros insetos secundários. Quando as gemas das pereiras estavam no estádio de ponta verde foi realizada aplicação de Dormex + Óleo Mineral (0,4% + 3%, respectivamente) para auxiliar na superação da dormência. Semeadura de aveia preta para cobertura do solo, contribuindo com a redução da erosão, aumento da matéria orgânica, protegendo o solo contra o impacto da chuva, insolação, aumento da infiltração de água e melhoraria das qualidades químicas, físicas e biológicas do solo. Para a realização das avaliações foram marcados os caules das plantas com tinta logo acima do ponto de enxertia para posterior coleta dos dados de diâmetro de tronco. Todas as plantas tiveram seus ramos arqueados três vezes durante o período em que o trabalho foi desenvolvido, no intuito de reduzir a dominância apical e melhor distribuir os fotoassimilados e fitohormônios, com vistas a proporcionar uma maior formação de gemas mistas. Em todos os experimentos foram realizadas mensurações em cada ciclo produtivo durante o período de 2011 a 2013, conforme descrito nos materiais e métodos. No período de crescimento vegetativo foram coletadas as variáveis diâmetro de tronco, crescimento de ramos e massa de ramos retirados por ocasião da poda. A coleta das frutas para verificação da produtividade e de qualidade ocorreu na primeira quinzena de fevereiro para as cultivares Carrick, Packham's e William's. As condições climáticas durante o período em que o experimento foi realizado são apresentadas no Apêndice B. Para maiores detalhes vide materiais e métodos descritos para cada experimento.

Experimentos desenvolvidos nos Estados Unidos (Doutorado Sanduíche): Os trabalhos no exterior tiveram início em março de 2012, com o planejamento dos experimentos. É importante ressaltar que a região de Hood River/Oregon, apresenta as quatro estações bem definidas, porém dispostas ao longo do ano diferentemente do Sul do Brasil (Inverno: 21 dezembro-21 de março; Primavera: 21 março-21 junho; Verão: 21 junho-21 setembro e; Outono: 21 setembro-21 dezembro). No período de inverno foram realizadas ~2 aplicações com fungicidas cúpricos e a poda de frutificação. Na primavera foram aplicados fungicidas sistêmicos e de contato durante a floração e inseticidas quando necessário ao longo da estação de crescimento. A população de pragas é monitorada constantemente, sendo que uma das principais pragas da pereira durante o período de crescimento é a *Psylla*, um psilídeo que suga a seiva dos ramos das pereiras. O principal dano, além da redução do crescimento em ataques severos, é a depreciação dos frutos pela deposição dos excrementos açucarados na superfície dos mesmos. Em muitos casos é necessária a lavagem dos frutos após a colheita, onerando a produção. A aplicação de produtos indutores de brotação não é necessária pois o requerimento em frio é totalmente suprido nessa região. O solo do pomar foi mantido coberto com vegetação natural e, durante o período de crescimento, as linhas foram mantidas livres de vegetação através da aplicação de herbicidas, principalmente glifosato. Todos os experimentos foram irrigados por microaspersão, visto que praticamente não chove durante grande parte da primavera e verão. Para a realização dos experimentos as plantas foram selecionadas por uniformidade de tamanho, floração e diâmetro de tronco, o qual foi mensurado 20 cm acima do ponto de enxertia no momento da instalação do experimento e no final do ciclo de crescimento. As plantas foram agrupadas em blocos de acordo com o diâmetro de tronco. As avaliações vegetativas e produtivas dos experimentos foram realizadas durante o período de março/2012 a outubro/2012 e de pós-colheita até fevereiro/2013. As condições climáticas durante o período em que o experimento foi realizado são apresentadas no Apêndice C. Para maiores detalhes vide materiais e métodos descritos para cada experimento.

ARTIGOS DESENVOLVIDOS

1 Artigo 1

A ser submetido à revista Journal of the American Pomological Society

1.1 **Strategies to Control Vegetative Growth of Pear Trees**

Mateus S. Pasa, José C. Fachinello, and Todd C. Einhorn

Additional index words: *Pyrus* sp, vigor control, orchard management, labor saving, high-density planting.

1.2 Abstract.Vegetative growth control of pear trees is necessary to provide an adequate balance between vegetative and reproductive development. There are several approaches to managing vegetative growth, such as pruning (winter, summer), reduction of in-row spacing between adjacent trees (higher tree density), root pruning, girdling, branch manipulation (bending, xylem fracturing, and modification of branch angle), deficit irrigation, rootstock selection, plant growth regulators, and genetic technologies, but none of them have proven to be universally successful. Each unique situation, therefore, requires a specific strategy, or set of strategies, in order to achieve the optimum balance between vegetative growth and productivity. The aim of this paper was to gather information regarding vegetative growth control of pears as means to inform researchers and practitioners of recent advances and issues surrounding the development of efficient pear systems.

1.3 Introduction

Shoot growth control is of fundamental importance in a pear orchard. Excessive shoot growth directly competes with fruit growth for assimilates (Forshey and Elfving, 1989), particularly during the early stages of fruit development when shoot and fruit growth are maximal. This competition may reduce the number of fruit cells, thereby, limiting fruits from reaching their potential fruit size and adversely impacting yield. Excessive vigor leads to overcrowding of vegetative organs producing reduced light penetration (Sharma et al., 2009) and distribution (Einhorn et al. 2012) into the canopy, thus impairing flower bud formation in pear (Khemira et al. 1993). Moreover, shading has been shown to reduce yield (Garriz et al., 1998) and fruit quality of pear (Kappel, 1989) in addition to lowering the efficiency and efficacy of pest control (Rademacher, 2003).

Worldwide, growers aim for both early returns on capital and labor savings. These goals are achievable with intensive plantings of small trees (Maas, 2008). Trees of reduced stature allow the majority of tree management and hand-harvesting to be carried out from ground level, and are amendable to labor saving, harvest-assist technologies. On the contrary, large trees require the use of ladders or expensive mechanical aids. Importantly, there are environmental benefits associated with dwarfed trees, such as the ability to utilize precision pest management strategies (i.e., targeted spray applications) and significant reduction of spray drift (Webster, 2002 b). However, without implementing measures to control vegetative growth these goals remain unattainable. Vegetative growth control in the Brazilian conditions is even more important because pear orchards are predominantly established on *Pyrus* sp. rootstocks, which usually induce excessive vigor. Additionally, climatic variables such as the mean and maxima temperatures during the summer, in combination with the length of the growing season worsen the situation.

A wide range of vegetative growth control techniques are available for pears, such as pruning (winter, summer), root pruning, girdling, branch manipulation, deficit irrigation, rootstocks, plant growth regulators, and genetic approaches. The ability to control vigor of each of these strategies is highly dependent on cultivar, rootstock, climate, soil, training system, etc. Despite the multitude of approaches for regulating growth, none of them have proven to be universally successful or complete (Sharma, 2009). In fact, for each situation a set of strategies should be developed to achieve an appropriate balance between vegetative growth and yield.

1.4 Pruning

Pruning pome trees consists in the removal of undesirable branches, shoots, or spurs in order to provide a suitable tree framework for fruit production with an adequate balance between vegetative and reproductive growth. In general, all pruning techniques tend to reduce dry matter, despite the often localized and vigorous growth response in proximity to heading cuts (Forshey et al., 1992). Usually, the increment in trunk growth and new roots is decreased following severe pruning, as assimilates and minerals are directed toward the rebuilding shoots (Mika, 1986).

The effects of pruning on vegetative growth depend, in part, on the intensity and time of pruning, and type of pruning cut. According to Barritt (1992) there are four main types of pruning cuts: 1) heading cuts, which comprises the shortening of current season or 1-yr-old shoots; (2) shortening cuts, where branching systems are cut back to old wood; (3) thinning cuts, where current season or 1-yr-old shoots are completely removed at their base; (4) renewal cuts, where old branching systems are totally removed. Pruning is commonly performed during the winter (dormant phase) or summer; each producing different physiological effects over vegetative growth.

Winter pruning increases shoot growth and decreases yield in the following season relative to the degree of pruning (Barden and Marini, 1998; Elfving, 1990). Dormant pruned trees always produce longer shoots (Mika, 1986). Moreover, the severity of dormant pruning is positively related to the production of watersprouts from latent buds. Bussi et al. (2011) reported that the number and total length of watersprouts tended to be higher under severe dormant pruning than under light dormant pruning in peach trees. Therefore, to avoid invigorating effects, it is recommended that dormant pruning consists primarily of thinning cuts and few heading cuts be used. Thinning cuts that remove an entire shoot or branch back to the point of origin accomplish the dwarfing effect without stimulating invigoration of adjacent buds (Sharma et al., 2009). Besides, it increases leaf area of remaining shoots and light interception by the tree canopy through a decreased shoot density and a better distribution of shoots in space (Willaume et al., 2004).

Summer pruning is a common practice to reduce vegetative growth and improve light penetration into de canopy in pome trees. It also improves fruit red color, as reported by Autio and Greene (1992) in ‘McIntosh’ apple. Asín et al. (2007) reported that summer pruning was a good strategy in ‘Blanquilla’ pears because it eliminates de active growing shoots. By doing this, the remaining shoots will be favored because the better light interception provided, improving CO_2 assimilation and so photosynthesis. Mierowska et al., (2002), observed spur leaves of ‘Golden Delicious’ and ‘Granny Smith’ apple responded positively to summer pruning. Therefore, photosynthetic productivity may be best maximized by training and pruning trees over the entire season. However, despite controlling vegetative growth in ‘Blanquilla’ pears, summer pruning reduced return bloom in the following year, resulting in reduced yield (Asín et al., 2007). This effect was attributed to the secondary growth observed in the summer pruned trees, which coincided with flower bud differentiation. Maas (2005) reported that summer regrowth caused the loss of terminal flower buds in Conference and Doyenne´ du Comice pears. In the other hand, ‘Bartlett’ pears summer pruned over a period of three years slightly increased flower bud formation in some canopy locations, but these changes did not result in increased fruit production (Grossman et al., 1997).

Regardless the type and severity of pruning and season it is performed, special attention has to be given to the genotype you are working with. Stephan et al. (2007) have shown that the variability of responses to contrasted pruning strategies in apples partly depends on the genetically determined growth and flowering habit of the cultivar. Besides, the rootstock also influences pruning strategies by changing the bearing habit of the scion variety as shown for ‘Carrick’, ‘Packham’s' and ‘William’s’ pear (Pasa et al., 2011).

1.5 Root Pruning

Root pruning is a mechanical technique of vegetative growth control that has been used mainly in apple and pear orchards. This technique comprises a reduction of the root area by pruning, then reducing nutrient, water and hormones uptake to the upper part of the tree, limiting its growth. The water absorption reduction after performing root pruning was observed in ‘Conference’ pear (Mass, 2007) and ‘Melrose’ apple (Schupp and Ferree, 1990). Due to these effects, it is recommended that root pruned orchards have available irrigation (Maas, 2007) combined with a suitable fertilization (Vercammen et al., 2005).

The intensity and timing of root pruning should be fit according various factors, such as climate, cultivar, yield in the previous year, nutritional status and healthiness of the orchard, water availability, among others. In general, performing root pruning close to bloom is not recommended, due to strong stress caused, which might result in low fruit set and fruit thinning (Vercammen et al., 2005). However, for those cultivars showing high fruit set, a thinning effect might be desirable to reduce the need for hand or chemical thinning, coupled with vegetative growth control. The same thinking line could be used in relation to root pruning intensity (distance from the trunk, depth, and sides of the row to be root pruned).

Asín et al. (2007) noticed a reduction in vegetative growth and number of shoots and a 57% increase in return bloom of 'Blanquilla' root pruned (40cm from the trunk, both sides, and 40cm deep) during three years. Similarly, Vercammen et al. (2005) observed a vegetative growth reduction of 44% in 'Conference'. According to these authors, besides reducing vegetative growth, root pruned trees showed a higher number of flowering buds and a trend towards regular yields.

The completion of root pruning during nine years (50 cm from the trunk, both sides and 45 cm deep) in 'Golden Delicious' reduced its trunk diameter and shoot length, with a slight negative influence over yield and fruit size (Ferree and Knee, 1997). The yield and fruit size reduction could be explained by the reduction in the photosynthetic capacity of root pruned trees, mainly in the year it was performed. Khan et al. (1998) observed and average reduction of 28% in the number of leaves in various apple cultivars in the year root pruning was performed (20cm from the trunk, both sides, and 30 cm deep), impairing the photoassimilate supply to support fruit set and fruit growth. However, in the second year after root pruning, it was observed an increment up to 98% of the fruiting spurs, thus improving the vegetative and reproductive balance of the trees. Root pruning also acts reducing alternate bearing and increasing return bloom, which were observed in 'Jonathan' (Ferree, 1992), 'Empire' and 'McIntosh' (Elfving et al, 1996) apples.

1.6 Girdling

Girdling consists in removing a strip of bark around a tree's outer circumference, causing a temporary block in phloem flow. In doing so, it stops photosynthate translocation from source sites distal to the area in which phloem tissue has been removed (Goren et al., 2004). It also decreases photosynthesis due to a feedback inhibition (De Schepper et al., 2010). Since growth is directly related to the supply of carbohydrates, treatments which limit carbohydrate production or translocation, such as girdling reduce shoot growth (Forshey and Elfving, 1989). This technique has to be used carefully because it could lead to the death of the tree. The likelihood of this occurring depends on the width of the girdle, the frequency of girdling, tree vigor and whether the depth of girdling was too severe. In principle, the girdle should not damage the cambium and xylem, but in practice this is not as easily adhered to (Theron and Steyn, 2011).

Early spring trunk girdling reduced vegetative growth and increased fruit set and fruit bud formation in ‘McIntosh’ and ‘Mutsu’ apple trees (Hoying and Robinson, 1992), probably due to a change in assimilate allocation within the tree (Smith and Samach, 2013). Smit et al. (2005), studying the effect of girdling the bark approximately 30 cm above the ground using a chain saw, between full bloom and three/four petal drop, reported a tendency to increased final fruit size and return bloom in ‘Rosemarie’, ‘Forelle’, ‘Packham’s Triumph’ and ‘Golden Russet Bosc’ pears, but no effect on shoot growth control and yield were observed. In the other hand, Raffo et al. (2011) observed a reduction in shoot growth of girdled ‘Bartlet’ pear trees and a tendency to increase yield. According to Sousa et al. (2008), girdling allowed vigor control of ‘Rocha’ pears without the need of chemical growth regulator sprays, with production of fruits of better quality. The pruning weight of girdled ‘Bartlett’ pears was reduced by 30% to 40% compared to no-girdled trees (Ingels, 2002). Although girdling is a potential technique to control vegetative growth, its use could facilitate the infection by diseases and shorten lifespan of the trees. So, other methods for reducing vigor, such as size-controlling rootstocks, and plant growth regulators should be the first step in controlling vigor. But if trees are still too vigorous, trunk girdling could aid slowing down growth.

1.7 Branch Bending

Among traditional methods of orchard management and cultural practices applied in an orchard to control growth and fruiting, branch bending has proved the most successful (Colaric et al., 2007; Sherif, 2012). According to Costes et al. (2006), branch bending is necessary to regulate excessive vegetative growth and increase flowering and fruiting. Shoots grow faster if they are vertical and grow more slowly as their angle to vertical increases (Wilson, 2000). Most of branch bending effects are associated with hormonal balance.

The hormonal effects of branch bending can be explained by its effects over apical dominance. According to Taiz and Zeiger (2004) this phenomenon is defined as the inhibition effect of apical bud over the axillary buds, through its higher levels of auxins. However, if the ratio auxins/cytokinis is reduced, such as promoted by branch bending, the apical dominance effect is reduced, and thus allowing the development of axillary buds. In Japanese pears, the branch bending decreased the AIA concentration in the lateral buds, but increased the cytokinins, which might lead to an improved flower bud development (Ito et al., 2004) and decreased shoot growth.

Lawes et al. (1997) reported shoot bending resulted in higher floral precocity and in reduced shoot vigor of "Doyenne ducomice "pear. The response of trees to branch bending is genotype and timing dependent. Summer shoot bending has the potential to increase both the number and weight of individual fruit, while reducing lateral growth (Lauri and Lespinasse, 2001) probably by reducing the demand of vegetative growing points for carbon, allowing higher exports to the fruit (Corelli-Grappadelli et al., 1994). However, in more vigorous cultivars, summer bending promotes lateral growth, thus impairing fruit number and weight. In this case winter bending might be a good option to reduce lateral growth, distributing it along the shoot, to maintain a good fruit potential. Sherif (2012) reported a higher number of vegetative and flowering spurs, fruit set and number of current shoots of ‘Le Conte’ pears when shoots were bent in early summer (90°). These results were attributed to a more uniform distribution of carbohydrates along the bent shoots along with a reduction in nitrogen content, so increasing the C/N ratio.

Given the characteristically excessive vegetative growth of pears in warm climates, winter bending might be the better option to control shoot growth and promote fruiting. Besides, it is a potential management tool to reduce the effects of insufficient winter chilling over dormancy release of lateral buds. The failure of lateral buds to break under these conditions leads to bare unbranched shoots with just a tuft of leaves and fruits at the tips. This condition may be, in part, a consequence of the terminal buds breaking long before lateral buds in warm winter areas and therefore establishing greater dominance (Jackson, 2003). So, by bending the shoots in the winter the inhibition of the terminal buds over the lateral ones would be reduced, allowing a more uniform bud breaking.

1.8 Deficit Irrigation

During the last few years deficit irrigation techniques, including regulated deficit irrigation (RDI) have been developed for controlling excessive vegetative growth or saving water (Marsal et al., 2002), by applying less than the calculated water needed. The term regulated deficit irrigation (RDI) is commonly used to describe deficit irrigation early in the season when shoot growth is rapid but before rapid fruit growth (Jackson, 2003).

Cheng et al. (2012) observed a reduction in shoot growth and decreased need for summer pruning in ‘Yali’ pears, when RDI was adopted between pollination and 25 days after bloom (DAFB). They also found no negative effects of RDI over fruit weight and yield. Similar results were found by Marsal et al (2002) in ‘Blanquilla’ pears using RDI during stage I of fruit development. On the other hand, deficit irrigation slightly reduced shoot length whereas it increased return bloom of ‘Blanquilla’ pear (Asín et al., 2007).

In ‘Delicious’ apple trees it was found that RDI can be used to control vegetative growth and improve yield efficiency (Ebel et al., 1995). However, these researchers propose a RDI managing program where regular measurements of fruit size should be done to compare with fruit size standards curves. Assuming that fruit growth resumes at a normal rate when full irrigation is restored, RDI should be ended before fruit volume falls below the standard curve.

RDI was initially used to control tree vigor in high-density plantings by imposing water deficit at a period of rapid shoot and slow fruit growth (Chalmers et al., 1986.). However, further studies have shown that RDI could be used by means of improving fruit quality. Cheng et al. (2012) found that withholding of late-season irrigation improved fruit characteristics by increasing total soluble sugars of ‘Yali’ pears. RDI also increased soluble solids concentration in ‘Conference’ pears, as well as fruit firmness and acidity at harvest (Lopez et al., 2011).

It is clear that deficit irrigation is more relevant to arid than humid climates where controlling water deficit is difficult. However, even in more humid climates, deficit irrigation might be a tool to manage vigor of pome trees in specific situations such as when dwarfing rootstocks are used in high-density plantings. In this case, pear and apple trees are usually grafted on quince rootstocks, which need irrigation during the summer due to its shallow root system.

1.9 Rootstocks

Vegetative growth control of pears by rootstocks has been used for centuries (Webster, 2002 a). According to Gjamovski and Kiprijanovski (2011), the capacity to control vegetative growth of the scion cultivar is one of the most important traits of a pear rootstock. The way rootstocks control vigor is not well understood yet (Webster, 2002 b) but it seems to be related to changes in water, nutrients and photoassimilates (Jackson, 2003) and plant hormones (Hooijdonk et al., 2011) flow between the rootstock and scion caused by the graft union. *Pyrus* sp. are the most common rootstocks for pears but its insufficient size control has been limiting the development of new *Pyrus* rootstocks (Brewer and Palmer, 2011). Alternatively, quince (*Cydonia Oblonga* Mill.) rootstocks can be used to induce rapid cropping and reduce vigor of pear trees (Dondini and Sansavini, 2012).

Worldwide, there is a wide range of pear and quince rootstocks available for European pear (see review by Elkins et al., 2012; Wherteim, 2002). However, due the fact the deadly pear disease fireblight (*Erwinia amylovora*) does not occur in Brazil, but does in most of the regions these rootstocks are available, importing these materials would be difficult and risky to Brazilian growers. Thus, attempts have been made in order to evaluate the domestic available rootstocks. In this sense, Pasa et al. (2012) found suitable quince rootstock options for controlling vigor and obtaining acceptable yields of ‘Carrick’ (‘Portugal’ and ‘MC’) and ‘Packham’s (‘Adam’s’ and ‘D’Angers’) pears. These researchers also found that yield was inversely related to the vigor induced by the rootstocks. Similar results were found for ‘Conference’ and ‘Doyenné du Comice’ pears (Maas, 2008). However, Alonso et al. (2011) observed that ‘Adams’ (considered as a dwarfing rootstock) induced the higher yield with ‘Doyenne du Comice’ but not with ‘Conference’ pear, suggesting an interaction between scion and rootstock. Recently, the quince selection ‘CPP’ was reported as a suitable rootstock for ‘Tenra’ and ‘Cascatense’ pears under subtropical conditions (Botelho et al., 2012).

According to Wertheim (2002), besides being influenced by rootstock, tree performance is also determined by soil, climate and scion cultivar. So, for a certain tree size, rootstocks need to be more dwarfing on fertile land than on poorer soils, as well as vigorous cultivars need a more dwarfing rootstock than week ones. In this way, the availability of rootstocks ranging from high to low vigor, such as found by Pasa et al. (2012), is desirable in order to make it possible growing pears in a wider range of situations.

Rootstocks should also improve or at least keep fruit quality. Quince rootstocks also often produce better fruit size and quality of pears than when seedling or clonal *Pyrus communis* rootstocks are used (Webster, 2002). Improved fruit quality induced by quince rootstocks have been shown in ‘Carrick’, ‘Packham’s’ (Pasa et al., 2012) and ‘Conference’ (Kviklys and Kvikliene, 2004) pears.

1.10 Plant Growth Regulators (PGRS)

The majority of PGRs used to control vegetative growth are inhibitors, at some extent, of gibberellin (GA) metabolism (Rademacher et al., 2004). Most of these PGRs have been banned in pome trees due to their toxicity and unacceptable residue levels. However, the new compound prohexadione calcium (PCa) has been released becoming an option to shoot growth control of pome trees. Reduction of longitudinal shoot growth is the most obvious effect caused by PCa, by reducing the biosynthesis of the plant hormone GA, which regulates cell elongation. This is achieved by PCa blocking of 2-oxoglutaric acid-dependent dioxygenases involved in the biosynthesis of GAs, mainly the GA_{20}-3ß-hydroxylase, which catalyzes the conversion of inactive GA_{20} into highly active GA_1 (Rademacher and Kober, 2003). Its biological half-life in plants is in the range of 10–14 days (Rademacher et al., 2004).

Recent studies have shown that PCa controls shoot growth of different pear varieties (Asin et al., 2007; Costa et al., 2004; Elfving et al., 2002, 2003; Rademacher et al., 2004; Smit et al., 2005). Smit et al. (2005) reported a shoot growth reduction by up to 50% of ‘Packham’s Triumph’, ‘Golden Russet Bosc’, ‘Early Bon Chretien’ and Rosemarie with 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), which obtained shoot growth reduction of ‘Hosui’ pears grated on 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 PCa are shown to control shoot growth of some cultivars (Smit et al., 2005), split applications might be preferred since this would enable the relatively short-lived PCa to control flushes of shoot growth, which may occur later in the season (Rademacher et al., 2004).

Aside from shoot growth control PCa has varied influences over other horticultural traits. Sugar et al. (2004) reported smaller fruit size of ‘Bartlett’, but not ‘Bosc’, ‘Red Anjou’ in the year of PCa application, while ‘Anjou’ fruit size was affected in just one trial; ‘Bosc’ return bloom and yields were markedly reduced the year following application, but ‘Bartlet’ and ‘Anjou’ were not similarly affected. Reduced fruit size might be an indirect effect of higher fruit set when PCa is applied, such as found by Smit et al. (2005), for ‘Rosemerie’ and ‘Early Bon Chretien’ pears. The reduced return bloom observed in some cases as a result of PCa application seems to be cultivar and rate dependent (Rademacher et al., 2004) and it could be overcome by simultaneously ethephon application (Duyvelshoff and Cline, 2013). So a specific protocol for PCa application has to be developed to each growing situation in order to achieve the expected results.

1.11 Genetic Approaches

Modern techniques of genetic modification where specific genes controlling valuable tree attributes are introduced into commercial cultivars may provide a significant contribution to achieving well balanced trees (vegetative x reproductive growth). Little is known about the genetic mechanisms of vegetative growth control and most of the studies are focused on reducing vegetative growth by developing pear trees with an early and stable cropping through favoring flower bud development. In this case a reduced vegetative growth is a consequence of developing fruit over shoots meristems in their competition for resources (Smith and Samach, 2013).

Recent research with the model plant *Arabidopsis thaliana* suggests that the meristem transition from the vegetative to the reproductive phase is controlled by flowering group genes (Corbesier and Coupland, 2006). They include *Leafy* (*LFY*), *Flowering Locus T* (*FT*) and *Supressor of Overexpression of Constans 1* (*SOC 1*), which when activated trigger floral transition (Boss et al., 2004; Tan and Swain, 2006). The *Terminal Flower 1* (*TFL1*) is a fundamental gene involved in flowering repression, hindering *Apetala 1* (*AP1*) and *LFY* expression (Boss et al, 2004). According to Freiman et al. (2012), the genes *TFL1* and *FT* play opposite functions on flowering control: *FT* overexpression anticipates flowering of transgenic *A. thaliana* plants while *TFL1* delays it.

The *TFL1* and *LFY* genes have been isolated in various temperate fruit trees, such as apple (*Malus domestica*), Japanese pear (*Pyrus pyrifolia*) and European pear (*Pyrus communis*) (Esumi et al., 2005). Transgenic apple trees expressing *LFY* from *A. thaliana* showed a columnar phenotype with short internodes, but it did not result in flowering precocity (Flachowsky et al., 2010). One should note that this phenotype is similar to that observed in pear trees treated with PGRs to control shoot growth like PCa, suggesting that *LFY* might be directly involved in vegetative growth of pears. *MdFTL1* and *MdFTL2* are expressed in vegetative tissuess of young and adult trees, acting as flowering repressors and on maintenance of vegetative meristems identity (Mimida et al., 2009). Before floral induction the transcriptional levels of *MdTFL1* are reduced, allowing the meristem transition from vegetative to reproductive development, rising again with the onset of floral development (Hattasch et al., 2008).

Silencing of *MdTFL1* reduced the juvenile phase in apple (Kotoda et al., 2006) as well as *PcTFL1* and *PcTFL2* did in pear (Freiman et al., 2012), probably by increasing the expression of *FT* (Tränkner et al., 2010). Pear trees expressing *FT* from *Citrus* showed early flowering (Matsuda et al., 2009). The overexpression of *FT* in various species resulted in early flowering, suggesting that its function has been maintained conserved (Tränkner et al., 2010). In *A. thaliana*, the *FT* gene is expressed in the leaves and its proteins move to the apical meristem through phloem in order to trigger floral development (Notaguchi et al., 2008). It is important to highlight the importance of obtaining an early flowering on pears to set fruits, which will compete with vegetative growing points for assimilates, thus restricting vegetative growth.

1.12 Conclusion

The need to manage excessive vegetative growth of pears is well known. This is necessary to promote an adequate balance between vegetative and reproductive processes. There are many approaches for controlling vegetative growth in pears but none of them are totally complete, i.e, usually they are not able to satisfactorily regulate vegetative growth by itself. However, if the orchard is well planned since the beginning fewer techniques might be required to manage vegetative growth.

The first option to control vegetative growth should be the choice of a suitable rootstock according to edaphic and climate conditions, as well as training system. For example, for a high-density pear orchard planted in a fertile soil a more dwarfing rootstock should be chosen. If the rootstock by itself is not enough to control vigor, other techniques should be used. The choice of the next option should be based on costs and expected outcomes. In cases of excessively vigorous trees with low yield and acrotonic behavior, bending all shoots to promote formation of flowering spurs would be a good option. Also, any or light pruning would be performed in the winter, because it promotes strong shoot regrowth as a reiteration process.

Girdling has little effects over vegetative growth, but in many cases acts promoting flower bud formation and improving fruit set, which indirectly would help controlling tree vigor by competition between fruits and vegetative growing points. Further attention should be given to this technique, because it causes an injury in the trunk thus favoring pathogen infection. Besides, the carry over effects of these injuries could reduce the lifespan of the orchard. Root pruning provides an acceptable vegetative growth control but has to be used carefully because it is a stressful situation for the trees. Adoption of root pruning requires extra attention on fertilization and irrigation once root volume is reduced. Also, trees should be root pruned during the period of dormancy to avoid a decrease in fruit set caused by stressing the trees when they have already been released from dormancy, thus in active growing.

PCa seems to be a promising option to regulate shoot growth and even to increase fruit set in pears. Primarily, the decision for applying PCa should be taken based on the balance between costs and expected incomes resulting from spraying it. Second, it should be observed the necessary dosage for satisfactory shoot growth control because high doses may impair return bloom, albeit decreases in yield the following year have been rarely observed in pear.

Genetic studies have been developed mainly towards the discovery of a way to manage genes responsible for meristem transition from vegetative to reproductive development. The development of cultivars capable of flowering and setting fruit as early as tree framework is made up would be the uppermost achievement for pear growing. In this situation, the need for vegetative growth control would be reduced. Even so, the fertilization necessary to support high crop loads sometimes induce excessive vegetative growth that has to be controlled to avoid its negative effects previously discussed.

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2 Artigo 2

Aceito para publicação na revista HortScience (Apêndice A)

2.1 **'D'Anjou' Pear Shoot Growth and Return Bloom, but Not Fruit Size, Are Reduced by Prohexadione-Ca**

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Additional Index Words. European Pear, *Pyrus communis*, plant growth regulators, cropload management, ethephon, Apogee, vegetative growth

2.2 Abstract. Prohexadione-calcium (P-Ca) was applied to 'd'Anjou' pear (*Pyrus communis* L.) trees in the lower and upper Hood River Valley (HRV), Oregon to determine its effectiveness for managing the excessive vigor of 'd'Anjou' under different growing climates. Vegetative growth and development (weekly shoot growth rate, total annual extension growth, number of initiated shoots, internodal length, and number of nodes), yield (fruit number and fruit size), and return bloom dynamics were evaluated between 2010 and 2013. P-Ca consistently reduced shoot elongation by ~40% in all years and at both sites when doses of 250 ppm were applied in early spring (i.e., ~5 cm of annual shoot extension), compared to untreated trees. Shorter shoots were due to both reduced internodal growth and fewer nodes. In the cooler, upper HRV a single P-Ca application controlled shoot elongation for the entire season, but in the warmer, lower HRV, a second flush of growth was generally

observed ~ 60 d after the first application. A subsequent P-Ca application (250 ppm) provided added growth control in some instances. Yield was unaffected by P-Ca the season of application, though, in one year an increase in fruit number indirectly led to reduced fruit size; otherwise fruit size was not affected by P-Ca. Postharvest fruit quality was not influenced substantially by P-Ca. Return bloom, however, was consistently reduced by P-Ca. Yield, the year following P-Ca application (recorded in 2013 only), was reduced in proportion to the decrease in return bloom, relative to untreated trees. In 2012, ethephon was also evaluated, alone or in combination with P-Ca. When applied on its own either once (150 ppm, 5 cm growth), or twice [150 ppm, 5 cm growth; 300 ppm, 57 d after full bloom (dafb)] ethephon did not affect vegetative growth or yield components, but did improve return bloom and yield relative to other treatments; however, when combined with P-Ca, ethephon did not reverse reductions in return bloom, or return yield induced by P-Ca. The most effective ethephon treatment for promoting flowering and return yield (300 ppm, 57 dafb) was not tested in combination with P-Ca. We conclude that P-Ca is an effective tool for controlling vigor of ‘d’Anjou’ trees, but the decrease in return bloom requires additional investigation. Further work testing combinations of ethephon and P-Ca are warranted to optimize growth and productivity of ‘d’Anjou’ trees.

2.3 Introduction

The inherent, high vigor of commercial pear cultivars is not sufficiently controlled by the semi-dwarfing rootstocks currently available in the US. A recent, 10-year evaluation of Pacific Northwest (PNW) pear cultivars on promising, dwarfing rootstock selections from international programs yielded no plausible candidates for the US (Einhorn et al., 2013). Considerable research effort is ongoing to understand and develop dwarfing in the pear germplasm (Elkins et al., 2012); in the interim, new acreage will continue to be established at low to moderate tree densities since few options exist to reduce inter- and intra-canopy shading previously shown to limit fruit growth and productivity of pear (Einhorn et al., 2012; Garriz et al., 1998; Kappel and Neilsen, 1994). While these plantings may cost less in the short-term, they limit early returns and opportunities to improve harvest efficiencies in the future (i.e., low density plantings require time to develop large, complex canopies to maximize space efficiency, which, in turn, are dependent upon tall ladders for harvest). Alternative solutions to managing vigor of both new and established pear plantings are desperately needed.

The growth controlling compound, P-Ca, has been shown to effectively manage vegetative growth in several tree-fruit crops, including pear (Asin et al., 2007; Costa et al., 2001, 2004; Elfving et al., 2002, 2003b; Rademacher et al., 2004; Smit et al., 2005), apple (*Malus* x *domestica* Borkh.) (Byers and Yoder, 1999; Duyvelshoff and Cline, 2013; Greene, 1999; Owens and Stover, 1999; Unrath, 1999), and sweet cherry (*Prunus avium* L.) (Elfving et al., 2003a), but not peach (*Prunus persica* L.) (Byers and Yoder, 1999). In several cases, P-Ca markedly reduced the vigor of pear cultivars despite the growth-promoting influence of non-dwarfing rootstocks (Elfving et al., 2003b; Smit et al., 2005). Depending upon cultivar and environmental conditions, plant response to the number of applications and dosage of P-Ca vary (Costa et al., 2004; Elfving et al., 2002; Rademacher et al., 2004; Smit et al., 2005; Sugar et al., 2004; Unrath, 1999), illustrating a major limitation to extrapolating P-Ca results from one cultivar to another.

In the US, P-Ca (trade-name Apogee®) was initially labeled for use with pear, but substantial reductions in return bloom of ‘Bosc’ (Sugar et al., 2004) and reduced fruit size of ‘Bartlett’ (Elfving et al., 2003b; Sugar et al., 2004) resulted in the removal of pear from the label. ‘D’Anjou’ trees, on the contrary, did not exhibit notable, negative responses to P-Ca with respect to fruit growth, return bloom or yield (Sugar et al., 2004). Moreover, P-Ca effectively reduced vegetative growth of ‘d’Anjou’ (Elfving et al., 2002). Of the commercially important pear cultivars currently produced in the PNW, ‘d’Anjou’ is by far the least precocious and most vigorous and, hence, would benefit the most by techniques that control vigor and/or impart early production. Our main objective, therefore, was to thoroughly evaluate the fruiting and vegetative growth responses of ‘d’Anjou’ to P-Ca in two distinct, yet equally important regions of the HRV, to determine if reconsideration of a specimen label solely for ‘d’Anjou’ pear was warranted.

2.4 Materials and Methods

Experiment 1 (2010-2011). Trials evaluating different rates and timings of P-Ca on vegetative and reproductive growth of pear trees were performed in 2010 and 2011 at the Oregon State University’s Mid-Columbia Agricultural Research and Extension Center (MCAREC) in Hood River, OR (lat. 45.7 °N, long. 121.5 °W) and in a commercial orchard in Parkdale, OR (lat. 45.53 °N, long. 121.61 °W). In Parkdale, 11-year-old ‘d’Anjou’/OH × F 97 pear trees were selected from an orchard trained to a central-leader system (2.8 m x 4.6 m; 797 trees/ha). Trees at MCAREC were 9-year-old ‘d’Anjou’/ OH × F 97 (3.1 x 4.9 m; 672 trees/ha) trained to a multi-leader system. Solutions of P-Ca (Apogee, BASF Corp., Research Triangle Park, NC) were prepared in water (pH 6.96) as ppm of a.i. and supplemented with 0.1% (v:v) nonionic surfactant (Simulaid, Genesis AGRI Products Inc., Union Gap, WA). Solutions were applied to drip to entire primary scaffold limbs (one scaffold per tree) with a CO_2 pressurized hand gun sprayer (Model D Less Boom, Bellspray, Inc., Opelousas, LA).

Experimental units (scaffold limbs) were selected for uniformity of bloom and vegetative growth. Despite these general selection criteria, variability in scaffold size led us to block treatments on basal scaffold circumference, measured at 10 cm from the point of origin to the trunk. In 2010, three treatments were applied to five replicate scaffolds at the MCAREC: 1) Control (water + surfactant); 2) P-Ca (125 ppm) applied once; and, 3) P-Ca (125 ppm) + P-Ca (250 ppm) when shoots resumed growth. In Parkdale, two treatments each with six replicates were compared: 1) Control (water + surfactant) and 2) P-Ca (250 ppm) applied once.

In 2011, the trials were repeated at both sites on new scaffolds (i.e., different trees). Treatments differed from those applied in 2010, but were identical at both sites: 1) Control (water + surfactant); 2) P-Ca (250 ppm) applied once; 3) P-Ca (250 ppm) applied as needed when shoots resumed growth; and, 4) P-Ca (250 ppm) applied every 30 d. The final application of treatment 4 occurred prior to the start of the 45 d pre-harvest interval (PHI) effective in the US for apple.

In 2010 and 2011, shoot length was recorded weekly at both sites on 10, 1-year-old shoots selected at a similar canopy height and position and tagged at the time of the first application. Shoot length was measured until shoot growth ceased. In the fall, the total number of shoots and their annual shoot growth per scaffold were determined and expressed as either the length or number of shoots per cm^2 of scaffold-limb cross-sectional area (LCA). Additionally, in 2011, individual nodes were counted on the total annual extension growth to estimate average internode length (cm) and number of nodes per centimeter of shoot length (nodes/cm).

Fruits were harvested at commercial timing, counted and weighed. Harvests occurred on 10 Sept., 2010 (150 dafb) and 18 Sept., 2011 (147 dafb) at MCAREC and 5 Oct., 2010 (156 dafb) and 15 Oct., 2011 (152 dafb) at Parkdale. Return bloom was analyzed each year subsequent to the year of treatment from the total population of spurs and 1-year-old shoots on unpruned scaffolds; data are expressed as the percentage of the total population of fruiting spurs or 1-year-old extension shoots with flower clusters. Pruning was performed following measurement of return bloom. Full bloom occurred on 13 Apr., 2010, 24 Apr., 2011, and 21 Apr., 2012 at MCAREC and 2 May, 2010, 16 May, 2011, and 8 May, 2012 at Parkdale.

Experiment 2 (2012). A trial to evaluate the timing of P-Ca and ethephon, separately and in combination, was established within the same MCAREC orchard described above, but to different trees. Trees were selected for uniformity of size (canopy volume) and then grouped within blocks based on trunk circumference. Solutions (ppm of a.i.) of P-Ca and/or ethephon [Ethrel®, Bayer Crop-Science, Research Triangle Park, NC] were supplemented with 0.1% (v:v) nonionic surfactant and applied to achieve uniform, complete coverage. A hydraulic pressurized handgun (300 psi) was used to apply treatments to whole canopies.

Single-tree replicates were distributed in a randomized complete block design with six replicates per treatment as follows: 1) Control (unsprayed), 2) water + surfactant, 3) P-Ca (250 ppm) applied once, 4) P-Ca (250 ppm) applied twice, 5) ethephon (150 ppm) applied once, 6) ethephon applied twice (150 ppm first application + 300 ppm second application), 7) P-Ca (250 ppm) + ethephon (150 ppm) tank mixed and applied as a single application, and 8) P-Ca (250 ppm) + ethephon (150 ppm) applied twice; ethephon was mixed with both applications of P-Ca. Single application treatments (2, 3, 5, and 7) and the first application of multiple application treatments (4, 6, and 8) were applied when shoots were ~ 5 cm long. For those treatments receiving two P-Ca applications (4 and 8), the second application was provided when shoot growth resumed. In treatment 6, 300 ppm ethephon was applied at 57 dafb.

Shoot length was recorded weekly on 12, 1-year-old shoots as described above. In the fall, average internode length (cm) and number of nodes per centimeter of shoot length (nodes/cm) were calculated based on the length of shoots and number of nodes, respectively. One primary scaffold limb per replicate tree was selected prior to receiving treatment in order to estimate the total number of new shoots and the total annual shoot growth of the tree (Forshey and Elfving, 1979).

Trunk and scaffold limb circumference were measured at 25 cm and 10 cm above the graft union and the trunk, respectively, at the inception of the trial and, again, when leaves abscised in the fall. In the spring, a minimum of 200 flower clusters was recorded on each replicate scaffold limb. After June drop, fruits on these scaffolds were counted and fruit set was expressed as the number of fruit per cluster. In accordance with commercial practices 'd'Anjou' trees were not thinned. Full bloom occurred on 21 Apr., 2012 and 7 Apr., 2013, respectively.

Whole trees were harvested at commercial timing; 20 Sept., 2012 (152 dafb) and 30 Aug., 2013 (145 dafb). The total number of fruit per tree was counted. Fruits from pre-selected scaffolds were counted and weighed separately. Yield and average fruit weight were calculated and a distribution of fruit sizes was generated from individually weighed fruits (100 randomly selected fruit per canopy) and expressed as the number of fruits (<60, 60, 70, 80, 90, 100, 110, 120,135, and >135) per 20 kg commercial packed box. In 2012, fruit firmness (FF) was measured on 40 randomly selected fruit (20 each from the whole canopy and scaffold) at harvest. An additional 40 fruit per tree were immediately placed in regular air cold storage (RACS) at –1 ºC after harvest and analyzed at 3 and 4.5 months for determination of fruit quality attributes [FF; soluble solids concentration (SS); titratable acidity (TA); and, extractable juice (EJ)] according to methods described by Einhorn et al. (2012)EJ has previously been shown as a good ripening indicator (Chen et al., 1983). At each sampling period, a set of 10 fruit was analyzed immediately upon removal from cold storage and an additional 10-fruit sample was analyzed after a ripening period (RT) of 7 d at 20 °C.

Statistical analyses were performed using the SAS system software (SAS 9.0; SAS Institute, Cary, NC). Data expressed as percentage or counts were transformed by arcsin [square root (n + 1)] and square root (n + 0.5) analysis, respectively. Regression analysis for the relationship between fruit growth and cropload was performed by PROC REG. Treatment means were compared using analysis of variance with PROC GLM and significance was tested at $P \leq 0.05$. Mean separation was determined by Fisher's protected least significant difference test.

2.5 Results

Experiment 1. In 2010, extension growth of 'd'Anjou' shoots treated on 28 dafb with 125 ppm P-Ca was significantly reduced by 60 dafb at the MCAREC (Fig. 1A). The slope of shoot growth for P-Ca-treated shoots between 44 and 60 dafb, however, indicated limited growth suppression; therefore, a second application of P-Ca (250 ppm) was applied to one of the two P-Ca treatments at 60 dafb (i.e., P-Ca 125 ppm + 250 ppm). Growth cessation persisted for ~55 d after the second application. At the end of the season, P-Ca 125 ppm + 250 ppm shoots were ~15% shorter than Control shoots. Shoots treated only once with 125 ppm P-Ca, however, showed a marked growth phase between 90 and 120 dafb and, ultimately, surpassed untreated shoots, although the difference between the treatments was not significant. 'D'Anjou' scaffolds in Parkdale received an initial application of 250 ppm P-Ca. The three-week lag phase in bloom between the upper elevation Parkdale site and MCAREC, afforded time to assess the growth response to 125 ppm P-Ca at MCAREC and alter the application rate at Parkdale accordingly. Shoot growth at Parkdale was suppressed for the entire season by 250 ppm P-Ca applied at 37 dafb (Fig. 1B). P-Ca-treated shoots were ~46% of control shoots after cessation of growth in late summer.

At MCAREC, scaffolds treated with P-Ca 125 ppm + 250 ppm had significantly less cumulative vegetative growth (total shoot growth and average length) than controls (Table 1). Vegetative growth on scaffolds treated once with P-Ca 125 ppm was intermediate, but not significantly different than the other treatments. Shoot number, yield components (fruit weight and fruit number) and average fruit size were not affected by P-Ca treatment. Return bloom on spurs treated with P-Ca 125 ppm + 250 ppm was significantly reduced ~ 32% relative to controls, but not for spurs receiving only a single application of 125 ppm P-Ca. Flowering on one-year-old shoots was markedly reduced by P-Ca, irrespective of dose.

At Parkdale, one application of 250 ppm P-Ca reduced total annual shoot length and average shoot length compared to the Control (Table 1). The response of shoots to 250 ppm P-Ca in Parkdale was similar to that induced by the 125 ppm + 250 ppm P-Ca treatment at MCAREC (Table 1). P-Ca did not significantly reduce the number of shoots or the yield and size of fruit on Parkdale scaffolds. Return bloom of spurs was numerically reduced by P-Ca relative to controls, albeit nonsignificantly ($P = 0.0787$). The percentage of 1-year-old shoots with return bloom was significantly reduced by P-Ca.

In 2011, ‘d’Anjou’ growth at MCAREC and Parkdale was significantly lowest for shoots treated with 250 ppm P-Ca at 30 d intervals (Fig 2A). At both sites, growth of shoots treated with P-Ca once (1x) was reduced to ~ 70% of control shoots. Shoots treated a second time with P-Ca at MCAREC (2x) were not significantly shorter than shoots treated only once. The decision to delay the second P-Ca application of the 2x treatment at MCAREC until 89 dafb was associated with the high variability of this population (as shown by SE bars) which limited detectable differences between the growth of 2x-treated shoots and those treated every 30 d prior to 89 dafb. In Parkdale, extension growth ceased for the entirety of the season following the initial 250 ppm P-Ca application at 35 dafb (Fig 2B), as similarly observed in 2010. Consequently, a second P-Ca application was not provided to limbs of the 2x treatment, as was performed at MCAREC.

The number of nodes per unit length of shoot was increased, and the total annual shoot length, average shoot length, and average internode length of shoots borne on scaffolds were all significantly reduced by P-Ca at both sites; the effect being numerically more pronounced with increasing application frequency though not always significantly (Table 2). The number of shoots initiated on scaffolds, however, was not influenced by P-Ca at either site. Yield characteristics (number of fruit, yield and average fruit size) were also not affected by P-Ca treatments at either site. Return bloom was numerically lower, albeit nonsignificantly, for spur populations of P-Ca-treated scaffolds relative to Controls at both sites. Flowering on 1-year-old shoots was reduced by P-Ca, compared to Controls at both sites but only significantly at MCAREC.

Experiment 2. In 2012, P-Ca applied once, twice, or in combination with ethephon significantly reduced the growth of extension shoots compared to control shoots, or shoots treated with only ethephon (Fig. 3). A second treatment of P-Ca on 87 dafb resulted in significant, but minimal additive growth regulation relative to a single application of P-Ca. Ethephon did not improve the growth control elicited by P-Ca when the two chemicals were combined.

Shoots from P-Ca-treated trees had more nodes per unit shoot length but fewer nodes and shorter internodal length than shoots from either untreated Controls or ethephon-treated trees (Table 3). Scaffolds of trees treated with P-Ca alone or in combination with ethephon had significantly less total annual shoot growth than those of Controls or ethephon treated trees (Table 3). Ethephon did not affect the responses observed with P-Ca treatments when the two chemicals were combined. The number of shoots initiated on scaffold limbs was not altered by any of the treatments.

The number of fruits per tree was increased, albeit inconsistently, and in most cases nonsignificantly by P-Ca, ethephon, or combination treatments, relative to the controls. Yield was numerically higher for P-Ca treatments (alone or in combination with ethephon) and when ethephon was applied once, but results were not significant (P = 0.068). Average fruit size was reduced by P-Ca treatments, alone or in combination with ethephon, and when ethephon was applied 57 dafb compared to control treatments. Control and ethephon (applied once) treatments had significantly more large fruits (size 60) and significantly fewer small fruits (size 100, 110 and 120) than P-Ca treatments or ethephon when applied at 57 dafb. The negative effect on fruit size observed for P-Ca treatments compared to Controls was attributed to the markedly higher number of fruit per tree. Ethephon, when applied at 57 dafb, however, seemed to have a direct negative effect on fruit size. When applied at 57 dafb, ethephon-treated trees had the highest percentage of spurs with return bloom. P-Ca applied either once or twice reduced the percentage of spurs with return bloom relative to Controls. Ethephon, in the presence of P-Ca, appeared to counteract the effect, but not when P-Ca was applied twice. Bloom of 1-year-old shoots was significantly and markedly reduced by treatment with P-Ca. Return yield followed a similar trend as return bloom; ethephon applied twice (150 ppm + 300 ppm) significantly improved yield, but P-Ca treatments significantly reduced yield, relative to untreated trees. The improvement in return bloom from ethephon (when combined with P-Ca in the single application), did not translate to an improvement in return yield. Average fruit weight was inversely related to yield the year subsequent to treatments.

No clear trends were apparent in the postharvest quality of fruits treated with P-Ca relative to Control fruit (Table 4). Ethephon, when applied at 57 dafb, resulted in higher TA and SS following 3 and 4.5 months of RA storage relative to all other treatments. The relative increase in TA and SS of 57 dafb-treated ethephon fruit compared with other treatments remained following 7 d ripening periods.

2.6 Discussion

When scaffolds or entire canopies of ‘d’Anjou’ were treated with 250 ppm P-Ca early in the season (shoots ~ 5 cm of new growth), we consistently observed a 32% to 39% decrease in the total annual vegetative growth (Tables 1-3). A trend toward greater control of growth when an additional P-Ca application was provided was evident. Similar reductions in shoot growth by P-Ca have been reported for several pear cultivars (Costa et al., 2004; Elfving et al., 2002; Elfving et al., 2003b; Rademacher et al., 2004; Smit et al., 2005); however, in general, significant growth reductions in those studies were achieved primarily through multiple applications of P-Ca. Despite the relatively rapid metabolism of P-Ca in plant tissue (2 to 3 weeks; Evans et al., 1999), extension growth of ‘d’Anjou’ was effectively reduced for the entire season by a single P-Ca application, except when applied at 125 ppm (Fig 1A). Initial application doses between 50 and 125 ppm have been effective for inhibiting shoot growth of apple (Duyvelshoff and Cline, 2013; Greene, 1999; Unrath, 1999) and pear (Costa et al., 2004; Smit et al., 2005), but the excessive vigor of ‘d’Anjou’ necessitated higher rates as similarly shown for ‘Blanquilla’ pear (Rademacher et al., 2004) and several inherently vigorous cultivars of sweet cherry (Elfving et al., 2003a). Elfving et al. (2002) proposed different P-Ca strategies based on the unique growth habits of pear cultivars under production in the PNW of the US. Though we limited our study to ‘d’Anjou’, trees in the cooler, upper HRV only required a single application of 250 ppm P-Ca to achieve season-long control over extension growth (Figs 1B and 2B), while effects from an equivalent P-Ca application (both timing and rate) to similarly-aged trees in lower HRV did not persist beyond ~60 to 70 d from the first application (Figs 2A and 3). Unrath (1999) observed dissimilar growth responses to P-Ca for ‘Red Delicious’ apple growing in either warm or cool climates; the cooler climate was associated with an early, enduring cessation of growth. These results underscore the importance of evaluating cultivars in the environments where they are produced.

In addition to exhibiting less extension growth, shoots treated with P-Ca had fewer nodes and shorter internodes compared to untreated shoots, mostly due to the inhibitory P-Ca effect over growth-active GA_1 (Evans et al., 1999), which is responsible for internode elongation (Owens and Stover, 1999). This modification to the development of shoots resulted in limbs with more nodes per cm shoot length, implicating a potential for increased future fruiting efficiency on a shoot-basis. Shoot initiation, as a process, was not affected by P-Ca, in any of the trials.

P-Ca did not significantly alter fruit set of ‘d’Anjou’ in any of the seasons that it was applied (data not shown), as similarly demonstrated with other pear cultivars (Asin et al., 2007; Costa et al., 2001; Rademacher et al., 2004; Sugar et al., 2004), with the exception of a few cases where a positive effect on fruit set was observed (i.e., 2012; Costa et al., 2004; Smit et al., 2005). ‘D’Anjou’ is a cultivar that would benefit from practices that increase fruit set. The potential for P-Ca to improve fruit set may be attributed to its interfering action on ethylene metabolism (Rademacher, 2000). A large body of literature implicates an essential role of ethylene in fruit abscission (see reviews by Baird and Webster, 1979; Bangerth, 2000). Retention of pear fruitlets following applications of aminoethoxyvinylglycine (AVG), an ethylene inhibitor, was markedly higher for ‘Comice’ (Lombard and Richardson, 1982), ‘Abate Fetel’ and ‘Packham’s Triumph’ (Sanchez et al., 2011) and ‘d’Anjou’ (Einhorn, unpublished) when timed between anthesis and 14 dafb. The fact that fruit set is not unequivocally augmented in response to P-Ca treatment indicates the complexity of the process and the multiple factors that modulate it, such as genotypic response/sensitivity to ethylene, hormonal balance, preceding season's crop load, timing of P-Ca application, and environmental conditions prior, during and after applications (Stover and Greene, 2005).

Yield components (number and size of fruits) were affected by P-Ca in only one of three years (i.e., 2012). For this particular trial, P-Ca applied to whole canopies led to numerically higher and, in some treatments, statistically higher fruit numbers relative to untreated trees (Table 3). A negative relationship between crop load (fruit number/cm^2 trunk cross-sectional area) and final fruit size in 2012 (R^2= 0.37; P< 0.0001) suggests that reduced fruit size and a lower percentage of fruit in large size-classes (data not shown) were indirect consequences of a source:sink imbalance. In 'Rosemarie', increased fruit set induced by P-Ca, in part, led to decreased fruit size at harvest (Smit et al., 2005). Sugar et al. (2004), on the other hand, observed smaller fruit size in 'Bartlett', but not 'Bosc' or 'd'Anjou', the season of treatment; the effects of which appeared to be direct since 'Bartlett' fruit set was not simultaneously improved (i.e., no apparent carbohydrate deficits). Elfving et al. (2003b) suggested that high concentrations of P-Ca applied to 'Bartlett' trees during the fruit cell division period led to smaller fruit at harvest. It is unclear as to why 'Bartlett' fruit size would be more sensitive than other cultivars to P-Ca. Potentially the relatively short growing season of 'Bartlett' amplifies the early-season growth limitations associated with P-Ca. Fruit size is a function of both the number and size of cells, and despite limited evidence positively relating cell number to final fruit size in apple (Goffinet et al., 1995) late-season cultivars have a distinct advantage over early-season cultivars for compensatory growth via a markedly longer period of cellular expansion. Cumulative, seasonal fruit growth curves would be helpful to determine precisely when and to what degree fruit growth is compromised under these conditions. Reductions in the final fruit size of 'Rosemarie', an early-season cultivar, corroborate this argument but the lack of effects of P-Ca on fruit size of two other early-season cultivars, 'Early Bon Chretien' and 'Flamingo', do not (Smit et al., 2005).

Return bloom of ‘d’Anjou’ was consistently, adversely impacted by P-Ca in all years, albeit not always significantly. These results contradict those of a previous report that evaluated the flowering response of ‘d’Anjou’ to P-Ca (Sugar et al., 2004) over multiple years and sites. Importantly, in 2012, the percent reduction of return bloom was similar to the decrease in return yield (relative to untreated trees) posing a potential barrier to the reconsideration of P-Ca for use on ‘d’Anjou’. Rademacher et al. (2004) showed that reduced return bloom of ‘Conference’ pear, induced by P-Ca, did not translate to lower yields. Certainly, remaining spurs of ‘Passe Crassane’ had higher fruit setting efficiency when pruning treatments reduced the number of spurs (flower clusters) per branch (Sansavini, 2002). The marked reduction of flowers borne on 1-year-old shoots would not be expected to substantially limit ‘d’Anjou’ production given the cultivar’s ‘type 2’ spur-bearing habit (Sansavini, 2002), but the data were intriguing nonetheless. P-Ca may have more serious consequences on yield in the following season for cultivars which produce a significant proportion of their yield from tip bloom.

Ethephon, applied on its own, increased return bloom and return yield, especially when applied at 57 dafb; a treatment timing meant to coincide with floral bud initiation of ‘d’Anjou’ (Westwood, 1993). Ethephon did not, however, offset the adverse effects of P-Ca on return bloom, or yield, the year following combination treatments. These results may have been attributed to asynchrony in floral bud initiation and application timing (ethephon when used in P-Ca/ethephon combinations was either applied in early spring, or both early spring and 87 dafb) or a non-efficacious dose (both of the P-Ca/ethephon combination treatments comprised 150 ppm ethephon). Unfortunately, we were not able to combine a 57 dafb ethephon application with P-Ca, due to a limited number of trees. Such a combination requires evaluation to determine if ethephon can counteract the negative effects of P-Ca on return bloom and fruit set of ‘d’Anjou’. Improved vigor control from combinations of P-Ca and ethephon previously documented for apple (Byers et al., 2004; Duyvelshoff and Cline, 2013) and sweet cherry (Elfving et al., 2003a) was not observed for ‘d’Anjou’ (Fig 3; Table 3).

Fruit quality of ‘d’Anjou’ following cold storage was not affected by P-Ca. Elfving et al. (2003b) and Costa et al. (2004) found similar results for P-Ca-treated ‘Bartlett’ and ‘Abate Fetel’, respectively. Interestingly, fruit treated with 300 ppm ethephon at 57 dafb had the highest SS and TA, prior to, and following ripening. While this positive influence on key quality attributes may be of low priority to commercial producers, these fruit were likely of higher quality and may be more appealing to consumers; however, we did not collect sensory evaluation data to support this.

2.7 Conclusion

Management of ‘d’Anjou’ tree vigor is a fundamental prerequisite for moderate to high-density orchard systems. P-Ca was effective at markedly reducing shoot elongation at multiple sites over several growing seasons. In one case, the added benefits of increased fruit set and yield were also observed. However, the consistent reduction in return bloom and its translation to lower return yields, not previously documented for ‘d’Anjou’, counteracts these benefits. The potential for ethephon to ameliorate the activity of P-Ca on return bloom and production requires further investigation. Optimization of these combinations could provide consistent cropping potential on small-statured trees.

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Table 1. The effect of 2010 prohexadione-ca (P-Ca) application rate on vegetative and reproductive processes of 'd'Anjou' pear limbs at a lower Hood River Valley site [Mid-Columbia Agricultural Research and Extension Center (MCAREC)] and an upper Hood River Valley site (commercial orchard, Parkdale) in Oregon. Data are means of 5 and 6 replicates at MCAREC and Parkdale, respectively.

Treatment	Annual vegetative growth			Fruiting			2011 Return Bloom	
	Total shoot length ($cm \cdot cm^{-2}$ LCA)[z]	Shoots (no./cm^2 LCA)	Avg. shoot length (cm)	Fruits (no./scaffold)	Yield (kg/scaffold)	Avg. fruit wt. (g)	Flowering spurs (%)[y]	Flowering 1-year shoots (%)[x]
Lower Hood River Valley (MCAREC)								
0 ppm + surfactant	83.1 a[w]	2.3	37.1 a	35	8.9	255.9	74 a	26.8 a
P-Ca 125 ppm (1x)[v]	61.7 ab	1.8	33.4 ab	38.6	10	255.7	57 ab	9.6 b
P-Ca 125 ppm + 250 ppm	41.1 b	1.6	25.9 b	28.2	7.5	270	49 b	5.3 b
P > F	*0.0249*	*0.2221*	*0.0315*	*0.6595*	*0.7082*	*0.5717*	*0.022*	*0.0081*
Upper Hood River Valley (Parkdale)								
0 ppm + surfactant	71.7 a	1.8	38.6 a	10	2.1	219	19.8	6.1 a
P-Ca 250 ppm (1x)	44.1 b	1.5	29.5 b	16	3.4	217.4	12.7	1.7 b
P > F	*0.0239*	*0.2455*	*0.0123*	*0.1213*	*0.1271*	*0.8595*	*0.0787*	*0.0229*

[z] The data are expressed as the total growth in cm per cross-sectional area (LCA) of scaffold. LCA was calculated from the circumference of the scaffold, 10 cm from its point of origin to the trunk.

[y] The total population of spurs from each scaffold treated in 2010 were observed for the presence or absence of flower clusters in spring 2011. The data are expressed as the percentage of spurs per scaffold with flower clusters.

[x] The total population of shoots on selected scaffolds with measurable extension growth during 2010 were observed for the presence or absence of apical flower clusters in spring 2011. The data are expressed as the percentage of 1-year-old shoots with flower clusters.

[w] Means were separated within columns by Fisher's Protected Least Significant Difference (LSD) ($p < 0.05$), whereby means associated with different letters are significantly different.

[v] Application of 125 ppm P-Ca as Apogee (BASF Corp.) was applied to both P-Ca treatments at MCAREC 'to drip' to entire scaffolds when new shoots had ~ 5 to 10 cm of new growth. For the 125 ppm + 250 ppm treatment, 250 ppm P-Ca was applied when growth of shoots previously treated with 125 ppm had resumed. Application of 250 ppm P-Ca in Parkdale was applied when new shoot growth reached ~ 5 to 10 cm.

Table 2. The effect of 2011 prohexadione-ca (P-Ca) application rate on vegetative and reproductive processes of 'd'Anjou' pear limbs at a lower Hood River Valley site [Mid-Columbia Agricultural Research and Extension Center (MCAREC)] and an upper Hood River Valley site (commercial orchard, Parkdale) in Oregon. Data are means of 5 and 6 replicates at MCAREC and Parkdale, respectively.

Treatment	Annual vegetative growth						Fruiting[z]			2012 Return Bloom	
	Total shoot length ($cm\cdot cm^{-2}$LCA)[y]	Shoots (no./cm^2LCA)	Avg. shoot length (cm)	Nodes (no./shoot)	Avg. internode length (cm)	Nodes (no./cm shoot)[x]	Fruits (no./scaffold)	Yield (kg/scaffold)	Avg. fruit wt. (g)	Flowering spurs (%)[w]	Flowering 1-year shoots (%)[v]
					Lower Hood River Valley (MCAREC)						
Control	73.1 a[u]	2.4	29.9 ab	9 ab	3.2 a	0.3 b	44.8	9	201.3	53.5	40.2 a
0 ppm + surfactant	72 a	2	35.9 a	10.5 a	3.1 a	0.3 b	43.7	8.9	209.2	55.5	28.5 ab
P-Ca 250 ppm (1x)[t]	49.9 b	2.2	22.6 bc	8.1 b	2.6 b	0.36 a	52.3	10.6	199.7	31.8	4.2 c
P-Ca 250 ppm (2x)	47.8 b	1.9	24.7 bc	8.2 b	2.6 b	0.34 a	51.7	10.9	209.8	39.8	15.2 bc
P-Ca 250 ppm (every 30 d)	40 b	1.9	20.5 c	7.1 b	2.6 b	0.35 a	43.5	8.9	198.7	36.2	3 c
P > F	*0.0114*	*0.2168*	*0.0045*	*0.0392*	*0.0004*	*0.0022*	*0.9309*	*0.9132*	*0.7651*	*0.0592*	*0.0002*
					Upper Hood River Valley (Parkdale)						
Control	55.4 a [u]	2	27.5 a	9.0 a	2.8 a	0.33 c	6.2	1.1	186.1	70.7	23.5
0 ppm + surfactant	52 ab	2.2	23.4 a	8.1 a	2.7 a	0.35 bc	4	0.7	183.4	70.8	23.8
P-Ca 250 ppm (1x)	37.2 b	2.3	16.7 b	6 b	2.6 a	0.36 b	7	1.2	174.9	65	13.3
P-Ca 250 ppm (2x)	36.3 b	2.5	14.6 bc	5.8 b	2.3 b	0.4 a	5	0.8	164.4	57.7	17.5
P-Ca 250 ppm (every 30 d)	19.8 c	1.7	11.4 c	4.8 b	2.2 b	0.42 a	3.7	0.5	143.2	63	14.8
P > F	*0.0007*	*0.3474*	*<0.0001*	*<0.0001*	*<0.0001*	*<0.0001*	*0.59*	*0.3704*	*0.1167*	*0.3653*	*0.3024*

[z] Frost events in Nov. 2010 and Feb. 2011 resulted in significant flower mortality and low fruit set in Parkdale.

[y] The data are expressed as the total growth in cm per cross-sectional area (LCA) of scaffold. LCA was calculated from the circumference of the scaffold, 10 cm from its point of origin to the trunk.

[x] The number of nodes per cm of 2011 annual shoots from selected scaffolds.

[w] The total population of spurs from each scaffold treated in 2011 were observed for the presence or absence of flower clusters in spring 2012. The data are expressed as the percentage of spurs per scaffold with flower clusters.

[v] The total population of shoots on selected scaffolds with measurable extension growth during 2011 were observed for the presence or absence of apical flower clusters in spring 2012. The data are expressed as the percentage of 1-year-old shoots with flower clusters.

[u] Means were separated within columns by Fisher's Protected Least Significant Difference (LSD) ($p < 0.05$), whereby means associated with different letters are significantly different.

[t] The first application for all 250 ppm P-Ca treatments as Apogee (BASF Corp.) was applied 'to drip' to entire scaffolds when new shoots had ~ 5 to 10 cm of new growth. For the 250 ppm (2x) treatment at MCAREC, P-Ca was applied when growth of shoots previously treated with P-Ca had resumed (89 days after full bloom). At Parkdale, the 250 ppm (2x) treatment was not applied due to the season-long control of shoot growth from the first treatment timing; however, the P-Ca every 30 d treatment was provided.

Table 3. The effect of 2012 prohexadione-ca (P-Ca) and ethephon application rate and timing on vegetative and reproductive processes of 'd'Anjou' pear trees and scaffolds at the Mid-Columbia Agricultural Research and Extension Center (MCAREC) in the lower Hood River Valley, Oregon. Data are means of 6 replicates.

	Annual vegetative growth					Fruiting			2013 Return bloom		2013 Production	
Treatments	Total shoot length ($cm \cdot cm^{-2} LCA$)[z]	Shoots ($no./cm^2 LCA$)	Nodes (no./shoot)	Avg. internode length (cm)	Nodes (no./cm shoot)[y]	Fruits (no./tree)	Yield (kg/tree)	Avg. fruit wt (g)	Flowering spurs (%)[x]	Flowering shoots (%)[w]	Yield (kg/tree)	Avg. fruit wt (g)
Control	76.8 a[v]	2.2	22.6 a	2.5 a	0.44 b	266.8 c	72.9	273 a	47.6 bc	52.6 a	85.4 bc	261.2 bc
0 ppm + surfactant	71.3 ab	2.1	21.9 a	2.4 a	0.43 b	296.8 bc	81.0	273.9 a	54 ab	42.8 a	88.5 bc	269.8 abc
Ethephon 150 ppm (1x)[u]	82.1 a	2.2	22.3 a	2.4 a	0.43 b	357.5 abc	90.8	257.3 ab	52.9 ab	45.3 a	96.7 ab	260.2 bc
Ethephon (2x) (150 ppm + 300 ppm)	80.5 a	2.7	22.7 a	2.3 a	0.49 b	323 bc	72.3	228.4 d	64.9 a	47.1 a	110.3 a	255.7 c
P-Ca 250 ppm (1x)	50 bc	3.2	16.8 b	1.7 c	0.69 a	410.3 a	97.5	243.7 cd	30.4 d	10.2 bc	74.1 cd	271.5 abc
P-Ca 250 ppm (2x)	36 c	2.9	15.5 b	1.6 c	0.72 a	345.3 abc	85.6	250.2 bc	25.6 d	14.4 bc	56.9 d	285.2 a
P-Ca 250 ppm (1x) + Ethephon 150 ppm (1x)	47.7 c	2.7	15.9 b	2 b	0.63 a	352.7 ab	85.5	239.2 bcd	44.7 bc	17.9 b	63.2 d	277.3 ab
P-Ca 250 ppm (2x) + Ethephon 150 ppm (2x)	36.3 c	2.9	15.4 b	1.6 c	0.70 a	349.2 abc	84.8	243 bcd	33.6 cd	3.5 c	56.1 d	282.8 a
P > F	<0.0001	0.1692	<0.0001	<0.0001	<0.0001	0.0473	0.068	0.0003	<0.0001	<0.0001	<0.0001	0.0141

[z] The data are expressed as the total growth in cm per cross-sectional area (LCA) of scaffold. LCA was calculated from the circumference of the scaffold, 10 cm from its point of origin to the trunk.

[y] The number of nodes per cm of current-season shoot growth. Data are taken from the 12-shoot population graphed in Figure 3.

[x] The total population of spurs from each scaffold treated in 2012 were observed for the presence or absence of flower clusters in spring 2013. The data are expressed as the percentage of spurs per scaffold with flower clusters.

[w] The total population of shoots on primary scaffolds with measurable extension growth during 2012 were observed for the presence or absence of apical flower clusters in spring 2013 (i.e., 1-year-old shoots). The data are expressed as the percentage of 1-year-old shoots with flower clusters.

[v] Means were separated within columns by Fisher's Protected Least Significant Difference (LSD) ($p < 0.05$), whereby means associated with different letters are significantly different.

[u] All treatments received their first application 'to drip' to entire scaffolds on 20 days after full bloom when new shoots had ~ 5 cm of new growth; P-Ca as Apogee® and ethephon as Ethrel®. For treatments P-Ca 250 ppm + ethephon 150 ppm and P-Ca 250 ppm (2x) + ethephon 150 ppm (2x), products were applied together. Ethephon at 300 ppm was applied 57 days after full bloom. The second application for both P-Ca 250 ppm (2x) treatments was applied on 87 days after full bloom.

Table 4. The effect of 2012 prohexadione-ca (P-Ca) and ethephon application rate and timing on post-harvest 'd'Anjou' pear fruit quality (FF, fruit firmness; EJ, extractable juice; SS, soluble solids concentration; TA, titratable acidity) immediately following 3 and 4.5 months of regular air cold storage (RACS) at -1 °C and after a ripening period (RT) of 7 d at 20 °C. Treatments were applied at the Mid-Columbia AREC in the lower Hood River Valley, Oregon. Data are means of 6 replicates.

Treatment	FF (N)	EJ (ml·100 g^{-1}fw)	SS (°brix)	TA (%)	FF (N)	EJ (ml·100 g^{-1}fw)	SS (°brix)	TA (%)
	3 months RACS				3 months RACS + 7 days RT			
Control	54.7	70.8 a[z]	13.9 bc	0.26 b	22.9	58.1	14.3 b	0.26 b
0 ppm + surfactant	53.5	70.3 ab	13.9 b	0.26 b	22.4	58.4	14.3 b	0.25 bc
Ethephon 150 ppm (1x)[y]	54.6	70.1 ab	13.6 bcd	0.26 bc	25.8	58.8	14.0 bc	0.25 bc
Ethephon (2x) (150 ppm + 300 ppm)	56.3	68.3 cd	14.6 a	0.30 a	23.2	56.8	15.0 a	0.30 a
P-Ca 250 ppm (1x)	55.0	68.8 c	13.3 cd	0.20 d	23.6	58.5	13.8 c	0.21 e
P-Ca 250 ppm (2x)	56.8	68.3 cd	13.3 d	0.23 cd	29.9	59.8	13.9 bc	0.24 bcd
P-Ca 250 ppm (1x) + Ethephon 150 ppm (1x)	55.3	67.4 d	13.9 b	0.22 d	26.0	58.3	14.1 bc	0.23 cde
P-Ca 250 ppm (2x) + Ethephon 150 ppm (2x)	55.5	69.0 bc	13.9 bc	0.22 d	21.3	57.9	14.1 bc	0.22 de
P > F	0.31	<0.0001	0.0006	<0.0001	0.2784	0.8646	<0.0001	<0.0001
	4.5 months RACS				4.5 months RACS + 7 days RT			
Control	52.2	72.3 a	13.8 b	0.20 abc	12.2	56.6 a	13.8 bc	0.20 b
0 ppm + surfactant	51.2	71.8 ab	13.6 bc	0.19 bcd	12.6	56.0 ab	13.8 bc	0.21 ab
Ethephon 150 ppm (1x)	51.3	71.6 abc	13.4 bc	0.22 ab	12.0	53.5 abc	13.9 bc	0.19 bc
Ethephon (2x) (150 ppm + 300 ppm)	50.0	70.2 c	14.5 a	0.23 a	13.0	52.3 c	14.4 a	0.22 a
P-Ca 250 ppm (1x)	51.2	70.3 bc	13.4 bc	0.17 d	10.7	54.3 abc	13.4 c	0.17 d
P-Ca 250 ppm (2x)	54.2	70.4 bc	13.1 bc	0.20 abcd	13.4	54.2 abc	13.4 c	0.17 cd
P-Ca 250 ppm (1x) + Ethephon 150 ppm (1x)	51.9	70.2 c	13.6 bc	0.17 cd	10.7	51.6 c	13.9 bc	0.18 cd
P-Ca 250 ppm (2x) + Ethephon 150 ppm (2x)	51.3	71.0 abc	13.5 bc	0.20 abc	11.6	53.2 bc	13.9 b	0.17 d
P > F	0.1675	0.0514	0.0025	0.0123	0.0779	0.0326	0.0041	<0.0001

[z] Means were separated within columns by Fisher's Protected Least Significant Difference (LSD) ($p < 0.05$), whereby means associated with different letters are significantly different.

[w] All treatments received their first application 'to drip' to entire scaffolds on 20 days after full bloom when new shoots had ~ 5 cm of new growth; P-Ca as Apogee® and ethephon as Ethrel®. For treatments P-Ca 250 ppm + ethephon 150 ppm and P-Ca 250 ppm (2x) + ethephon 150 ppm (2x), products were applied together. Ethephon at 300 ppm was applied 57 days after full bloom. The second application for both P-Ca 250 ppm (2x) treatments was applied on 87 days after full bloom.

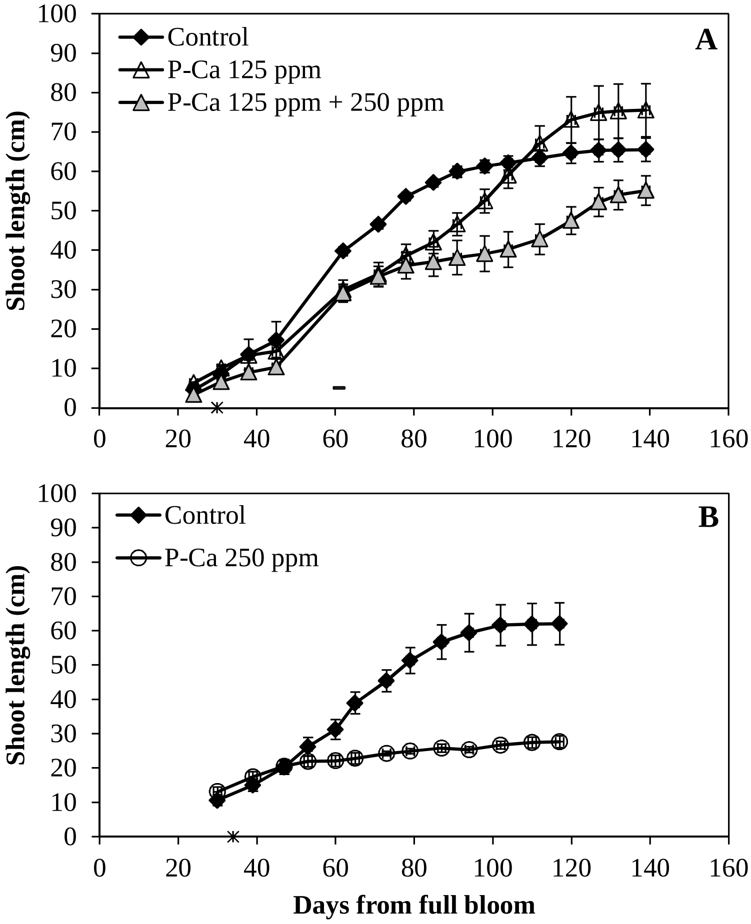

Control
P-Ca 125 ppm
P-Ca 125 ppm + 250 ppm
A
Shoot length (cm)
Control
P-Ca 250 ppm
B
Shoot length (cm)
Days from full bloom

Figure 1.

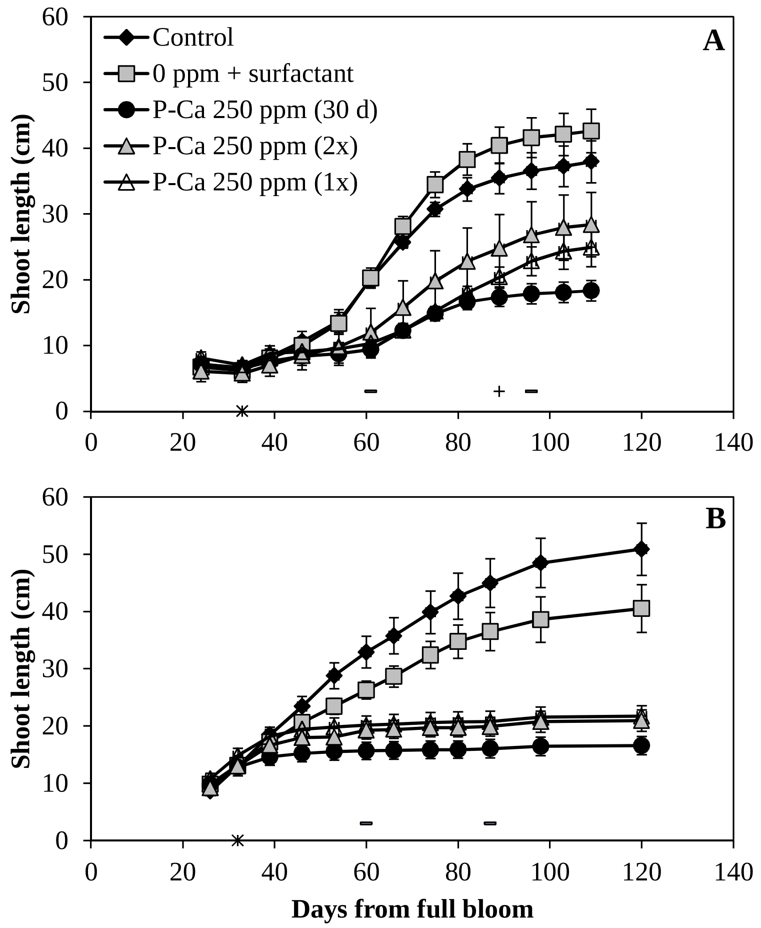
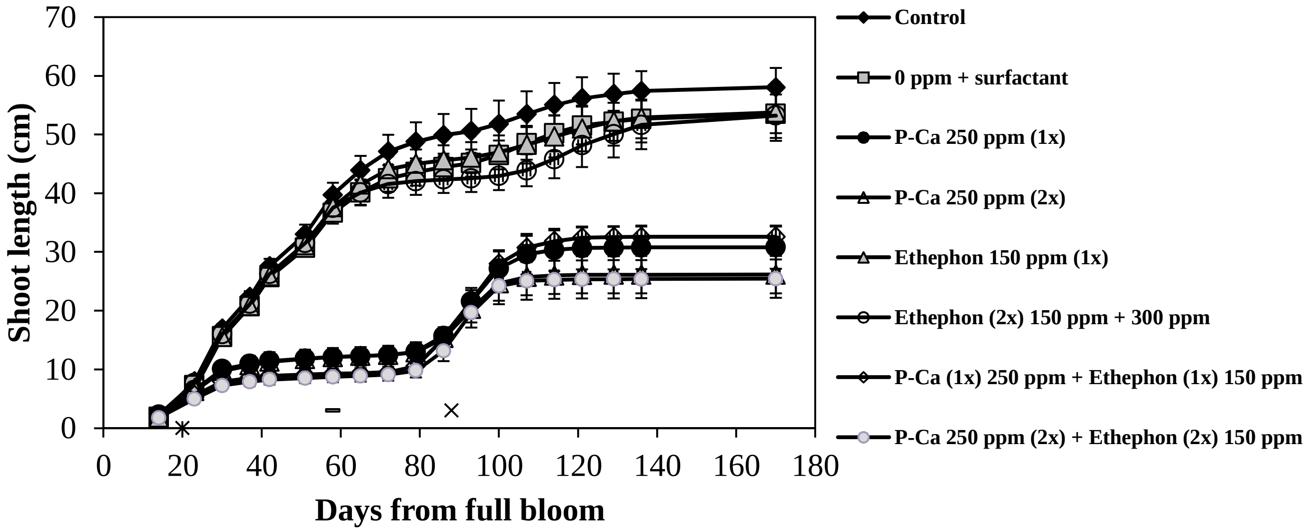

Control
0 ppm + surfactant
P-Ca 250 ppm (30 d)
P-Ca 250 ppm (2x)
P-Ca 250 ppm (1x)
A
B
Shoot length (cm)
Days from full bloom
0
10
20
30
40
50
60
0
20
40
60
80
100
120
140
+

Figure 2.



70
60
50
40
30
20
10
0
Shoot length (cm)
0
20
40
60
80
100
120
140
160
180
Days from full bloom
Control
0 ppm + surfactant
P-Ca 250 ppm (1x)
P-Ca 250 ppm (2x)
Ethephon 150 ppm (1x)
Ethephon (2x) 150 ppm + 300 ppm
P-Ca (1x) 250 ppm + Ethephon (1x) 150 ppm
P-Ca 250 ppm (2x) + Ethephon (2x) 150 ppm

Figure 3.

Figure 1. Effect of 2010 prohexadione-ca (P-Ca) treatments on ‘d’Anjou’ pear annual shoot growth at a lower (A) and higher elevation site (B) in the Hood River Valley, Oregon. Asterisk on x-axis denotes time of first application for all treatments; dash above x-axis denotes application timing of 250 ppm P-Ca for the P-Ca 125 ppm + 250 ppm treatment. Vertical bars represent SE.

Figure 2. Effect of 2011 prohexadione-ca (P-Ca) applied once, twice or every 30d on ‘d’Anjou’ pear annual shoot growth at a lower (A) and higher elevation site (B) in the Hood River Valley, Oregon. Asterisk on x-axis denotes time of first application for all treatments; dashes above x-axis denote successive 250 ppm P-Ca applications for the P-Ca 250 ppm 30 d treatment; plus symbol above x-axis denotes the second application for the P-Ca 250 ppm (2x) treatment. Vertical bars represent SE.

Figure 3. Effect of 2012 prohexadione-ca (P-Ca) and ethephon treatments applied separately or in combination on ‘d’Anjou’ pear annual shoot growth at a low elevation site in the Hood River Valley, Oregon. Asterisk on x-axis denotes time of application for ethephon 150 ppm treatments and the first application of all P-Ca treatments; the x above the x-axis denotes the second application timing for both P-Ca 250 ppm (2x) treatments. Combination treatments (P-Ca and ethephon) were tank mixed. Dash above x-axis denotes the application of 300 ppm ethephon for the ethephon 150 ppm + 300 ppm treatment. Vertical bars represent SE.

3 Artigo 3

Submetido à revista *Scientia Horticulturae*

3.1 **Heading cuts and prohexadione-calcium affect the growth and development of ‘d’Anjou’ pear shoots in a high-density orchard**

Mateus S. Pasa and Todd C. Einhorn

*Keywords***:** *Pyrus communis*, pruning, vegetative growth control, heading-back.

3.2 Abstract. Prohexadione calcium (P-Ca) was selectively applied to dormant-headed (1/3rd removed) and unpruned shoots in a high-density ‘d’Anjou’ pear orchard in Oregon, USA. Both sets of shoots were treated with 250 mg L-1 P-Ca in either a single or double application and compared to controls. The first application was delivered to shoots when ~ 5cm of new growth accrued; the second, only if shoot growth resumed. P-Ca reduced shoot growth of both headed and unpruned shoots relative to their respective controls. Growth of unpruned shoots ceased 3 weeks following the first P-Ca application. In contrast, headed shoots required 6 weeks from the initial application to cease elongating. A markedly higher maximum shoot growth rate (mm·d-1) was observed for P-Ca-treated, headed shoots compared to P-Ca-treated, unpruned shoots. At 87 days after full bloom, P-Ca-treated, unpruned shoots had a pronounced second flush of growth requiring an additional application of P-Ca. This growth resumption was 2 weeks earlier than unpruned, control shoots and 17 d earlier than P-Ca-

treated, headed shoots, for which only a negligible growth flush was observed. At the end of the season, unpruned shoot length was decreased by 28% and 41% for shoots treated with P-Ca once or twice, respectively, while headed shoots were 37% shorter than their controls (treated only once). The number of nodes and average internode length were significantly reduced for P-Ca-treated shoots, irrespective of pruning level, conferring a higher node density relative to control shoots. An increase in node density should result in improved yield efficiency once fruiting competency occurs on this wood. Heading, in contrast, increased the internodal space and decreased the number of nodes, ultimately decreasing node density. We did not observe any physiological effects on the growth or development of adjacent, un-treated shoots originating from identical scaffolds as P-Ca-treated shoots. Collectively, these results implicate P-Ca as a powerful tool for precision-management of tree vigor in intensive pear plantings via selective treatment to areas of high vigor.

3.3 Introduction

‘D‘Anjou’ pear (*Pyrus communis* L.) is the main winter pear cultivar produced in the US, solely in the Pacific Northwestern (PNW) states of Oregon and Washington. This pear variety is known for its inherent vigor and non-precocious fruiting habit. These traits are exacerbated by an insufficient degree of dwarfing conferred by rootstocks currently available in the US (Elkins et al., 2012). Consequently, the high cost of production associated with the management and harvest of large canopies has resulted in a decline of pear acreage over recent decades (Elkins et al, 2012). A similar trend has occurred in many other pear producing regions of the world. In order to overcome this situation, more efficient and profitable systems (i.e., high-density plantings) are required. Robinson (2011) recently demonstrated markedly higher yields and yield efficiency of young pear trees in high-density plantings using commercially available US rootstock selections, demonstrating that significant gains in efficiency can be achieved using the current germplasm. Such orchard configurations offer the advantages of early production, sustained high yields of high-quality fruit, and lower labor costs (Hampson et al, 2002), but their continued success relies on the application of horticultural techniques to control tree size; especially with highly vigorous cultivars.

P-Ca is a gibberellin (GA) biosynthesis inhibitor (Evans et al., 1999; Rademacher et al., 2004) used for vegetative growth control of certain tree fruit crops, depending on the country. P-Ca reduces the levels of highly active GA_1 resulting in the accumulation of its precursor, GA_{20} (inactive), in plant tissues (Evans et al., 1999). Previous studies have demonstrated significant control of shoot growth by P-Ca on a range of pear varieties (Asín et al., 2007; Costa et al., 2001, 2004; Elfving et al., 2002,2003; Rademacher et al., 2004; Smit et al., 2005). In a recent four-year study, P-Ca effectively reduced shoot growth of ‘d’Anjou’ pear trees in moderate-density orchards, but led to significant reductions in return bloom and return yields (Einhorn et al., in review [HortScience]), as similarly shown for ‘Bosc’ (Sugar et al., 2004). In fact, results from the latter study, in combination with the negative effects of P-Ca on fruit size (Elfving et al., 2003; Smit et al., 2005; Sugar et al., 2004) have limited the use of P-Ca for pear in the US and, for certain varieties, elsewhere.

Mechanized pruning is an important advancement in labor-saving management of high-density plantings. However, the non-selective nature of hedging produces a mix of headed and unpruned shoots (i.e., non-headed). Shoots originating from heading cuts show a high degree of invigoration following winter pruning (Forshey et al., 1992; Robinson, 2003), especially when compared to unpruned shoots (Mika, 1986). In addition to the heterogeneous distribution of vigor within a hedgerow, vigor is positively related with canopy height and, with time, reduces the light environment and yield of lower tiers of the canopy (Musacchi, 2011; Zai-Long, 1984). The influence of shade on flower bud formation of pome fruit is well documented (Jackson and Sweet, 1972; Wagenmakers, 1989).

P-Ca translocation *in-planta* is acropetal (Evans et al., 1999); therefore, P-Ca activity should be limited to tissues that have come in direct contact with, or reside downstream (i.e., distally) of the compound. Aside from directed applications to the tops of mature ‘Bartlett’ and ‘d’Anjou’ trees (Elfving et al., 2003), we are unaware of any studies that have targeted ‘high vigor’ areas of the canopy, or have evaluated the efficacy of P-Ca on the characteristic rapid growth emanating from heading cuts. To avoid the potential adverse effects of P-Ca when applied to whole-canopies, but to control vigorous portions of trees within intensive planting systems, a study was designed to evaluate the growth response of headed and unpruned shoots to discriminant applications of P-Ca.

3.4. Materials and Methods

3.4.1 Plant Material

Research plots were established at Oregon State University’s Mid-Columbia Agricultural Research and Extension Center (MCAREC), located in the lower Hood River Valley, Oregon (lat. 45.7 N, long.121.5 W). Soil was a Van Horn series, fine sandy loam. The experiment was carried out in a 7-year old ‘d’Anjou orchard (3.6 x 1.2 m; ~2300 trees/ha; ~3.7 m canopy height; north:south row orientation) on OH × F40 rootstock, trained to a planar vertical, 8-wire hedgerow system.

3.4.2 Experimental design and treatments

In Apr., five-tree plots of ‘d’Anjou trees were selected and arranged in a randomized complete block design with five replications. Within each plot, 80 individual, one-year shoots were randomly selected between 1 and 2.5 m of canopy height from a population of shoots having similar orientation (uniformly divided east and west of the hedgerow), diameter and length.

Treatments were assigned to shoots in a 2-way factorial design with four levels of P-Ca [1) Control (unsprayed), 2) surfactant + water, 3) P-Ca (250 mg L^{-1}) in a single application, and 4) P-Ca (250 mg L^{-1}) provided twice], and two levels of pruning [dormant headed (1/3rd removed), or unpruned]. For those treatments receiving two P-Ca applications, the second application was performed when shoot growth resumed (GR) [110 d after full bloom (DAFB)]. Solutions of P-Ca (Apogee®, BASF Corp., Research Triangle Park, NC) were prepared as mg L^{-1} of active ingredient (a.i.) and supplemented with 0.1% (v:v) nonionic surfactant (Simulaid, Genesis AGRI Products Inc., Union Gap, WA). Solutions were applied to runoff with a hand sprayer. In order to protect adjacent shoots from spray drift during all spray applications, a 150 mm diameter PVC pipe was cut longitudinally (1.3 m height) and placed behind the target shoots during P-Ca application.

3.4.3 Measurement of vegetative parameters

Shoot length for all treatments was measured on 10, one-year-old shoots, evenly selected and tagged at the time of the first application and then at weekly intervals until the end of the season. Average growth rate (mm day^{-1}) was calculated using weekly shoot length data. The number of nodes was counted on all tagged shoots at the end of the growing season. Derived from these data, average internode length (cm) and number of nodes per cm of shoot length were calculated.

3.4.4 Statistical analysis

Due to unequal P-Ca treatments per pruning treatment (i.e., headed shoots did not receive a second P-Ca application due to negligible shoot growth resumption) data were analyzed for the three P-Ca treatments common to both pruning treatments to detect interaction of main effects (i.e., pruning and P-Ca) for all response factors. Shoot length and shoot growth rate were also analyzed separately to detect differences among P-Ca treatments within pruning. Statistical analyses were performed using the SAS system software (SAS 9.0; SAS Institute, Cary, NC). Treatment means were compared using analysis of variance with PROC GLM and significance was tested at $P \leq 0.05$. Mean separation was determined by Tukey's test.

3.5 Results

Shoots receiving a surfactant + water treatment did not significantly differ from control shoots for any of the response variables measured (Fig. 1; Table 1). P-Ca significantly reduced shoot growth of both headed and unpruned shoots relative to their respective controls (Fig 1). Unpruned shoots were reduced by ~15% to 20% 2 weeks after the first P-Ca treatment (WAFT) and complete growth cessation occurred by 3 WAFT (Fig. 1 A). Headed shoot response to P-Ca, in contrast, required an additional week for growth retardation to manifest and 2-fold the time required (i.e., 6 WAFT) for growth to cease altogether (Fig. 1B). Headed shoots had a higher early-season maximum growth rate (21 DAFB) compared to unpruned shoots, irrespective of P-Ca treatment (Fig. C, D). This was followed by a similar, declining shoot growth rate for both pruning treatments. Unpruned and headed shoots treated with P-Ca were 51% and 37% shorter than their respective control shoots by 11 WAFT.

A pronounced, second growth flush occurred for P-Ca-treated, unpruned shoots on 87 DAFB; 2 weeks earlier than the unpruned control shoots. A second P-Ca application was provided on 110 DAFB (Fig. 1A) to which shoots responded rapidly, showing significantly less growth compared to shoots treated once with P-Ca by 1 week after the second treatment (WAST). In contrast, a negligible second growth flush for P-Ca-treated, headed shoots was not observed until 104 DAFB (~17 d after unpruned, P-Ca-treated shoots), but shoots never significantly exceeded their length prior to this flush; therefore, a second application of P-Ca was not provided. The growth rate of the secondary flush of P-Ca-treated shoots was 3 orders of magnitude greater for unpruned shoots compared to headed shoots on 110 DAFB (Fig. 1 C, D). At the end of the season, headed shoots treated with P-Ca remained ~ 37% shorter than their controls (Fig. 1B), and unpruned shoots were 28% and 41% shorter than their controls when receiving one or two P-Ca applications, respectively (Fig. 1A). Although final shoot length was significantly influenced by P-Ca, irrespective of pruning level, it was not significantly affected by pruning (Table 1).

The number of nodes, average node length, and nodes per cm of shoot length were all significantly affected by P-Ca and pruning, though ostensibly opposite in response and without significant interaction (Table 1); therefore, only main effects are presented. P-Ca applied at ~5 cm of new extension growth significantly decreased the number of nodes per shoot and the average inter-nodal length of shoots, producing future fruiting structures with significantly more nodes per cm shoot length than control shoots (Table 1). With respect to unpruned shoots, a second application of P-Ca resulted in incremental improvements to each of the factors evaluated, but not significantly (data not shown). Heading significantly increased internode length resulting in fewer nodes per cm of shoot length compared to unpruned shoots (Table 1).

3.6 Discussion

Response of pear shoots to P-Ca was consistent with previous studies (Asín et al., 2007; Costa et al., 2001, 2004; Elfving et al., 2002, 2003; Smit et al., 2005; Rademacher et al., 2004). The growth pattern of headed and unpruned shoots differed though, with heading inducing a significantly higher initial growth rate than unpruned shoots. In fact, growth rate was the only response variable that yielded significant interaction between P-Ca and pruning, depending on date. During early-season shoot extension, a significant interaction occurred on

31 DAFB when P-Ca was not nearly as effective at reducing the maximum growth rate of headed shoots relative to unpruned shoots (reductions of 25% and 42% relative to controls, respectively). Mika (1986) observed, and summarized, the invigorating effect of heading across many species of fruit trees. For headed shoots of ‘d’Anjou’, a higher P-Ca dose may be necessary to control initial vigor, as previously postulated (Evans et al., 1999) and documented (Rademacher et al., 2004) for high-vigor cultivars. Despite the often observed dramatic effect of heading on the production of long shoots when compared to growth from unpruned shoots (Elfving, 1990; Forshey et al., 1992; Fumey et al., 2011; Lord and Damon, 1983), un-treated, headed shoots in the present study were only 9.8% longer than untreated, unpruned shoots at the end of the season; a difference that was not significant. While the heading treatment removed 1/3rd of the 1-year-old growth segment, Jonkers (1982) demonstrated that the growth response of apple (*Malus* x *domestica* Borkh.) shoots to heading was positively related to the portion of 1-year growth removed (between 0% and 80%), indicating that our treatment may not have been expected to promote an excessively vigorous response. Irrespective, we are unaware of any previous studies that differentiated the growth response of pruned and unpruned shoots treated with P-Ca.

We observed an earlier and markedly stronger secondary growth flush of P-Ca-treated, unpruned shoots compared with headed shoots. We do not have an explanation for this disparity, although the delayed growth flush of headed shoots was nearly equivalent (in d) to the additional time required for growth to cease after the first P-Ca application, relative to unpruned shoots. This observation indicates a potential, prescribed duration of time for P-Ca metabolism and recurrence of active growth to occur in ‘d’Anjou’. Despite the relatively rapid metabolism of P-Ca in plant tissue (2 to 3 weeks; Evans et al., 1999), our data align with previous observations from a multi-year study which showed that moderate-density ‘d’Anjou’ trees required a minimum of 60 d from initial P-Ca treatment to produce a second flush of growth (Einhorn et al., in review [HortScience]). In fact, in those experiments 'd'Anjou' trees located at cooler sites were completely void of a secondary growth flush. The different growth patterns exhibited by unpruned and headed shoots treated with P-Ca have been previously described as type-2 and type-4, respectively (Elfving et al., 2002). These classifications, however, described the unique growth responses of different pear cultivars to P-Ca. In our case, these differences were associated with the interaction between pruning and P-Ca, since control shoots for both levels of pruning showed similar growth patterns. In fact, significant interactions between P-Ca and pruning were observed for growth rate at 31, 87, 94, 101 and 108 DAFB.

Directed applications of P-Ca to the top half of mature 'd'Anjou' and 'Bartlett' trees in low-density plantings reduced vigor and pruning weights from the tree tops, and improved light relations in the lower canopy (Elfving et al., 2003). That study, however, did not discriminate between P-Ca effects in the top half (treated) relative to the lower half (untreated) of the canopy. Our experimental design allowed for the treatment of shoots within each replicate (a contiguous five-tree section of hedgerow) without respect to their origin. In several cases, therefore, P-Ca-treated shoots were directly adjacent to untreated shoots; borne on the same horizontal scaffold. Yet physiological effects of P-Ca did not manifest in untreated shoots (i.e., no apparent travel from shoot-to-shoot via the scaffold). Evans et al. (1999) described the translocation of P-Ca *in-planta* to be quite limited due to its basipetal movement. Our results support the sustainable use of P-Ca for targeted applications to canopy zones with high vigor. Such a precision-management strategy is essential to avoid reduced fruit size (Elfving et al., 2003; Sugar et al., 2004), or excessive reductions in return bloom (Sugar et al., 2004) when treating significant portions of the canopy with P-Ca.

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Table 1. Number of nodes, final shoot length, average internode length, and number of nodes per cm of shoot length of 'd'Anjou' headed and unpruned shoots selectively treated with P-Ca.

Treatments	Number of nodes	Final shoot length (cm)	Average internode length (cm)	Node density (nodes cm^{-1})
<u>P-Ca</u>				
Control	18.11 a[z]	45.16 a	2.41 a	0.46 b
Surfactant + water	16.82 ab	39.96 a	2.27 a	0.49 b
P-Ca 250 (5cm)	15.04 b	30.74 b	1.87 b	0.66 a
<u>Pruning</u>				
Unpruned	17.23	37.31	2.00 b	0.63 a
Headed	16.09	39.94	2.37 a	0.45 b
<u>Significance</u>				
$P>F$ P-Ca	0.005	<.0001	<.0001	<.0001
$P>F$ Pruning	0.115	0.193	<.0001	0.001
$P>F$ P-Ca x Pruning	0.971	0.631	0.355	0.399

[z]Mean separation within columns by Tukey's test at $P < 0.05$; means followed by different letters are significantly different.

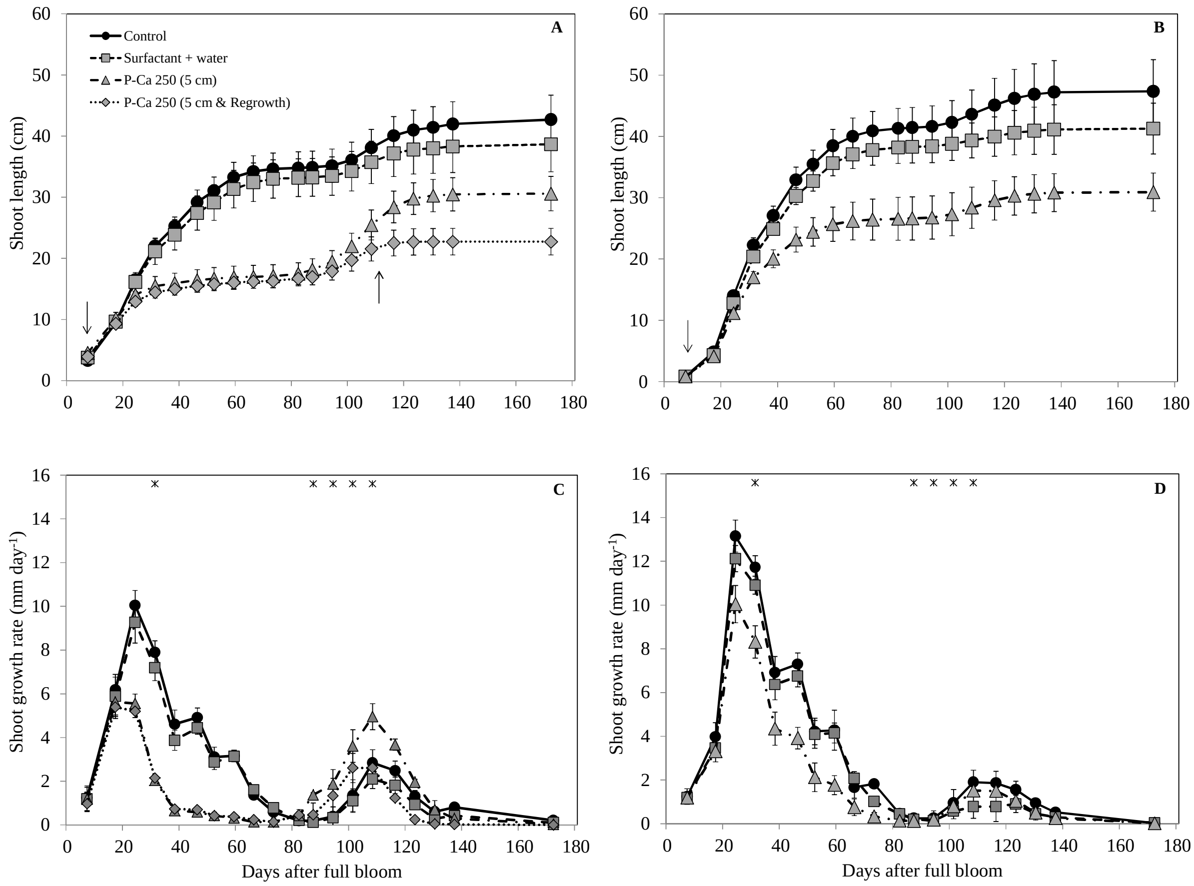
Control
Surfactant + water
P-Ca 250 (5 cm)
P-Ca 250 (5 cm & Regrowth)
A
B
C
D
Shoot length (cm)
Shoot growth rate (mm day-1)
Days after full bloom
0
10
20
30
40
50
60
0
2
4
6
8
10
12
14
16
0
20
40
60
80
100
120
140
160
180

Figure 1.

Figure 1. Effects of P-Ca application on shoot length and shoot growth rate of individual, unpruned (**A** and **C**, respectively) and headed (**B** and **D**, respectively) ‘d’Anjou’ pear shoots. Asterisks at top of graphs signify significant interaction between Pruning x P-Ca, at $P < 0.05$. Symbols in the graphs are the means of five replicate plots (n =10). Downward arrows indicate the first spray of P-Ca and upward arrows the second (when shoot growth resumed). Headed shoots did not require a second application given their negligible growth resumption.

4 Artigo 4

A ser submetido à Revista Brasileira de Fruticultura

4.1 **PROHEXADIONE CALCIUM CONTROLS SHOOT GROWTH OF PEAR TREES**

Mateus da Silveira Pasa, José Carlos Fachinello, Horacy Fagundes da Rosa Júnior, Émerson De Franceschi and Flavio Gilberto Herter.

PROHEXADIONA CÁLCIO CONTROLA O CRESCIMENTO DE RAMOS DE PEREIRAS

4.2 **ABSTRACT**

The aim of this study was to evaluate the effects of prohexadione calcium (PCa) on vegetative growth and production of ‘Carrick’, ‘Packham’s’ and ‘William’s’ pear. The trial was performed at the experimental field of the Federal University of Pelotas, Capão do Leão, RS, Brazil (31º 52’ 00" S; 52º 21’ 24" W), during the growing seasons of 2011 and 2012. Treatments were applied to single-tree replications in a randomized complete block design with four replications as follows: Control (unsprayed), PCa (PCa - 750 g ha^{-1} i.a.). The application was split in four (187,5g ha^{-1} a.i. each) and three timings (250g ha^{-1} a.i. each) in the 2011 and 2012 growing seasons, respectively. The assessed parameters were: shoot length, trunk cross sectional area (TCSA) increment, number of nodes, internode length, pruning weight, number of fruits, average fruit weight, production per tree and return bloom. It was possible to conclude that application of PCa at 750 g. ha^{-1} a.i satisfactorily controls shoot growth through the reduction of internode length of ‘Carrick’, ‘Packham’s’ and ‘William’s’ pears.

Besides, it was observed that return bloom is not negatively affected by PCa. So, this plant growth regulator is a potential management tool to reduce shoot growth and the need for pruning in pear orchards.

Index terms: *Pyrus* sp, vigor, vegetative growth, pruning, yield.

4.3 **RESUMO**

O objetivo desse trabalho foi de avaliar o efeito da prohexadiona cálcio (PCa) no crescimento vegetativo e produção de pereiras ‘Carrick’, ‘Packham’s’ e ‘William’s’. O experimento foi conduzido no campo experimental da Universidade Federal de Pelotas, Pelotas, Capão do Leão, RS, Brazil (31º 52’ 00" S; 52º 21’ 24" W), durante as safras de 2011 e 2012. O delineamento experimental foi de casualização por blocos, com quatro repetições de uma planta cada. Os tratamentos foram: Controle (sem aplicação), PCa (PCa - 750 g ha^{-1} i.a.). As aplicações foram divididas em quatro (187,5 g ha^{-1} i.a. cada) e três (250 g ha^{-1} a.i. cada) vezes em 2011 e 2012, respectivamente. As variáveis analisadas foram: comprimento de ramos, incremento da área da seção transversal do tronco (ASTT), número de entrenós, comprimento médio de entrenós, massa de poda, número de frutas, massa médio de fruta, produção por planta e retorno da floração. Concluiu-se que a aplicação de 750 g. ha^{-1} a.i de PCa controla satisfatoriamente o crescimento de ramos através da redução no comprimento dos entrenós de pereiras ‘Carrick’, ‘Packham’s’ e ‘William’s. Além disso, observou-se que o retorno da floração não é negativamente afetado pelo PCa. Então, a PCa é uma ferramenta potencial para reduzir o crescimento de ramos e a necessidade de poda em pomares de pereiras.

Termos para indexação: *Pyrus* sp., vigor, poda, crescimento vegetativo, produtividade.

4.4 INTRODUCTION

Pear leads Brazilian fruit imports both in quantity and in value. According to the Food and Agriculture Organization of the United Nations (2013), the imported amount of pears in 2010 was approximately 190,000 Mega gram (Mg), representing about 90% of domestic consumption, while in 2009 the amount of pears imported was nearly 160,000 Mg, which means an 18,75% increment in the period. The value of this import represented, in 2010, US$ 189 million. This scenario results from various factors, among which the most important are the lack knowledge about the best rootstock x scion cultivars combinations, bearing habit of this combinations, the development of fruiting buds and excessive vegetative growth of the main cultivars (PASA et al, 2011).

Vegetative growth control is a major concern in a pear orchard. Excessive vigor in pears has been shown to be negatively correlated with production 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 a lower number of 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 difficult 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 on *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), as they are for apples (ELFVING et al, 2003), pear growers rely mainly on winter 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.

PCa was currently registered in Brazil for vegetative growth control in apple under the trade name of Viviful® (Ihara Chemical Industry Co., Ltd). Reduction of longitudinal shoot growth is the most obvious effect caused by PCa, by reducing the biosynthesis of the plant hormone gibberellin (GA), which regulates cell elongation. This is achieved by PCa blocking of 2-oxoglutaric acid-dependent dioxygenases involved in the biosynthesis of GAs, mainly the GA_{20}-3ß-hydroxylase, which catalyzes the conversion of inactive GA_{20} into highly active GA_1 (RADEMACHER and KOBER, 2003). Its biological half-life in plants is in the range of 10–14 days (Rademacher et al., 2004).

Previous studies have demonstrated that PCa controls shoot growth of different pear varieties (ELFVING et al, 2003; SMIT et al, 2005; ASÍN et al, 2007; HAWERROTH et al., 2012) with varied influences over other horticultural traits. Sugar et al. (2004) reported smaller fruit size of ‘Bartlett’, but not ‘Bosc’, ‘Red Anjou’ in the year of PCa application, while ‘Anjou’ fruit size was affected in just one trial; ‘Bosc’ return bloom and yields were markedly reduced the year following application, but ‘Bartlet’ and ‘Anjou’ were not similarly affected. 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).

The aim of this study was to evaluate the effects of prohexadione calcium on vegetative growth and production of ‘Carrick’, ‘Packham’s’ and ‘William’s’ pears.

4.5 **MATERIALS AND METHODS**

The experiment was performed at the experimental field of the Federal University of Pelotas located in the city of Capão do Leão, RS, Brazil (31º 52’ 00" S; 52º 21’ 24" W; Altitude: 48m.), during the growing seasons of 2011 and 2012. Soil was a Eutrophic Yellow Argissol. The average accumulation of temperatures lower than 7,2 ºC in the region is 400h. The average annual rainfall is 1367 mm, minimum and maximum temperature are -3 ºC and 39,6ºC, respectively and the annual average temperature is 17,8º C.

Research plots were established in a seven year-old pear orchard of the cultivars Carrick, Packham’s and William’s pear grafted on *Pyrus calleryana*, at 1.5 x 5m spacing (1333 trees ha^{-1}). Trees were trained as a central leader in a structure consisting of three wires fixed to cements poles. The cultural management was 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, in 2011 and 2012, at the stage of green tip, trees were sprayed with hydrogen cyanamide (0,2%) mixed with mineral oil (3%) to standardize budburst and flowering.

Treatments were applied to single-tree replications in a randomized complete block design with four replications per treatment as follows: 1) Control (unsprayed), 2) Prohexadione calcium (PCa - 750 g a.i ha^{-1}). As source of PCa it was used the commercial product Viviful® (27,5% a.i; Ihara Chemical Industry Co., Ltd). The application was split in four (187,5g a.i ha^{-1} each) and three timings (250g a.i ha^{-1} each) in the 2011 and 2012 growing seasons, respectively. The first application was performed when current year shoots were an average 10cm long; the second, and third were performed 30 and 60 days after the first application (DAFA), respectively; the fourth application in 2011 was performed 120 DAFA. PCa applications were performed using a hand-gun backpack sprayer, considering a spraying volume of 1000 L ha^{-1}.

Shoot lengths were measured on 12 current year shoots, evenly selected and tagged, 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. Derivate 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 expression: $TCSA = \pi.r^2$, where $\pi = 3,1416$ and $r = d/2$, where d= trunk diameter, measured at 5 cm above graft union at the inception of the trial and the following fall of each year. Trees were pruned every year in January and pruning weight 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). Fruit were counted and weighed on per tree basis. From these data, production 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 in 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. The number of nodes and fruit were transformed as square root (n + 1). Duncan's test was used to compare treatments when analysis of variance showed significant differences among means.

4.6 **RESULTS AND DISCUSSION**

Shoot length of 'Carrick', 'Packham's' and 'William's' pear was significantly reduced relative to control trees in all assessment dates but the first, where shoots were about 10cm long, and in both growing seasons (Figure 1). In the 2011 growing season the greatest shoot length reduction was observed 60 days DAFA where PCa treated shoots of 'Carrick' (Figure 1A), 'Packham's' (Figure 1B) and 'William's' (Figure 1C) pears were 40.1%, 27.6% and 44.6% shorter than control shoots, respectively. After that, both PCa treated and control shoots followed a flat line without a second flush of growth. As in the 2011 growing season the fourth application did not yield any shoot growth reduction since even control shoots had stopped growing, in the 2012 growing season the PCa dose (750 g a.i ha^{-1}) was split in three applications, i.e 250 g a.i ha^{-1} each. So, as assumed, the fourth PCa application was not necessary once shoot length was reduced with three applications in all cultivars. In fact, shoot length reduction in comparison with control was even higher than in the 2011 growing season, probably because PCa dose was higher, since it was split in three timings. By the end of the 2012 growing season PCa treated shoots were 56.1%, 42.1% and 54.6% shorter than control shoots for 'Carrick' (Figure 1D), 'Packham's' (Figure 1E), and 'William's' (Figure 1F), respectively.

The above results show that PCa is effective for shoot growth control of pear cultivars investigated. Similar results were found by Smit et al. (2005) which obtained shoot growth reduction up to 50% of 'Packham's Triumph', 'Golden Russet Bosc', 'Early Bon Chretien' and Rosemarie with PCa 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), which obtained shoot growth reduction of 'Hosui' pears grated on 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 PCa are shown to 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 PCa to control flushes of shoot growth, which may occur later in the season (RADEMACHER et al., 2004).

The number of nodes in 2011 was lower in PCa treated ‘William’s’ than control. In 2012 ‘Carrick’ and ‘Packham’s’ treated with PCa had fewer nodes than control trees (Table 1). The internodes of PCa treated trees of all cultivars were shorter than those of control trees in both growing seasons (Table 1). It is likely that the reduction in the internode length and number of nodes was the responsible for the reduction in shoot growth of the investigated cultivars (Figure 1). Reduction of internode length is the most obvious effect caused by PCa, by reducing the biosynthesis of the plant hormone gibberellin (GA), which regulates internode elongation. This is achieved by PCa blocking the conversion of inactive GA_{20} into highly active GA_1 (RADEMACHER and KOBER, 2003). The reduction of the number of nodes is possibly also an effect of GA biosynthesis blocking, since node formation is given by the rate of shoot growth (JACKSON, 2003), which is reduced by PCa application. The reduction in the internode length as a response to PCa application was also observed in ‘Smoothee Golden Delicious’ apple (Medjdoub & Blanco, 2004).

Even though there was an overall trend towards a smaller TCSA increment on PCa treated trees it was observed significant differences only in 2012 with ‘William’s’, where PCa treated trees had a smaller TCSA increment compared to control trees (Table 1), such as found in apple for Medjdoub & Blanco (2004). The fact trunk growth was little affected indicates that the reduction in shoot growth was not too hard to the point of completely stoping tree growth. In such case tree production might be impaired by a lack of carbohydrates to supply fruits and flower bud formation.

Pruning weight of PCa treated ‘William’s’ pears was significantly lower in both 2011 and 2012 growing seasons and just in 2012 for ‘Packham’s’ (Table 1). The fact only ‘William’s’ was affected by PCa in both growing seasons is probably due to its higher vigor associated with a strong watersprout growth. So that, by the time of pruning they are cut off while in PCa treated trees some of them are left unpruned because they were not too long. Similarly, the pruning weight of ‘D’Anjou’ and ‘William’s’ pears treated with PCa was reduced in relation to control trees, and this reduction was in proportion to the amount of PCa applied (ELFVING et al., 2003). In ‘Hosui’ pears pruning weight was also reduced as PCa dose increased (HAWERROTH et al., 2012). The reduction in pruning weight associated with PCa indicates an obvious decrease in the need for pruning, which is an important component of pear orchards, equating to approximately 14% of total variable costs (SEAVERT et al. 2005).

The reduction in shoot growth and pruning weight mean a decreased canopy density. Such a situation implies in an improved spray deposition within the canopy when applying fungicides and insecticides (RADEMACHER and KOBER, 2003). In such a situation, diseases and pest would be better controlled so less applications would be necessary, then reducing spraying costs as well as the potentially environment damages.

Production per tree and number of fruit did not differ between treatments for all cultivars, but ‘Packham’s’ in 2011, where PCa treated trees were most productive and had a higher amount of fruits than control trees. No differences were found for average fruit weight in all tested cultivars (Table 2). The overall absence of production increase associated with PCa in this study agrees with the results found for ‘Shinseiki’ (HAWERROTH et al., 2011) and ‘Blanquilla’(ASÍN et al., 2007) pear. The higher production of PCa treated ‘Packham’s in 2011 was likely due to its higher number of fruits. The increase in the number of fruit as a response to PCa have been reported for some pear cultivars but it seems to be cultivar dependent and varies along the years (SMIT et al., 2005; ASÍN et al., 2007) making it difficult to assert if this is really a direct PCa effect. However, when a higher number of fruit is observed this is generally followed by a decrease in the average fruit size which is due to a crop load effect (SUGAR et al., 2004). So, it is reasonable to say that the average fruit weight was not affected by PCa because in general the number of fruit did not differ between treatments.

Regardless of cultivar, return bloom was not affected by PCa in any of the growing seasons, except for ‘Packham’s’ in 2012 where PCa sprayed trees showed a greater return bloom than control (Table 2). Similar results were observed in ‘Blanquilla’ (ASÍN et al., 2007), ‘Abbé Fétel’ and ‘William’s’ pear (COSTA et al., 2004) where PCa showed no negative effect on return bloom. In the other hand, Sugar et al. (2004) found that ‘Bartlet’, ‘Anjou’ and ‘Bosc’ return bloom was reduced the year following PCa application, as well as Smit et al. (2005) found similar results in ‘Forelle’ and ‘Packham’s’. These different responses of pear trees following PCa application seems to be cultivar dependent and PCa rate dependent (RADEMACHER et al., 2004). However, further studies are necessary in order to elucidate the actual effect of PCa over return bloom in pear.

4.7 **CONCLUSIONS**

1- Shoot growth and average node length of ‘Carrick’, ‘Packham’s’ and ‘William’s’ pears are reduced by application of prohexadione calcium at 750 g. ha^{-1} a.i.
2- Return bloom of the investigated cultivars is not negatively affected by prohexadione calcium.
3- Prohexadione calcium is a potential management tool to reduce the need for pruning in vigorous pear orchards.

4.8 **ACKNOWLEDGEMENTS**

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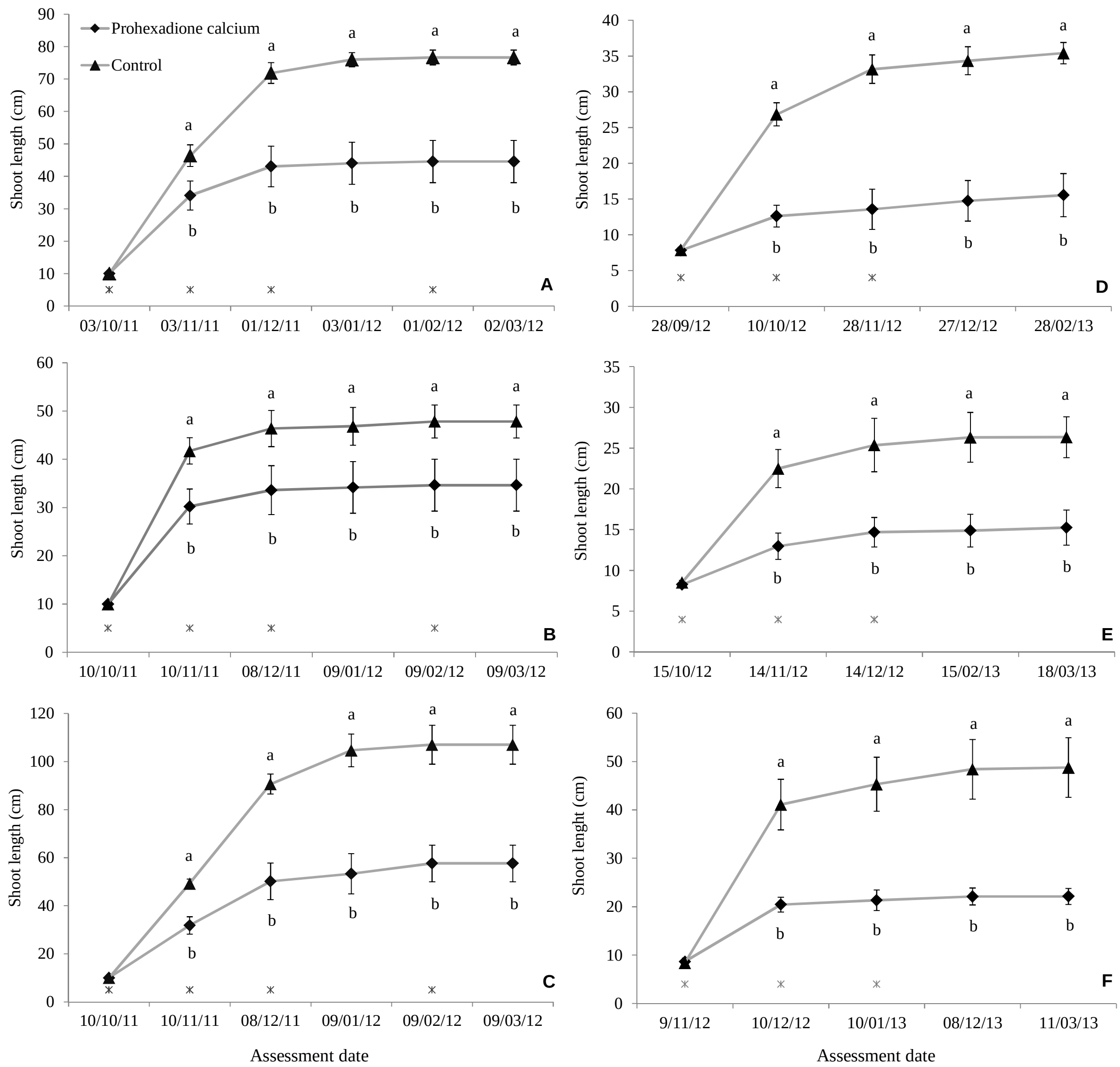

Figure 1. Shoot length of ‘Carrick’, ‘Packham’s’ and ‘William’s’ pears treated with prohexadione calcium (PCa) in the 2011 (A, B and C, respectively) and 2012 (D, E and F, respectively) growing seasons. Different letters within each assessment date indicate significant differences by Duncan’s test ($p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

Table 1. Trunk cross sectional area (TCSA) increment, number of nodes, average internode length and pruning weight of ‘Carrick’, ‘Packham’s’ and ‘William’s’ pears treated with prohexadione calcium (PCa) in the 2011 and 2012 growing seasons.

Treatment	TCSA increment (cm^2)		Number of nodes		Average Internode length (cm)		Pruning weight (kg)	
	2012	2013	2011	2012	2011	2012	2011	2012
				'Carrick'				
Control	15.0	14.70	19.9	13.9 a*	3.9 a	2.5 a	2.90	0.80
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
				'Packham's'				
Control	14.20	9.70	16.6	15.5 a	2.9 a	1.7 a	3.00	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
				'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

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

Table 2. Number of fruits, average fruit weight, production per tree and return bloom of ‘Carrick’, ‘Packham’s’ and ‘William’s’ pear treated with prohexadione calcium (PCa) in the 2011 and 2012 growing seasons.

Treatment	Number of fruits		Average fruit weight (g)		Production per tree (kg)		Return bloom (%)	
	2011	2012	2011	2012	2011	2012	2012	2013
				'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
				'Packham's'				
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
				'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

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

CONSIDERAÇÕES FINAIS

- O projeto de tese inicial incluía dois experimentos com o fitorregulador Promalin. Esses trabalhos foram inicialmente propostos em função do limitado número de plantas e de prohexadiona cálcio (PCa) para realizar todos os trabalhos de tese nessa linha de pesquisa. Dessa forma, o experimento apenas com PCa não seria suficiente para o trabalho de tese. Então, como havia um pomar recém implantado de Rocha e Santa Maria, decidiu-se por realizar os experimentos com Promalin, objetivando o controle de crescimento, assim como a indução de brotações laterais e formação de estruturas de frutificação. Devido aos resultados do primeiro ano terem mostrado limitado controle de crescimento pelo Promalin, os tratamentos não foram repetidos no ano seguinte. Os dados de produção e qualidade de frutas seguiram sendo coletados, mas com a finalidade de verificar o efeito da densidade de plantio. Além disso, desde o início do doutorado, o planejamento sempre foi de fazer o doutorado sanduíche nos Estados Unidos (EUA) em 2012. Felizmente o contato com o Dr. Todd Einhorn foi bem sucedido e conseguimos realizar parte do projeto na principal região produtora de peras dos EUA e do mundo, no *Hood River Valley*. Durante esse período, foram conduzidos dois experimentos com PCa e Ethephon, os quais vieram a compor a versão final da tese. Tenho plena convicção que o fato de manter os trabalhos focados em apenas uma linha de pesquisa, gerou melhores resultados, assim como o meu aprendizado acerca do tema.

- A redução no crescimento vegetativo de pereiras proporcionada pela aplicação de prohexadiona cálcio é muito importante para auxiliar os produtores na obtenção de produções regulares e rentáveis, tanto pela diminuição na necessidade de poda hibernal quanto pelo aumento na frutificação efetiva em algumas cultivares. Além disso, também pode ser utilizado para controlar o vigor das plantas quando há frustração de safra por geadas ou baixa frutificação. A sua utilização no futuro ainda depende do registro do produto por alguma empresa para uso na cultura da pereira e do cálculo custo x benefício da aplicação em cada situação.

- Os resultados do presente estudo mostram que a prohexadiona cálcio é eficiente no controle do crescimento vegetativo de pereiras, seja através de aplicações na planta inteira, ou de aplicações localizadas. Nesse contexto, ela constítui-se como ferramenta potencial para o manejo do crescimento vegetativo em pomares de pereiras em alta densidade.

- A redução no retorno da floração observada com a cultivar ‘D’Anjou’ em resposta à aplicação da prohexadiona cálcio possivelmente tenha sido efeito do aumento na frutificação efetiva, resultando em maior carga de frutas, a qual reconhecidamente exerce efeitos negativos sobre a diferenciação floral. Os resultados obtidos com a aplicação de Etefon, durante o período de diferenciação floral (~60 dias após a plena floração), visando a superação desse problema são promissores. No entanto, recomenda-se a realização de estudos adicionais com diferentes doses e períodos de aplicação. Para as cultivares estudas no Brasil, não foi observada redução no retorno da floração, mas a aplicação de Etefon para aumentar a formação de gemas produtivas seria de grande interesse, uma vez que as produções obtidas ainda são insatisfatórias.

- Os resultados obtidos no presente trabalho com aplicação de prohexadiona cálcio e etefon são promissores, mas estudos adicionais testando diferentes épocas e doses, além de outras cultivares e em diferentes condições edafocimáticas, são necessários.

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APÊNDICES

APÊNDICE A – Carta de aceite do Artigo 2 - "D'Anjou' Pear Shoot Growth and Return Bloom, but Not Fruit size, Are Reduced by Prohexadione-Ca

From: <hortscience@ashs.org>
Date: November 14, 2013, 9:35:36 AM PST
To: <Todd.Einhorn@oregonstate.edu>
Subject: HORTSCI-08129R accepted for publication in HortScience
Reply-To: <hortscience@ashs.org>

November 14, 2013

Dear Todd Einhorn,

The review of your revised manuscript titled "'D'Anjou' Pear Shoot Growth and Return Bloom Are Reduced by Prohexadione-Ca but Not Fruit Size" has been completed, and I am pleased to accept it for publication in HortScience. Publication will be at the earliest possible time, the queue being established by receipt of your final version, the acceptance date at the top of this letter, and available space.

Submit your final version as follows:

TEXT: Please e-mail the final version of your paper in Microsoft Word tohortscience@ashs.org. If you use another word processing program, include an ASCII or rich text file.

GRAPHICS: Send your figures in either TIFF, EPS, or JPG formats via e-mail, disk, or CD. If figures appear in color, tell us if you want them in black-and-white, or will pay for color ($800 per page for print; $25 per image file for online). Production will be delayed if you do not provide this information, as we will need to contact you.

If you cannot e-mail EPS or TIFF formats, you must submit the figures on disk or CD and note the file type and program (name and version) in which they were created. The mailing address is 1018 Duke St., Alexandria, VA 22314, USA.

Please review your paper before submitting your final version. Check for factual errors, incomplete references, and readability. Use double-spacing throughout the paper, including the abstract and references. When your paper nears publication, you will be sent a page proof (galley) in PDF format via e-mail attachment. Look for an email message from "ashrproofs@dartmouthjournals.com" with your manuscript number and eProof in the subject line. NOTE that more than five author alterations on the page proof will be billed to the corresponding author at $10 PER CORRECTION.

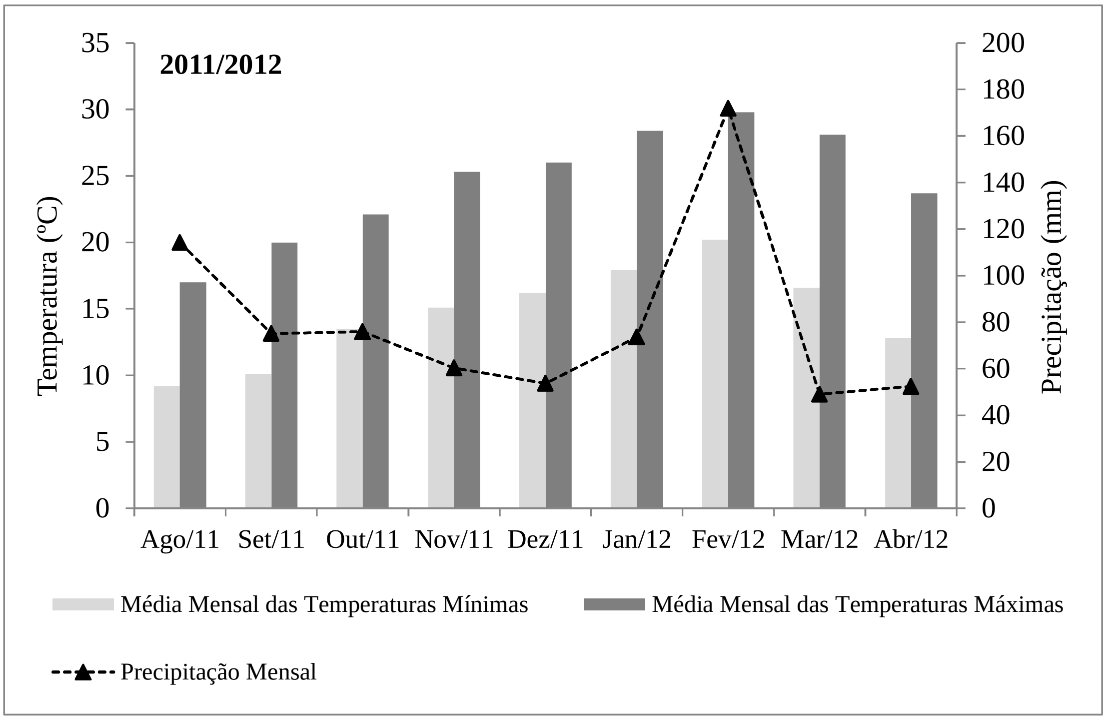
Perhaps you will submit also an impact statement, explaining in laymen's terms the benefits and possible use of your research results, to assist in any efforts toward publicizing your research to the media.

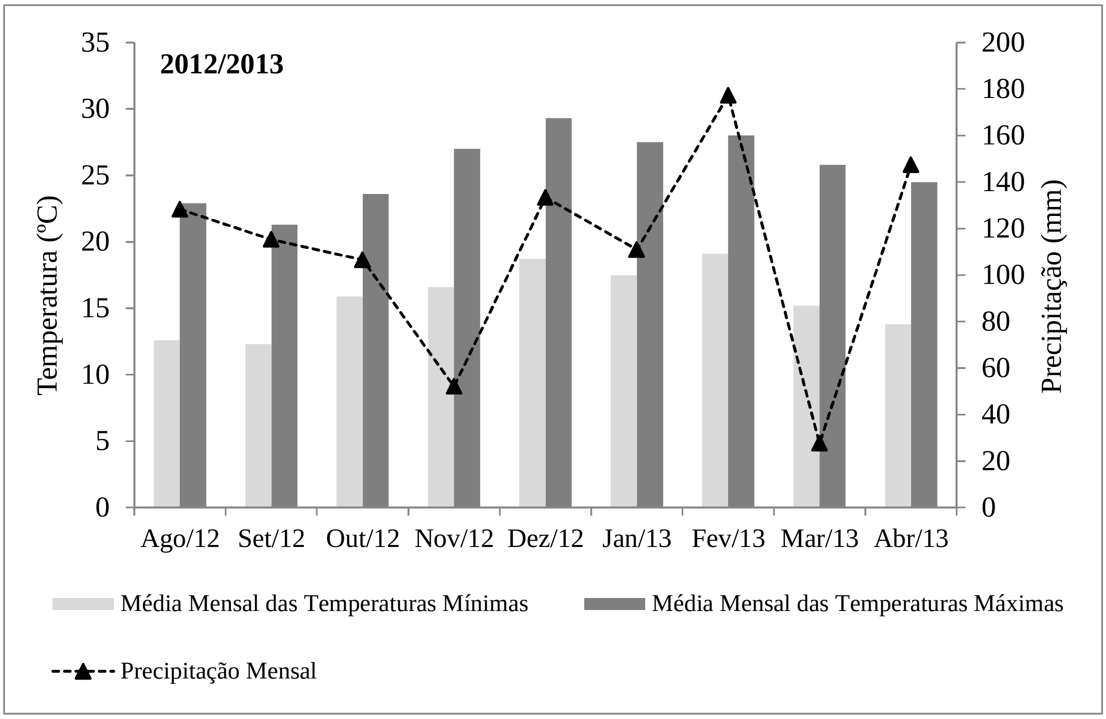
Thank you for publishing in HortScience.

Sincerely,

M. LeRon Robbins
Editor-in-Chief
HortScience
rrobbins@agcenter.lsu.edu

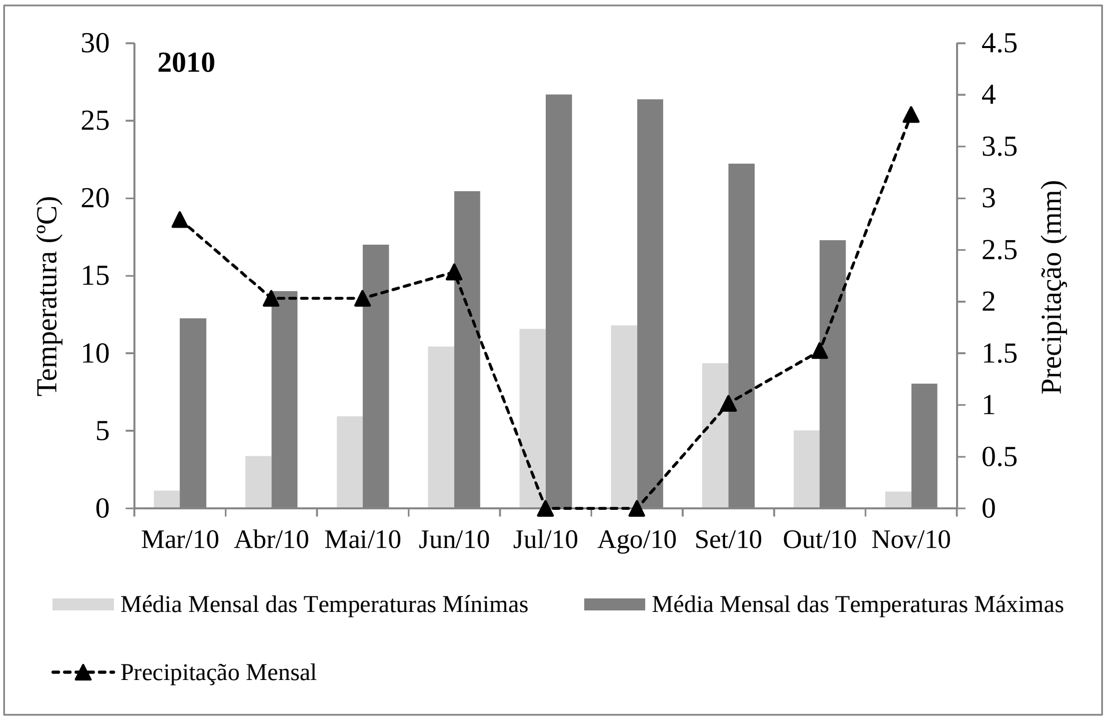
APÊNDICE B – Dados Climáticos da região de Pelotas, RS/Brasil, nas estações de crescimento de 2011/12 e 2012/13.

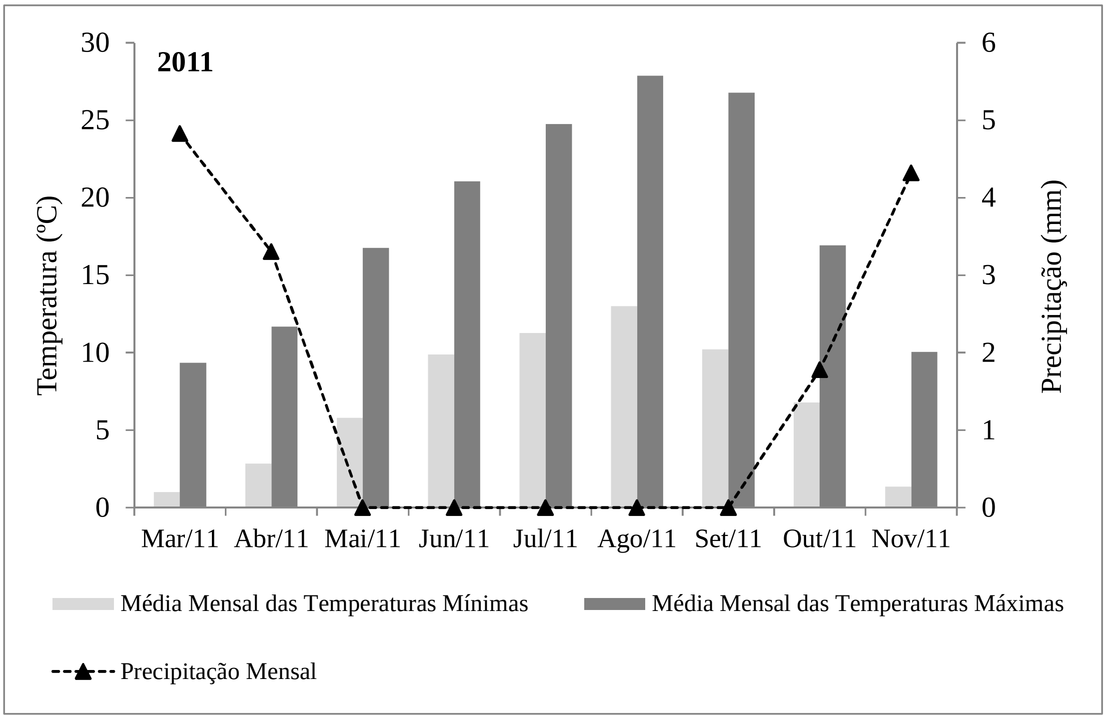


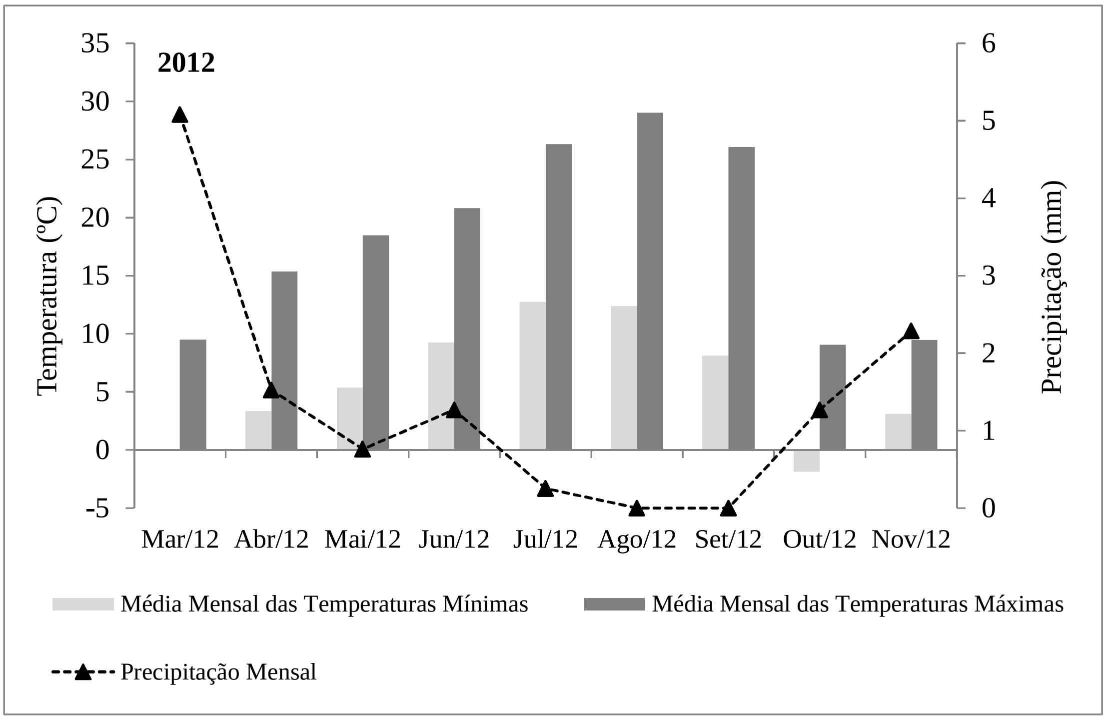


Fonte: Estação Agroclimatológica de Pelotas Convênio Embrapa / UFPel / INMET. Pelotas, RS/Brasil.

APÊNDICE C – Dados Climáticos da região de Hood River, OR/USA, nas estações de crescimento de 2010, 2011 e 2012.







Fonte: Mid Columbia Agricultura Research and Extension Center (MCAREC). Hood River, OR/USA.