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Short communication

Heading cuts and prohexadione-calcium affect the growth and development of 'd'Anjou' pear shoots in a high-density orchard☆

Mateus S. Pasa[a,*], Todd C. Einhorn[b]

[a] CAPES Foundation, Ministry of Education of Brazil, Brasília DF 70040-020, Brazil
[b] Department of Horticulture, Oregon State University, Mid-Columbia Agricultural Research and Extension Center, 3005 Experiment Station Drive, Hood River, OR 97031, USA

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ABSTRACT

Prohexadione calcium (P-Ca) has been shown to effectively reduce the vigor of pear trees. However, an analysis of the effects of P-Ca on growth and development of headed and unheaded shoots has not been performed. Therefore, 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 ~5 cm 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 headed shoots treated with P-Ca compared to unpruned shoots treated with P-Ca. 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 higher yield efficiency once fruiting 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, untreated 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.

1. 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 amplified 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

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* Corresponding author. Tel.: +55 53 81371563.
E-mail address: mateus.pasa@gmail.com (M.S. Pasa).

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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. When applied during early stages of shoot growth, 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). On the contrary, late-season applications of P-Ca may promote shoot growth by protecting endogenous, active GAs from being metabolically inactivated (Rademacher, 2000). 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., 2014), 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. With respect to fruit quality, P-Ca did not affect fruit quality attributes of 'Bartlett' (Elfving et al., 2003), 'Abate Fetel' (Costa et al., 2004) or, 'D'anjou' (Einhorn et al., 2014).

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). Thus, localized shoot growth control in the upper canopy by P-Ca would reduce the negative effects on yield associated with shading.

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.

2. Materials and methods

2.1. 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 m × 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.

2.2. Experimental design and treatments

In April, five-tree plots 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.

2.3. 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. All competing shoots generated below the heading cut, with the exception of the measurement shoot, were removed. 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.

2.4. Statistical analysis

Statistical analyses to detect interaction of main effects (i.e., pruning and P-Ca) were performed using the SAS system software (SAS 9.0; SAS Institute, Cary, NC). The data generated from the second P-Ca application were not used in the interaction analyses since headed shoots did not receive a second P-Ca application. 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. 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 terminated growth by 3 WAFT (Fig. 1 A). Headed shoot response to P-Ca, in contrast, required an additional week to respond 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. 1C, 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.