SHOOT GROWTH CONTROL OF APPLE, PEAR AND PLUM TREES WITH PROHEXADIONE-CALCIUM.

BY

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DECLARATION

I, the undersigned, hereby declare that the work contained in this thesis is my own, original work and that I have not previously, in its entirety or in part, submitted it at any university for a degree.

Mariska Smit Date

LOOTGROEI BEHEER VAN APPEL-, PEER- EN PRUIMBOME MET PROHEKSADIOON-KALSIUM.

OPSOMMING

Oormatige lootgroei van vrugtebome kan verskeie negatiewe effekte tot gevolg hê, insluitende 'n afname in vrugset, vruggrootte, rooi kleur en 'n verlaging in die daaropvolgende jaar se blom. Boordpraktyke soos die gebruik van dwergende onderstamme, ringelering en snoei, beheer nie altyd lootgroei doeltreffend nie. Die gebruik van groeireguleerders, in kombinasie met hierdie boordpraktyke, bied bykomende geleenthede. Proewe is uitgevoer om die effek van die nuwe groeireguleerder proheksadioon-kalsium (P-Ca) op appel, peer en pruim lootgroei te evalueer. Die effek van P-Ca op vrugset, vruggrootte, opbrengs, vrugkwalitiet en die daaropvolgende jaar se blom is ook geëvalueer.

Gedurende die 1999/2000 seisoen is P-Ca toegedien aan voldraende twaalfde blad 'Golden Delicious' bome op M793 onderstamme, ses-en-twintigste blad 'Granny Smith' bome op saailing onderstamme, negende blad 'Royal Gala' bome op M793 onderstamme, sewende blad 'Rosemarie' bome op saailing onderstamme en agste blad 'Songold' bome op 'Marianna' onderstamme in die Villiersdorp area in die Wes Kaap (33°25' S, 19°12' O; ligging ong. 270 m.; Meditereense klimaat). P-Ca is aan die appelbome toegedien teen konsentrasies van 3 x 50, 4 x 50 en 3 x 67 $mg.l^{-1}$ met die eerste toediening by blomblaarval. Geen benatter is by enige van die toedienings gevoeg nie. P-Ca is aan die peer- en pruimbome toegedien teen konsentrasies van 2 x 62.5, 125, 250 en 2 x 125 $mg.l^{-1}$ met die eerste toediening by blomblaarval en pitverharding vir onderskeidelik die peer- en pruimbome. Agral-90 is as benatter gebruik slegs saam met die eerste toediening op die peerbome. Tydens die 2000/2001 seisoen is dieselfde 'Golden Delicious' en 'Royal Gala' bome gebruik as in die 1999/2000 seisoen. Derde blad 'Granny Smith' bome op M793 onderstamme in die Villiersdorp area is gebruik. Sesde blad 'Rosemarie' bome op BP3 onderstamme, vyfde blad 'Golden Russet Bosc' bome op BP1 onderstamme, sewende blad 'Forelle' bome op BP3 onderstamme en sestiende blad 'Packham's Triumph' bome op saailing onderstamme in die Wolseley area in die Wes Kaap is gebruik. P-Ca is weereens aan die appelbome toegedien teen konsentrasies van 3 x 50, 4 x 50 en 3 x 67 $mg.l^{-1}$. Die eerste toediening aan die 'Golden Delicious' en 'Granny Smith' bome was by volblom en die eerste

toediening aan die 'Royal Gala' bome by blomblaarval. Die laaste toediening is 45 dae voor oes gedoen. Geen benatter is met enige van die toedienings bygevoeg nie. P-Ca is aan die peerbome toegedien teen konsentrasies van 50, 75, 150, 2 x 50, 2 x 75 en 3 x 50 $mg.l^{-1}$ met die eerste toediening toe vier tot vyf blare ontvou was en die laaste een 45 dae voor oes. Agral-90 is as benatter gebruik met al die peer bespuitings. By die peer proef is ook 'n ringeleer behandeling ingesluit.

In beide seisoene het P-Ca die lootgroei van al drie appel kultivars verminder. Hergroei het in beide seisoene in al drie kultivars plaasgevind. Dit is dus onduidelik watter behandeling(s) optimaal is vir lootgroei beheer. In die 1999/2000 seisoen het P-Ca 'Royal Gala' vruggrootte verbeter. In die 2000/2001 seisoen is 'Golden Delicious' opbrengs, uitgedruk as kg vrugte geoes / cm stamomtrek, verlaag. Hierdie verlaging in opbrengs kan toegeskryf word aan die lae blom aantal in die lente van 2000 wat gevolg het op die P-Ca behandeling in 1999. In beide seisoene het P-Ca die aantal ontwikkelde sade in 'Royal Gala' verminder terwyl die aantal sade met geaborteerde embrio's verhoog is in die 2000/2001 seisoen. Na vier weke koelopberging (± 5°C) en een week by kamertemperatuur (± 20°C) het P-Ca geen effek op die voorkoms van bitterpit in 'Golden Delicious' gehad nie. Die 'Granny Smith' bome is in die 2000/2001 seisoen geoes voordat enige data ingesamel kon word.

Ringelering het geen effek op lootgroei gehad in enige van die peer kultivars nie, maar P-Ca het lootgroei effektief beheer in 'Rosemarie' en 'Golden Russet Bosc' en tot 'n mindere mate 'Packham's Triumph', maar het geen effek op 'Forelle' lootgroei gehad nie. Ten spyte van die hergroei wat voorgekom het in die 'Rosemarie' bome ongeveer vier weke na oes in die 2000/2001 seisoen, wil dit voorkom asof P-Ca toegedien teen 'n enkele hoë konsentrasie (250 en 150 $mg.l^{-1}$ vir die 1999/2000 en 2000/2001 seisoene onderskeidelik) meer effektief was om lootgroei te beheer as 'n enkele lae konsentrasie of veelvuldige lae konsentrasies. P-Ca het vrugset in 'Rosemarie' en 'Forelle' verhoog in die 2000/2001 seisoen. In beide seisoene het P-Ca 'Rosemarie' vruggrootte verlaag terwyl ringelering 'Forelle' en 'Packham's Triumph' vruggrootte verbeter het in die 2000/2001 seisoen. P-Ca het 'Rosemarie' vrugfermheid en 'Forelle' vrugkleur verhoog in die 2000/2001 seisoen en die aantal 'Packham's Triumph' vrugte met kurkvlek verlaag. Ringelering het 'Packham's Triumph' vrugkleur en TSS-konsentrasie verhoog, maar vrugfermheid verlaag in die 2000/2001 seisoen. P-Ca het die aantal blomme in 'Forelle' en 'Packham's Triumph' verlaag in 2001, terwyl ringelering blom in 'Golden Russet Bosc' en 'Forelle' verhoog het. As gevolg van 'n lae blom- en dus vruggetal in 'Golden Russet Bosc' kon vrugset in 2000 nie bepaal word nie en geen vrugontledings kon gedoen word nie.

Al vier P-Ca behandelings het lootgroei in 'Songold' beheer, maar die 2 x 125 $mg.l^{-1}$ toediening was die effektiefste, beide in terme van totale lootgroei en in beheer van die hergroei wat ongeveer twee weke voor die eerste kommersieële oesdatum plaasgevind het. P-Ca het vrugfermheid verhoog en die TSS-konsentrasie verlaag, beide tydens oes en na vier weke koelopberging by dubbel temperatuur (10 dae by –0.5°C + 18 dae by 7.5°C).

Om saam te vat kan gesê word dat P-Ca 'n effektiewe inhibeerder van lootgroei van die appels 'Golden Delicious', 'Granny Smith' en 'Royal Gala', die pere 'Rosemarie', 'Golden Russet Bosc' en 'Packham's Triumph' en die pruim 'Songold' is. Meer werk is egter nodig om die hergroei te beheer.

SUMMARY

Excessive shoot growth of fruit trees may have various negative effects. These include a decrease in fruit set, fruit size, red colour and in return bloom. Cultural practices that are currently in use, such as the use of dwarfing rootstocks, girdling and pruning do not always give sufficient shoot growth control. The use of plant growth retardants, in combination with these cultural practices, offer additional possibilities. Trials were conducted to evaluate the effect of the new plant growth retardant prohexadione-calcium (P-Ca) on apple, pear and plum shoot growth. In addition, the effect of P-Ca on fruit set, fruit size, yield, fruit quality and return bloom were also evaluated.

During the 1999/2000 season P-Ca was applied to full bearing twelfth leaf 'Golden Delicious' trees on M793 rootstock, twenty-sixth leaf 'Granny Smith' trees on seedling rootstock, ninth leaf 'Royal Gala' trees on M793 rootstock, seventh leaf 'Rosemarie' trees on seedling rootstock and eighth leaf 'Songold' trees on 'Marianna' rootstock in the Villiersdorp area in the Western Cape (33°59' S, 19°17' E; ca. 365 m a.s.l.; Mediterranean climate). P-Ca was applied at concentrations of 3 x 50, 4 x 50 and 3 x 67 $mg.l^{-1}$ to the apple trees. The first application was at petal drop with no surfactant added with any of the treatments. P-Ca was applied at concentrations of 2 x 62.5, 125, 250 and 2 x 125 $mg.l^{-1}$ to the pear and plum trees. The first application was at petal drop and pit-hardening for the pear and plum trees respectively. Agral-90 was used as surfactant only with the first spray applied to the pear trees. During the 2000/2001 season the same 'Golden Delicious' and 'Royal Gala' trees were used as in the 1999/2000 season. Thirteenth leaf 'Granny Smith' trees on M793 rootstock in the Villiersdorp area were used. Sixth leaf 'Rosemarie' trees on BP3 rootstock, fifth leaf 'Golden Russet Bosc' trees on BP3 rootstock, seventh leaf 'Forelle' trees on BP3 rootstock and 16^{th} leaf 'Packham's Triumph' trees on seedling rootstock in the Wolseley area in the Western Cape were used. P-Ca was again applied at concentrations of 3 x 50, 4 x 50 and 3 x 67 $mg.l^{-1}$ to the apple trees. The first application in the 'Golden Delicious' and 'Granny Smith' trees was at full bloom and at petal drop in the 'Royal Gala' trees. The last application was at 45 days before harvest. No surfactant was added with any of the sprays. P-Ca was applied at concentrations of 50, 75, 150, 2 x 50, 2 x 75 and 3 x 50 $mg.l^{-1}$ to the pear trees with the first spray when 4 to 5 leaves were unfolded and the last one 45 days before harvest. Agral-90 was added as surfactant with all the pear sprays. The pear trial also included a girdling treatment.

P-Ca effectively inhibited shoot growth of all three apple cultivars in both seasons. Re-growth occurred in both seasons in all the cultivars, therefore it is not clear which treatment(s) is optimal for reducing shoot growth. P-Ca increased fruit size in 'Royal Gala' in the 1999/2000 season and decreased yield expressed as kg fruit harvested / cm trunk circumference in 'Golden Delicious' in the 2000/2001 season. This reduction in yield can be attributed to the low number of flower clusters in the spring of 2000 following P-Ca treatment in 1999. P-Ca decreased the number of developed seeds in 'Royal Gala' in both seasons and increased the number of seeds with aborted embrio's in the 2000/2001 season. After four weeks of cold storage (± 5°C) and one week at room temperature (± 20°C), P-Ca had no effect on the occurrence of bitter pit in 'Golden Delicious'. The 'Granny Smith' trees were harvested before fruit analysis could be done in the 2000/2001 season.

In pear, girdling was not effective in inhibiting shoot growth in any of the cultivars, but P-Ca proved to be an effective inhibitor of shoot growth of 'Rosemarie' and 'Golden Russet Bosc', and to a lesser degree 'Packham's Triumph', but not 'Forelle'. Despite the re-growth that occurred ca. four weeks after harvest in 'Rosemarie' in the 2000/20001 season, it appears that a single high rate (250 and 150 $mg.l^{-1}$ for the 1999/2000 and 2000/2001 seasons respectively) P-Ca application is more effective than a single low rate or multiple low rates in inhibiting shoot growth. In the 2000/2001 season P-Ca increased fruit set in 'Rosemarie' and 'Forelle'. In both seasons P-Ca reduced 'Rosemarie' fruit size while girdling increased 'Forelle' and 'Packham's Triumph' fruit size in 2000/2001. P-Ca increased 'Rosemarie' fruit firmness and 'Forelle' fruit colour in the 2000/2001 season and decreased the percentage of 'Packham's Triumph' fruit with cork spot. Girdling increased 'Packham's Triumph' fruit colour and TSS concentration while decreasing fruit firmness in 2000/2001. P-Ca reduced return bloom in 'Forelle' and 'Packham's Triumph' in 2001, while girdling increased 'Golden Russet Bosc' and 'Forelle' return bloom. Due to poor flowering and thus low fruit number in 'Golden Russet Bosc', fruit set in 2000 could not be determined and no fruit analysis could be done.

In 'Songold' all four P-Ca treatments inhibited shoot growth, but the 2 x 125 $mg.l^{-1}$ treatment were the most effective, both in terms of total shoot growth and in reduction of the re-growth that occurred ca. two weeks before the first commercial harvest date. P-Ca increased fruit firmness and decreased TSS concentration both at harvest and after four weeks of cold storage at dual temperature (10 days at –0.5°C + 18 days at 7.5°C).

In conclusion P-Ca is an effective inhibitor of shoot growth of the apples ‘Golden Delicious’, ‘Granny Smith’ and ‘Royal Gala’, the pears ‘Rosemarie’, ‘Golden Russet Bosc’ and ‘Packham’s Triumph’ and the plum ‘Songold’, but more work is needed to control re-growth.

To my parents,

Willem and René Smit.

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1. INTRODUCTION

The management of shoot growth of fruit trees is probably one of the most important orchard management practices, especially in the light of the increasing trend towards the establishment of higher density orchards (Fallahi, 1999).

According to Evans et al. (1997) some potential benefits which may arise from managing excessive shoot growth include:

* A reduction in canopy density which should cause a reduction in tree row volume and a net reduction in pesticide use through reduced rates as well as increased efficiency.
* An increase in light penetration and air movement.
* A reduction in host susceptibility to certain diseases and lush feeding insects.
* An increase in fruit colour, size and packout.
* An increase in return bloom.
* An increase in fruit set.

Various cultural practices are currently in use to control excessive shoot growth of trees. These practices include the use of dwarfing rootstocks, tree training, girdling and perhaps the most common one of them all, dormant and summer pruning, but despite the use of these practices, the management of excessive growth continuous to be a challenge (Fallahi, 1999; Davis and Curry, 1991). The use of plant growth retardants offer additional possibilities, especially if it is used in combination with these cultural practices.

The first plant growth retardants were discovered in 1949 (Mitchell et al., 1949) and since then many other compounds have been detected, some of which have been introduced into horticultural practice (Rademacher, 2000). Daminozide was an important growth retardant and improver of fruit quality, especially in apples (Rademacher, 1995). After the withdrawal of daminozide from the market, other growth retardants such as paclobutrazol or uniconazole-P could replace it only to a small extent, since they are registered only in a restricted number of countries for use in fruit production and are relatively difficult to apply (Basak and Rademacher, 2000). No growth retardant is currently registered for use on apples in South Africa, while chlormequat chloride is registered for autumn application on 'Doyenne du

Comice' pears and paclobutrazol for autumn or spring appplications on the Japanese plums 'Songold', 'Harry Pickstone' and 'Casselmann' (Vermeulen et al., 1997).

The purpose of this study was to evaluate the use of the new plant growth retardant, prohexadione-calcium, on apple, pear and plum trees.

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2. THE USE OF PROHEXADIONE-CALCIUM AS GROWTH RETARDANT FOR DECIDUOUS FRUIT TREES

2.1 INTRODUCTION

Managing excessive vegetative growth of fruit trees continues to be a challenge (Fallahi, 1999). Although various cultural practices such as the use of dwarfing rootstocks, girdling, reduced application of fertiliser and water, regulation of cropping, root restriction, limb scoring, tree training and perhaps the most common cultural practice of them all, dormant and summer pruning, have been used, the search for a chemical means of managing vegetative growth continues (Fallahi, 1999; Davis and Curry, 1991).

The potential for chemical control of plant growth has intrigued plant scientists since at least the 1940's (Davis and Curry, 1991). The first plant growth retardants, nicotinium compounds, became known when Mitchell et al. (1949) reported that they decreased stem elongation in bean plants without inducing growth malformations. Many other compounds have subsequently been detected, some of which have been introduced into agronomic or horticultural practice (Rademacher, 2000). Maleic hydrazide was the first commercially significant growth retardant and was used considerably in the 1950's. The use of chemicals to control fruit tree growth began in the early 1960's when daminozide was used on young apple trees (Davis and Curry, 1991).

Researchers have evaluated, amongst others, inhibitors of gibberellin biosynthesis as tools for restricting vegetative growth or shifting the balance from vegetative growth to cropping. A compound that has been tested for such purposes is prohexadione-calcium (P-Ca) (Owens and Stover, 1999).

The aim of this literature review is to give a general overview of P-Ca as well as a summary of the results obtained with some of the work done on this compound.

2.2 GIBBERELLINS

Gibberellins (GAs) are diterpenoids consisting of 19 or 20 carbon atoms (Rademacher, 1989, 1991a, 2000) and they act throughout the life cycle of plants (Hedden and Kamiya, 1997). They are present in all higher plants, usually at concentrations ranging from a few micrograms or less per kilogram of old vegetative tissue to several milligrams per kilogram in young tissue or immature seeds (Rademacher, 1989).

GA biosynthesis occurs mainly in actively growing tissues with young leaves and rapidly growing internodes important sites (Jones and Phillips, 1966; Cleland, 1969; Smith, 1992). Their most obvious function within the hormonal system of higher plants is to regulate the rate of growth and final length of internodes. This is best seen in certain "dwarf" cultivars which, due to disturbed GA relations, have very short internodes, but upon treatment with GA grow to normal or intermediate heights depending on the dose of GA supplied (Graebe and Ropers, 1978).

GAs determine internode lengths by stimulating cell elongation, and, to a lesser degree, cell division (Rademacher, 1989). It has been proposed that GA_1 is the primary endogenous GA active in promoting shoot elongation in many plant species (Phinney, 1984, 1985; Ingram et al., 1986; Fujioka et al., 1988; Kobayashi, 1989; Nakayama et al, 1990b, 1992; Junttila et al., 1991). Seed germination, flower induction, anther development, seed and pericarp growth and the breaking of dormancy is also examples of processes that depend on the action of endogenous GAs (Graebe and Ropers, 1978; Hedden and Kamiya, 1997). Regulation of GA biosynthesis is therefore of fundamental importance to plant development and it's adaptation to the environment (Hedden and Kamiya, 1997).

The biosynthesis of GAs is relatively well understood and can be separated into three stages: (1) The formation of *ent*-kaurene from mevalonic acid (MVA), (2) the oxidation of *ent*-kaurene to GA_{12}-aldehyde and (3) the further oxidation of GA_{12}-aldehyde to the different GAs (Graebe and Ropers, 1978; Hedden et al., 1978; Graebe et al., 1980; Graebe, 1987; Rademacher, 1989, 1991a, 1995, 2000; Hedden and Kamiya, 1997).

Only a few of the GAs possess biological activity per se, whereas the majority are precursors or catabolites (Rademacher, 2000).

2.3 GROWTH RETARDANTS

The regulation of the growth and development of higher plants are controlled by the plant's own hormones. Besides these, there are a great number of synthetic compounds that also exercise growth-regulating effects on the plant when applied exogenously (Nitsche et al., 1985).

Plant growth retardants are synthetic compounds that are used to reduce the shoot length of responsive plants in a desired way without being phytotoxic or causing malformations (Dicks, 1980; Davis and Curry, 1991; Rademacher, 1995, 2000). This is primarily achieved by reducing cell elongation, but also by lowering the rate of cell division (Rademacher, 1991a, 1995, 2000).

We can classify the existing plant growth retardants into three main groups: (1) Ethylene-releasing compounds, (2) inhibitors of GA translocation and (3) inhibitors of GA biosynthesis (Rademacher, 1991a).

Four groups of GA biosynthesis inhibitors are known: (1) Onium compounds, (2) compounds with an N-containing heterocycle, (3) acylcyclohexanediones and related compounds and (4) 16,17-dihydro GAs. Each of these groups inhibit GA metabolism at distinct steps (Rademacher, 2000).

P-Ca falls into the group acylcyclohexanediones and related compounds (Rademacher, 1993; Brown et al., 1997).

2.4 PROHEXADIONE-CALCIUM

2.4.1 Description and formula

Structural formula: See Fig. 1.

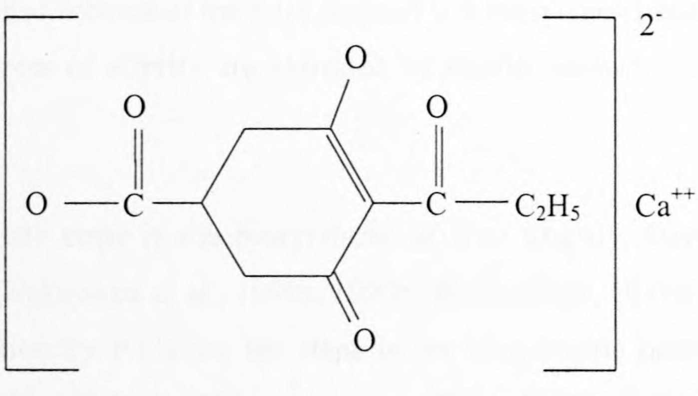

Fig. 1. Structural formula of prohexadione-calcium (Elvers et al., 1992)

Empirical formula: $C_{10}H_{10}O_5Ca$ (Elvers et al., 1992)

Chemical name: Calcium 3-oxido-4-propionyl-5-oxo-3-cyclohexenecarboxylate (Evans et al., 1999; Yoder et al., 1999)
Molecular weight: 250.2 (Elvers et al., 1992)

2.4.2 Uptake and translocation

Foliar absorption of P-Ca is the only significant means of plant uptake. Uptake is generally complete within four hours following application (Rademacher, 2001). P-Ca is then primarily translocated acropetally to the growing points of individual shoots with minimal basipetal movement (Evans et al., 1997, 1999).

Typically, only the growth of treated shoots is affected. P-Ca does not persist in the plant or directly affect vegetative growth the following season (Evans et al., 1999).

2.4.3 Mode of action

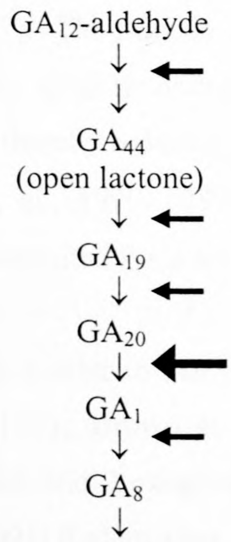

Fig. 2. Simplified scheme of the third stage of GA biosynthesis and points of inhibition by P-Ca (lower degrees of activity are indicated by smaller arrows) (Adapted from Rademacher, 1995)

P-Ca inhibits late steps in the biosynthesis of GAs directly, thereby reducing longitudinal shoot growth (Nakayama et al., 1990a, 1990b; Rademacher, 1991b; Brown et al., 1997). The sites of inhibition by P-Ca are the steps in the biosynthetic pathway of GAs distal to the synthesis of GA_{12}-aldehyde (Nakayama et al, 1990a, 1990b; Rademacher et al., 1990). That means P-Ca inhibits some of the steps of the third stage in the biosynthesis of GAs which primarily takes place in the cytocol (Rademacher, 2000). These reactions involve both microsomal (membrane-bound) and soluble (not membrane associated) oxidases (Rademacher, 1989, 1991a). The early hydroxylations are often catalysed by microsomal mono-oygenases (Graebe, 1987; Rademacher, 2000) while the intermediate and late hydroxylations tend to be catalysed by soluble dioxygenases (Graebe, 1987; Rademacher, 1989, 2000), which require 2-oxoglutarate, Fe^{2+} and oxygen (Hedden and Graebe, 1982; Kamiya and Graebe, 1983; Graebe, 1987; Kwak et al., 1988; Nakayama et al., 1990b; Griggs et al., 1991) and are stimulated by ascorbate (Hedden and Graebe, 1982; Graebe, 1987; Kwak et al., 1988; Griggs et al., 1991).

Studies with cell-free enzyme systems derived from seeds of different plant species, for example *Phaseolus vulgaris* and *Cucurbita maxima* as well as with rice seedlings, showed that P-Ca mainly inhibits 3 β-hydroxylase activity and to a lesser extent 2 β-hydroxylase activity (Nakayama et al., 1990a, 1990b; Griggs et al., 1991; Hedden, 1991; Davis and Curry, 1991; Brown et al., 1997). The primary target of P-Ca seems to be the 3 β-hydroxylation of GA_{20} (inactive) to GA_1 (highly biologically active) (Rademacher, 1991b, 1993, 1995; Nakayama et al. 1992), thereby reducing the levels of GA_1 and increasing the levels of GA_{20} (Fig. 1) (Nakayama et al., 1990a, 1990b; Brown et al., 1997). These 2β - and 3β - hydroxylations that are inhibited P-Ca are catalysed by soluble dioxygenases.

The structure of P-Ca is similar to that of the co-substrate 2-oxoglutarate (Nakayama et al., 1990a; Griggs et al., 1991; Brown et al., 1997; Rademacher, 2000). These structural similarities between P-Ca and 2-oxoglutarate might be responsible for the blocking of GA metabolism (Hedden, 1991; Rademacher, 1991b) due to competitive inhibition with respect to 2-oxoglutarate (Rademacher et al., 1990; Griggs et al., 1991; Hedden, 1991).

Histological studies on the second leaf in wheat demonstrated that low concentrations of P-Ca primarily reduced cell elongation, whereas with increasing concentrations cell division was also inhibited (Grossmann et al., 1994). While the reduction in cell elongation appears to be caused by the inhibition of GA biosynthesis, the mechanism of the effect of P-Ca on cell division remains unclear, since there is little evidence for direct participation in this process (Sauter and Kende, 1992).

2.4.4 Metabolism

P-Ca effectively reduces the level of gibberellin in higher plants for three to six weeks, at most eight, following application (Rademacher, 2001), and after deacylation and ring cleavage the naturally occurring propane-1,2,3-tricarboxylic acid (tricarballylic acid) is formed, which is incorporated into the plant matrix (Evans et al., 1999).

In soil, P-Ca rapidly dissipates, mostly to carbon dioxide (Evans et al., 1997, 1999; Winkler, 1997a), as a result of natural microbial metabolism (Winkler, 1997a, 1997b), with a half-life time of less than one day (Evans et al., 1997; Winkler, 1997a; Rademacher, 2000). In water, P-Ca degrades by photolysis to carbon dioxide and other natural products (Evans et al., 1999) while in mammals, P-Ca is rapidly absorbed and then excreted. Accumulation in tissues of mammals has not been observed (Evans et al., 1999).

2.4.5 Toxicological and eco-toxicological properties

P-Ca is relatively non-toxic (Evans et al., 1997; Winkler, 1997a; Owens and Stover, 1999). Acute studies (rats) have determined an oral $LD_{50} > 5000$ mg/kg, an acute dermal $LD_{50} > 2000$ mg/kg and an acute inhalation $LD_{50} > 4.21$ mg.l-1 (Evans et al., 1997, 1999; Winkler, 1997a). Additional studies have indicated that P-Ca will not cause any skin irritation and may cause only minimal eye irritation. Chronic studies have shown only minor effects at high doses (Evans et al., 1997; Winkler, 1997a). P-Ca has no carcinogenic, mutagenic or tetragenic effects (Evans et al., 1997, 1999; Winkler, 1997a) and also no negative effects on birds, fish, honeybees or soil micro-organisms (Evans et al., 1999).

2.4.6 Side effects

Related enzymatic reactions may be found in the biosynthesis of GAs as well as in the metabolism of other terpenoids or further compounds (Rademacher, 1991a). That is, P-Ca may also have an influence on reactions besides those involved in the biosynthesis of GAs.

It has been observed that relatively high dosages of P-Ca reduced anthocyanin production in carrot cell suspension cultures (Ilan and Dougall, 1992) and inhibited anthocyanin production in the petals of petunias, linseed and corn-flowers (Rademacher, 1991a). It has also been observed that after treatment with P-Ca, at a concentration of 250 $mg.l^{-1}$, the leaves of the apple 'Weirouge', normally coloured intensively red, almost completely lost their colour (Roemmelt et al., 1999a). This effect can be explained by the fact that the biosynthesis of anthocyanins, similar to GA biosynthesis, also comprises steps that are catalysed by 2-oxoglutarate-dependant dioxygenases (Rademacher, 1991b; Heller and Forkmann, 1998). In particular, 3-hydroxylation of flavanones to flavanonoles must be considered as a target enzyme for this side effect (Rademacher, 1991a).

Luteoliflavan, a flavonoid which has not been described to occur in apple so far could be detected within four hours after P-Ca treatment in leaves and flowers of the apple rootstock M9. It reached the highest levels in the youngest leaves. Several other flavonoid-type compounds were also observed, probably belonging to an unusual pathway induced by P-Ca (Roemmelt et al., 1999a).

It has also been observed by Grossmann et al. (1994) that P-Ca decreases ethylene formation in plants. The effect of P-Ca on ethylene levels may be explained by the fact that ethylene is generated from 1-aminocyclopropane-1-carboxylate (ACC) in a reaction catalysed by ACC-oxidase. 2-Oxoglutarate and similar compounds inhibit ACC-oxidase activity (Iturriagagoitia et al., 1996). Thus, due to structural similarities between P-Ca and 2-oxoglutarate, P-Ca inhibits ACC-oxidase activity.

P-Ca led to increased concentrations of cytokinins and abscisic acid (ABA) in the shoots of wheat- and oilseed rape seedlings, and to a reduction in the 3-indoleacetic acid (IAA) concentration in the shoots of the wheat seedlings (Grossmann et al., 1994). Since no immediate effect of P-Ca on the metabolism of cytokinins, ABA and IAA are conceivable, indirect effects seem to play a role (Rademacher, 2000).

2.5 THE USE OF PROHEXADIONE-CALCIUM

Here follows a summary of the results obtained with some of the P-Ca experiments that were previously done. This is only to give a general overview of the results obtained with different concentrations and application times of P-Ca.

2.5.1 Apple

2.5.1.1 Fuji

Seven year old bearing trees as well as vigorous non-bearing trees (from the same orchard) on EMLA7 in Ohio (USA) were used. The first application was at two days after petal fall, with the second one 29 days later.

Table 1. The effect of P-Ca on shoot growth in the year of treatment and on flowering intensity in the following year

Treatment	Bearing trees		Non-bearing trees
	Average length of terminal shoots (cm)	**Fruit/100 flower clusters**	**Average length of terminal shoots (cm)**
Control	33.4 a	71 a	34.7 a
125 mg.l^{-1}	24.8 b	76 a	24.4 b
250 mg.l^{-1}	14.9 c	115 a	23.9 b
125+125 mg.l^{-1}	18.6 bc	82 a	22.8 b

$P \leq 0.05$

At eight weeks after treatment with P-Ca, the non-bearing control trees were actively growing, while the non-bearing treated trees had apparently quit growing and set terminal buds. However, shoot growth from eight weeks after treatment until the end of the season reinitiated in the non-bearing treated trees. No re-growth was observed with the bearing trees With the bearing trees, results suggest that the 250 mg.l^{-1} treatment or the 2 x 125 mg.l^{-1} treatment tended to provide superior, as well as more uniform growth control than 125 mg.l^{-1} applied once. Results also indicate that trees that are poorly cropped will require higher rates and more aggressive use patterns than trees with adequate crop load. Although P-Ca did not significantly affect fruit/100 flower clusters, there was a trend towards increased fruit set at the 250 mg.l^{-1} treatment (Evans et al., 1997).

2.5.1.2 Gloster

Six year old trees on M9 in Poland were used. The first application was at one week after flowering (shoots ±12 cm long), with the second one four weeks after flowering.

Table 2. The effect of P-Ca on shoot growth characteristics

	In the year of treatment		In the following year
Treatment	**Average length of terminal shoots (cm)**	**Number of spurs/tree**	**Average length of terminal shoots (cm)**
Control	35.6 c	217 c	37.9 b
75 mg.l^{-1}	21.2 ab	197 bc	37.7 b
100 mg.l^{-1}	23.8 ab	137 a	-
200 mg.l^{-1}	20.7 a	176 abc	24.8 a
250 mg.l^{-1}	25.1 b	221 c	43.8 b
75+50 mg.l^{-1}	20.2 a	145 a	-
100+50 mg.l^{-1}	19.7 a	133 a	-
200+50 mg.l^{-1}	22.8 ab	157 ab	-

$P \leq 0.05$

P-Ca applied once at 200 mg.l^{-1} or twice at the doses 75, 100 and again 50 mg.l^{-1} acted very intensively and caused a significant reduction in the number and length of terminal shoots in the year of treatment. Sufficient shoot length reduction was achieved already at the lower concentrations of 75 to 100 mg.l^{-1}.

Table 3. The effect of P-Ca on fruit set and on yield, fruit size and fruit quality at harvest in the year of treatment

Treatment	**Number of fruit/cm^2 TCSA***	**Yield (kg/tree)**	**Average fruit weight (g)**	**% fruits with red colour on >75 % of surface**
Control	9.3 a	32 bc	176 c	80 ab
75 mg.l^{-1}	10.7 ab	32 bc	178 c	93 b
100 mg.l^{-1}	11.7 b	29 abc	164 bc	81 ab
200 mg.l^{-1}	12.3 b	27 ab	142 a	93 b
250 mg.l^{-1}	11.8 b	34 c	156 ab	71 a
75+50 mg.l^{-1}	11.2 ab	25 a	159 b	91 b
100+50 mg.l^{-1}	10.1 ab	26 ab	154 ab	90 b
200+50 mg.l^{-1}	11.8 b	31 abc	158 b	73 a

$P \leq 0.05$

*TCSA – trunk cross section area

All the trees were flowering very abundantly in the following year, with the control trees displaying the most intensive flowering. Treatments with P-Ca did not visibly affect yield and fruit size. P-Ca had no significant influence on the intensity of russeting or the firmness of the fruits at $P \leq 0.05$ (Basak and Rademacher, 2000).

2.5.1.3 Granny Smith

Eleven year old trees on M7 in North Carolina (USA) were used (in 1996) and P-Ca applied as summarised in Table 4.

Table 4. The effect of P-Ca treatments on shoot growth in the year of treatment

Concentration ($mg.l^{-1}$ P-Ca) applied at (DAPF)*					**Total**	**Average shoot length (cm)**
0	**7**	**14**	**21**	**30**		**107 DAPF***
0	-	-	-	-	0	48 a
-	250	-	-	-	250	20 cd
-	-	-	250	-	250	30 bc
-	-	62	188	-	250	25 bcd
620	-	62	126	-	250	18 d
-	62	-	188	-	250	22 bcd
-	-	62	188	250	500	26 bcd
-	-	-	500	-	500	31 b

$P \leq 0.05$

*DAPF - days after petal fall

A single application of 250 $mg.l^{-1}$ applied at either 7 or 21 DAPF was just as effective as 500 $mg.l^{-1}$ applied 21 DAPF. However, the treatment at 7 DAPF was more effective because it was applied when less growth had occurred. When P-Ca was applied at 62 and 188 $mg.l^{-1}$ at 14 and 21 DAPF, respectively, a third application of 250 $mg.l^{-1}$ at 30 DAPF, which doubled the total amount of P-Ca applied, had no additional effect on shoot growth.

Twelve year old trees on M7 in North Carolina (USA) were used (in 1997) and P-Ca applied as summarised in Table 5.

Table 5. The effect of P-Ca treatments on shoot growth in the year of treatment

Concentration ($mg.l^{-1}$ P-Ca) applied at (DAPF)*					Total	Average shoot
0	**10**	**20**	**30**	**60**		**length (cm)**
0	-	-	-	-	0	75 a
31	31	31	-	-	93	41 b
31	31	31	31	-	124	31 bcd
31	-	-	-	125**	156	29 bcd
62	62	-	-	125**	187	24 cd
62	62	62	-	-	186	38 bc
62	62	62	62	-	248	29 bcd
62	-	-	-	125**	187	21 d
62	62	-	-	125**	249	23 d
94	94	-	-	-	188	34 bc
94	94	94	-	-	282	30 bcd
94	94	94	94	-	376	39 b
94	-	-	-	125**	219	32 bcd

$P \leq 0.05$

*DAPF - days after petal fall

**An additional $125 mg.l^{-1}$ P-Ca was applied to treatments that showed renewed terminal bud break and shoot extension at 60 DAPF.

Regardless of the concentration used, numbers of applications or total concentration applied, all P-Ca treatments significantly reduced shoot length. Trees receiving a single application of 31, single or double applications of 62 $mg.l^{-1}$, or a single application of 94 $mg.l^{-1}$ all showed re-growth by 60 DAPF. Three or four sequential applications of 31, 62 or 94 $mg.l^{-1}$, none of which permitted re-growth at 60 DAPF, were all equally effective. Applying P-Ca in four equal applications was much more effective than applying low rates followed by a higher concentration. An additional application of 125 $mg.l^{-1}$ at 60 DAPF had no additional effect on growth.

Thirteen year old trees on M7 in South Carolina (USA) were used (in 1997) and P-Ca applied as summarised in Table 6.

Table 6. The effect of P-Ca treatments on shoot growth in the year of treatment

Concentration ($mg.l^{-1}$ P-Ca) applied at (DAPF)*					Total	Average shoot
0	**10**	**20**	**30**	**60**		**length (cm)**
0	-	-	-	-	0	119 ab
0	-	-	-	125	125	120 a
40	40	40	120	-	240	108 abc
40	40	40	120	125	365	96 bcd
40	40	40	40	-	160	90 cde
40	40	40	40	125	285	90 cde
60	60	60	60	-	240	70 ef
60	60	60	60	125	365	68 ef
80	80	80	80	-	320	60 f
80	80	80	80	125	445	73 def
100	100	100	100	-	400	66 f
100	100	100	100	125	525	74 ef

$P \leq 0.05$

*DAPF - days after petal fall

Shoot growth continued all summer in South Carolina in 1997, while in North Carolina growth had almost stopped by 8 July. A sequence of four P-Ca applications at 10 day intervals beginning at petal fall was effective until early July at both locations. However, growth resumed in South Carolina, paralleling that of the control. The P-Ca treatment in North Carolina retarded growth until the control stopped growing in early July, but was unable to retard growth as effectively in South Carolina where control trees grew all summer (Unrath, 1999)

2.5.1.4 Jonagold

Two year old trees on M26 in Poland were used. The trees were bearing fruits for the first time. The first application (T_1) was one week after flowering (shoots ±10 cm long) and the second one (T_2) three weeks after flowering.

Table 7. The effect of P-Ca on shoot growth characteristics in the year of treatment

Treatment	**Average length of terminal + lateral shoots (cm)**	**Number of spurs/tree**
Control	27.6 bc	51 cd
75 $mg.l^{-1}$ T_1	25.8 ab	44 bcd
150 $mg.l^{-1}$ T_1	23.2 a	62 e
75 $mg.l^{-1}$ T_1+75 $mg.l^{-1}$ T_2	23.4 a	58 e
75 $mg.l^{-1}$ T_2	27.6 bc	62 e
150 $mg.l^{-1}$ T_2	30.3 c	42 bc

$P \leq 0.05$

A significant reduction of shoot growth was found only after early treatments with 150 $mg.l^{-1}$ P-Ca. Only in these trees a reduction of the number of long shoots (>40 cm) and an increase of the number of short shoots (>20 cm) was encountered. When trees were sprayed at the lowest concentration or were treated too late, there was no response or even a certain degree of growth stimulation occurred. When P-Ca was applied at a dosage rate inhibiting the growth, it slightly increased the number of spurs.

Table 8. The effect of P-Ca on fruit set and on yield and fruit size at harvest in the year of treatment and on flowering intensity in the following year

Treatment	**% fruit set**	**Yield (kg/tree)**	**Average fruit weight (g)**	**Number of flower clusters/tree in the following year**
Control	9.7 a	2.4 abc	204 ab	199 n.s.
75 $mg.l^{-1}$ T_1	12.4 ab	2.0 a	244 bc	180 n.s.
150 $mg.l^{-1}$ T_1	16.7 bc	3.4 c	208 abc	186 n.s.
75 $mg.l^{-1}$ T_1+75 $mg.l^{-1}$ T_2	11.0 ab	2.1 ab	248 c	166 n.s.
75 $mg.l^{-1}$ T_2	11.2 ab	2.6 abc	238 bc	188 n.s.
150 $mg.l^{-1}$ T_2	12.8 ab	2.8 abc	216 abc	185 n.s.

$P \leq 0.05$

Only the early 150 $mg.l^{-1}$ treatment increased fruit set and trees from this treatment also had the highest yield. The largest fruit were found on the trees sprayed twice with the low dosages. P-Ca had no significant influence on the intensity of russeting on the fruits at $P \leq 0.05$ (Basak and Rademacher, 2000).

2.5.1.5 Lobo

Nine year old trees on M26 in Poland were used. The trees were typically biennial bearing and during the year of treatment they were fruiting very abundantly ("on" year). The first application was one week after flowering (shoots ±17 cm long) and the second one 18 days later.

Table 9. The effect of P-Ca on shoot growth characteristics and on flowering intensity

Treatment	In the year of treatment			In the following year	
	Average shoot length (cm)	**Average internode length (cm)**	**Number of leaves/shoot**	**Average shoot length (cm)**	**Return bloom (number of flower clusters/tree)**
Control	63.5 b	2.8 b	23.0 b	30.4 a	46 n.s.
100 $mg.l^{-1}$	40.0 a	2.1 a	18.9 a	39.5 ab	119 n.s.
75+100 $mg.l^{-1}$	38.4 a	2.1 a	18.7 a	36.6 ab	141 n.s.
200 $mg.l^{-1}$	38.2 a	2.0 a	18.7 a	43.1 b	66 n.s.

$P \leq 0.05$

P-Ca reduced the shoot length by 37 to 40% as compared to the control trees. P-Ca acted similarly at both concentrations of 100 and 200 $mg.l^{-1}$. Repeat spraying of the trees with the low concentrations caused slower onset of growth inhibition but resulted in a similar final reduction of shoot length as compared to a single application of a higher rate. In essence, the repeated treatment proved to be more efficient in this case. The trees were flowering very scarcely the following year. However, under these conditions the trees treated with P-Ca, especially at low concentrations, formed more flower buds than the controls. Trees which had been treated with the highest dosage were growing more intensively the following year than the controls.

Table 10. The effect of P-Ca on yield and fruit size at harvest

Treatment	In the year of treatment		In the following year	
	Yield (kg/tree)	Average fruit weight (g)	Yield (kg/tree)	Average fruit weight (g)
Control	55.8 a	119 a	10.9 a	134 ab
100 mg.l^{-1}	63.6 a	132 ab	31.8 b	128 ab
75+100 mg.l^{-1}	62.9 a	141 b	30.4 b	125 a
200 mg.l^{-1}	77.6 a	143 b	16.7 ab	141 b

$P \leq 0.05$

The retardation of shoot growth in the year of treatment became visible as early as 17 days after treatment. The treated trees also stopped their growth earlier than the untreated trees. Concentrations of 200 and 75 + 100 mg.l^{-1} P-Ca slightly increased yield, but both caused a significant increase in the average fruit weight in the year of treatment.

Table 11. The effect of P-Ca on fruit set and on fruit quality at harvest in the year of treatment

Treatment	% fruit set	% fruit with diameter > 75mm	% fruit with red colour on > 75% of surface	Shape of fruits (length: diameter)	Firmness (kg/cm^2)	°Brix
Control	28 ab	22 a	58 ab	0.85 a	12.2 a	10.0 a
100 mg.l^{-1}	22 a	41 ab	27 a	0.84 a	13.9 b	11.2 b
75+100 mg.l^{-1}	22 a	54 b	53 ab	0.83 a	12.8 b	10.4 a
200 mg.l^{-1}	41 b	61 b	64 b	0.84 a	13.1 ab	10.3 a

$P \leq 0.05$

There was an increase in fruit set only after the 200 mg.l^{-1} application. P-Ca had no significant influence on the intensity of russeting on the fruits at $P \leq 0.05$ (Basak and Rademacher, 2000).

2.5.1.6 Macoun

Mature trees on M7 in Massachusetts (USA) were used. The first application was at petal fall (PF), the second one two weeks after PF and the third one four weeks after PF.

Table 12. The effect of P-Ca on shoot growth in the year of treatment

Treatment	Average length of terminal shoots (cm)
Control	35.0
3 x 30 $mg.l^{-1}$	20.6
3 x 60 $mg.l^{-1}$	19.4
3 x 90 $mg.l^{-1}$	19.4
90 + 180 $mg.l^{-1}$	21.0
270 $mg.l^{-1}$	15.8
Significance	
P-Ca	*

*Significant at $P \leq 0.001$.

The 270 $mg.l^{-1}$ P-Ca treatment had significantly reduced terminal growth two weeks after application. An additional six days were required after the second application to significantly slow terminal growth on trees receiving lower P-Ca concentrations. Treatment with P-Ca had little or no influence on fruit weight for the 3 x 50 and 90 + 180 $mg.l^{-1}$ P-Ca treatments, but the 270 $mg.l^{-1}$ treatment significantly reduced size. In general, fruit on trees treated with P-Ca was more highly coloured. No treatment influenced flesh firmness or soluble solids. The time required to prune trees decreased linearly with increasing concentration of P-Ca (Greene, 1999).

2.5.1.7 McIntosh

Mature trees on M7 in Massachusetts (USA) were used. P-Ca was applied at shoot length 12 to 13 cm.

Table 13. The effect of P-Ca on shoot growth in the year of treatment

Treatment	**Average length of terminal shoots (cm)**
Control	35.4
125 $mg.l^{-1}$	21.0
250 $mg.l^{-1}$	21.1
375 $mg.l^{-1}$	22.0
Significance	
P-Ca	Q*

*Significant at $P \leq 0.001$; Q = quadratic

The lowest concentration (125 $mg.l^{-1}$) was as effective as the highest concentrations. Trees treated with P-Ca required less time to prune.

Table 14. The effect of P-Ca on fruit set and on fruit size and yield at harvest in the year of treatment and on flowering intensity in the following year

Treatment	**Fruit/100 flower clusters**	**Fruit weight (g)**	**Total yield (kg/tree)**	**Number of flower clusters/cm^2 limb x-sectional area in the following year**
Control	47	150	177	8.4
125 $mg.l^{-1}$	58	142	165	6.1
250 $mg.l^{-1}$	76	126	190	4.1
375 $mg.l^{-1}$	101	120	192	3.3
Significance				
P-Ca	L*	L*	NS	Q*

NS, *Nonsignificant or significant at $P \leq 0.001$; L = linear, Q = quadratic.

Fruit set increased linearly with increasing P-Ca concentration, the highest rate (375 $mg.l^{-1}$) nearly doubling the final fruit set. Fruit size was decreased linearly with increasing P-Ca concentration. Return bloom declined quadratically with increasing dosage of P-Ca and appeared to be inversely related to fruit set the previous year.

Table 15. The effect of P-Ca on fruit quality at harvest in the year of treatment

Treatment	Flesh firmness (N)	Soluble solids (%)	Starch rating	Red surface colour (%)
Control	65.6	10.6	5.6	62
125 $mg.l^{-1}$	67.9	10.6	5.8	67
250 $mg.l^{-1}$	67.4	10.3	5.9	69
375 $mg.l^{-1}$	68.3	10.2	6.1	71
Significance				
P-Ca	L*	L**	L*	L***

*, **, ***Significant at $P \leq 0.05$, 0.01 or 0.001 respectively; L = linear

(Greene, 1999)

2.5.1.8 Mercier St. Delicious

Ten year old trees on M7 in North Carolina (USA) were used and P-Ca applied as summarised in Table 16.

Table 16. The effect of P-Ca treatments on average shoot length (cm) in the year of treatment

Treatment ($mg.l^{-1}$ P-Ca)	Time of application (DAPF*) 0	7	14	20
0	40 a	-	-	-
125	-	21 b	-	-
250	13 b	23 b	21 b	19 b
375	-	18 b	-	-

$P \leq 0.05$

*DAPF - days after petal fall

P-Ca significantly reduced shoot growth, but response did not differ with concentration used. The time of application did not affect subsequent shoot growth response.

Table 17. The effect of time of application of P-Ca (250 $mg.l^{-1}$) on fruit set and on percentage of shoots by length in the year of treatment

Time of application (DAPF)*	**Fruit set (no./cm limb circ.)**	**Percentage of shoots by length** (cm)**			
		>10	**10-25**	**25-40**	**40+**
Control	4.1 a	2	23	35	40
0	6.7 c	65	20	10	5
7	6.7 c	20	47	23	10
14	5.5 bc	20	55	10	15
21	4.8 ab	30	40	23	10

$P \leq 0.05$

*DAPF - days after petal fall

** No statistical analysis; observational data only

The number of pruning cuts per tree and the weight of the prunings were significantly reduced by the P-Ca treatments at $P \leq 0.05$. The most graphic illustration of the influence of P-Ca on tree growth is shown in the shift in distribution of shoot length (Unrath, 1999).

2.5.1.9 Stayman

Vigorous thirteen year old trees on seedling rootstock in Virginia (USA) were used. P-Ca was applied 23 days after full bloom.

Table 18. The effect of P-Ca on shoot growth characteristics and fruit yield at harvest in the year of treatment

Treatment	Average shoot*		Average internode length (cm)	Number of fruit/cm² limb CSA**
	Length (cm)	Weight (g)		
Control	137.8	90.4	2.8	3.30
125 mg.l^{-1}	99.6	48.8	2.4	3.48
250 mg.l^{-1}	94	40.4	2.3	4.14
375 mg.l^{-1}	92.2	41.9	2.3	4.00
Regression				
L	*	*	*	NS
Q	**	**	*	NS

NS, *, **Nonsignificant or significant at $P \leq 0.01$ or 0.001 respectively; L = linear, Q = quadratic

* Average for longest 10 shoots in top of tree

**CSA – cross sectional area

The pruning time, number of pruning cuts per tree and the weight of the prunings were reduced by the P-Ca treatments, although not significantly at $P \leq 0.05$. Fruit length:diameter ratio, flesh firmness, soluble solids, starch, red colour and fruit cracking were not affected by P-Ca (Byers and Yoder, 1999).

2.5.2 Pears

2.5.2.1 Conference

Eight year old trees grafted on Caucasian type of *Pyrus communis* in Poland were used. P-Ca was applied when new shoots were ±23 cm long.

Table 19. The effect of P-Ca on shoot growth in the year of treatment

Treatment	Average length of terminal shoots (cm)
Control	37.6 bc
150 mg.l^{-1}	30.4 ab
225 mg.l^{-1}	27.0 a

$P \leq 0.05$

Only at the highest concentration used (225 $mg.l^{-1}$), P-Ca caused a significant reduction of shoot growth by 28% (Basak and Rademacher, 2000)

2.5.3 Plum

2.5.3.1 Stanley, Dabrowice and Lowics

Four year old trees grafted on Myrobalan rootstocks in Poland were used. P-Ca was applied when new shoots were ±25 cm long.

Table 20. The effect of P-Ca on shoot growth characteristics in the year of treatment

	Stanley	**Dabrowice**	**Lowics**	
Treatments	**Shoot length (cm/cm^2 TCSA*)**	**Shoot length (cm/cm^2 TCSA*)**	**Shoot length (cm/cm^2 TCSA*)**	**Number of spurs/cm^2 TCSA***
Control	71 b	102 ab	71 c	5.4 a
75 $mg.l^{-1}$	76 b	116 b	57 bc	6.5 ab
150 $mg.l^{-1}$	63 ab	92 a	46 ab	8.0 b
225 $mg.l^{-1}$	48 a	87 a	31 a	8.6 b

$P \leq 0.05$

*TCSA – trunk cross section area

Marked differences in the sensitivity of cultivars towards P-Ca have been found. All cultivars responded towards the treatment with 225 $mg.l^{-1}$ P-Ca. The most sensitive cultivar was 'Lowics' in which 225 $mg.l^{-1}$ P-Ca reduced shoot growth by 56%. In contrast, the same concentration caused a reduction in shoot growth by only 32 and 14% in the cultivars 'Stanley' and 'Dabrowice' respectively. At the lower concentration of 150 $mg.l^{-1}$ P-Ca, shoot growth reduction could only be induced in 'Lowics' (Basak and Rademacher, 2000).

2.5.4 Peach

2.5.4.1 Redhaven

When 375 $mg.l^{-1}$ P-Ca was applied to six year old trees in Virginia (USA), it did not affect the length of the five longest shoots on the tree. It also had no effect on fruit diameter, weight, colour, firmness or soluble solids (Byers and Yoder, 1999)

2.6 THE EFFECT OF PROHEXADIONE-CALCIUM ON FIRE BLIGHT AND SCAB

P-Ca showed pronounced effects on the incidence of fire blight caused by the bacterium *Erwinia amylovora* in apple and pear (Yoder et al., 1999). Also scab in apples, caused by the fungus *Venturia inaequalis*, was controlled (Rademacher et al., 1999a). Both these control mechanisms were not due to any fungicidal or bacterial effect of the compound (Winkler, 1997a; Rademacher et al., 1999a)

When apple trees were treated with P-Ca before artificial inoculation of the leaves with *E. amylovora*, the young leaves treated with P-Ca showed a reduced symptom development as compared to the untreated control (Roemmelt et al., 1999a).

Winkler (1997a) has suggested that the resistance of plants against fire blight is caused by a more rapid hardening off of new shoot leaves, but Roemmelt et al. (1999a) observed an effect of P-Ca on fire blight even when the treatment had been made only 2 hours before inoculation. A time span as small as this seems to be unlikely to allow any hardening of the leaves. There was an accumulation of phenolic compounds such as phenolic acids, simple phenols and eriodictyol in the leaves after the P-Ca treatment and since a correlation between the accumulation of phenolic compounds (in specific phenolic acids and simple phenols) and a successful defence reaction of the plant's leaves against fire blight was shown by Roemmelt et al. (1999b), these phenolic compounds were most probably responsible for the reduced symptom development of the leaves. The accumulation of phenolic compounds was due to changes in phenylpropanoid metabolism, most likely by inhibiting flavanone-3-hydroxylase (Rademacher et al.,1999a).

When apple trees of 'Golden Delicious' and 'Jonathan' were treated with P-Ca before artificial inoculation with *E. amylovora,* the percentage of inoculated shoots that were infected by fire blight were reduced (Winkler, 1997a; Fernando and Jones, 1999; Yoder et al., 1999). On 'Rome Beauty', on the other hand, P-Ca had no effect on the percentage of shoots that developed fire blight following artificial inoculation with *E. amylovora* (Yoder et al., 1999). When apple trees of 'Law Rome' and 'Fuji' were treated with P-Ca before natural inoculation with *E. amylovora,* the number of shoots infected per tree and the percentage of shoots infected per tree respectively, were also reduced (Winkler, 1997a, Yoder et al., 1999).

When apple trees of 'Idared', 'Jonathan' and 'Golden Delicious' were treated with P-Ca before artificial inoculation with *E. amylovora,* the mean canker length in the current season's shoot growth were reduced (Winkler, 1997a; Fernando and Jones, 1999; Momol et al., 1999, Yoder et al., 1999).

When apple shoots of 'Rome Beauty' were treated with P-Ca before artificial inoculation with *E. amylovora,* fewer cankers advanced beyond current season growth (Yoder et al., 1999) and when apple trees of 'Jonathan' and 'Golden Delicious' were treated with P-Ca before artificial inoculation with *E. amylovora*, fewer non-inoculated shoots in the trees developed fire blight compared to the inoculated control trees (Fernando and Jones, 1999).

The increased resistance of shoots against fire blight after P-Ca treatments are probably because of the reduced shoot growth obtained with P-Ca treatments, rather than a result of the increase in the concentration of phenolic compounds, since tree vigour is an important element in fire blight susceptibility (Yoder et al., 1999) with rapidly growing, succulent shoot tissue being more susceptible to initiation, development and extension of *E. amylovora* infections than slow- or non-growing tissues (Momol et al., 1999). A reduction in shoot growth was indeed observed in most of the cases where P-Ca treatments reduced fire blight susceptibility of shoots.

On the pears 'Abate Fetel' and 'Conference', P-Ca controlled fire blight in the orchard and greenhouse under natural and artificial *E. amylovora* infection conditions (Costa et al., 2000).

After artificial inoculation of apple seedlings with the fungus *V. inaequalis,* scab infestations were reduced by pre-treatment with P-Ca (Rademacher et al., 1999b). It can be assumed that, similar to the situation with fire blight, changes in phenylpropanoid metabolism are mainly responsible for the reduced scab incidence. It should not be ruled out, however, that anatomical and morphological changes caused by P-Ca might also contribute to this effect (Rademacher et al., 1999b).

2.7 ADDITIONAL OBSERVATIONS

When Owens and Stover (1999) treated nursery trees of 'Gibson Golden Delicious' and 'Sun Fuji', each with three to four well developed (>20 cm in length) lateral branches with P-Ca, they observed that the midwinter non-structural carbohydrate concentration and N-levels were increased in the shoots of the 'Gibson Golden Delicious' trees. In the shoots of the 'Sun Fuji' trees there was a decrease in the carbohydrate concentration, while the N-levels were increased. Vegetative growth the following season were increased in the 'Gibson Golden Delicious' trees, but no effect was observed on 'Sun Fuji' shoot growth.

Owens and Stover (1999) also observed that for the leaders of both 'Gibson Golden Delicious' and 'Sun Fuji', terminal bud set in P-Ca treated nursery trees was induced before terminal bud set in the control trees. The lateral branches of P-Ca treated 'Sun Fuji' trees also induced terminal bud set before the control's lateral branches, but P-Ca had no effect on the terminal bud set in the lateral branches of the 'Gibson Golden Delicious' nursery trees.

Basak and Rademacher (2000) observed that trees of the apples 'Lobo', 'Gloster' and 'Jonagold', the pear 'Conference' and the plums 'Stanley', 'Dabrowice' and 'Lowics', treated with P-Ca, displayed a dark green colour of the leaves, more intense than in the untreated controls. The individual leaves also appeared to be thicker and larger in area, especially in the apical part of the shoots.

Vegetative growth control following P-Ca treatments also reduced tree row volume (TRV) and therefore spray volumes of pesticides (Winkler, 1997a; Unrath, 1999).

2.8 CONCLUSION

If applied at the right time and concentration, P-Ca can be effectively used to reduce unwanted vegetative growth of especially apple trees, with little, if any, negative influence on internal or external fruit quality.

Many additional benefits resulting from the use of P-Ca could be observed. These include a reduction in the occurrence of fire blight (especially shoot blight) and scab, resulting again in a reduction in antibiotic and fungicide spray volumes. However, for P-Ca to have an effect on fire blight and scab, it must be applied prior to infection. Because of the earlier cessation of shoot growth after P-Ca treatments, the period of susceptibility to fire blight and scab are also reduced. The reduced shoot growth obtained with P-Ca also reduced the pruning needs of the trees as well as the TRV spray volumes of other chemicals.

Since a fine balance exists between vegetative and reproductive growth, it can be assumed that the observed effects on fruit set and -size as well as on return bloom after P-Ca treatments, are mainly a result of this balance. However, the reproductive state of the tree, especially the fruit load, plays an important roll as well.

The reduced shoot growth obtained with P-Ca treatments, as a result of the inhibition of GA biosynthesis, will result in more assimilates available for reproductive growth, thereby increasing fruit set and –size. Since GAs also inhibit flower bud initiation, the inhibition in GA biosynthesis might also increase return bloom the following year. The reduction in fruit size that was sometimes observed might be because P-Ca reduced shoot growth too much, thereby reducing the amount of photosynthetic tissue available, which will again result in fewer assimilates available to the fruit. Another possible explanation for the reduced fruit size might be because of a direct effect on the sink strength of the fruit via reduced GAs produced by the seeds, since P-Ca is a GA biosynthesis inhibitor.

Adequate fruit thinning will result in more assimilates being available to go to the rest of the fruit on the tree, thereby increasing fruit size and *vice versa.* Since seeds are also rich sources of GAs, adequate fruit thinning might also lead to an increase in return bloom and *vice versa.*

The rate of internodal growth of rice has been shown by Hoffmann-Benning and Kende (1992) to be determined by the balance of the endogenous growth promotor GA and of ABA, a growth inhibitor. Therefore, it can be postulated that the reduced shoot growth in trees, caused by P-Ca , might also be a result not only of the lowered GA_1 levels, but of the increase in ABA content as well. Since ethylene is an promotor of senescence and abortion of flowers, leaves and fruit (Ross, 1992), another postulation can be made, and that is that the observed decrease in ethylene concentration after P-Ca treatments, might also play a role in the increased fruit set that was sometimes observed.

Since ca. 75% of tree shoot growth occurs in the first 30 days after flowering (Byers and Yoder, 1999), it is best to apply P-Ca as early as possible to get sufficient growth inhibition, keeping in mind that enough leaves have to be present for uptake of P-Ca. Due to its short-term effect, P-Ca can be applied at a variety of timings to get the results that the user wants. An additional advantage is that it also constitutes no risk to humans or the rest of the environment.

The main factor in determining the concentration and application time of P-Ca is tree vigour, which is again determined by a variety of factors, such as the kind of rootstock used, fruit set, age and also by altitude and related climatic conditions. Therefore, experience will be needed to apply P-Ca at the right time and concentration to get the growth control that the user wants.

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PAPER 1: SHOOT GROWTH CONTROL OF APPLE TREES (*MALUS DOMESTICA* BORKH.) WITH PROHEXADIONE-CALCIUM

Abstract

Prohexadione-calcium (P-Ca), a new plant growth retardant, inhibits late stages of gibberellin biosynthesis. Trials with P-Ca were carried out in the 1999/2000 and 2000/2001 seasons in the Western Cape area of South Africa to control shoot growth of apple trees. In both seasons the P-Ca without surfactant was foliar applied (3 sprays x 50, 3 x 67 or 4 sprays x 50 $mg.l^{-1}$) to the same trees of 'Golden Delicious' and 'Royal Gala' in both seasons, but to different trees of 'Granny Smith' for the two years. The first application in both seasons was at ca. the same time, but in the 2000/2001 season the applications were distributed more over the growing season with the final application applied later in the season. P-Ca significantly reduced shoot growth of all three cultivars, but did not effectively control re-growth. The percentage of shoots with re-growth was decreased in 'Golden Delicious' and 'Royal Gala' in the 2000/2001 season. P-Ca did not negatively affected fruit size, yield, fruit quality or flowering in both years in any of the cultivars used, except in 'Golden Delicious' a significant reduction was found in the number of flower clusters in 2000 and as a result of this, yield was also significantly decreased in 2001. Whether this reduction in the number of flower clusters was due to a high fruit set in 1999 or a direct effect of P-Ca is not clear. The use of surfactants should be considered when P-Ca is sprayed to control re-growth and the compound should also be sprayed when temperature is lower and relative humidity higher in order to increase the uptake.

Introduction

Moderate shoot growth of trees and good light penetration into the tree canopy are among the prerequisites for good yields of high quality fruit (Basak and Rademacher, 2000). Gibberellins produced by strong growing shoots presumably inhibit flower bud formation (Greene, 1999). Also, flower bud formation does not occur in apple buds exposed to light levels below 30% full sun and weak flower buds are formed at light levels slightly above this (Cain, 1971). Shading due to excessive shoot growth reduce red colour development (Greene, 1999). It is also widely accepted that excessive shoot growth decrease fruit calcium concentrations due to competition for available calcium (Fallahi et al., 1997), which may cause bitter pit of fruit.

Cultural practices used to control vegetative growth include dwarfing rootstocks, pruning and limiting fertiliser and water. These practices are often not as effective as chemical inhibitors of growth (Elfving and Proctor, 1986). Daminozide was an important growth retardant which also improved fruit quality, especially in apples (Rademacher, 1995). After the withdrawal of daminozide, other growth retardants such as paclobutrazol and uniconazole-P could replace it only partially, since they are registered only in a limited number of countries for use in fruit production and are relatively difficult to apply (Basak and Rademacher, 2000).

Daminozide inhibits GA biosynthesis by blocking 2-oxoglutarate-dependant dioxygenases which catalyse the later steps in the biosynthetic sequence, specifically the 3ß-hydroxylation of biologically inactive GA_{20} to biologically active GA_1 is inhibited (Browne et al., 1997). Prohexadione-Ca (P-Ca) is a new plant growth retardant with the same mode of action as daminozide (Browne et al., 1997). From work done by previous researchers (Evans et al., 1997; Byers & Yoder, 1999; Greene, 1999; Theron, 1999; Unrath, 1999; Basak & Rademacher, 2000) it is clear that P-Ca is a promising new plant growth retardant for the control of excessive shoot growth of apple trees.

The purpose of this study was to determine the optimum concentration(s) and time(s) of application of P-Ca for controlling shoot growth of apple trees, as well as the effects of P-Ca on fruit growth, yield, fruit quality and return bloom.

Material and Methods

Plant material. Trials were conducted over two seasons and at two sites.

Trial 1: The trials were conducted during the 1999/2000 season at two sites in the Villiersdorp area in the Western Cape, South Africa (33°59' S, 19°17' E; ca. 365 m a.s.l.; Mediterranean climate). 'Golden Delicious' and 'Royal Gala' apple trees in commercial orchards on the farm High Noon and 'Granny Smith' apple trees in a commercial orchard on Theewaterskloof Farm were used. The 'Golden Delicious' trees on M793 rootstock were planted in 1987 at a spacing of 4.57 x 2.74 m. Trees were planted with 'Granny Smith' as cross-pollinator. Full bloom was on 20 October 1999. Chemical thinning was done two days after full bloom using Golden Thin® at 70g/100l water in a tank-mix with Promalin® at 125ml/100l water. Fruit were hand thinned after natural fruit drop according to commercial standards. Fruit were harvested on 7 March 2000 which was the commercial harvest date. Yield in 1997 was 51 $t.ha^{-1}$, in 1998 54 $t.ha^{-1}$, in 1999 53 $t.ha^{-1}$ and in 2000 53 $t.ha^{-1}$. The

'Royal Gala' trees on M793 rootstock were planted in 1990 at a spacing of 4.75 x 2.00 m. Trees were planted with 'Golden Delicious' as cross-pollinator with two rows for every four rows of 'Royal Gala'. Full bloom was on 14 October 1999. Chemical thinning was done two days after full bloom using Golden Thin® at 70g/100l water in a tank-mix with Promalin® at 125ml/100l water with a follow-up Promalin® (125ml/100l water) application 14 days after full bloom. Fruit were hand thinned after natural fruit drop according to commercial standards. Fruit were harvested on the commercial harvest dates of 8, 15 and 21 February 2000. Yield in 1997 was 33 $t.ha^{-1}$, in 1998 43 $t.ha^{-1}$, in 1999 46 $t.ha^{-1}$ and in 2000 47 $t.ha^{-1}$. The 'Granny Smith' trees on seedling rootstock were planted in 1973 at a spacing of 4.5 x 2.5 m. 'Golden Delicious' was used as cross-pollinator as well as some 'Braeburn' grafted to each scaffold branch of every sixth 'Granny Smith' tree. Full bloom was on 25 October 1999. Chemical thinning was done 15 days after full bloom using Sevin® at a concentration of 90g/100l water. Fruit were hand thinned after natural fruit drop according to commercial standards. Fruit was harvested on 13 April 2000 which was the commercial harvest date. Yield in 1998 was 64 $t.ha^{-1}$, 52 $t.ha^{-1}$ in 1999 and 76 $t.ha^{-1}$ in 2000.

Trial 2: The trials were conducted during the 2000/2001 season in the Villiersdorp area in the Western Cape, South Africa (33°59' S, 19°17' E; ca. 365 m a.s.l.; Mediterranean climate). The same 'Golden Delicious' and 'Royal Gala' trees were used as in the 1999/2000 season. Full bloom in 'Golden Delicious' was on 20 October 2000 with return bloom on 14 October 2001. Chemical fruit thinning was done five days after full bloom using the same tank mix as in the 1999/2000 season. Fruit were hand thinned after natural fruit drop according to commercial standards. Fruit were harvested on 1 March 2001 which was the commercial harvest date. Yield in 2001 was 52 $t.ha^{-1}$. Full bloom in 'Royal Gala' was on 15 October 2000 with return bloom on 13 October 2001. Chemical fruit thinning was done two days after full bloom using the same tank mix as in the 1999/2000 season, followed up by a 125ml/100l water Promalin® application 19 days after full bloom. Fruit were hand thinned after natural fruit drop according to commercial standards. Fruit were harvested on 7, 14 and 21 February 2001 which were the commercial harvest dates. Yield in 2001 was 41 $t.ha^{-1}$. The 'Granny Smith' trees that served as cross-pollinators for the 'Golden Delicious' trees in the 1999/2000 season, were used in this trial. The trees on M793 rootstock were planted in 1987 at a spacing of 4.57 x 2.74 m. Full bloom was on 20 October 2000 and return bloom on 14 October 2001. Chemical thinning was done 17 days after full bloom using 90g Sevin® / 100l water. Fruit were hand thinned after natural fruit drop according to commercial standards. Yield in 1998 was 41 $t.ha^{-1}$, 35 $t.ha^{-1}$ in 1999, 57 $t.ha^{-1}$ in 2000 and 54 $t.ha^{-1}$ in 2001.

Treatments and experimental design.

The wettable granular formulation BAS 125 10W, containing 10% (w:w) of P-Ca as active ingredient, was applied as indicated in Table 1.

The chemical was applied at high volume with the first application in the 1999/2000 season (trial 1) at petal drop on 26 October 1999, 2 November 1999 and 19 October 1999 respectively for 'Golden Delicious', 'Granny Smith' and 'Royal Gala'. In 'Royal Gala' the third application was applied one week too early. In the 2000/2001 season (trial 2) the first application on the 'Golden Delicious' and 'Granny Smith trees was at full bloom on 19 October 2000, and at petal drop on 19 October 2000 for the 'Royal Gala' trees. No surfactant was added with any of the treatments and temperature and relative humidity were not measured.

The experimental design was a randomised complete block design with ten single tree plot replications of each treatment.

Data collected.

Trial 1: Ten representative shoots per tree were tagged and their length determined at the time of the first application and then at weekly intervals until the cessation of shoot growth. Tagged shoots showing signs of terminal re-growth was also recorded and the average length of the re-growth measured. Ten representative fruit per tree were tagged and their diameter measured at the time of the first application and then at weekly intervals until harvest. At harvest (second harvest date for 'Royal Gala'), a randomly selected sample of 25 fruit per tree was collected and the average fruit weight, length, diameter, colour, number of developed seeds, number of seeds with aborted embrio's and severity of stem-end-russet determined. At harvest the percentage of 'Golden Delicious' apples with bitter pit lesions on the outside was counted. An additional sample of 25 fruit per tree was collected from the 'Golden Delicious' trees one week before the commercial harvest date as well as at the commercial harvest date and stored for four weeks at ±0.5°C, then kept at room temperature (±20°C) for one week. The percentage of fruit with bitter pit lesions on the outside was counted and the number of pits recorded. The fruit were then sectioned along the transversal axis and the percentage of fruit with bitter pit lesions on the inside was counted and the number of pits recorded. At harvest the total yield per tree was recorded. For 'Royal Gala' this was done by combining the weight of the fruit picked at the three harvest dates. The trunk circumference of each tree was measured.

'Golden Delicious' fruit colour was evaluated on a scale of 1 to 9 (1 = green; 9 =yellow) using the Decidious Fruit Board (DFB) chart nr. A28, 'Granny Smith' fruit colour was evaluated on a scale of 1 to 12 (1 = green; 12 = yellow) using the DFB chart nr. A38 and 'Royal Gala' fruit colour was evaluated on a scale of 1 to 12 (1 = red; 12 = yellow) using the DFB chart nr. A42. Stem-end-russet was evaluated on a scale of 1 to 12 (1 = least russet; 12 = most russet) on 'Golden Delicious', 'Granny Smith' and 'Royal Gala' using the DFB chart nr's. A43, A40 and A31 respectively.

Trial 2: At full bloom 2000 two representative branches per tree were tagged on the 'Golden Delicious' and 'Royal Gala' trees. The number of flower clusters on each branch was counted and the length and diameter of each branch measured. At full bloom 2001 the number of flower clusters on the same tagged branches was counted. Two representative branches were also tagged on the 'Granny Smith' trees at full bloom 2001, their lengths and diameters measured and the number of flower clusters counted. Five representative shoots per tree were tagged and their length measured at two weekly intervals until the cessation of shoot growth. Shoot measurements for 'Golden Delicious' and 'Granny Smith' were started two weeks after the first P-Ca application while shoot measurements for 'Royal Gala' were started one week after the second P-Ca application. Tagged shoots showing signs of terminal re-growth was recorded and the length of the re-growth measured. At the end of the growing season the severity of the abnormal shoot thickening in each 'Golden Delicious' tree was visually rated on a scale of 1 to 3 (1 = least severe; 3 = most severe) and correlated with the yield of each tree using the Pearson Correlation Coefficient. The same data were recorded at harvest and after storage as in trial 1. Unfortunately the 'Granny Smith' trees were harvested before data could be recorded.

Statistical analysis. Shoot and fruit measurements were converted to percentages using the formula: $((x - y)/y)*100$ where x = the shoot length/fruit diameter at the measurement date and y = the initial shoot length/fruit diameter. The General Linear Models (GLM) procedure of the Statistical Analysis System (SAS) was used to analyse the data (SAS Institute Inc., 1990).

Results and Discussion

Shoot growth

'Golden Delicious'. In the 1999/2000 season P-Ca caused a significant reduction in shoot growth compared to the control trees (Table 2; Fig.1). The reduction in shoot growth was visible ca. one week after the first P-Ca application. P-Ca suppression of shoot growth lasted until ca. seven weeks before harvest when re-growth occurred on the more vigorous shoots (Fig.1). The percentage of shoots with re-growth did not differ between treatments, but the average length of the re-growth was significantly less for P-Ca sprayed trees (Table 2). Results for the 2000/2001 season were comparative to the 1999/2000 season (Table 3; Fig. 2). To reduce the possibility of re-growth in the 2000/2001 season, the final P-Ca applications were made 45 days before harvest. This late application was effective in preventing re-growth before harvest, but re-growth again occurred on the more vigorous shoots in all the P-Ca treatments except the 4 x 50 $mg.l^{-1}$ P-Ca treatment (Table 3; Fig. 2). This re-growth occurred ca. one week after harvest (Fig. 2). The control trees had no re-growth and in general re-growth was less than in the 1999/2000 season (Table 3). The interval between the last P-Ca application and when the re-growth occurred was ca. seven weeks (Fig. 2). An abnormal thickening of some shoots sprayed with P-Ca was observed in the 2000/2001 season, but not in the 1999/2000 season. Byers and Yoder (1999) referred to Emerson who also found that apple trees had enlarged terminal buds and shoot diameters after treatment with daminozide.

'Granny Smith'. By the end of the 1999/2000 growing season P-Ca treated shoots were significantly shorter than control shoots (Table 4; Fig. 3). Re-growth occurred on some shoots of control and P-Ca treated trees. This occurred ca. 11 weeks before harvest (Fig. 3). The percentage re-growth or the average length of the re-growth did not differ between treatments (Table 4). During the 2000/2001 season P-Ca caused a significant reduction in shoot growth (Table 5; Fig. 4) which was already visible at the time of the first shoot measurements two weeks after the first P-Ca application (Fig. 4). Re-growth again occurred in the more vigorous shoots in all the P-Ca treatments, but not in the control trees (Table 5; Fig. 4). The re-growth occurred at different times during the season, with the 3 x 67 $mg.l^{-1}$ P-Ca treatment having the highest percentage of shoots with re-growth. The earliest signs of

re-growth occurred in the 4 x 50 $mg.l^{-1}$ P-Ca treatment in which re-growth occurred ca. three weeks after the second P-Ca application, and the latest re-growth occurred in the 4 x 50 and 3 x 67 $mg.l^{-1}$ P-Ca treatments ca. three days before harvest, which was about six weeks after the last P-Ca application (Fig. 4). As with the 'Golden Delicious' trees in the 2000/2001 season, an abnormal thickening was observed in some 'Granny Smith' shoots in the 2000/2001 season, but not in the 1999/2000 season.

'Royal Gala'. Similar to 'Golden Delicious' and 'Granny Smith', P-Ca caused a significant reduction in shoot growth in the 1999/2000 season (Table 6; Fig. 5) which was visible from ca. one week after the first P-Ca application (Fig. 5). Shoots on the P-Ca treated trees resumed growth again ca. three weeks before the first commercial harvest date which was about ten weeks after the last application in the treatments where P-Ca was applied three times and about seven weeks after the last application in the treatments where P-Ca was applied four times. Re-growth also ocurred in the control trees (Table 6; Fig. 5). No significant differences were found between treatments in the percentage of shoots with re-growth or the average length of the re-growth (Table 6). In the 2000/2001 season P-Ca again caused a reduction in shoot growth, although not significantly (Table 7; Fig. 6). The reason for this being that shoot measurements were only started a week after the second P-Ca application when most of the shoot growth had already taken place. Approximately 75% of apple shoot growth occurs in the first 30 days after flowering (Byers and Yoder, 1999). Re-growth again occurred in all the treatments (Table 7; Fig. 6). As with 'Granny Smith' the re-growth occurred at different times during the season with the first flush of re-growth occurring ca. five weeks after the last P-Ca application in all the P-Ca treatments, which was ca. two weeks before the first commercial harvest date. The latest re-growth occurred in the 3 x 50 and 3 x 67 $mg.l^{-1}$ treatments ca. 13 weeks after the last P-Ca application which was ca. four weeks after the last commercial harvest date (Fig. 6). The thickening that occurred in the shoot of the 'Golden Delicious' and 'Granny Smith' trees in the 2000/2001 season was not observed in 'Royal Gala', although a slight thickening was observed in the top few centimeters of some shoots.

Fruit size and yield

Except for an increase in fruit size in 'Royal Gala' in the 1999/2000 season (Table 8) and a decrease in yield expresses as kg fruit harvested/cm trunk in 'Golden Delicious' in the 2000/2001 season (Table 9), P-Ca had no effect on fruit size or yield (Tables 9, 10, 11, 12, 13, 14 & 15; Figs. 7, 8 & 9). This reduction in 'Golden Delicious' yield can be attributed to the reduction in the number of flower clusters in the spring of 2000 following P-Ca treatment in 1999/2000 (Table 16).

With the severe shoot growth reduction obtained, a significant increase in fruit size was expected as a result of more assimilates being available for fruit growth. A negative correlation was found between the abnormal shoot thickening (malformation) and yield in 'Golden Delicious' in the 2000/2001 season (Table 9) indicating allocation to secondary shoot growth rather than fruit growth. The number of fruit sinks was also low due to the lack of flower clusters at the start of the season.

Fruit quality

In both seasons P-Ca had no effect on fruit colour or the severity of russeting in any of the cultivars (Tables 17, 18, 19, 20 & 21). P-Ca also had no effect on the seed contents of 'Golden Delicious' in both the 1999/2000 and 2000/2001 seasons (Tables 17 & 20) and no effect on the seed contents of 'Granny Smith' in the 1999/2000 season (Table 18). In both seasons P-Ca significantly reduced the number of seeds with embrio's in 'Royal Gala' (Tables 19 & 21). In the 1999/2000 season P-Ca had no effect on the number of seeds with aborted embrio's (Table 19), but significantly increased the number of seeds with aborted embrio's in the 2000/2001 season (Table 21). In both seasons P-Ca had no effect on the occurrence of bitter pit, either at harvest (Tables 17 & 20) or after cold storage (Tables 22, 23 & 24). Since actively growing shoots compete with fruit for calcium (Fallahi et al., 1997), a reduction in the occurrence of bitter pit was expected as a result of the reduced shoot growth obtained with P-Ca.

Return bloom

The 1999 application of P-Ca caused a significant reduction in the number of flower clusters in 2000 in 'Golden Delicious' ($P = 0.0008$; 0.0001). This did not occur the following season ($P = 0.2426$; 0.5181) (Table 16). Unfortunately fruit set was not determined in 1999 and it is unknown whether this reduction in return bloom was due to a high initial fruit set or a direct effect of P-Ca. P-Ca had no effect on return bloom of 'Granny Smith' (Table 25). In 'Royal Gala' P-Ca had no effect on the number of flower clusters in 2000. In the next season P-Ca had no effect on the number of flower clusters / cm branch length, but caused a significant, although very small, reduction in the number of flower clusters / mm branch circumference (Table 26).

Conclusion

The results show that P-Ca is an effective inhibitor of shoot growth of 'Golden Delicious', 'Granny Smith' and 'Royal Gala' apple trees in the concentration range and number of applications used. However, re-growth still occurred in the 2000/2001 season, even though P-Ca was applied later in the growing season. The effect of a single P-Ca application lasts three to six weeks, at most eight (Rademacher, 2001), which would partly explain the re-growth that occurred, particularly in the 1999/2000 season. Poor uptake of P-Ca with late applications when relative humidity is low and temperature high should also be considered as a cause for re-growth. It is therefore advised that surfactants are tested in the future. Also, the chemical should be sprayed early morning or late afternoon or on cool days when temperature is lower and relative humidity higher to increase uptake. The effect of a post-harvest spray should also be evaluated to prevent any possible re-growth after harvest.

Because of the re-growth that occurred it is not clear which concentrations and application times is optimal for controlling shoot growth. Basak and Rademacher (2000) found that P-Ca sufficiently reduced 'Gloster' shoot growth at concentrations of 75 and 100 $mg.l^{-1}$, 'Jonagold' shoot growth at concentrations of 150 and 2 x 75 $mg.l^{-1}$ and 'Lobo' shoot growth at concentrations of 75 + 100 $mg.l^{-1}$ when the first application was made one week after flowering. Evans et al. (1997) found that P-Ca applied at 250 and 2 x 125 $mg.l^{-1}$, with the first application two days after petal fall, gave the best shoot growth control in 'Fuji'.

P-Ca had no significant positive or negative effect on fruit size, yield, fruit quality or return bloom in any of the seasons in any of the cultivars evaluated, except in 'Golden Delicious' where the number of flower clusters was significantly reduced in the spring of 2000 following the P-Ca application in 1999/2000. As a result of this, yield in the P-Ca treated trees was also significantly reduced. It is however not clear whether this reduction in flowering was a direct effect of P-Ca or whether it was because of a high initial but not recorded fruit set in 1999.

In conclusion it can be said that, in spite of the re-growth that occurred, P-Ca proved to be an effective inhibitor of shoot growth of apple trees. More work is needed to control re-growth.

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Table 1. Concentration and time of application of prohexadione-Ca in the 1999/2000 and 2000/2001 seasons.

P-Ca concentration	Time of application
Trial 1 (1999/2000):	
Control (unsprayed)	-
3 x 50 $mg.l^{-1}$	Petal drop (PD) + 2 weeks after PD + 4 weeks after PD
4 x 50 $mg.l^{-1}$	PD + 2 weeks after PD + 4 weeks after PD + 6 weeks after PD
3 x 67 $mg.l^{-1}$	PD + 2 weeks after PD + 4 weeks after PD
Trial 2 (2000/2001):	
Control (unsprayed)	-
3 x 50 $mg.l^{-1}$	Full bloom (FB)/Petal drop (PD) + 5 weeks after FB/PD + 45 days before harvest
4 x 50 $mg.l^{-1}$	FB/PD + 5 weeks after FB/PD + between 2^{nd} and last spray + 45 days before harvest
3 x 67 $mg.l^{-1}$	FB/PD + 5 weeks after FB/PD + 45 days before harvest

Table 2. The effect of prohexadione-Ca on shoot growth characteristics of 'Golden Delicious' apples in the 1999/2000 season.

Treatments	Total shoot increase (%)	Final shoot length (cm)*	Shoots with re-growth (%)	Average length of re-growth (cm)
Control	376.2	56.3	49.8	11.1
3 x 50 $mg.l^{-1}$ P-Ca	139.8	27.6	41.0	3.6
4 x 50 $mg.l^{-1}$ P-Ca	155.7	29.8	61.3	4.2
3 x 67 $mg.l^{-1}$ P-Ca	147.0	28.6	50.3	3.9
Sign. level				
Trt	**0.0001**	**0.0001***	**0.2701**	**0.0001**
Control vs P-Ca	**0.0001**	**0.0001**	**0.8983**	**0.0001**

* Initial shoot length used as covariate

Table 3. The effect of prohexadione-Ca on shoot growth characteristics of 'Golden Delicious' apples in the 2000/2001 season.

Treatments	**Total shoot increase (%)**	**Final shoot length (cm)***	**Shoots with re-growth (%)**	**Average length of re-growth (cm)**
Control	75.6	26.2	0.0	0.0
3 x 50 $mg.l^{-1}$ P-Ca	52.9	22.6	13.5	9.6
4 x 50 $mg.l^{-1}$ P-Ca	32.8	19.9	0.0	0.0
3 x 67 $mg.l^{-1}$ P-Ca	46.1	21.7	10.5	5.3
Sign. level				
Trt	**0.0809**	**0.0977***	-	-
Control vs P-Ca	**0.0244**	**0.0311**	-	-

* Initial shoot length used as covariate

Table 4. The effect of prohexadione-Ca on shoot growth characteristics of 'Granny Smith' apples in the 1999/2000 season.

Treatments	**Total shoot increase (%)**	**Final shoot length (cm)***	**Shoots with re-growth (%)**	**Average length of re-growth (cm)**
Control	118.8	33.4	16.0	22.6
3 x 50 $mg.l^{-1}$ P-Ca	66.9	25.9	13.4	25.6
4 x 50 $mg.l^{-1}$ P-Ca	55.3	22.8	9.6	24.8
3 x 67 $mg.l^{-1}$ P-Ca	73.9	27.1	19.2	25.7
Sign. level				
Trt	**0.0060**	**0.0058***	**0.5810**	**0.3266**
Control vs P-Ca	**0.0008**	**0.0281**	**0.7388**	**0.7064**

* Initial shoot length used as covariate

Table 5. The effect of prohexadione-Ca on shoot growth characteristics of 'Granny Smith' apples in the 2000/2001 season.

Treatments	**Total shoot increase (%)**	**Final shoot length (cm)***	**Shoots with re-growth (%)**	**Average length of re-growth (cm)**
Control	358.4	69.9	0.0	0.0
3 x 50 $mg.l^{-1}$ P-Ca	154.5	31.1	6.1	17.8
4 x 50 $mg.l^{-1}$ P-Ca	169.3	27.5	11.8	15.3
3 x 67 $mg.l^{-1}$ P-Ca	149.5	27.9	30.8	12.7
Sign. level				
Trt	**0.0066**	**0.0003***	-	-
Control vs P-Ca	**0.0006**	**0.0001**	-	-

* Initial shoot length used as covariate

Table 6. The effect of prohexadione-Ca on shoot growth characteristics of 'Royal Gala' apples in the 1999/2000 season.

Treatments	**Total shoot increase (%)**	**Final shoot length (cm)***	**Shoots with re-growth (%)**	**Average length of re-growth (cm)**
Control	264.3	26.3	23.0	8.7
3 x 50 $mg.l^{-1}$ P-Ca	117.7	20.7	18.6	4.9
4 x 50 $mg.l^{-1}$ P-Ca	155.5	22.7	26.3	4.4
3 x 67 $mg.l^{-1}$ P-Ca	145.7	22.5	19.0	8.1
Sign. level				
Trt	**0.0002**	**0.0615***	**0.7518**	**0.0510**
Control vs P-Ca	**0.0001**	**0.1296**	**0.7959**	**0.1366**

* Initial shoot length used as covariate

Table 7. The effect of prohexadione-Ca on shoot growth characteristics of 'Royal Gala' apples in the 2000/2001 season.

Treatments	Total shoot increase (%)	Final shoot length (cm)*	Shoots with re-growth (%)	Average length of re-growth (cm)
Control	49.1	31.6	4.3	12.0
3 x 50 $mg.l^{-1}$ P-Ca	35.7	27.3	15.4	17.4
4 x 50 $mg.l^{-1}$ P-Ca	22.1	25.5	18.2	11.3
3 x 67 $mg.l^{-1}$ P-Ca	27.0	27.1	14.8	16.5
Sign. level				
Trt	**0.4890**	**0.3610***	-	-
Control vs P-Ca	**0.1793**	**0.0808**	-	-

* Initial shoot length used as covariate

Table 8. The effect of prohexadione-Ca on fruit growth characteristics of 'Royal Gala' apples in the 1999/2000 season.

Treatments	Total fruit increase (%)	Final fruit diameter (mm)*
Control	1093.9	60.2
3 x 50 $mg.l^{-1}$ P-Ca	1032.2	61.7
4 x 50 $mg.l^{-1}$ P-Ca	919.3	61.5
3 x 67 $mg.l^{-1}$ P-Ca	1043.7	63.0
Sign. level		
Trt	**0.2512**	**0.0677***
Control vs P-Ca	**0.1882**	**0.0133**

* Initial fruit diameter used as covariate

Table 9. The effect of prohexadione-Ca on the weight, length, diameter and yield of 'Golden Delicious' apples in the 2000/2001 season.

Treatments	Weight (g)*	Length (mm)*	Diameter (mm)*	Yield (kg/cm trunk)	Malformation vs Yield (Pearson Correlation Coefficient)
Control	152.6	62.5	64.3	1.0	-0.4280
3 x 50 mg.l^{-1} P-Ca	158.9	62.7	65.0	0.5	
4 x 50 mg.l^{-1} P-Ca	158.9	62.7	65.3	0.8	
3 x 67 mg.l^{-1} P-Ca	157.5	63.3	64.3	0.5	
Sign. level					**0.0059**
Trt	**0.8389***	**0.9552***	**0.7718***	**0.0099**	
Control vs P-Ca	**0.3710**	**0.5680**	**0.7752**	**0.0037**	

* Total yield used as covariate

Table 10. The effect of prohexadione-Ca on fruit growth characteristics of 'Golden Delicious' apples in the 1999/2000 season.

Treatments	Total fruit increase (%)	Final fruit diameter (mm)*
Control	490.7	69.0
3 x 50 mg.l^{-1} P-Ca	517.1	67.7
4 x 50 mg.l^{-1} P-Ca	482.4	71.2
3 x 67 mg.l^{-1} P-Ca	471.2	67.1
Sign. level		
Trt	**0.7124**	**0.0457***
Control vs P-Ca	**0.9885**	**0.7831**

* Initial fruit diameter used as covariate

Table 11. The effect of prohexadione-Ca on fruit growth characteristics of 'Granny Smith' apples in the 1999/2000 season.

Treatments	Total fruit increase (%)	Final fruit diameter (mm)*
Control	291.5	63.9
3 x 50 mg.l^{-1} P-Ca	296.1	61.1
4 x 50 mg.l^{-1} P-Ca	309.7	65.6
3 x 67 mg.l^{-1} P-Ca	297.8	61.8
Sign. level		
Treatment	**0.8957**	**0.2777***
Control vs P-Ca	**0.8158**	**0.5174**

* Initial fruit diameter used as covariate

Table 12. The effect of prohexadione-Ca on the weight, length, diameter and yield of 'Golden Delicious' apples in the 1999/2000 season.

Treatments	Weight (g)*	Length (mm)*	Diameter (mm)*	Yield (kg/cm trunk)
Control	158.6	66.9	69.9	1.7
3 x 50 mg.l^{-1} P-Ca	154.0	65.0	69.4	1.8
4 x 50 mg.l^{-1} P-Ca	166.4	67.1	71.3	1.5
3 x 67 mg.l^{-1} P-Ca	158.6	65.5	70.0	1.9
Sign. level				
Treatment	**0.1495***	**0.0835***	**0.0934***	**0.1360**
Control vs P-Ca	**0.8506**	**0.1517**	**0.5992**	**0.7002**

* Total yield used as covariate

Table 13. The effect of prohexadione-Ca on the weight, length, diameter and yield of 'Granny Smith' apples in the 1999/2000 season.

Treatments	Weight (g)*	Length (mm)*	Diameter (mm)*	Yield (kg/cm trunk)
Control	124.4	58.6	66.1	1.0
3 x 50 $mg.l^{-1}$ P-Ca	122.7	57.5	65.7	1.2
4 x 50 $mg.l^{-1}$ P-Ca	125.2	57.8	66.3	1.0
3 x 67 $mg.l^{-1}$ P-Ca	125.8	57.9	66.3	1.1
Sign. level				
Treatment	**0.9083***	**0.5841***	**0.9064***	**0.8969**
Control vs P-Ca	**0.9449**	**0.1758**	**0.8845**	**0.6901**

* Total yield used as covariate

Table 14. The effect of prohexadione-Ca on the weight, length, diameter and yield of 'Royal Gala' apples in the 1999/2000 season.

Treatments	Weight (g)*	Length (mm)*	Diameter (mm)*	Yield (kg/cm trunk)
Control	126.9	60.8	63.8	0.8 a
3 x 50 $mg.l^{-1}$ P-Ca	128.8	59.7	63.6	0.9 a
4 x 50 $mg.l^{-1}$ P-Ca	129.3	60.0	63.9	0.9 a
3 x 67 $mg.l^{-1}$ P-Ca	131.5	60.5	64.7	0.9 a
Sign. level				
Treatment	**0.5244***	**0.2528***	**0.2691***	**0.5933**
Control vs P-Ca	**0.3212**	**0.0785**	**0.5602**	**0.1878**

* Total yield used as covariate

Table 15. The effect of prohexadione-Ca on the weight, length, diameter and yield of 'Royal Gala' apples in the 2000/2001 season.

Treatments	Weight (g)*	Length (mm)*	Diameter (mm)*	Yield (kg/cm trunk)
Control	128.7	60.9	63.5	0.8
3 x 50 mg.l^{-1} P-Ca	132.2	61.3	64.5	1.0
4 x 50 mg.l^{-1} P-Ca	132.1	61.0	64.0	0.9
3 x 67 mg.l^{-1} P-Ca	132.8	60.2	62.9	0.8
Sign. level				
Trt	**0.8746***	**0.7889***	**0.3725***	**0.1412**
Control vs P-Ca	**0.4503**	**0.5168**	**0.3356**	**0.2888**

* Total yield used as covariate

Table 16. The effect of prohexadione-Ca on the number of flower clusters of 'Golden Delicious' apple trees.

	Return bloom (Spring 2000)		**Return bloom (Spring 2001)**	
Treatments	**Clusters / cm branch length**	**Clusters / mm branch circumference**	**Clusters / cm branch length**	**Clusters / mm branch circumference**
Control	0.3	0.5	1.0	1.9
3 x 50 mg.l^{-1} P-Ca	0.1	0.2	1.2	2.2
4 x 50 mg.l^{-1} P-Ca	0.2	0.3	1.1	1.9
3 x 67 mg.l^{-1} P-Ca	0.1	0.2	1.2	2.0
Sign level				
Trt	**0.0052**	**0.0001**	**0.6650**	**0.7791**
Control vs P-Ca	**0.0008**	**0.0001**	**0.2423**	**0.5181**

Table 17. The effect of prohexadione-Ca on seed content and external quality of 'Golden Delicious' apples in the 1999/2000 season.

Treatments	Colour	Seed contents		Stem-end russeting	Bitter pit at harvest (%)
		With embrio	Aborted embrio		
Control	3.0	5.3	0.1	4.5	20.1
3 x 50 mg.l^{-1} P-Ca	2.9	5.5	0.2	3.8	24.3
4 x 50 mg.l^{-1} P-Ca	2.9	5.2	0.2	4.4	26.4
3 x 67 mg.l^{-1} P-Ca	3.0	5.2	0.1	4.4	24.1
Sign. level					
Treatment	**0.9081**	**0.4868**	**0.1224**	**0.2411**	**0.7000**
Control vs P-Ca	**0.6484**	**0.7771**	**0.0613**	**0.4523**	**0.2792**

Table 18. The effect of prohexadione-Ca on the seed contents and external quality of 'Granny Smith' apples in the 1999/2000 season.

Treatments	Colour	Seed contents		Stem-end russet
		With embrio	Aborted embrio	
Control	4.8	4.5	0.2	1.7
3 x 50 mg.l^{-1} P-Ca	4.6	3.9	0.2	2.2
4 x 50 mg.l^{-1} P-Ca	4.6	4.3	0.2	2.1
3 x 67 mg.l^{-1} P-Ca	4.7	4.4	0.1	1.9
Sign. level				
Treatment	**0.8769**	**0.0863**	**0.6977**	**0.2876**
Control vs P-Ca	**0.5155**	**0.1837**	**0.9461**	**0.1064**

Table 19. The effect of prohexadione-Ca on seed contents and external quality of 'Royal Gala' apples in the 1999/2000 season.

Treatments	Colour	Seed contents		Stem-end russet
		With embrio	Aborted embrio	
Control	8.1	3.3	1.0	2.8
3 x 50 mg.l^{-1} P-Ca	7.4	2.5	1.5	2.8
4 x 50 mg.l^{-1} P-Ca	8.2	2.8	0.8	2.5
3 x 67 mg.l^{-1} P-Ca	7.4	3.1	1.4	2.6
Sign. level				
Trt	**0.7456**	**0.0198**	**0.1066**	**0.3500**
Control vs P-Ca	**0.5927**	**0.0293**	**0.3261**	**0.2047**

Table 20. The effect of prohexadione-Ca on seed contents and external quality of 'Golden Delicious' apples in the 2000/2001 season.

Treatments	Colour	Seed contents		Stem-end russet	Bitter pit at harvest (%)
		With embrio	Aborted embrio		
Control	3.4	5.4	0.2	4.9	12.5
3 x 50 mg.l^{-1} P-Ca	3.6	5.2	0.3	5.5	15.5
4 x 50 mg.l^{-1} P-Ca	3.7	5.5	0.3	5.2	16.6
3 x 67 mg.l^{-1} P-Ca	3.7	5.1	0.2	5.5	18.1
Sign. level					
Trt	**0.4103**	**0.5984**	**0.4415**	**0.3297**	**0.6257**
Control vs P-Ca	**0.1050**	**0.5861**	**0.1990**	**0.1004**	**0.2459**

Table 21. The effect of prohexadione-Ca on seed contents and external quality of 'Royal Gala' apples in the 2000/2001 season.

Treatments	**Colour**	**Seed contents**		**Stem-end russet**
		With embrio	**Aborted embrio**	
Control	5.8	2.8	1.2	3.9
3 x 50 mg.l^{-1} P-Ca	4.3	2.3	1.5	4.0
4 x 50 mg.l^{-1} P-Ca	5.3	2.2	1.6	3.6
3 x 67 mg.l^{-1} P-Ca	5.7	2.3	1.8	3.7
Sign. evel				
Treatment	**0.1460**	**0.0971**	**0.1339**	**0.4851**
Control vs P-Ca	**0.2214**	**0.0145**	**0.0328**	**0.5221**

Table 22. The effect of prohexadione-Ca on the occurrence of bitter pit in 'Golden Delicious' apples after 4 weeks of cold storage in the 1999/2000 season (fruit collected one week before commercial harvest date).

Treatments	**Outside**		**Inside**	
	% fruit with BP	**Number of BP lesions**	**% fruit with BP**	**Number of BP lesions**
Control	36.3	3.1	1.6	3.0
3 x 50 mg.l^{-1} P-Ca	42.8	3.2	0.4	3.0
4 x 50 mg.l^{-1} P-Ca	47.2	3.6	4.4	1.5
3 x 67 mg.l^{-1} P-Ca	48.6	3.7	2.0	1.4
Sign. level				
Treatment	**0.3912**	**0.8842**	**0.1209**	-
Control vs P-Ca	**0.1266**	**0.8645**	**0.6226**	-

Table 23. The effect of prohexadione-Ca on the occurrence of bitter pit in 'Golden Delicious' apples after 4 weeks of cold storage (fruit collected at commercial harvest date).

Treatments	Outside		Inside	
	% fruit with BP	**Number of BP lesions**	**% fruit with BP**	**Number of BP lesions**
Control	50.2	3.0	0.4	2.0
3 x 50 $mg.l^{-1}$ P-Ca	48.3	2.7	0.4	1.0
4 x 50 $mg.l^{-1}$ P-Ca	51.3	3.1	2.8	2.2
3 x 67 $mg.l^{-1}$ P-Ca	56.8	2.9	1.6	1.5
Sign. level				
Treatment	**0.6831**	**0.8788**	**0.1281**	-
Control vs P-Ca	**0.7514**	**0.8746**	**0.2044**	-

Table 24. The effect of prohexadione-Ca on the occurrence of bitter pit in 'Golden Delicious' apples after 4 weeks of cold storage in the 2000/2001 season.

Treatments	Outside		Inside	
	% fruit with BP	**Number of BP lesions**	**% fruit with BP**	**Number of BP lesions**
Control	26.7	2.5	4.8	4.0
3 x 50 $mg.l^{-1}$ P-Ca	36.3	4.9	10.5	2.3
4 x 50 $mg.l^{-1}$ P-Ca	37.1	5.2	10.7	2.4
3 x 67 $mg.l^{-1}$ P-Ca	27.9	4.7	7.2	3.0
Sign. level				
Trt	**0.1668**	**0.2128**	**0.1951**	**0.3495**
Control vs P-Ca	**0.1422**	**0.0394**	**0.0770**	**0.0909**

Table 25. The effect of prohexadione-Ca on the number of flower clusters of 'Granny Smith' apple trees.

	Return bloom (Spring 2001)	
Treatments	**Clusters / cm branch length**	**Clusters / mm branch circumference**
Control	0.7	1.6
3 x 50 mg.l^{-1} P-Ca	0.8	1.9
4 x 50 mg.l^{-1} P-Ca	0.9	1.9
3 x 67 mg.l^{-1} P-Ca	0.7	1.5
Sign. level		
Trt	**0.2595**	**0.3009**
Control vs P-Ca	**0.3686**	**0.5290**

Table 26. The effect of prohexadione-Ca on the number of flower clusters of 'Royal Gala' apple trees.

	Return bloom (Spring 2000)		Return bloom (Spring 2001)	
Treatments	**Clusters / cm branch length**	**Clusters / mm branch circumference**	**Clusters / cm branch length**	**Clusters / mm branch circumference**
Control	0.3	0.6	0.7	1.4
3 x 50 mg.l^{-1} P-Ca	0.2	0.6	0.7	1.2
4 x 50 mg.l^{-1} P-Ca	0.3	0.6	0.6	1.1
3 x 67 mg.l^{-1} P-Ca	0.2	0.5	0.6	1.1
Sign. level				
Treatment	**0.0836**	**0.0618**	**0.0369**	**0.1962**
Control vs P-Ca	**0.0979**	**0.0739**	**0.0813**	**0.0485**

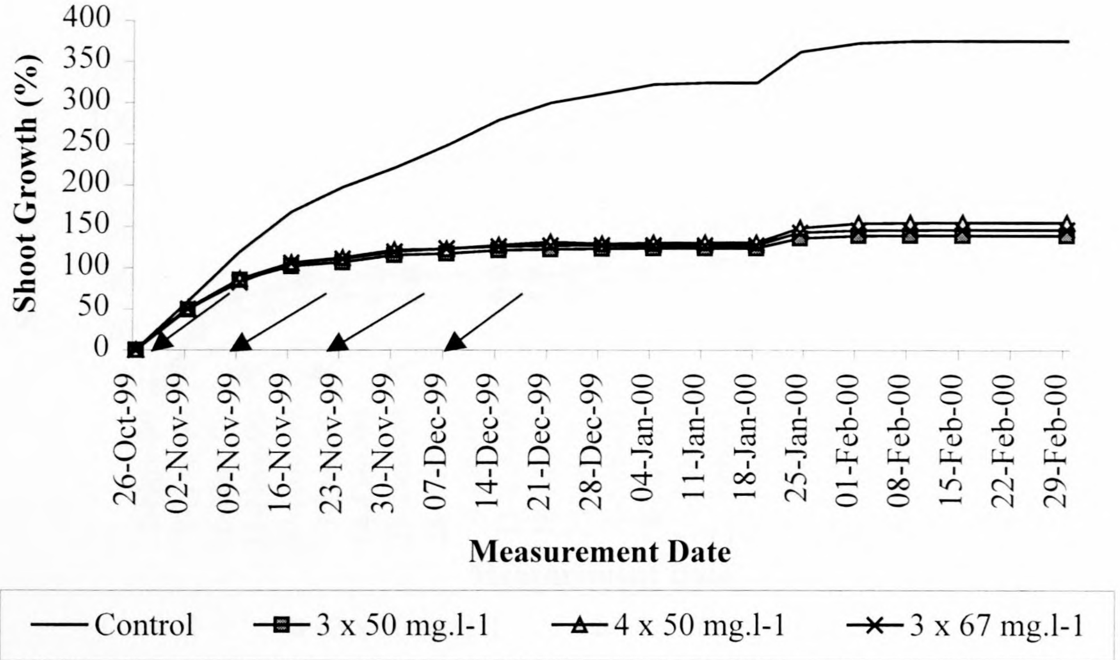

Fig. 1. The effect of prohexadione-Ca on shoot growth of 'Golden Delicious' apple trees in the 1999/2000 season (application dates are indicated by arrows).

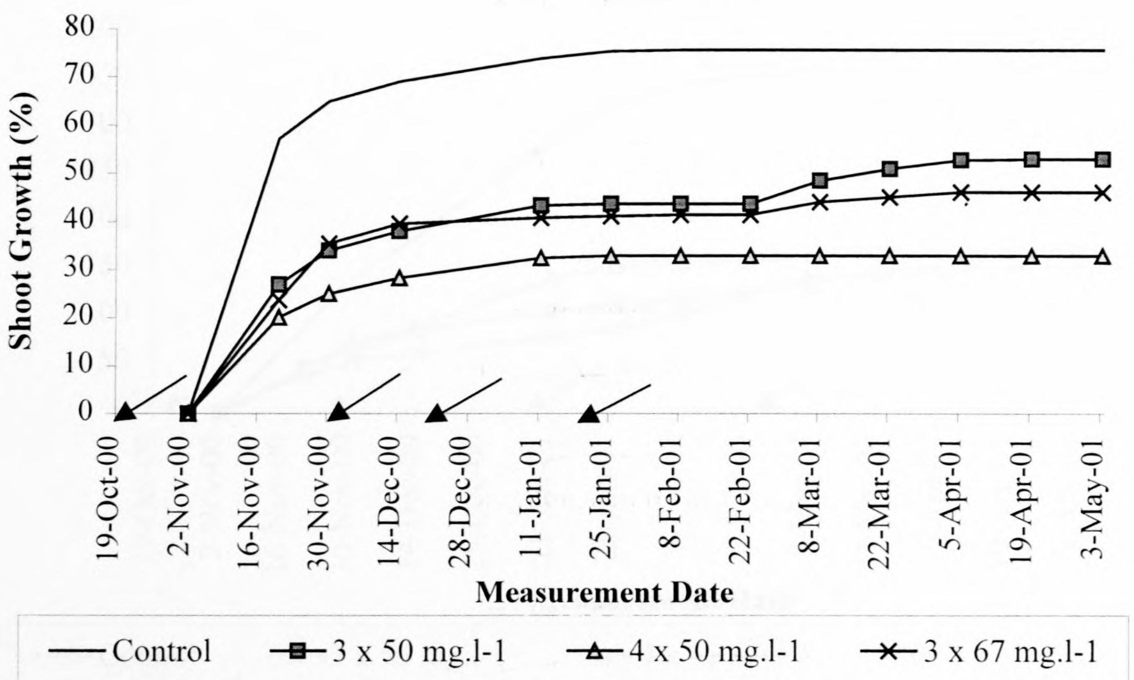

Fig. 2. The effect of prohexadione-Ca on shoot growth of 'Golden Delicious' apple trees in the 2000/2001 season (application dates are indicated by arrows).

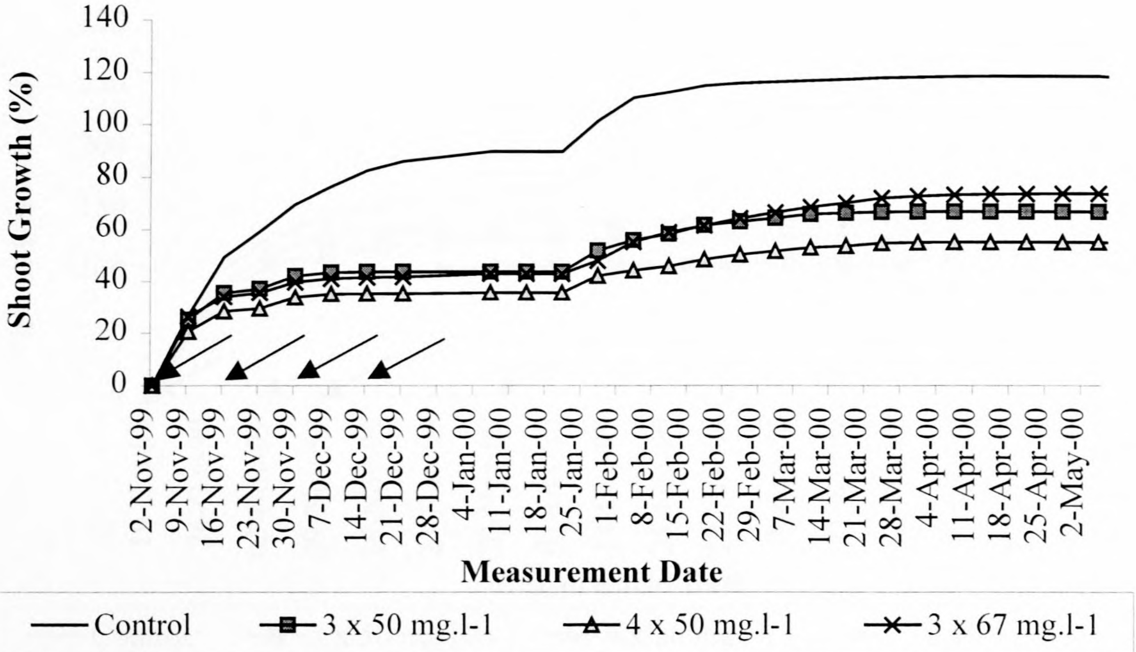

Fig. 3. The effect of prohexadione-Ca on shoot growth of 'Granny Smith' apple trees in the 1999/2000 season (application dates are indicated by arrows).

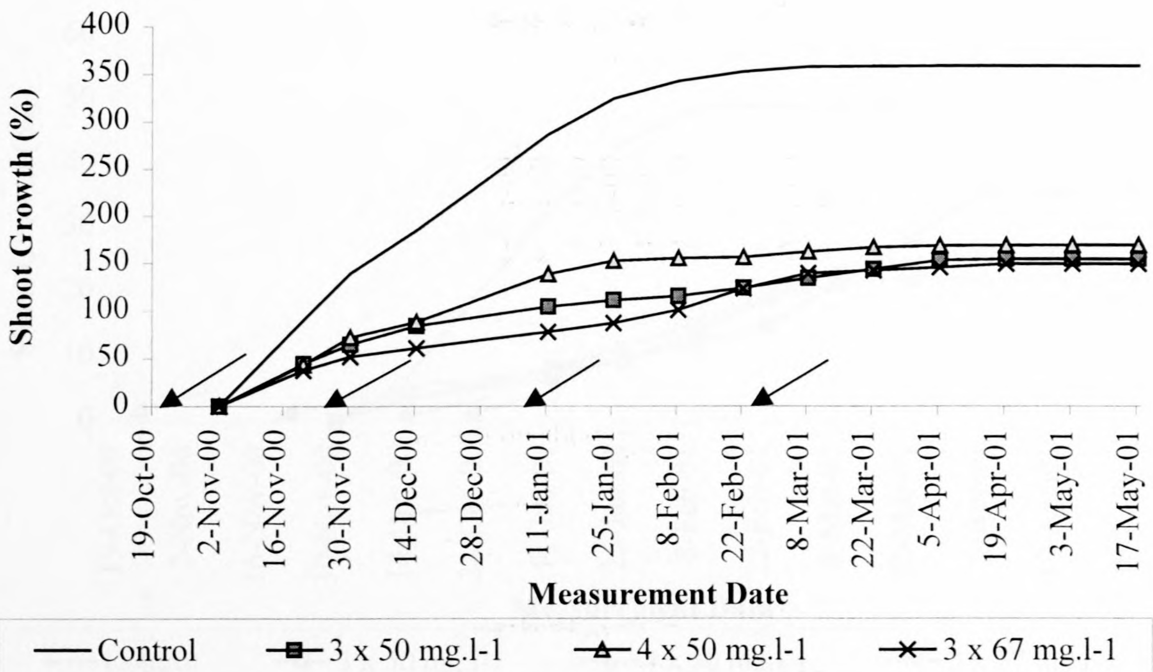

Fig. 4. The effect of prohexadione-Ca on shoot growth of 'Granny Smith' apple trees in the 2000/2001 season (application dates are indicated by arrows).

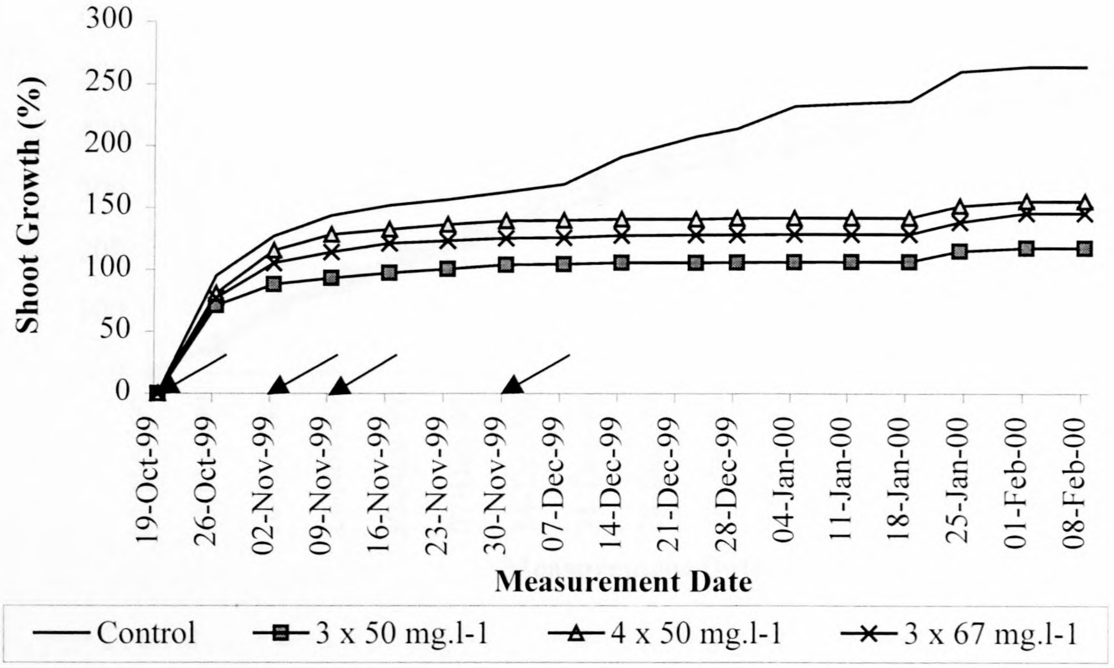

Fig. 5. The effect of prohexadione-Ca on shoot growth of 'Royal Gala' apple trees in the 1999/2000 season (application dates are indicated by arrows).

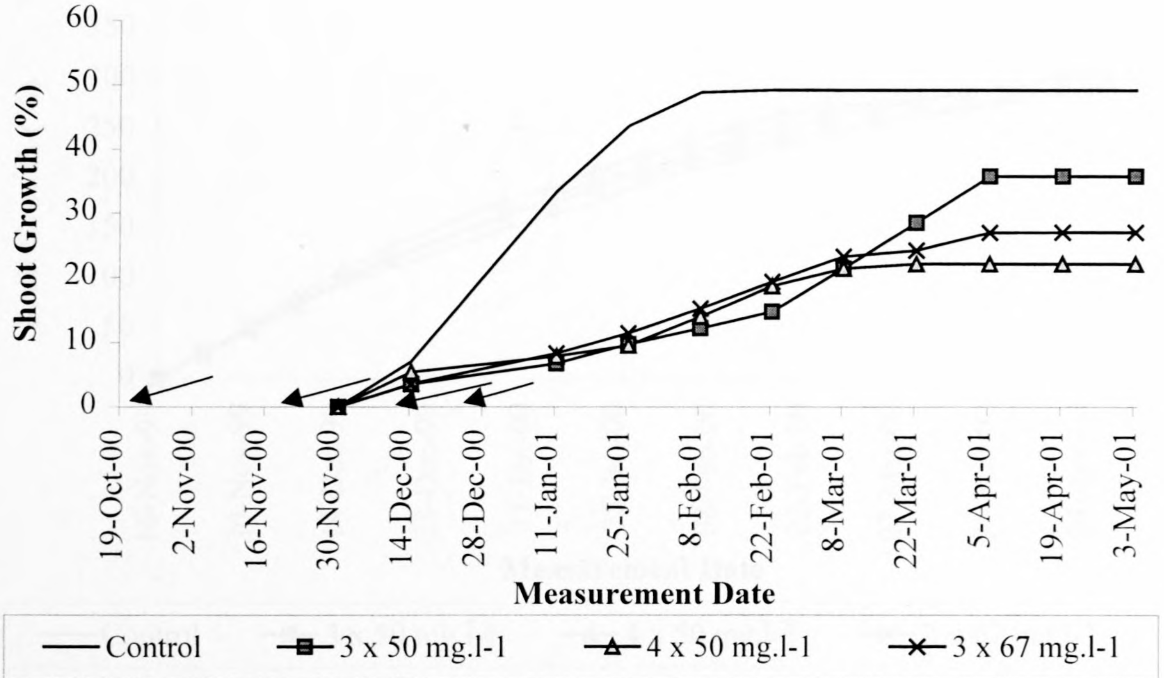

Fig. 6. The effect of prohexadione-Ca on shoot growth of 'Royal Gala' apple trees in the 2000/2001 season (spraying dates are indicated by arrows).

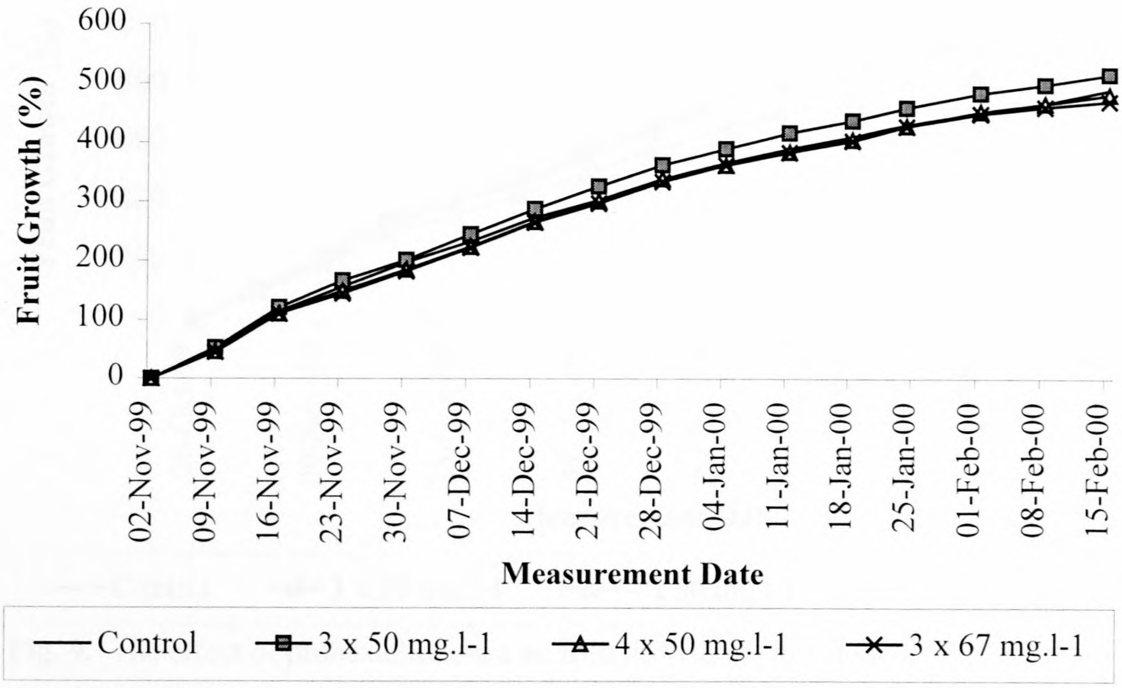

Fig. 7. The effect of prohexadione-Ca on fruit growth of 'Golden Delicious' apples in the 1999/2000 season.

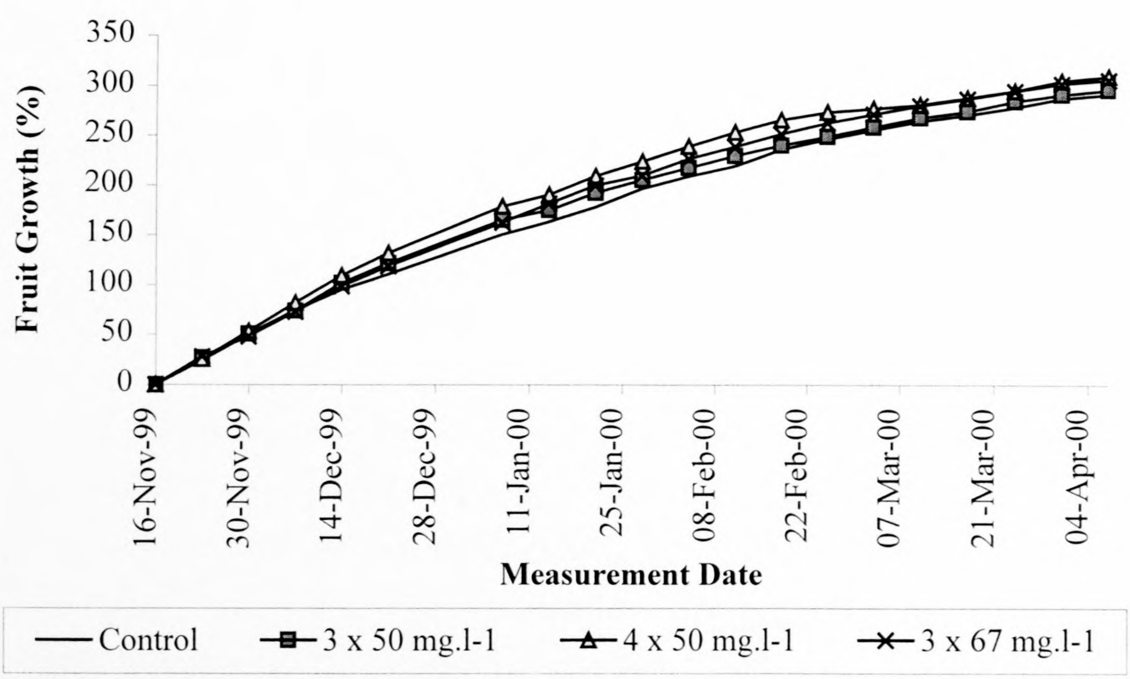

Fig. 8. The effect of prohexadione-Ca on fruit growth of 'Granny Smith' apples in the 1999/2000 season.

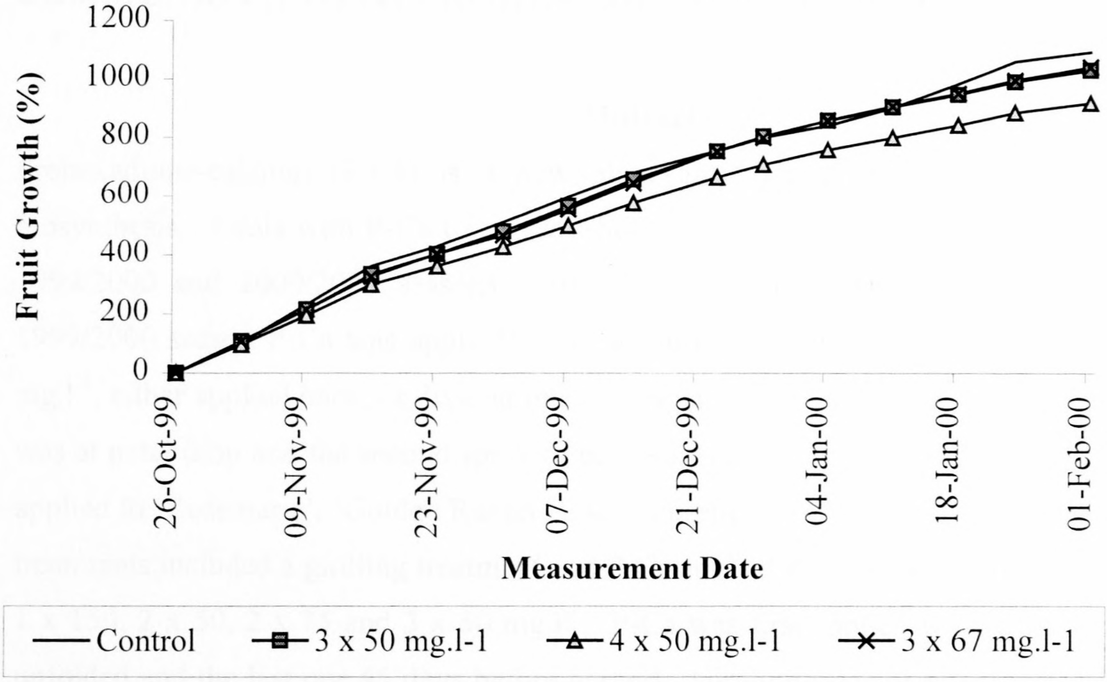

Fig. 9. The effect of prohexadione-Ca on fruit growth of 'Royal Gala' apples in the 1999/2000 season.

PAPER 2: SHOOT GROWTH CONTROL OF PEAR TREES (*PYRUS COMMUNIS* L.) WITH PROHEXADIONE-CALCIUM

Abstract

Prohexadione-calcium (P-Ca) is a new plant growth retardant that inhibits gibberellin biosynthesis. Trials with P-Ca to control shoot growth of pear trees were carried out in the 1999/2000 and 2000/2001 seasons in the Western Cape area of South Africa. In the 1999/2000 season P-Ca was applied to 'Rosemarie' trees at concentrations of 125 and 250 $mg.l^{-1}$, either applied once, or divided into two equal foliar applications. The first application was at petal drop and the second spray three weeks later. In the 2000/2001 season P-Ca was applied to 'Rosemarie', 'Golden Russet Bosc', 'Forelle' and 'Packham's Triumph' trees. The treatments included a girdling treatment and P-Ca applied at the concentrations 1 x 50, 1 x 75, 1 x 150, 2 x 50, 2 x 75 and 3 x 50 $mg.l^{-1}$. P-Ca was first applied when 4 to 5 leaves were unfolded and the last one 45 days before harvest. Girdling was not effective to reduce shoot growth in any of the cultivars, but P-Ca proved to be an effective inhibitor in 'Rosemarie', 'Golden Russet Bosc' and 'Packham's Triumph', but not 'Forelle'. The 1 x 250 and 1 x 150 $mg.l^{-1}$ treatments gave the best shoot growth control in the 1999/2000 and 2000/2001 seasons respectively, suggesting that a single high rate application is more effective than a single low rate or multiple low rates. A post-harvest P-Ca application should be considered to inhibit the re-growth that occurred in 'Rosemarie' about four weeks after harvest. P-Ca had no significant negative effect on fruit set, -size, yield, fruit quality or return bloom, except in 'Rosemarie' where P-Ca caused a significant reduction in fruit size and in 'Forelle' and 'Packham's Triumph' where return bloom was negatively affected.

Introduction

The control of excessive vegetative growth and shading in fruit trees is a major concern for the producer (Williams, 1984). Shading caused by growth in the current season is detrimental to pest control, fruit quality (especially red colour) and yield (Byers and Yoder, 1999; Basak and Rademacher, 2000). Various cultural practices are used to control vegetative growth. These include many forms of winter and summer pruning to allow more sunlight into the trees to increase fruitfulness and improve fruit quality, the use of dwarfing rootstocks to improve the manageability of fruit trees, optimum levels of fertilizer to give a proper balance between vegetative growth, fruit load and return bloom (Williams, 1984) and girdling to reduce vegetative growth and increase fruit set and size. However, some negative aspects are associated with most of these cultural practices; pruning is very expensive and labour intensive (Byers and Yoder, 1999), the proper choice of rootstock combinations for each soil is difficult (Williams, 1984) and girdling may compromise long-term tree health. Because regulation of growth by cultural practices are also not always sufficient, chemical inhibitors of growth is a logic alternative (Elfving and Proctor, 1986).

Paclobutrazol and chlormequat chloride are currently registered for controlling vegetative growth of pear trees in several countries (Davis and Curry, 1991). Unfortunately both have the disadvantage of a relatively high persistency, especialy paclobutrazol in which the effect of a single application may last up to four years (Greene, 1986). Chlormequat chloride can persist in the tree in an unmetabolized form for six months after a spring application (Nicotra, 1982).

High rates of gibberellin (GA) biosynthesis stimulate excessive vegetative growth (Rademacher, 1991). Prohexadione-Ca (P-Ca), a new plant growth retardant, interfere with GA biosynthesis by blocking 2 oxoglutarate-dependant dioxygenases which catalyse the later steps in the biosynthetic sequence. Especially the 3-ß hydroxylation of GA_{20} (biologically inactive) into GA_1 (biologically active) is inhibited (Rademacher, 1993). P-Ca can be easily applied by spraying and constitute no risk to the consumer or the environment (Rademacher, 1995) and it also has a low propensity for crop residues (Winkler, 1997). Basak and Rademacher (2000) found that on the pear 'Conference' the higher concentration (250 $mg.l^{-1}$) was more effective than the lower concentration (150 $mg.l^{-1}$) in inhibiting shoot growth when applied when new shoots were ca. 23 cm long.

The purpose of this study was to determine the optimum concentration(s) and time(s) of application of P-Ca for controlling shoot growth of pear trees, as well as the effect of P-Ca on fruit set, fruit size, yield, fruit quality and return bloom.

Material and Methods

Plant material. Trials were conducted over two seasons and at two sites.

Trial 1: The trial was conducted during the 1999/2000 season in a commercial orchard on Theewaterskloof Farm in the Villiersdorp area in the Western Cape, South Africa (33°59' S, 19°17' E; ca. 365m a.s.l.; Mediterrranean climate). 'Rosemarie' pear trees on seedling rootstock planted in 1992 at a spacing of 4.5 x 1.75 m were used. Trees were selected for uniformity in size. 'Packham's Triumph' served as cross-pollinator, planted as every eighth tree in a row. Full bloom was on 22 September 1999 and fruit were hand thinned five weeks after full bloom (after natural fruit drop) according to commercial standards. All the trees were girdled on 22 October 1999. Fruit were harvested on 14, 24 and 26 January 2000, which were the commercial harvest dates. Yield in 1998 was 23 $t.ha^{-1}$, 18 $t.ha^{-1}$ in 1999 and 25 $t.ha^{-1}$ in 2000.

Trial 2: The trials were conducted during the 2000/2001 season at two sites in the Wolseley area in the Western Cape, South Africa (33°25' S, 19°12' E; ca. 270 m a.s.l.; Mediterranean climate). 'Golden Russet Bosc' pear trees in a commercial orchard on the farm Romansrivier and 'Forelle', 'Packham's Triumph' and 'Rosemarie' pear trees in a commercial orchard on the farm La Plaisante Estate were used. The 'Golden Russet Bosc' trees on BP1 rootstock were planted in 1995 at a spacing of 4.0 x 7.5m. Trees were planted with no cross pollinator, but 'Bon Chretien' bouquets are brought in at flowering. Full bloom was on 1 October 2000 and return bloom on 9 October 2001. No fruit thinning was done. The 'Forelle' trees on BP3 rootstock were planted in 1993 at a spacing of 4.5 x 1.5 m. 'Early Bon Chretien' served as cross pollinator, planted as every tenth tree in the row. Full bloom was on 4 October 2000 and return bloom on 21 September 2001. Fruit were hand thinned five weeks after full bloom (after natural fruit drop) according to commercial standards. Fruit were harvested on 15 March 2001, which was the commercial harvest date. Yield in 1999 was 4 $t.ha^{-1}$, in 2000 33 $t.ha^{-1}$ and in 2001 18 $t.ha^{-1}$. The 'Packham's Triumph' trees on seedling rootstock were planted in 1984 at a spacing of 4.57 x 2.0 m. Every tenth tree in the row was top worked to 'Clapp's Favourite' and 'Winter Nelis' and served as cross pollinators. There is also 'December' pear grafts in the 'Packham's Triumph' trees. Full bloom was on 20 October 2000 return bloom on 19 October 2001. No fruit thinning was done. Fruit were harvested on 9 March 2001 which was the commercial harvest date. Production in 1999 was 60 $t.ha^{-1}$, in 2000 82 $t.ha^{-1}$ and in 2001 79 $t.ha^{-1}$. 'Rosemarie' trees on BP3 rootstocks were planted in 1994 at a spacing of 4.5 x 1.5 m. Trees were planted with no cross pollinator, but 'Packham's Triumph' bouquets are brought in at flowering. Full bloom was on 15 October 2000 and return bloom on 6 October 2001. Fruit were hand thinned five weeks after full bloom (after natural fruit drop) according to commercial standards. Fruit were harvested on 12 and 17 January 2001, which were the commercial harvest dates. Yield in 1999 was 21 $t.ha^{-1}$, in 2000 41 $t.ha^{-1}$ and in 2001 28 $t.ha^{-1}$. All the trees were selected for uniformity in size.

Treatments and experimental design. The wettable granular formulation BAS 125 10W, containing 10% (w:w) of P-Ca as active ingredient, was applied as indicated in Table 1. Control trees were unsprayed and the girdling treatment done between full bloom and ¾ petal drop.

The chemical was applied at high volume with the first application in the 1999/2000 season at petal drop on 8 October 1999. Agral-90 was added as surfactant at a concentration of 6 $ml.100\ l^{-1}$ water only with the first application. In the 2000/2001 season the first application in all the cultivars was when four to five leaves were unfolded on 26 October 2000, 28 September 2000, 13 October 2000 and 16 October 2000 on 'Golden Russet Bosc', 'Forelle', 'Packham's Triumph' and 'Rosemarie' respectively. Agral-90 was added as surfactant at a concentration of 6 $ml.100\ l^{-1}$ water with all the applications.

The experimental design was a randomised complete block design with ten single tree plot replications of either 5 or 8 treatments.

Data collected.

Trial 1: Ten representative shoots per tree were tagged and their length measured at the time of the first application and then at weekly intervals until the cessation of shoot growth. Ten representative fruit per tree were tagged and their diameter measured at the time of the first application and then at weekly intervals until harvest. At the second harvest date (24 January 2000), a randomly selected sample of 25 fruit per tree was collected and the average fruit weight, length, diameter and colour determined. At the time of harvest total yield per tree was recorded by combining the weight of the fruit picked at the three harvest dates. The trunk circumference of each tree was measured.

'Rosemarie' fruit colour was evaluated on a scale of 1 to 12 using the Deciduous Fruit Board colour chart number P23 (1 = most blush; 12 = least blush).

Trial 2: For the 'Forelle' and 'Rosemarie' trees two representative branches per tree were tagged and for the 'Packham's Triumph' trees one representative branch per tree was tagged at full bloom 2000 and the number of flower clusters on these branches were counted After natural fruit drop, but before hand thinning, the number of fruit on these branches was counted. This was not done for 'Golden Russet Bosc' due to low flower numbers. At full bloom 2001 the number of flower clusters was counted on the same branches and the length and diameter of the branches were measured. This was also done on two representative branches on each 'Golden Russet Bosc' tree. Five representative shoots per tree were tagged and their length measured at the time of the first application and then at two weekly intervals until the cessation of shoot growth. The percentage of tagged shoots showing signs of terminal re-growth during the season was recorded and the length of the re-growth measured.

A randomly selected sample of 25 fruit per tree was collected at harvest from the 'Packham's Triumph', 'Forelle' and 'Rosemarie' (second harvest date) trees, but not from the 'Golden Russet Bosc' trees due to low fruit number. The average fruit weight, length, diameter, colour, firmness, total soluble solids (TSS) concentration, number of developed seeds and number of seeds with aborted embrio's were determined. For 'Packham's Triumph' and 'Forelle' the percentage of fruit with cork spot and water core was determined. At the time of harvest total yield per tree was recorded for 'Packham's Triumph' and 'Forelle'. For 'Rosemarie' total yield per tree was recorded by combining the weight of the fruit picked at the two harvest dates. The circumference of each tree was measured. At the time of winter pruning all the one-year-old prunings from each 'Golden Russet Bosc' tree was collected and the weight of the shoots determined. The length of a randomly selected sample of ten shoots from the prunings of each tree was also measured.

'Rosemarie' and 'Forelle' fruit colour was evaluated on a scale of 1 to 12 (1 = most blush; 12 = least blush) using the Deciduous Fruit Board (DFB) colour chart numbers P23 and P16 respectively. 'Packham's Triumph' fruit colour was evaluated on a scale of 0.5 to 5.0 (0.5 = green; 5.0 = yellow) using the Unifruco Research services (PTY) Ltd colour chart for apples and pears. Fruit firmness was evaluated by paring opposite sides of the fruit and each fruit was then tested twice by inserting a penetrometer (Southtrade model FT 327 with 8 mm tip) directly into the flesh. A slice was removed from each fruit and the juice squeezed onto a refractometer (Atago N1; 0-32% Brix) to determine the TSS concentration.

Statistical analysis. Shoot and fruit measurements were converted to percentages using the formula: $((x - y)/y)*100$ where x = the shoot length/fruit diameter at the measurement date and y = the initial shoot length/fruit diameter. The General Linear Models (GLM) procedure of the Statistical Analysis System (SAS) was used to analyse the data (SAS Institute Inc., 1990).

Results and Discussion

<u>*Shoot growth.*</u>

'Rosemarie'. By the end of the 1999/2000 season trees treated with P-Ca had significantly less shoot growth than the control trees (Table 2; Fig. 1). This reduction in shoot growth caused by P-Ca was visible from ca. one week after the first P-Ca application throughout the growing season in all the P-Ca treatments except for the 125 $mg.l^{-1}$ P-Ca treatment. For this treatment the reduction in shoot growth first became apparent from ca. three weeks after the first application (Fig. 1) and was the least effective in reducing growth (Table 2; Fig. 1). In the 2000/2001 season the trees grew more vigorously than in the 1999/2000 season, with an average shoot length of ca. 58 cm by the end of the season (Table 3), compared to the ca. 46 cm by the end of the 1999/2000 season (Table 2). In the 2000/2001 season the P-Ca treated trees again had significantly less shoot growth by the end of the season than the control and girdled trees. Differences between the P-Ca treatments and between the control and girdled trees were not significant (Table 3; Fig. 2). The reduction in shoot growth caused by P-Ca was visible from ca. one week after the first P-Ca application (Fig. 2). The control trees had no re-growth, but re-growth occurred ca. nine weeks after terminal bud set on the more vigorous shoots in the girdled and P-Ca treated trees, which was ca. four weeks after the last harvest date (Fig. 2). Although none of the tagged shoots on the trees that received the 1 x 50 $mg.l^{-1}$ P-Ca treatment had re-growth (Table 3), some of the untagged shoots on these trees had re-growth (personal observation). Fruit growth is normally a stronger sink than vegetative growth (Forsey and Elving, 1989), therefore the re-growth that occurred after harvest is probably a result of no shoot-fruit competition for assimilates. It seems that fewer shoots had re-growth and that the average length of the re-growth was less on the trees that received the multiple P-Ca treatments than on the trees that received only one P-Ca treatment (Table 3).

'Golden Russet Bosc'. Trees treated with P-Ca had significantly less shoot growth by the end of the 2000/2001 season than the control and girdled trees, but the control and girdled trees did not differ (Table 4; Fig. 3). This was also evident in the average length of the one-year-old shoots removed during winter pruning, but not in the weight of shoots removed (Table 5). The reason for this is that shoot weight included watershoots, but watershoots were eliminated from the shoot length determinations. This reduction in shoot growth caused by P-Ca was evident from ca. one week after the first P-Ca application throughout the growing season. No re-growth occurred (Fig. 3).

'Forelle'. P-Ca and girdling had no significant effect on shoot growth (Table 6; Fig. 4).

'Packham's Triumph'. All the P-Ca treatments except the 3 x 50 $mg.l^{-1}$ treatment significantly reduced shoot growth compared to the control trees. Girdling did not reduce shoot growth compared to the control (Table 7; Fig. 5). The reduction in shoot growth was evident from ca. one week after the first P-Ca application. No re-growth occurred in any of the treatments (Fig. 5).

Fruit set

In the 2000/2001 season fruit set was increased in the P-Ca treated trees, in the cultivars 'Rosemarie' and 'Forelle', but not in 'Packham's Triumph'. Girdling had no effect on fruit set in any of the cultivars (Tables 8, 9, & 10).

Fruit size and yield

At the end of the 1999/2000 season P-Ca had no effect on percentage increase in fruit size of the 'Rosemarie' pears (Table 11; Fig. 6), but fruit diameter was less for P-Ca treated fruit (Table 11). Compared to the control, mean fruit weight, length and diameter were less for P-Ca treated fruit but this was not reflected in the yield expressed as kg fruit harvested / cm trunk circumference (Table 12). With the observed shoot growth reduction, an increase in fruit size was expected as a result of more assimilates being available for fruit growth, but no correlation was found between shoot and fruit growth.

In the 2000/2001 season P-Ca again caused a significant decrease in fruit weight, length and diameter, but had no effect on the yield of the 'Rosemarie' trees (Table 13). The reduction in fruit size could be due to the increased fruit set (Table 8). It is also possible that P-Ca reduced shoot growth to the extent that photosynthetic supply became limited for the early maturing 'Rosemarie'. Girdling had no effect on fruit length and diameter, or fruit weight and yield when compared to the control, but was significantly better than P-Ca (Table 13). In 'Forelle' and 'Packham's Triumph' P-Ca had no effect on fruit weight, length or diameter, and therefore also no effect on yield (Tables 14 & 15). In 'Forelle' girdling significantly increased fruit length and diameter, and therefore also the fruit weight, but yield was not effected (Table 14). In 'Packham's Triumph' girdling significantly increased fruit weight but not in the other measurements (Table 15).

Fruit quality

In 'Rosemarie' P-Ca had no effect on fruit colour (Tables 16 & 17), TSS concentration or seed contents, but fruit were more firm (Table 17). None of the parameters were affected by girdling (Table 17). In 'Forelle' girdling had no effect on fruit colour while P-Ca had a positive effect on fruit colour. Neither girdling nor P-Ca had any effect on fruit firmness, TSS concentration or seed contents of 'Forelle' (Table 18). Girdling and P-Ca also had no effect on the percentage of fruit with water core or cork spot (Table 19). In 'Packham's Triumph' P-Ca had no effect on the colour, firmness or TSS concentration of the fruit, but girdling increased fruit colour and TSS concentration while decreasing firmness. Neither P-Ca nor girdling had an effect on the seed contents of the fruit (Table 20). P-Ca but not girdling caused a reduction in the percentage of fruit with cork spot (Table 21). Since actively growing shoots compete with fruit for calcium (Fallahi et al., 1997), a reduction in the occurrence of cork spot was expected as a result of the reduced shoot growth obtained with P-Ca. The percentage of fruit with water core varied and no constant trend was established (Table 21).

Return bloom

Neither the 2000 P-Ca application nor girdling had any significant effect on return bloom of 'Rosemarie' (Table 8). As in 2000, the 'Golden Russet Bosc' trees again flowered sparsely in 2001. However, return bloom was increased by girdling while P-Ca had no effect (Table 22). P-Ca significantly reduced return bloom in 'Forelle' in 2001, while girdling improved it (Table 9). P-Ca, but not girdling, reduced the number of flower clusters in 'Packham's Triumph' in 2001 (Table 10).

Conclusion

Girdling was not very effective in inhibiting shoot growth in any of the cultivars, but P-Ca proved to be an effective inhibitor of shoot growth of 'Rosemarie' and 'Golden Russet Bosc' pear trees and to a lesser degree 'Packham's Triumph', but not 'Forelle'. The 1 x 250 $mg.l^{-1}$ P-Ca treatment gave the best shoot growth control in 'Rosemarie' in the 1999/2000 season, while in the 2000/2001 season the 1 x 150 $mg.l^{-1}$ treatment gave the best growth control in 'Rosemarie', 'Golden Russet Bosc' and 'Packham's Triumph'. This suggests that a single high rate application is more effective than a single low rate or multiple low rate applications in inhibiting shoot growth.

However, although P-Ca significantly reduced 'Rosemarie' shoot growth in the 2000/2001 season, the re-growth that occurred after harvest was unacceptable. Re-growth has a negative effect on the following season's flower differentiation and carbohydrate reserves of the tree. The effect of a single P-Ca application lasts three to six weeks, at most eight (Rademacher, 2001), which would explain the re-growth. A post-harvest P-Ca application should be considered to prevent re-growth.

P-Ca increased fruit set in 'Rosemarie' and 'Forelle', but girdling had no effect in any of the cultivars. P-Ca caused a significant reduction in fruit size in 'Rosemarie', but had no effect on 'Forelle' and 'Packham's Triumph' fruit size while girdling caused an increase in fruit size in 'Forelle' and 'Packham's Triumph'. P-Ca and girdling did not affect yield. P-Ca treated 'Rosemarie' fruit were more firm and P-Ca treated 'Forelle' fruit had better colour. In 'Packham's Triumph' girdling increased fruit colour and TSS concentration and decreased fruit firmness while P-Ca decreased the percentage fruit with cork spot. P-Ca had no effect on return bloom of 'Rosemarie' and 'Golden Russet Bosc', but caused a significant reduction in return bloom of 'Forelle' and 'Packham's Triumph'. Girdling increased return bloom in 'Golden Russet Bosc' and 'Forelle'.

In conclusion it can be said that P-Ca is an effective inhibitor of shoot growth of 'Rosemarie', 'Golden Russet Bosc' and 'Packham's Triumph' pear trees; even more effective than girdling. Unfortunately, P-Ca had a negative effect on 'Rosemarie' fruit size as well as a negative effect on return bloom of 'Packham's Triumph'. More trials are therefore needed to determine the cause of these negative effects and possibly eliminate them in future.

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Table 1. Concentration and time of application of prohexadione-Ca in the 1999/2000 and 2000/2001 seasons.

P-Ca concentration	Time of application
Trial 1 (1999/2000):	
1. Control (unsprayed)	-
2. 2 x 62.5 mg.l^{-1}	Petal drop (PD) + 3 weeks after PD
3. 1 x 125 mg.l^{-1}	PD
4. 1 x 250 mg.l^{-1}	PD
5. 2 x 125 mg.l^{-1}	PD + 3 weeks after PD
Trial 2 (2000/2001):	
1. Control (unsprayed)	-
2. Girdled (unsprayed)	-
3. 1 x 50 mg.l^{-1}	4 - 5 leaves unfolded
4. 1 x 75 mg.l^{-1}	4 - 5 leaves unfolded
5. 1 x 150 mg.l^{-1}	4 - 5 leaves unfolded
6. 2 x 50 mg.l^{-1}	4 - 5 leaves unfolded + 45 days before harvest
7. 2 x 75 mg.l^{-1}	4 - 5 leaves unfolded + 45 days before harvest
8. 3 x 50 mg.l^{-1}	4 - 5 leaves unfolded + between 1st and last spray + 45 days before harvest

Table 2. The effect of prohexadione-Ca on shoot growth characteristics of 'Rosemarie' pear trees in the 1999/2000 season.

Treatments	Total shoot increase (%)	Final shoot length (cm)*
Control	214.0	46.3
2 x 62.5 mg.l^{-1} P-Ca	87.1	28.8
1 x 125 mg.l^{-1} P-Ca	140.9	29.1
1 x 250 mg.l^{-1} P-Ca	71.1	25.8
2 x 125 mg.l^{-1} P-Ca	83.8	32.5
Sign. level		
Treatment	**0.0062**	**0.0001***
Control vs P-Ca	**0.0007**	**0.0005**

* Initial shoot length used as covariate

Table 3. The effect of prohexadione-Ca on shoot growth characteristics of 'Rosemarie' pear trees in the 2000/2001 season.

Treatments	**Total shoot increase (%)**	**Final shoot length (cm)***	**Shoots with re-growth (%)**	**Average length of re-growth (cm)**
Control	316.2	57.7	0.0	0.0
Girdled	302.0	54.1	2.6	14.0
1 x 50 $mg.l^{-1}$ P-Ca	174.9	35.6	0.0	0.0
1 x 75 $mg.l^{-1}$ P-Ca	174.7	36.8	7.9	61.0
1 x 150 $mg.l^{-1}$ P-Ca	139.2	33.8	7.9	27.0
2 x 50 $mg.l^{-1}$ P-Ca	152.5	34.6	5.3	8.3
2 x 75 $mg.l^{-1}$ P-Ca	160.1	35.1	6.7	19.9
3 x 50 $mg.l^{-1}$ P-Ca	173.3	37.5	5.1	14.5
Sign. level				
Treatment	**0.0001**	**0.0001***	**0.6105**	-
Control vs P-Ca	**0.0001**	**0.0001**	**0.1656**	-
Girdled vs P-Ca	**0.0001**	**0.0001**	**0.3992**	-
Control vs Girdled	**0.6728**	**0.2777**	**0.6719**	-

* Initial shoot length used as covariate

Table 4. The effect of prohexadione-Ca on shoot growth characteristics of 'Golden Russet Bosc' pear trees in the 2000/2001 season.

Treatments	**Total shoot increase (%)**	**Final shoot length (cm)***
Control	352.7	51.2
Girdled	368.4	57.6
1 x 50 $mg.l^{-1}$ P-Ca	156.6	36.8
1 x 75 $mg.l^{-1}$ P-Ca	182.6	35.5
1 x 150 $mg.l^{-1}$ P-Ca	102.7	27.3
2 x 50 $mg.l^{-1}$ P-Ca	241.7	46.2
2 x 75 $mg.l^{-1}$ P-Ca	116.0	29.3
3 x 50 $mg.l^{-1}$ p-Ca	204.9	39.7
Sign. level		
Treatment	**0.0008**	**0.0001***
Control vs P-Ca	**0.0009**	**0.0012**
Girdled vs P-Ca	**0.0003**	**0.0002**
Control vs girdled	**0.8217**	**0.6922**

* Initial shoot length used as covariate

Table 5. The effect of prohexadione-Ca on the weight and length of one year old shoots of 'Golden Russet Bosc' pear trees removed during winter pruning in the 2001/2002 season.

Treatments	**Shoot weight (g)**	**Shoot length (cm)**
Control	33.2	82.8
Girdled	31.3	79.8
1 x 50 $mg.l^{-1}$ P-Ca	34.3	74.5
1 x 75 $mg.l^{-1}$ P-Ca	33.2	58.5
1 x 150 $mg.l^{-1}$ P-Ca	27.9	60.4
2 x 50 $mg.l^{-1}$ P-Ca	33.1	74.3
2 x 75 $mg.l^{-1}$ P-Ca	36.7	71.2
3 x 50 $mg.l^{-1}$ P-Ca	29.3	70.8
Sign. level		
Treatment	**0.5007**	**0.0001**
Control vs P-Ca	**0.8075**	**0.0007**
Girdled vs P-Ca	**0.7237**	**0.0062**
Control vs Girdled	**0.6484**	**0.5693**

Table 6. The effect of prohexadione-Ca on shoot growth characteristics of 'Forelle' pear trees in the 2000/2001 season.

Treatments	**Total shoot increase (%)**	**Final shoot length (cm)***
Control	7199.3	73.0
Girdled	6661.4	67.6
1 x 50 $mg.l^{-1}$ P-Ca	6612.5	67.1
1 x 75 $mg.l^{-1}$ P-Ca	8003.3	81.0
1 x 150 $mg.l^{-1}$ P-Ca	7246.1	73.5
2 x 50 $mg.l^{-1}$ P-Ca	6578.7	66.8
2 x 75 $mg.l^{-1}$ P-Ca	7506.8	76.1
3 x 50 $mg.l^{-1}$ P-Ca	6893.9	69.8
Sign. level		
Treatment	**0.7403**	**0.7403***
Control vs P-Ca	**0.9303**	**0.9303**
Girdled vs P-Ca	**0.4917**	**0.4917**
Control vs Girdled	**0.5531**	**0.5531**

* Initial shoot length used as covariate

Table 7. The effect of prohexadione-Ca on shoot growth characteristics of 'Packham's Triumph' pear trees in the 2000/2001 season.

Treatments	Total shoot increase (%)	Final shoot length (cm)*
Control	4498.2	46.0
Girdled	3923.3	40.2
1 x 50 mg.l^{-1} P-Ca	3695.3	38.0
1 x 75 mg.l^{-1} P-Ca	3262.5	33.6
1 x 150 mg.l^{-1} P-Ca	3159.7	32.6
2 x 50 mg.l^{-1} P-Ca	3776.0	38.8
2 x 75 mg.l^{-1} P-Ca	3790.8	38.9
3 x 50 mg.l^{-1} P-Ca	4272.0	43.7
Sign. level		
Trt	**0.0697**	**0.0697***
Control vs P-Ca	**0.0183**	**0.0183**
Girdled vs P-Ca	**0.4488**	**0.4488**
Control vs Girdled	**0.2096**	**0.2096**

* Initial shoot length used as covariate

Table 8. The effect of prohexadione-Ca on fruit set in the 2000/2001 season and on return bloom of 'Rosemarie' pear trees.

Treatments	Fruit set / cluster	Return bloom (Spring 2001)	
		Clusters/cm branch length	Clusters/mm branch circumference
Control	1.0	0.2	0.5
Girdled	1.3	0.2	0.7
1 x 50 mg.l^{-1} P-Ca	1.5	0.2	0.6
1 x 75 mg.l^{-1} P-Ca	1.6	0.2	0.5
1 x 150 mg.l^{-1} P-Ca	1.8	0.3	0.5
2 x 50 mg.l^{-1} P-Ca	1.7	0.2	0.6
2 x 75 mg.l^{-1} P-Ca	1.3	0.2	0.6
3 x 50 mg.l^{-1} P-Ca	1.6	0.2	0.6
Sign. level			
Treatment	**0.0022**	**0.4422**	**0.4132**
Control vs P-Ca	**0.0001**	**0.7794**	**0.8350**
Girdled vs P-Ca	**0.0644**	**0.3789**	**0.0322**
Control vs Girdled	**0.0819**	**0.6452**	**0.0712**

Table 9. The effect of prohexadione-Ca on fruit set in the 2000/2001 season and on return bloom of 'Forelle' pear trees.

Treatments	Fruit set / cluster	Return bloom (Spring 2001)	
		Clusters/cm branch length	Clusters/mm branch circumference
Control	0.9	0.09	0.29
Girdled	1.3	0.13	0.41
1 x 50 mg.l^{-1} P-Ca	1.2	0.04	0.10
1 x 75 mg.l^{-1} P-Ca	1.6	0.02	0.05
1 x 150 mg.l^{-1} P-Ca	1.4	0.04	0.11
2 x 50 mg.l^{-1} P-Ca	1.4	0.03	0.10
2 x 75 mg.l^{-1} P-Ca	1.1	0.03	0.07
3 x 50 mg.l^{-1} P-Ca	0.9	0.01	0.04
Sign. level			
Treatment	**0.0330**	**0.0001**	**0.0001**
Control vs P-Ca	**0.0325**	**0.0001**	**0.0001**
Girdled vs P-Ca	**0.7780**	**0.0001**	**0.0001**
Control vs Girdled	**0.0635**	**0.0509**	**0.0504**

Table 10. The effect of prohexadione-Ca on fruit set in the 2000/2001 season and on return bloom of 'Packham's Triumph' pear trees.

Treatments	Fruit set / cluster	Return bloom (Spring 2001)	
		Clusters/cm branch length	Clusters/mm branch circumference
Control	0.6	0.3	0.7
Girdled	0.5	0.2	0.6
1 x 50 mg.l^{-1} P-Ca	0.6	0.1	0.3
1 x 75 mg.l^{-1} P-Ca	0.6	0.2	0.4
1 x 150 mg.l^{-1} P-Ca	0.7	0.1	0.3
2 x 50 mg.l^{-1} P-Ca	0.8	0.2	0.4
2 x 75 mg.l^{-1} P-Ca	0.6	0.1	0.3
3 x 50 mg.l^{-1} P-Ca	0.6	0.2	0.4
Sign. level			
Treatment	**0.6108**	**0.0049**	**0.0012**
Control vs P-Ca	**0.7507**	**0.0003**	**0.0001**
Girdled vs P-Ca	**0.0930**	**0.0210**	**0.0054**
Control vs Girdled	**0.2936**	**0.2521**	**0.3570**

Table 11. The effect of prohexadione-Ca on fruit growth characteristics of 'Rosemarie' pears in the 1999/2000 season.

Treatments	Total fruit increase (%)	Final fruit diameter (mm)*
Control	392.2	50.9
2 x 62.5 $mg.l^{-1}$ P-Ca	376.2	49.4
125 $mg.l^{-1}$ P-Ca	379.8	48.1
250 $mg.l^{-1}$ P-Ca	385.7	48.7
2 x 125 $mg.l^{-1}$ P-Ca	365.4	48.3
Sign. level		
Treatment	**0.5791**	**0.2136***
Control vs P-Ca	**0.2507**	**0.0347**

* Initial fruit diameter used as covariate

Table 12. The effect of prohexadione-Ca on the weight, length, diameter and yield of 'Rosemarie' pears in the 1999/2000 season.

Treatments	Weight (g)*	Length (mm)*	Diameter (mm)*	Yield (kg/cm trunk)
Control	108.5	72.8	55.9	0.6 a
2 x 62.5 $mg.l^{-1}$ P-Ca	96.1	67.7	54.1	0.7 a
125 $mg.l^{-1}$ P-Ca	100.3	68.8	54.4	0.7 a
250 $mg.l^{-1}$ P-Ca	94.9	65.5	54.3	0.6 a
2 x 125 $mg.l^{-1}$ P-Ca	98.4	68.0	54.0	0.7 a
Sign. level				
Treatment	**0.1158***	**0.0035***	**0.4320***	**0.8850**
Control vs P-Ca	**0.0099**	**0.0003**	**0.0463**	**0.3781**

* Total yield used as covariate

Table 13. The effect of prohexadione-Ca on the weight, length, diameter and yield of 'Rosemarie' pears in the 2000/2001 season.

Treatments	**Weight (g)***	**Length (mm)***	**Diameter (mm)***	**Yield (kg/cm trunk)**
Control	97.9	72.0	55.1	0.5
Girdled	100.3	72.6	55.1	0.6
1 x 50 $mg.l^{-1}$ P-Ca	93.0	69.2	54.3	0.4
1 x 75 $mg.l^{-1}$ P-Ca	92.1	68.8	54.0	0.4
1 x 150 $mg.l^{-1}$ P-Ca	85.9	66.4	53.0	0.3
2 x 50 $mg.l^{-1}$ P-Ca	96.4	69.5	54.7	0.4
2 x 75 $mg.l^{-1}$ P-Ca	90.4	67.5	53.9	0.4
3 x 50 $mg.l^{-1}$ P-Ca	87.6	66.8	53.0	0.4
Sign. level				
Treatment	**0.0128***	**0.0003***	**0.0652***	**0.0020**
Control vs P-Ca	**0.0114**	**0.0002**	**0.0186**	**0.0861**
Girdled vs P-Ca	**0.0004**	**0.0001**	**0.0090**	**0.0001**
Control vs Girdled	**0.3889**	**0.5843**	**0.8307**	**0.0569**

* Total yield used as covariate

Table 14. The effect of prohexadione-Ca on the weight, length, diameter and yield of 'Forelle' pears in the 2000/2001 season.

Treatments	**Weight (g)***	**Length (mm)***	**Diameter (mm)***	**Yield (kg/cm trunk)**
Control	141.7	78.7	59.2	0.3
Girdled	173.9	83.9	64.7	0.4
1 x 50 $mg.l^{-1}$ P-Ca	147.7	79.7	60.9	0.3
1 x 75 $mg.l^{-1}$ P-Ca	140.8	79.3	60.1	0.3
1 x 150 $mg.l^{-1}$ P-Ca	144.4	78.2	61.3	0.3
2 x 50 $mg.l^{-1}$ P-Ca	146.0	78.8	61.1	0.3
2 x 75 $mg.l^{-1}$ P-Ca	139.8	78.7	60.5	0.3
3 x 50 $mg.l^{-1}$ P-Ca	143.4	79.5	61.3	0.2
Sign. level				
Treatment	**0.0023***	**0.0334***	**0.0199***	**0.3030**
Control vs P-Ca	**0.7069**	**0.7922**	**0.1178**	**0.7454**
Girdled vs P-Ca	**0.0001**	**0.0002**	**0.0007**	**0.0651**
Control vs Girdled	**0.0002**	**0.0022**	**0.0002**	**0.2398**

* Total yield used as covariate

Table 15. The effect of prohexadione-Ca on the weight, length, diameter and yield of 'Packham's Triumph' pears in the 2000/2001 season.

Treatments	**Weight (g)***	**Length (mm)***	**Diameter (mm)***	**Yield (kg/cm trunk)**
Control	267.9	84.3	78.8	1.5
Girdled	294.7	87.7	82.2	1.6
1 x 50 mg.l^{-1} P-Ca	256.4	84.5	80.2	1.6
1 x 75 mg.l^{-1} P-Ca	261.3	85.6	79.8	1.7
1 x 150 mg.l^{-1} P-Ca	241.9	77.7	73.5	1.6
2 x 50 mg.l^{-1} P-Ca	267.2	83.2	79.7	1.7
2 x 75 mg.l^{-1} P-Ca	255.0	84.2	79.8	1.5
3 x 50 mg.l^{-1} P-Ca	281.3	84.6	79.8	1.4
Sign. level				
Treatment	**0.0017***	**0.0634***	**0.1131***	**0.4435**
Control vs P-Ca	**0.4053**	**0.5316**	**0.8446**	**0.3291**
Girdled vs P-Ca	**0.0003**	**0.0445**	**0.1005**	**0.7582**
Control vs Girdled	**0.0269**	**0.2817**	**0.2658**	**0.3272**

* Total yield used as covariate

Table 16. The effect of prohexadione-Ca on the colour of 'Rosemarie' pears in the 1999/2000 season.

Treatments	**Colour**
Control	6.7 a
2 x 62.5 mg.l^{-1} P-Ca	7.2 a
125 mg.l^{-1} P-Ca	7.0 a
250 mg.l^{-1} P-Ca	7.2 a
2 x 125 mg.l^{-1} P-Ca	7.6 a
Sign. level	
Treatment	**0.6247**
Control vs P-Ca	**0.2735**

Table 17. The effect of prohexadione-Ca on the internal and external quality of 'Rosemarie' pears in the 2000/2001 season.

Treatments	Colour	Firmness (kg)	TSS (%)	Seed contents	
				With embrio	Aborted embrio
Control	8.1	8.2	15.1	1.4	8.7
Girdled	7.9	8.2	15.0	1.3	8.8
1 x 50 $mg.l^{-1}$ P-Ca	7.4	8.5	14.9	1.7	8.5
1 x 75 $mg.l^{-1}$ P-Ca	7.6	8.8	14.8	1.3	8.7
1 x 150 $mg.l^{-1}$ P-Ca	6.7	9.4	14.7	1.2	8.8
2 x 50 $mg.l^{-1}$ P-Ca	8.5	8.5	14.3	1.2	8.9
2 x 75 $mg.l^{-1}$ P-Ca	8.3	8.8	14.8	1.4	8.7
3 x 50 $mg.l^{-1}$ P-Ca	7.9	9.1	15.0	1.5	8.7
Sign. level					
Treatment	**0.0450**	**0.0268**	**0.3270**	**0.1506**	**0.5178**
Control vs P-Ca	**0.4068**	**0.0334**	**0.1350**	**0.6980**	**0.8598**
Girdled vs P-Ca	**0.6301**	**0.0271**	**0.3056**	**0.6751**	**0.5838**
Control vs Girdled	**0.7894**	**0.9461**	**0.7145**	**0.5379**	**0.5802**

Table 18. The effect of prohexadione-Ca on the internal and external quality of 'Forelle' pears in the 2000/2001 season.

Treatments	Colour	Firmness (kg)	TSS (%)	Seed contents	
				With embrio	Aborted embrio
Control	9.7	6.4	13.6	0.4	9.3
Girdled	9.2	6.2	14.1	0.6	8.9
1 x 50 $mg.l^{-1}$ P-Ca	8.4	6.4	13.8	0.4	9.2
1 x 75 $mg.l^{-1}$ P-Ca	8.9	6.5	13.5	0.5	9.1
1 x 150 $mg.l^{-1}$ P-Ca	9.1	6.4	13.2	0.6	8.0
2 x 50 $mg.l^{-1}$ P-Ca	8.8	6.4	13.4	0.6	8.8
2 x 75 $mg.l^{-1}$ P-Ca	9.1	6.5	13.3	0.6	9.2
3 x 50 $mg.l^{-1}$ P-Ca	9.6	6.7	13.8	0.7	8.7
Sign. level					
Treatment	**0.1368**	**0.1328**	**0.4575**	**0.8312**	**0.3187**
Control vs P-Ca	**0.0084**	**0.6307**	**0.8032**	**0.3303**	**0.2711**
Girdled vs P-Ca	**0.5331**	**0.0176**	**0.0571**	**0.6972**	**0.9120**
Control vs Girdled	**0.1142**	**0.1397**	**0.2014**	**0.2980**	**0.4475**

Table 19. The effect of prohexadione-Ca on the occurrence of cork spot and water core in 'Forelle' pears in the 2000/2001 season.

Treatments	Cork spot (%)	Water core (%)
Control	2.8	0.0
Girdled	7.7	0.4
1 x 50 mg.l^{-1} P-Ca	8.1	0.0
1 x 75 mg.l^{-1} P-Ca	3.2	0.4
1 x 150 mg.l^{-1} P-Ca	5.3	0.0
2 x 50 mg.l^{-1} P-Ca	0.8	0.0
2 x 75 mg.l^{-1} P-Ca	4.9	0.0
3 x 50 mg.l^{-1} P-Ca	6.7	0.4
Sign. level		
Treatment	**0.2199**	**0.6718**
Control vs P-Ca	**0.3908**	**0.6159**
Girdled vs P-Ca	**0.2128**	**0.3156**
Control vs Girdled	**0.1094**	**0.2507**

Table 20. The effect of prohexadione-Ca on the internal and external quality of 'Packham's Triumph' pears in the 2000/2001 season.

Treatments	Colour	Firmness (kg)	TSS (%)	Seed contents	
				With embrio	Aborted embrio
Control	2.2	6.6	11.8	0.8	8.5
Girdled	2.5	6.3	12.4	0.6	8.6
1 x 50 mg.l^{-1} P-Ca	2.3	6.6	12.0	0.7	8.5
1 x 75 mg.l^{-1} P-Ca	2.5	6.5	12.4	0.7	8.3
1 x 150 mg.l^{-1} P-Ca	2.4	6.6	12.0	0.6	8.1
2 x 50 mg.l^{-1} P-Ca	2.3	6.3	11.9	0.5	8.6
2 x 75 mg.l^{-1} P-Ca	2.3	6.6	11.8	0.6	8.5
3 x 50 mg.l^{-1} P-Ca	2.4	6.4	12.1	0.6	9.1
Sign. level					
Treatment	**0.0473**	**0.0810**	**0.1629**	**0.5507**	**0.2995**
Control vs P-Ca	**0.0860**	**0.1739**	**0.2620**	**0.1507**	**0.9885**
Girdled vs P-Ca	**0.0437**	**0.0805**	**0.0822**	**0.5487**	**0.9047**
Control vs Girdled	**0.0051**	**0.0190**	**0.0305**	**0.1211**	**0.9359**

Table 21. The effect of prohexadione-Ca on the occurrence of cork spot and water core in 'Packham's Triumph' pears in the 2000/2001 season.

Treatments	**Cork spot (%)**	**Water core (%)**
Control	7.3	11.6
Girdled	4.5	10.1
1 x 50 $mg.l^{-1}$ P-Ca	4.0	7.6
1 x 75 $mg.l^{-1}$ P-Ca	2.4	11.2
1 x 150 $mg.l^{-1}$ P-Ca	2.4	3.2
2 x 50 $mg.l^{-1}$ P-Ca	2.8	8.0
2 x 75 $mg.l^{-1}$ P-Ca	4.0	2.4
3 x 50 $mg.l^{-1}$ P-Ca	2.4	13.4
Sign. level		
Treatment	**0.3820**	**0.0740**
Control vs P-Ca	**0.0151**	**0.1990**
Girdled vs P-Ca	**0.4147**	**0.4198**
Control vs Girdled	**0.2047**	**0.7117**

Table 22. The effect of prohexadione-Ca on return bloom of 'Golden Russet Bosc' pear trees.

Treatments	**Return bloom (Spring 2001)**	
	Clusters/cm branch length	**Clusters/mm branch circumference**
Control	0.01	0.06
Girdled	0.03	0.10
1 x 50 $mg.l^{-1}$ P-Ca	0.00	0.01
1 x 75 $mg.l^{-1}$ P-Ca	0.01	0.04
1 x 150 $mg.l^{-1}$ P-Ca	0.01	0.04
2 x 50 $mg.l^{-1}$ P-Ca	0.02	0.06
2 x 75 $mg.l^{-1}$ P-Ca	0.01	0.04
3 x 50 $mg.l^{-1}$ P-Ca	0.01	0.02
Sign. level		
Treatment	**0.0032**	**0.0297**
Control vs P-Ca	**0.2988**	**0.2136**
Girdled vs P-Ca	**0.0001**	**0.0011**
Control vs Girdled	**0.0197**	**0.1039**

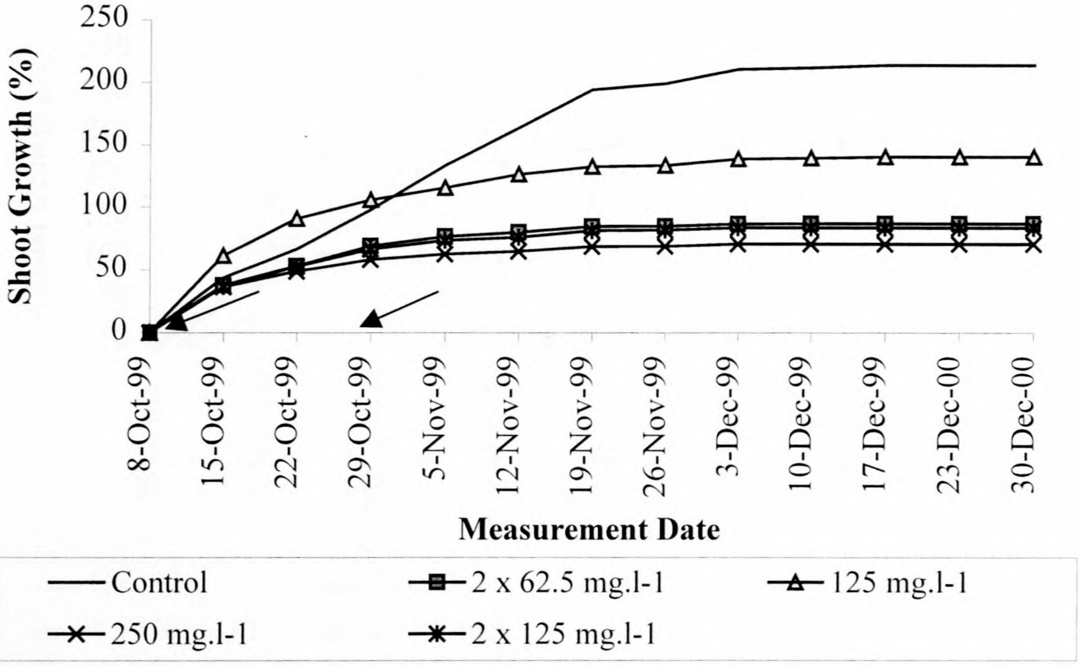

Fig. 1. The effect of prohexadione-Ca on shoot growth of 'Rosemarie' pear trees in the 1999/2000 season (spraying dates are indicated by arrows).

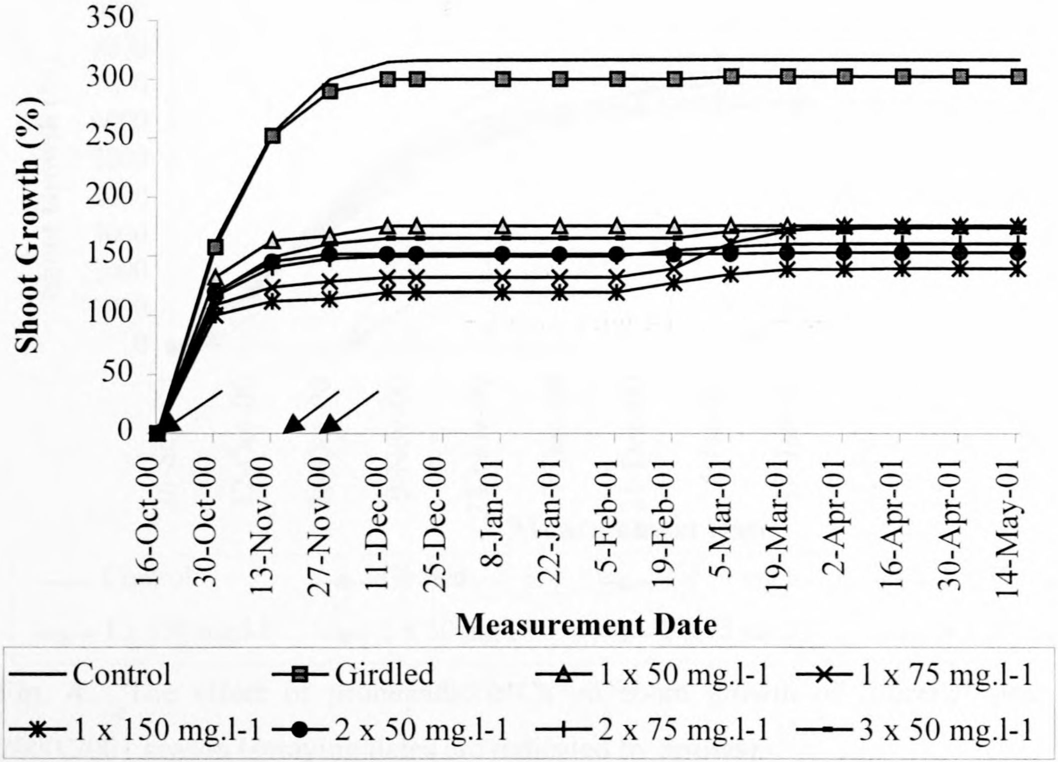

Fig. 2. The effect of prohexadione-Ca on shoot growth of 'Rosemarie' pear trees in the 2000/2001 season (spraying dates are indicated by arrows).

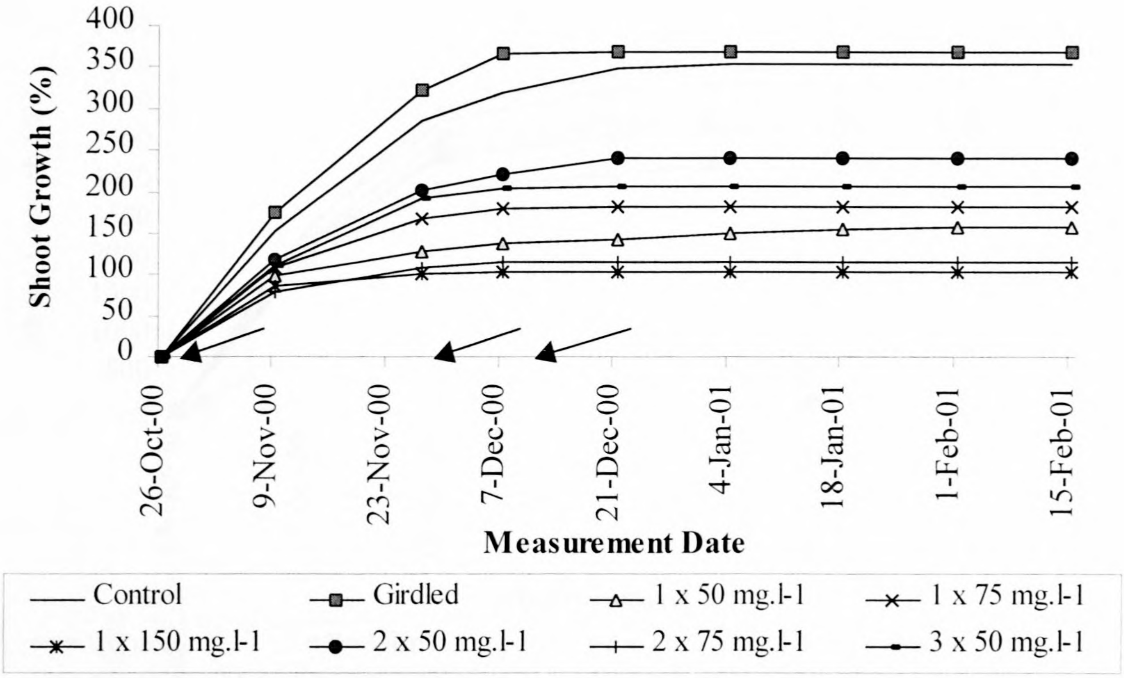

Fig. 3. The effect of prohexadione-Ca on shoot growth of 'Golden Russet Bosc' pear trees in the 2000/2001 season (spraying dates are indicated by arrows).

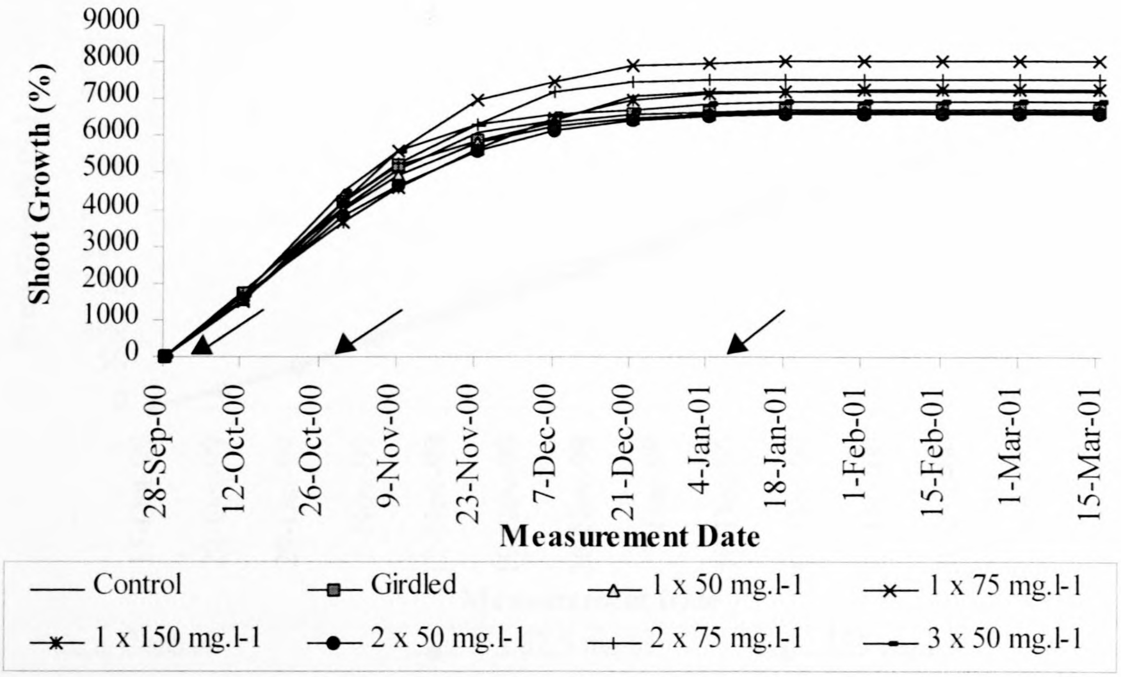

Fig. 4. The effect of prohexadione-Ca on shoot growth of 'Forelle' pear trees in the 2000/2001 season (spraying dates are indicated by arrows).

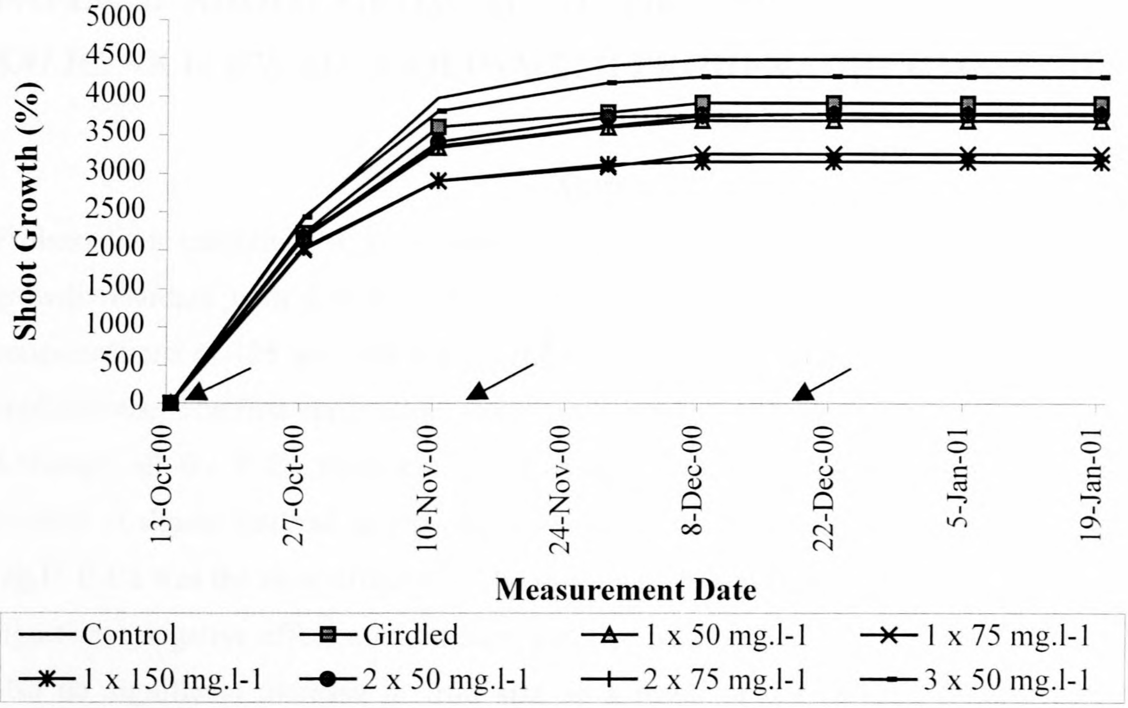

Fig. 5. The effect of prohexadione-Ca on shoot growth of 'Packham's Triumph' pear trees in the 2000/2001 season (spraying dates are indicated by arrows).

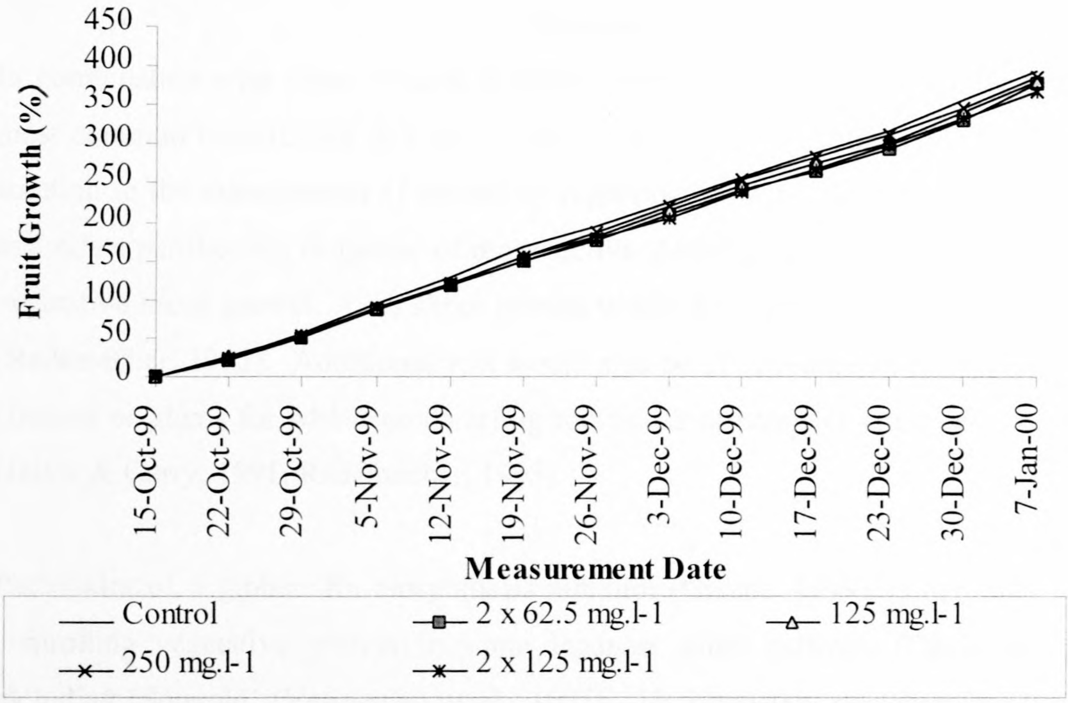

Fig. 6. The effect of prohexadione-Ca on fruit growth of 'Rosemarie' pears in the 1999/2000 season.

PAPER 3: SHOOT GROWTH CONTROL OF PLUM TREES (*PRUNUS SALICINA* L. CV. SONGOLD) WITH PROHEXADIONE-CALCIUM

Abstract

Prohexadione-calcium (P-Ca), a gibberellin biosynthesis inhibitor, is a promising new plant growth retardant with low toxicity and limited persistence. The compound was used at concentrations of 125 and 250 $mg.l^{-1}$, either foliarly applied once, or divided into two equal applications. The first application was at pit-hardening and the second one three weeks later. Although all the P-Ca treatments reduced shoot growth significantly and suppressed the number of shoots that had re-growth, as well as the average length of the re-growth, 2 x 125 $mg.l^{-1}$ P-Ca was the most effective. The re-growth, however, was unacceptable. P-Ca had no significant negative effect on fruit size, yield or fruit quality. On the other hand, there was also no significant increase in fruit size as a result of the reduced shoot growth as was expected. More trials need to be done with earlier and later applications and the use of a surfactant with the compound should also be evaluated.

Introduction

In combination with other cultural methods, of which summer and winter pruning are the most common ones (Davis & Curry, 1991), plant growth retardants would provide an ideal solution to the management of excessive vegetative growth. Growth retardants should alter assimilate partitioning in favour of reproductive growth (flowers and fruit) at the expense of vegetative shoot growth. Less shoot growth would also lower the costs required for pruning (Rademacher, 1995). Additionally, it would also be of relevance in fruit trees such as sweet cherries or plums for which no dwarfing rootstocks or compact scion cultivars are available (Davis & Curry, 1991; Rademacher, 1995).

Paclobutrazol, a gibberellin biosynthesis inhibitor (Greene, 1999), is currently registered for controlling vegetative growth in some Japanese plum cultivars (Davis & Curry, 1991), including 'Songold' (Vermeulen et al., 1997). Unfortunately paclobutrazol has a relatively high persistency which does not allow widespread use of this compound (Davis & Curry, 1991; Rademacher, 1991a, 1995).

Prohexadione-Ca (P-Ca), also a gibberellin biosynthesis inhibitor, is a promising new plant growth retardant with low toxicity and limited persistence (Owens & Stover, 1999), but very little work has been done so far with this growth retardant on Japanese plum trees. Basak and Rademacher (2000) found that on the plums 'Lowics', 'Stanley' and 'Dabrowice' the higher concentration (225 $mg.l^{-1}$) was more effective than the lower concentrations (75 and 150 $mg.l^{-1}$) in inhibiting shoot growth when applied when new shoots were ca. 25 cm long.

The primary target of P-Ca seems to be the 3 ß-hydroxylation of GA_{20} (inactive) to GA_1 (highly biologically active) (Nakayama et al., 1992; Rademacher, 1991b, 1993, 1995). This then leads to a shortening of internodes and thus to a reduction in shoot length (Evans et al., 1997), since an important function of gibberellins is to regulate the rate of growth and final length of internodes (Graebe & Ropers, 1978).

The purpose of this study was to determine the optimum concentration(s) and time(s) of application of P-Ca for controlling shoot growth of 'Songold' plum trees, as well as the effects of P-Ca on fruit growth, yield and fruit quality.

Material and Methods

Plant material. The trial was conducted during the 1999/2000 season in a commercial orchard on Theewaterskloof Farm in the Villiersdorp area in the Western Cape, South Africa (33°59' S, 19°17' E; ca. 365 m a.s.l.; Mediterranean climate). 'Songold' plum trees on Marianna rootstock planted in 1991 at a spacing of 4.5 x 2.0 were used. Trees were selected for uniformity in size. Trees were planted with 'Laetitia' as cross pollinator, with two rows of each cultivar alternating in an east-west row orientation on a southerly slope. Full bloom was on 18 September 1999 and fruit were hand thinned three weeks after full bloom, leaving one fruit per cluster with a three-finger space in between fruit. Fruit were harvested on 7 and 12 February 2000, which were the commercial harvest dates. Yield in 1998 was 43 $t.ha^{-1}$, in 1999 40 $t.ha^{-1}$ and in 2000 30 $t.ha^{-1}$.

Treatments and experimental design. The wettable granular formulation BAS 125 10W, containing 10% (w:w) of P-Ca as active ingredient, was applied as follows: (1) Control (unsprayed), (2) 62.5 $mg.l^{-1}$ P-Ca at pit-hardening (19 November 1999) + 62.5 $mg.l^{-1}$ P-Ca 3 weeks later (3) 125 $mg.l^{-1}$ P-Ca at pit-hardening (4) 250 $mg.l^{-1}$ P-Ca at pit-hardening (5) 125 $mg.l^{-1}$ P-Ca at pit-hardening + 125 $mg.l^{-1}$ P-Ca 3 weeks later

The chemical was applied at high volume with no surfactant added.

The experimental design was a randomised complete block design with ten single tree plot replications.

Data collected.

Ten representative shoots per tree were tagged and their length measured at the time of the first application and then at weekly intervals until the cessation of shoot growth. The percentage of tagged shoots showing signs of terminal re-growth during the season was recorded and the length of the re-growth measured. Ten representative fruit per tree were tagged and their diameter measured at the time of the first application and then at weekly intervals until harvest.

At the first harvest date (7 February 2000), a randomly selected sample of ten fruit per tree was collected and the fruit weight, firmness, colour, total soluble solids (TSS) concentration and acid concentration determined. The percentage fruit with the distal part of the endocarp broken off and the percentage fruit with splitpit was recorded. An additional sample of 10 fruit per tree was stored at dual temperature for four weeks (10 days at –0.5°C + 18 days at 7.5°C). After storage the same measurements were made as described above for the fruit at harvest. In addition, the percentage of fruit with gel breakdown and aerated tissue was also recorded. At the time of harvest total yield per tree was recorded by combining the weight of the fruit picked at the two harvest dates. The trunk circumference of each tree was measured.

Fruit firmness was done on opposite sides of the fruit and two readings were recorded with a penetrometer (Southtrade model FT 327 with 11 mm tip). Fruit colour was evaluated in terms of lightness (L), chroma (C) and hue angle (H) values using the Nippon Denshoku NR 3000 colorimeter. A slice was removed from each fruit and the juice squeezed onto a refractometer (Atago N1; 0-32% Brix) to determine the TSS concentration. Acid concentration of the fruit at harvest was determined by titration with 0.1N NaOH, using the automated Metrohm 7195 titrino. Acid concentration of the fruit after storage was determined by titration with 0.1N NaOH, using a hand titrator, with phenolphtaline as indicator.

Statistical analysis. Shoot and fruit measurements were converted to percentages using the formula: ((x -y)/y)*100 where x = the shoot length/fruit diameter at the measurement date and y = the initial shoot length/fruit diameter. The General Linear Models (GLM) procedure of the Statistical Analysis System (SAS) was used to analyse the data (SAS Institute Inc., 1990).

Results and Discussion

Shoot growth. Trees treated with P-Ca had significantly less shoot growth by the end of the season compared to the control trees (Table 1, Fig. 1). This reduction in shoot growth caused by P-Ca could be seen from ca. one week after the first P-Ca application. Terminal bud set on the P-Ca treated trees occurred ca. two weeks before terminal bud set on the control trees. Re-growth occurred on the more vigorous shoots in the control and P-Ca treated trees ca. two weeks before the first commercial harvest date. In the treatment where P-Ca was applied once, the re-growth occurred about nine weeks after the trees were sprayed and in the treatments where P-Ca was applied twice, the re-growth occurred about six weeks after the last P-Ca application (Fig. 1.). Significantly fewer shoots on the P-Ca treated trees had re-growth compared to the control trees. The average length of the re-growth was not affected. It appears that less shoots had re-growth on the trees that received the multiple P-Ca treatments than on the trees that received only one P-Ca treatment (Table 1.).

Fruit growth. Fruit growth was not affected by P-Ca (Table 2; Fig. 2). With the severe shoot growth reduction, a significant increase in fruit size was expected as a result of more assimilates being available for fruit growth, but no correlation was found between shoot- and fruit growth.

Yield. No significant differences were found between the different treatments in terms of kg fruit harvested/cm trunk circumference (Table 3). This could also be seen in the fact that there was no significant differences between the average fruit weight from the different treatments (Tables 3 & 4).

Fruit quality. P-Ca had no effect on fruit colour or acidity at harvest (Table 5) or after cold storage (Table 4). Nor was endocarp abnormalities or gel breakdown affected (Tables 6 & 7). No constant trend in the occurrence of aerated fruit was found (Table 7). All the P-Ca treatments caused an increase in fruit firmness and a decrease in the TSS concentration, both at harvest (Table 5) and after cold storage (Table 4). Although these differences were statistically significant, they were very small.

As previously mentioned, an increase in fruit growth was expected as a result of the reduced shoot growth. The first P-Ca application was thus only made at the pit-hardening stage of fruit growth, because endocarp abnormalities occur in fruit when the cell division stage occurs too rapidly. Therefore, no significant negative effect of P-Ca was expected on endocarp abnormalities at harvest or after cold storage as was indeed observed.

Conclusion

All the different P-Ca treatments reduced shoot growth, but the 2 x 125 $mg.l^{-1}$ P-Ca treatment was the most effective, both in terms of total shoot growth and re-growth reduction.

The response to a single P-Ca application lasts three to six weeks, at most eight (Rademacher, 2001), which is a possible explanation for the re-growth that occurred later in the season in the more vigorous shoots. Another possible explanation can be attributed to the low solubility of P-Ca (Rademacher, 2001) which leads to poor uptake when temperature is higher and relative humidity lower later in the season. A P-Ca application 55 days before harvest, which is the latest spray allowed before harvest in order to minimize the risk of P-Ca residues in the fruit at harvest (Rademacher, 2001), should be evaluated in order to inhibit the re-growth that occurred just before harvest. The addition of a surfactant or penetrant to the spray solution should also be evaluated in order to increase P-Ca uptake. Trials also need to be done with earlier applications, since P-Ca had no effect on fruit growth and therefore no negative effects are expected in the percentage of fruit with endocarp abnormalities if P-Ca is applied before pit-hardening. Since the most shoot growth occurs in the first few days after flowering (Byers & Yoder, 1999), earlier applications will probably suppress shoot growth more. Trials will also have to be done to determine why the reduced shoot growth did not result in an increase in fruit size. This might be because P-Ca mainly inhibits shoot growth by reducing internode length and therefore have no effect on leaf surface, suggesting that the same amount of dry matter is allocated to leaves in control and P-Ca treated trees with no additional dry matter available for fruit growth.

Growth varies with latitude and related climatic conditions (Unrath, 1999), therefore the time and concentration for P-Ca applications will probably also vary in different plum production areas. Experience will thus be needed to apply P-Ca correctly in order to get the growth control that the user wants.

In conclusion, P-Ca reduced unwanted shoot growth, with no positive or negative effect on fruit size, yield or fruit quality, except for an increase in fruit firmness and decrease in TSS concentration both at harvest and after cold storage. More work is needed to control re-growth.

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Table 1. The effect of prohexadione-Ca on shoot growth characteristics of 'Songold' plums.

Treatments	Total shoot increase (%)	Final shoot length (cm)*	Shoots with re-growth (%)	Average length of re-growth (cm)
Control	69.0	59.9	45.1	19.7
2 x 62.5 mg.l^{-1} P-Ca	31.1	47.4	27.8	18.8
125 mg.l^{-1} P-Ca	26.9	45.9	33.5	17.2
250 mg.l^{-1} P-Ca	33.3	48.4	38.6	18.2
2 x 125 mg.l^{-1} P-Ca	19.4	43.4	20.8	10.1
Sign. Level				
Treatment	**0.0015**	**0.0111***	**0.1051**	**0.5711**
Control vs P-Ca	**0.0001**	**0.0598**	**0.0479**	**0.3860**

* Initial shoot length used as covariate

Table 2. The effect of prohexadione-Ca on fruit growth characteristics of 'Songold' plums.

Treatments	Total fruit increase (%)	Final fruit diameter (mm)*
Control	97.0	58.4
2 x 62.5 mg.l^{-1} P-Ca	98.3	58.6
125 mg.l^{-1} P-Ca	98.7	58.6
250 mg.l^{-1} P-Ca	101.6	59.6
2 x 125 mg.l^{-1} P-Ca	101.2	59.3
Sign. Level		
Treatment	**0.3363**	**0.3485***
Control vs P-Ca	**0.1575**	**0.8737**

* Initial fruit diameter used as covariate

Table 3. The effect of prohexadione-Ca on the weight and yield of 'Songold' plums at harvest.

Treatments	**Weight (g)***	**Yield (kg/cm trunk)**
Control	121.0	0.5
2 x 62.5 $mg.l^{-1}$ P-Ca	120.8	0.5
125 $mg.l^{-1}$ P-Ca	116.7	0.5
250 $mg.l^{-1}$ P-Ca	125.0	0.5
2 x 125 $mg.l^{-1}$ P-Ca	132.9	0.6
Sign. Level		
Treatment	**0.3985***	**0.8545**
Control vs P-Ca	**0.5875**	**0.3334**

* Total yield used as covariate

Table 4. The effect of prohexadione-Ca on the weight, firmness, colour, TSS and acidity of 'Songold' plums after cold storage.

Treatments	**Weight (g)***	**Firmness (kg)**	**Colour**			**TSS (%)**	**Acid (%)**
			L	**C**	**H**		
Control	114.2	2.5	61.9	37.8	96.8	13.3	1.7
2 x 62.5 $mg.l^{-1}$ P-Ca	119.4	2.6	61.9	37.9	95.1	13.2	1.7
125 $mg.l^{-1}$ P-Ca	118.3	2.8	62.5	38.4	96.5	13.0	1.6
250 $mg.l^{-1}$ P-Ca	118.4	2.9	62.1	38.4	96.1	12.8	1.7
2 x 125 $mg.l^{-1}$ P-Ca	117.4	3.2	61.8	37.9	97.4	13.0	1.8
Sign. Level							
Trt	**0.7071***	**0.0004**	**0.9074**	**0.9923**	**0.1818**	**0.0261**	**0.2571**
Control vs P-Ca	**0.1666**	**0.0057**	**0.8282**	**0.6015**	**0.4709**	**0.0319**	**0.3663**

* Total yield used as covariate

Table 5. The effect of prohexadione-Ca on the firmness, colour, TSS and acidity of 'Songold' plums at harvest.

Treatments	Firmness (kg)	Colour			TSS (%)	Acid (%)
		L	C	H		
Control	7.2	60.0	38.9	109.4	13.0	1.9
2 x 62.5 mg.l^{-1} P-Ca	8.2	58.3	38.7	110.1	12.7	1.9
125 mg.l^{-1} P-Ca	8.1	57.5	38.3	110.3	12.2	1.9
250 mg.l^{-1} P-Ca	7.8	57.5	38.0	110.8	12.1	1.9
2 x 125 mg.l^{-1} P-Ca	8.7	57.8	38.7	111.3	12.3	2.0
Sign. Level						
Treatment	**0.0001**	**0.6207**	**0.6773**	**0.3131**	**0.0037**	**0.5236**
Control vs P-Ca	**0.0001**	**0.1828**	**0.3673**	**0.0984**	**0.0017**	**0.8324**

Table 6. The effect of prohexadione-Ca on endocarp abnormalities of 'Songold' plums at harvest.

Treatments	Endocarp tip broken off (%)	Splitpit (%)
Control	68.0	0.0
2 x 62.5 mg.l^{-1} P-Ca	63.0	3.0
125 mg.l^{-1} P-Ca	65.0	0.0
250 mg.l^{-1} P-Ca	68.0	1.0
2 x 125 mg.l^{-1} P-Ca	65.0	2.0
Sign. Level		
Treatment	**0.8736**	**0.3856**
Control vs P-Ca	**0.5358**	**0.2943**

Table 7. The effect of prohexadione-Ca on the internal quality of 'Songold' plums after cold storage.

Treatments	**Endocarp tip broken off (%)**	**Splitpit (%)**	**Gel breakdown (%)**	**Aerated tissue (%)**
Control	76.0	0.0	9.0	13.0
2 x 62.5 $mg.l^{-1}$ P-Ca	66.0	1.0	6.0	8.0
125 $mg.l^{-1}$ P-Ca	78.0	0.0	6.0	9.0
250 $mg.l^{-1}$ P-Ca	74.0	2.0	8.0	14.0
2 x 125 $mg.l^{-1}$ P-Ca	67.0	2.0	4.0	4.0
Sign. Level				
Trt	**0.1425**	**0.2227**	**0.5708**	**0.1910**
Control vs P-Ca	**0.2933**	**0.1794**	**0.2440**	**0.2390**

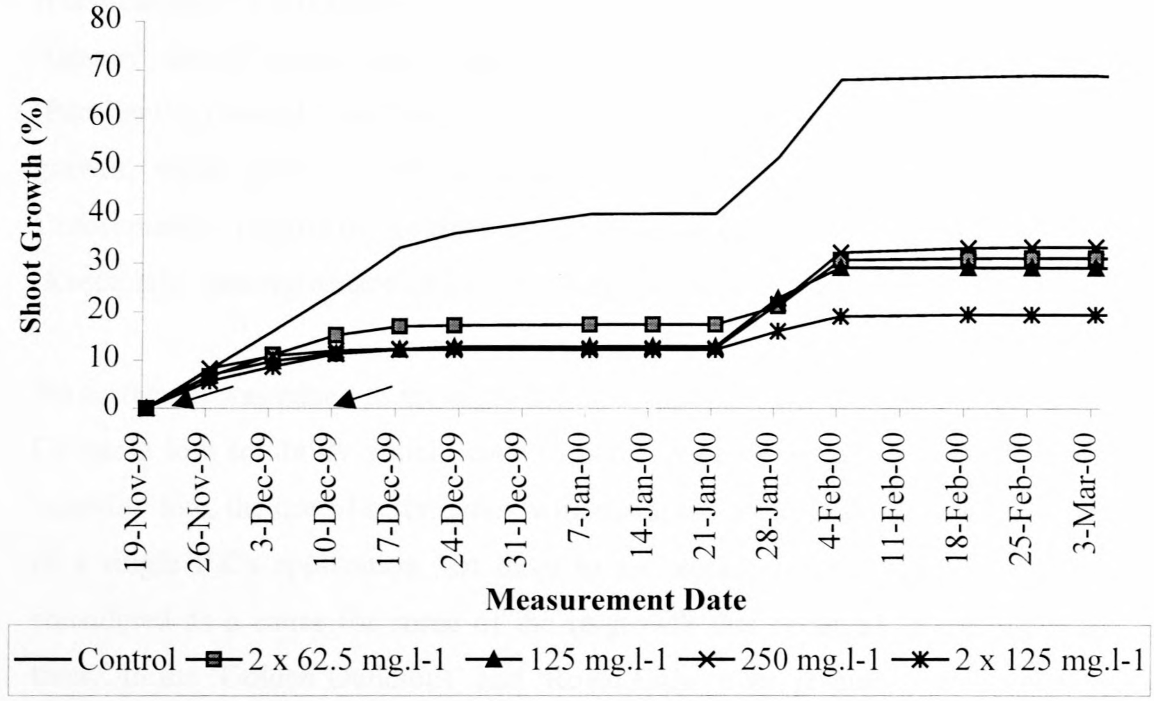

Fig. 1. The effect of prohexadione-Ca on shoot growth of 'Songold' plum trees (application dates are indicated by arrows).

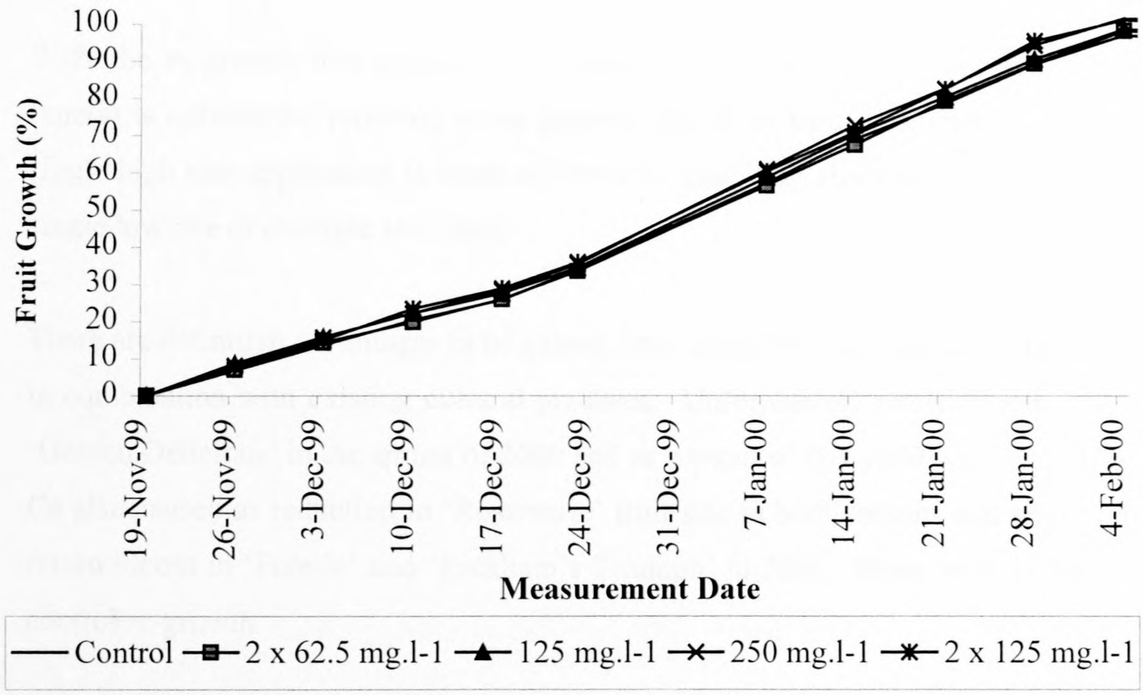

Fig. 2. The effect of prohexadione-Ca on fruit growth of 'Songold' plums.

6. CONCLUSION

It is clear that P-Ca is an effective inhibitor of shoot growth of the apples 'Golden Delicious', 'Granny Smith' and 'Royal Gala', the pears 'Rosemarie', 'Golden Russet Bosc' and 'Packham's Triumph' and the plum 'Songold'. P-Ca had no effect on 'Forelle' pear shoot growth, while girdling had no effect on shoot growth in any of the pear cultivars. Unfortunately, re-growth occurred in all the apple cultivars (both seasons) as well as in the 'Rosemarie' (second season only) and 'Songold' trees.

No surfactant was added to the spray solution applied to the apple and plum trees and since P-Ca has a low solubility which leads to poor uptake when temperature is high and relative humidity low, the use of a surfactant with the spray solution should be evaluated. The effect of a single P-Ca application last three to six weeks, at most eight, which should also be considered as a cause for some of the re-growth that occurred in the apple and 'Songold' trees. In the 'Golden Delicious' and 'Royal Gala' trees, re-growth was sometimes observed after harvest while in the 'Rosemarie' trees the re-growth only occurred after harvest. Here, a post-harvest application should be considered. In general, P-Ca should also be applied when temperature is lower and relative humidity higher to increase uptake.

With the re-growth that occurred it is not clear which concentrations(s) and application time(s) is optimal for reducing shoot growth, but under these circumstances it seems that a single high rate application is more effective in inhibiting shoot growth of pear trees than a single low rate or multiple low rates.

There are definitive advantages to be gained from using P-Ca as a growth retardant, especially in combination with existing cultural practices. Unfortunately return bloom was reduced in 'Golden Delicious' in the spring of 2000 and as a result of this yield was reduced in 2001. P-Ca also caused as reduction in 'Rosemarie' fruit size in both seasons and negatively affected return bloom in 'Forelle' and 'Packham's Triumph' in 2001. More work is firstly needed to control re-growth.

7. STATISTICS

Data from Papers 1 to 3 were statistically analysed using the SAS (Statistical Analysis System) computer programme. The relevant data for the SAS programme have been saved as SAS files on the diskette stored on the inside back cover of this thesis.