Rootstock and Dormancy Studies in Apple and Pear
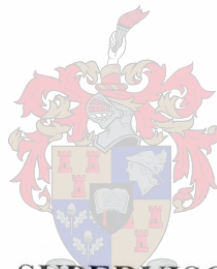
By

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Declaration

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

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Abstract

Delayed foliation is commonly observed in apple and pear producing countries with warm and/or short winter climates, resulting in less synchronised budburst, of fewer buds and reduced yield. Applications of rest-breaking agents minimise the symptoms of delayed foliation. According to chilling models used in fruit producing areas of the world, the climate of South Africa is not suitable for deciduous fruit production, however fruit has been successfully produced here for a long time. This study aimed to quantify the effects of freezing temperatures, different chilling temperatures and the period of chilling, to obtain a better knowledge of bud dormancy release on apple and pear shoots.

The chilling period was the most important factor influencing the progression of dormancy. While in some cases the chilling temperature and the freeze treatment effects were significant, the contribution to differences in the progression of dormancy was negligible. Our findings indicate that currently used chilling models should emphasise the time of exposure to low temperatures more than the difference in temperatures between 1 to 10°C.

The South African apple and pear industry made good progress in moving towards high density plantings, but large variation in soil types, non-optimum growing conditions, replant situations and a lack experience with dwarfing rootstocks limited further development. However, there is still an urgency to obtain higher early yields of good quality fruit applying the most efficient production practices. We aimed to quantify the field performance of locally available apple and pear rootstocks, in particular from data outside of previously reported local trials, as well as early production of newly planted trials.

Information obtained form the industry indicates that BP1 and BP3 are the preferred pear rootstocks. From production records of 'Packham's Triumph' pears, it appeared that BP3 and OHxF97 produced the best yields compared to the other rootstocks. Production of 'Doyenne du Comice' was the best on QA and BP3. In newly planted 'Rosemarie', 'Flamingo', and 'Forelle' trials, different rootstocks were evaluated. 'Rosemarie' showed indications of incompatibility with QA and QC51, but on BP1 and QA with a 'Beurre

Hardy' interstock produced good initial yields although BP1 induced slightly larger trees. 'Flamingo' on QA and QC51 produced the best yields. 'Forelle' on BP1, BP3, and QA produced similar yields up to the 4th leaf.

For apples M793 seems to be the preferred rootstock in the South African industry. From production records of 'Golden Delicious' and 'Granny Smith' apples, it appeared that M793 and MM106 produced the best yields when compared to Seedling rootstock. In a 'Cripps' Pink' trial, MM109, M793 and M25 were more vigorous than M7, MM111 and MM106. MM106 was cumulatively, over four years from planting, the most yield efficient, although no consistent trend regarding fruit quality was observed between the rootstocks evaluated.

Opsomming

Vertraagde bot word algemeen opgemerk in appel en peer produserende lande met n' warm en/of kort winter klimaat, wat veroorsaak dat bot van minder knoppe, meer ongelyk plaasvind en gevolglik lei tot swakker opbrengste. Toediening van rus-breek middels beperk die simptome van vertraagde bot. Volgens koue modelle wat in vrugte produserende areas in die wêreld gebruik word, is Suid Afrika se klimaat nie geskik vir die verbouing van sagtevrugte nie alhoewel sagtevrugte al vir n lang tyd met groot sukses hier verbou word. Hierdie studie is daarop gemik om die effek van vries temperature, verskillende koue temperature en die periode van koue op die vrystelling van dormansie op knoppe van appel en peer lote te kwantifiseer.

Die periode van koue was die mees belangrikste faktor wat die ontwikkeling van dormansie beinvloed het. In sommige gevalle was die effek van die koue temperature betekenisvol, maar die bydrae tot die verskille in die ontwikkeling van dormansie was weglaatbaar klein. Ons bevindinge dui aan dat die huidige koue modelle wat gebruik word, meer klem moet lê op die periode van blootstelling aan koue as aan die effek van verskillende temperature tussen 1 en 10°C.

Die Suid Afrikaanse appel en peer bedryf het goeie vordering in die beweging na hoë digtheid aanplantings gemaak, maar groot verskille in grond tipes, sub-optimale groei toestande, herplant probleme en n' tekort aan ondervinding met dwergende onderstamme het verdere ontwikkeling beperk. Ten spyte hiervan is daar steeds n' dringendheid om hoër produksies, van goeie kwaliteit vrugte so vroeg as moontlik te kry deur die toepassing van die mees effektiewe produksie praktyke. Ons het gepoog om die prestasie van plaaslik beskikbare appel en peer onderstamme te kwantifiseer, in besonder deur data wat nog nie van tevore oor verslag gedoen is nie en ook deur te meld van vroeë produksies op nuut aangeplante proewe.

Informasie uit die bedryf het aangedui dat BP1 en BP3 die voorkeur peer onderstamme is. Deur na die produksie geskiedenis van 'Packham's Truimph' pere te kyk kom dit voor of BP3 en OHxF97 die beste produksies in vergelyking met die ander onderstamme gelewer het. Die produksie van 'Doyenne du Comice' was die beste op QA en BP3. In nuut geplante 'Rosemarie', 'Flamingo', en 'Forelle' proewe was verskillende onderstamme geëvalueer. 'Rosemarie' het tekens van onverenigbaarheid getoon met QA en QC51, maar op BP1 en QA met n 'Beurré Hardy' tussenstam het 'Rosemarie' goeie aanvanklike opbrengste gelewer, al was bome op BP1 effens groter. 'Flamingo' op QA en QC51 het die beste opbrengste gelewer. 'Forelle' op BP1, BP3, en QA het ongeveer ewe veel tot die 4de blad geproduseer.

By appels is M793 die voorkeur onderstam van die Suid-Afrikaanse appel bedryf. M793 en MM106 gee beter opbrengste as Saailing onderstam wanner die produksie geskiedenis van 'Golden Delicious' en 'Granny Smith' appels evalueer word. In n' 'Cripps' Pink' proef was MM109, M793 en M25 meer groeikragtig as M7, MM111 en MM106. MM106 het kumulatief meer geproduseer en was ook meer produsie doeltreffend tot en met die 4de blad na plant. Daar was egter geen konstante neiging rakende vrug kwaliteit tussen die verskillende onderstamme wat getoets is nie.

Bedankings

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Besondere dank ook aan Prof. Gerard Jacobs en Prof. Karen Theron vir hul raad met die statistiese verwerking van my data en vir Me. Des Fortuin vir haar getroue hulp met die insameling daarvan.

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Contents

1. The effect of temperature on dormancy release in deciduous fruits

1.1 Introduction

Buds of deciduous fruit trees need cold to enter and exit from endodormancy. Endodormancy develops in the fall, and is characterised by a requirement for sustained exposure to low, near freezing temperatures before active shoot growth can resume in the spring (Fuchigami and Nee, 1987). The effective 'chilling' temperature and the duration of the chilling period required to satisfy the rest requirement is dependent on the genetic makeup of the plant (Erez *et al.*, 1979a). The development of endodormancy is an important adaptive strategy in woody perennial plants because dormant plants are more resistant to freezing and dehydration stress. The physiological processes taking place during endodormancy are currently not clearly understood and research in manipulating the factors that influence edodormancy is performed to try and understand endodormancy better.

The need of the bud for exposure to low temperatures is called the chilling requirement. In areas with mild winters and subsequent insufficient chilling, budburst is uneven which results in delayed foliation. Delayed foliation complicates thinning, fruit size and even ripening of the fruit. In areas with cold winters the chilling requirement is exceeded before spring and the plant enters a state called ecodormancy. During this state of ecodormancy the ambient temperatures that are too low for growth inhibit the growth of the bud. The purpose of this study is to investigate the effectiveness of dormancy release of deciduous fruit buds after exposure to different temperature regimes.

1.2 Chilling temperature

Hours below 7.2°C was proposed by Weinberger (1950) as an index of chilling weather, but Erez and Lavee (1971) showed that temperatures above 7.2°C also have rest breaking ability. They found that low temperature efficiency in releasing peach buds from dormancy follows an optimum curve in which 6°C is the optimum for axillary leaf buds and 10°C is about half as efficient. Scalabrelli and Couvillon (1986) found that 7.2°C and Erez and Couvillon (1987) found that 8°C of continuous chilling to be the most effective in satisfying the chilling requirement. Gilreath and Buchanan (1981), Erez and Lavee (1971) and Richardson *et al.* (1974) also found a similar optimum temperature (6-8°C) for rest breaking in peach plants. Erez and Lavee (1971) proposed the use of "weighted" chilling hours for countries with mild winters where temperatures between 6 and 10°C are common.

1.3 High temperatures during chilling

High temperature (15-23°C) during winter were shown to antagonise the dormancy releasing effect of low temperatures (Vegis, 1964). In contrast, a daily cycle of low and high temperatures (up to 18°C) had an effect similar to that of continuous chilling on vegetative budburst (Erez and Lavee, 1971; Erez *et al.*, 1979b). When chilling was interrupted by periods of 11 to 12 days of high (20°C) temperatures, no antagonistic effect was observed, but an enhancing effect over the uninterrupted chilling treatment was evident (Erez and Lavee, 1971). The high-temperature negation of the chilling effect is dependent upon cycle length, with a reduced effect the longer the cycle.

Erez *et al.* (1979a) found no difference in lateral budburst of Redhaven peach plants when the continuous chilling (4-6°C) control was compared to a 3, 6 or 9 day cycle where 2/3 of the cycle length was exposure at 4-6°C and 1/3 of the cycle length was exposure at 24°C. This shows a fixation effect of chilling and that chilling accumulated during the 20-40 hours prior to the onset of high temperature, was susceptible to high temperature negation. Negation of chilling during this 20-40 hour period could occur in a

10-20 hour period of exposure to temperatures of 24°C (Erez *et al.*, 1979a). In a similar study where Erez *et al.* (1979b) examined high temperatures (15, 18, 21 and 24°C) in a daily cycle with 6°C, he found that 18°C or lower did not antagonise chilling but 21 and 24°C resulted in full reversion of the chilling effect. Thus 16 hours of chilling is negated by 8 hours of 21or 24°C. This means a value of at least -2, rather than the -1 coefficient as suggested in the Utah model is more acceptable. The treatment of 6°C cycled diurnally with 15°C shows an increased efficiency in releasing buds from rest. Since 15°C by it self is not active in breaking rest (Richardson *et al.*, 1974) it would seem that the positive effect obtained resulted from its cycling with low temperatures. The chilling negation by diurnal high temperatures is more severe the longer the exposure to the high temperatures and the higher the temperature above 19°C (Couvillon and Erez, 1985).

1.4 Chill units

A few models have been established to calculate the amount of chilling received and to estimate the amount of chilling required to release dormancy. Richardson *et al.* (1974) were of the first to establish such a model. Their model was called the Utah model and they defined a chill unit as one hour of exposure to the optimum temperature of chill unit accumulation. A temperature of 6°C was found to be the optimum temperature in the temperature range of 1.4 - 18°C, while the other temperatures were less effective in accumulating chill units. The chilling contribution becomes less than one as temperatures drop below or rise above the optimum value. (Table 1).

While this model was developed on peach trees, Gilreath and Buchanan (1981) worked on nectarines and found that 7°C was as effective as 10°C in releasing floral bud break. They developed their own model with a broader range of effective temperatures and a higher optimum for rest completion as compared to the Utah model (Table 1). This model predicted rest completion more accurately than other methods when applied to orchard temperature data. Gilreath and Buchanan (1981) found that high temperatures did not have as much inhibitory effecct as observed previously (Erez *et al.*, 1979b). They suggest that low chilling peaches and nectarines reach an acclimation base at a higher

temperature, thus the same trend is likely for the chilling requirement and such cultivars should be more tolerant of high temperatures.

Table 1: Different norms for accumulating chill units by three different researchers.

Utah Chill Units		Gilreath an Buchanan		North Carolina Model	
Temp. (°C)	Chill units	Temp. (°C)	Chill units	Temp. (°C)	Chill units
<1.4	0.0	-1.0	0.0	-1.1	0.0
1.5-2.4	0.5	1.8	0.5	1.6	0.5
2.5-9.1	1.0	8.0	1.0	7.2	1.0
9.2-12.4	0.5	14.0	0.5	13.0	0.5
12.5-15.9	0.0	17.0	0.0	16.5	0.0
16.0-18.0	-0.5	19.5	-0.5	19.0	-0.5
>18.0	-1.0	21.5	-1.0	20.7	-1.0
				22.1	-1.5
				23.3	-2.0

Richardson, E.A., Seeley, S.D. and Walker, D.R., 1974. A model for estimating the completion of rest for 'Redhaven' and 'Elberta' peach trees. *HortScience*, **9**, 331-332.

Gilreath, P.R. and Buchanan, D.W., 1981. Rest prediction model for low-chilling 'Sungold' nectarine[1]. *Journal of the American Society for Horticultural Science*, **106**, 426-429.

Shaltout, A.D. and Unrath, C.R., 1983. Rest completion prediction model for 'Starkrimson Delicious' apples. *Journal of the American Society for Horticultural Science*, **108**, 957-961.

Shaltout and Unrath (1983) working on 'Starkrimson Delicious' apples developed a chill unit model for North Carolina. Their model supposedly predicts rest completion more accurately than previously reported models. The model also proposes a broader range of effective temperatures and incorporates a greater negative effect when temperatures exceed 21°C for rest (Table 1).

According to Richardson *et al.* (1974) positive chill-units begin to accumulate just after the day in the fall when the largest negative accumulation is experienced. The time of rest

completion is when shoots grow within a 2 to 3 week period of exposure to growing temperatures (18-24°C) in a greenhouse.

Richardson *et al.* (1975) also present a model that allows a forecast of the approximate timing of stages of bud growth and development after a tree has completed its interval of rest by defining a growing degree hour Celsius (GDH°C). One GDH°C is defined as 1 hour at a temperature 1°C above the base temp of 4.5°C from each hourly temperature between 4.5 and 25°C. All temperatures above 25°C are assumed equal to 25°C; thus the greatest accumulation for any 1 hour is 20.5 GDHs. With this model the delay in bloom development by cooling can be predicted to help prevent frost damage.

The Utah model is not acurate in warm fruit producing areas. In certain years negative accumulation of Utah chill units occurs even though enough chilling was received for low-chill peaches to sprout and flower. This lead to the development of Daily Positive Utah Chill Units (Linsley-Noakes et al., 1994). The calculation of chill units is the same as for Utah chill units, except for that if the daily 24-hour total accumulation is negative, it is counted as zero instead of subtracted from those previously accumulated. This was found to give a more effective estimation of the winter chilling received at locations with mild winters in South Africa, than the original Utah chill unit model (Linsley-Noakes et al., 1994).

1.5 Chilling period

The percentage of bursting buds increases with chilling (Shaltout and Unrath, 1983). Couvillon and Erez (1985) reported that a number of species (apple, cherry, peach and pear) responded to prolonged chilling with a reduced number of GDH°C required for bud break. The response curve in many instances was curvilinear, indicating that a point is reached after which chilling has no significant effect on the GDH°C required for budburst. They concluded from their work that fruit species do not have specific heat requirement for bloom and bud break, but that bud break and bloom dates are determined by the chilling requirement. Thus, the transmittance of time of bloom seems mainly

through the chilling requirement of the individual, rather than totally through an influence on the GDH°C required for bloom. It is conceivable that bloom at low temperatures by certain species could be due to GDH°C accumulation at temperatures below 4.5°C. Thus plants held below this temperature could accumulate GDH°C during chilling.

1.6 Rootstock

As the scion and the rootstock differ genetically they may have different chilling requirements. Couvillon *et al.* (1984) found in a low-chilling winter in Brazil that symptoms of insufficient chilling were evident in most apple cultivars growing in the area. In a rootstock trial he found that MM 104 and MM 106 (vigorous) had classical symptoms of insufficient chilling. Lateral vegetative budburst was sparse and most vegetative growth occurred form the terminal buds, which have the shortest chilling requirement of all bud types. Trees on M 7 and M 26 (dwarfing) had a greater level of lateral vegetative budburst and did not have the varying stages of flower bud development evident in trees on MM 104 and MM 106 rootstocks.

Couvillon *et al.* (1984) speculated that the cause of this phenomenon might be because M26 has the shortest chilling requirement of the Malling and Malling-Merton series and the long chilling cultivar 'Northern Spy' was a parent of both MM 104 and MM 106. Another reason for this behavior may be because of the dwarfing effect of the rootstocks M 7 and M 26, but this remains to be proven. The rootstock only has an effect when the chilling requirement of the rootstock is satisfied but not the chilling requirement of the scion

1.7 Bud type

Terminal vegetative buds on intact shoots had the shortest chilling requirement (600 hours) and show no difference in response to 2, 3 or 7.2°C chilling temperatures even when prolonged chilling (2040 hours) was applied to dormant 'Redhaven' peach cuttings (Scalabrelli and Couvillon, 1986). Lateral vegetative and flower buds had similar (1340

hours) chilling and GDH°C requirements for bud break, although both reacted positively on prolonged chilling (Scalabrelli and Couvillon, 1986). Their results showed that no correlative inhibition was evident on lateral vegetative bud break with completely chilled trees compared to strong correlative inhibition with non-chilled trees.

1.8 Moderate Temperatures

A constant 0°C was much less efficient than a constant 6°C in satisfying rest, but when cycled diurnally with 15°C no difference was evident (Erez and Couvillon, 1987). In all instances, cycling with moderate temperatures (15°C) increased the chilling efficiency of low temperatures (0-8°C). Thus, the actual chilling effect of temperatures between 0 and 8°C is about the same, but the lack of moderate temperatures is responsible for the differences in chilling efficiency. Moderate temperatures were shown to promote chilling mostly in the later stages of the rest period. (Erez and Couvillon, 1987).

Erez and Couvillon (1987) adopted a scheme from Purvis and Purvis (1952) who worked on vernalisation of rye plants, to describe the temperatures effects on rest in peach buds. Of the two steps, the first one is reversible and the second is fixed:

$$A \overset{b}{\underset{a}{\leftrightarrow}} B \overset{c}{\to} C$$
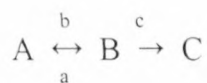
Where: A = the resting state;

B = the product of low temperature exposure which can revert

to "A" depending on temperature;

C = the product of B, which is fixed and thus non-reversible;

a = the chilling negation reaction (favoured by high temperatures);

b = the chilling reaction (favoured by low temperatures); and

c = conversion of B to C at moderate temperatures, which fixes

the chilling effect

The chilling effect (reaction 'b') responds to temperatures between 0 and 13°C. Chilling efficiency decreases as the temperature rises above 8°C, reaching zero at 14°C. Reaction

'a' occurs at temperatures >16°C, reaching a high level of activity at 24°C. The influence of temperatures >24°C is unknown. Reaction 'c' occurs at a wide range of temperatures but is most rapid at moderate temperatures (13-15°C). It is most difficult to describe because its effects overlap those of reactions 'a' and 'b'. Reaction 'c' occurs at 0°C since bud break will occur on plants chilled continuously at this temperature, but its maximal observed effect is at 13°C (Erez and Couvillon, 1987).

1.9 Conclusion

The amount of chilling required for effective release from dormancy of each cultivar seems to be genetically determined. The temperatures at which chilling accumulate also seems to differ, although there is a general trend of temperatures below 8°C to be the most effective. Chilling temperatures (<10°C) cycled diurnally with moderate temperatures (12-15°C) have an enhancing effect on dormancy release while high temperatures (>20°C) have a negative effect on chilling already received. High temperatures for an extended period, however, seem to only have a negative effect on the most recently received chilling, i.e., from the last cycle. The period of chilling has a curvilinear effect on dormancy release, indicating that there is a point were further chilling does not increase the efficacy of dormancy release. The rootstock only has an effect when the chilling requirement of the rootstock is satisfied but not the chilling requirement of the scion. Terminal buds on intact shoots have the lowest chilling requirement followed by lateral vegetative and flower buds that have a roughly equal, but a higher chilling requirment.

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2. Why dwarfing rootstocks are less vigorous

2.1 Introduction

The size of a tree plays a central role in orchard management and production of quality fruit in the modern orchard. Except for the advantage of dwarfed trees in high-density orchards that bear fruit early and, therefore, start to deplete investment costs early, dwarfed fruit trees also have other advantages. Light penetrates a dwarfed tree better, which favours photosynthesis and thus fruit quality. Other advantages such as more efficient use of chemicals, as well as easier harvesting, pruning and thinning practices can also be obtained with less vigorous rootstocks (Faust, 1989). There are many approaches to control tree size including genetic control, shoot and root manipulation, application of growth regulators and girdling. However, the most efficient way to control growth is through the use of tree size-controlling rootstocks; hence interest in the mechanism of vigour control by rootstocks work. This study investigates the influence of some factors involved in vigour induced by rootstocks.

2.2 Rootstock and rootstock/interstock interactions on scion vigour

The anchorage of many dwarfing rootstocks of apple is weak. Better anchorage can be maintained and dwarfing still can be achieved if a piece of stem of a dwarfing rootstock is grafted between the relatively vigorous rootstock and the scion. Lockard, (1976) found that interstocks cause dwarfing proportional to the length of the interstock up to 20cm where no further increase in dwarfing is observed. The degree of dwarfing is, increased if the entire stempiece is above the ground as opposed to the lower (rootstock/interstock) union being buried under the soil (Ferree and Carlson, 1987). The height at which the rootstock is grafted has a similar effect as mentioned above. The tree is considerably smaller if grafted 25 cm in comparison to 10cm above the soil level (Faust 1987).

According to Jones (1984) the graft union of the dwarfing rootstock or interstock with the

scion appears to deplete the solutes of the xylem sap. This depletion increases as the dwarfing character of the interstock increases. His studies with interstocks indicated that the effect of interstocks on sap composition is created by the upper graft union between the dwarfing interstock and the scion. This is analogous to the graft union between a dwarfing rootstock and the scion. Jones (1984) also concluded that the graft union does not affect water flow in the tree. Later work by Jones (1986) reported depletion not only of solutes but also cytokinins in xylem sap passing through the graft union between dwarfing apple rootstocks or interstocks, and the scion.

Even the bark of the dwarfing rootstock is sufficient to cause dwarfing. Insertion of bark of M26 (dwarfing stock) on a stock scion combination of Gravenstein/MM111 resulted in a dwarfed tree (Lockard and Schneider, 1981). In this case only the bark was transferred, and similar to that of an interstock, the longer piece of bark grafted the more dwarfing the effect. When the bark of a vigorous tree is removed from the stem and replaced inverted, it produces a stronger dwarfing effect than the interstock or the bark graft of a dwarfing rootstock. The inverted bark, a dwarfing rootstock or a dwarfing interstock seems to inhibit the downward movement of IAA. This strengthens the idea that IAA reaching the roots, is somehow important in determining the vigour of the tree (Lockard and Schneider, 1981).

Kamboj (1996) found in his studies that root systems of vigorous rootstocks were found to accumulate higher levels of $[^3H]$-IAA and $[^{14}C]$-sorbitol than the more dwarfing ones which support the hypothesis that a vigorous rootstock acts as a stronger sink for photoassimilates and auxin. Using a donor-receiver system Kamboj (1996) found that polar transport of $[^3H]$-IAA was higher for vigorous rootstock explants. Also the acropetal transport of $[^3H]$-GA$_1$ through shoot explants was studied and again the more vigorous rootstock explants transported higher levels of activity to the agar receptors. These studies show that dwarfing rootstocks metabolise $[^3H]$-GA$_1$ largely to conjugated GA's while more free GA's were found in vigorous rootstocks especially.

Kamboj (1996) measured the ABA and IAA content in the shoot bark of apple rootstocks

by means of gas chromatography-mass spectrometry (GC-MS). He found the dwarfing rootstocks exhibited consistently higher ABA levels than more vigorous rootstocks although no statistical difference was found for IAA. Also by means of GC-MS zeatin and zeatin riboside (major transport cytokinin forms in apple) in shoot xylem sap and root pressure exudates were measured in a range of rootstocks. The shoot xylem and root pressure exudate sap from unworked vigorous rootstocks contained greater cytokinin levels than M.27 (dwarfing) rootstocks. The total cytokinin per shoot was also higher in the more vigorous rootstocks (Kamboj, 1996).

2.3 The effect of cropping on scion vigour

2.3.1 Dry matter production

It is widely known that heavy cropping reduces vegetative growth excessively while failure to crop leads to excess vigour in terms of vegetative growth. Jackson (1984) outlined a simple model which, he stated, defines dry weight gain (ΔW) and partitioning by an apple tree:

$$\Delta W / \Delta t = \Delta W / \Delta t \, (P_L + P_S + P_R + P_F)$$

$P_{L, S, R,}$ and $_F$ express the portions contributed respectively by the leaves, frame (stem), roots and fruits of the apple tree. The sum of P_L, P_S, P_R, P_F is equal to one. This model indicates that any increase in cropping must reduce vegetative growth correspondingly. Hanson (1980) showed that short-term experiments could be interpreted in this way. He found that fruiting trees produce a very similar amount of total dry matter to non-fruiting trees. The actual effects are however more complex, involving feed-back and feed-forward effects.

There is clear evidence that the presence of fruits on a tree, or the proximity of fruits to particular leaves, can increase assimilation rates, increase the degree of stomatal opening and reduce leaf respiration rates (Avery, 1970). Average increases of 51% to 59% in

young fruiting trees compared with deblossomed trees were found. These effects are generally attributed to the sink strength of the fruits, and in the absence of fruit, the accumulation of photosynthates lead to a reduction in photosynthesis through a feed-back mechanism. In some cases the reduced leaf area of the fruiting tree and the consequently improved light environment for the individual leaves may also have contributed substantially to the increase in assimilation, or dry-matter production per unit leaf. There is no evidence, however, of a direct contribution of this increased rate of photosynthesis to vegetative growth. The reverse usually happens; fruit sink strength, which stimulates increased photosynthetic productivity also enables the fruit to compete successfully with the vegetative growth centres for assimilates.

When Maggs (1963) deblossomed young trees, he reported that root growth was reduced by about 25% by the presence of a crop. Total dry matter production was about 10% lower in the cropping than in the deblossomed trees.

Avery (1970) did similar work but included four different rootstocks. He found that heavy cropping on the most dwarfing rootstock stopped root system growth, and only on this rootstock was total dry-matter production as great on cropping as on deblossomed trees. Hanson (1980) found that cropping reduced vegetative dry-weight increment to only about 30% of that of non-cropping controls, with root growth being reduced to virtually nothing.

2.3.2 Residual effects of cropping

There are also residual effects of cropping on growth in subsequent years. Rogers and Booth (1964) established a significant negative relationship between yield and shoot growth in the following year when studying a long-term cropping trial. They suggested that this residual effect of cropping might have resulted from fewer reserves being stored in roots or branches in years of heavy cropping. Different imposed crop loads on growth in the year of treatment and in the following year showed that both the direct and residual effects of cropping on shoot growth were a linear function of weight of crop per unit of

tree size (Jackson, 1984).

2.3.3 Precocity

A question that arises when thinking of fruiting and tree vigour, is whether a rootstock is dwarfing, or whether it induces flowering, and through fruiting alters the physiology of the tree, which limits growth.

Barlow (1971) approached this question by planting Laxton's Superb apple cultivar on dwarfing (M9) and vigorous (M16) rootstocks. He deblossomed some trees, and allowed others to fruit, and also imposed two levels, of pruning (low and high) on the rootstock combinations. His results clearly indicated that the deblossomed trees on dwarfing M9 rootstock were much smaller after 13 years than on the vigorous M16 rootstock, and pruning decreased size by more in the deblossomed trees. On the dwarfing M9 increased precocity resulted in the fruit constituting 70% of the total dry-matter accumulation largely at the expense of tree structure. In contrast, on the vigorous M16 rootstock, the fruit were 40-50% of the dry matter and the framework could develop much more. Two interrelated effects on size are observed: one directly on growth, the other indirectly through enhancing cropping.

The hard pruning produces the expected results, namely, a smaller tree and a lower level of cropping. The strongest effect of pruning was observable on the cropped dwarf tree. This shows that the effect of pruning is additive to the dwarfing imposed by the rootstock.

Although cropping increases photosynthetic efficiency, the production of additional photosynthates is not great enough in heavily cropping trees to prevent the decrease in vegetative growth. The effect on shoot growth appears to be a function of total fruit yield, not the number of fruit *per se*. Root growth is very sensitive to effects of cropping and can be stopped almost totally (Jackson 1984).

Cropping also has an effect in lowering the water potential of the tree, which has a secondary effect in decreasing the shoot growth. The two effects then act synergistically in reducing tree growth. Which of the two effects (utilisation of carbohydrates or lowering the water potential) is more important, depends on the environment to which the trees are exposed. Head (1969), working in cool, low-light environments (England and Denmark) with apples, place the emphasis on carbohydrate partitioning. Chalmers *et al.* (1984) working in a high-energy environment (Australia) with peaches has shown that the photosynthate component is less important than the water status of the tree.

2.4 Hormonal involvement in vigour

2.4.1 Auxin

2.4.1.1 *Auxin location*

Auxins are mostly produced in young tissues, such as active meristems and growing leaves. The movement of auxin is polar mainly in a basipetal direction in shoots and acropetal in roots (Lochard and Schneider, 1981). According to Sheldrake (1973) auxin applied or synthesised in terminals moves in or near the cambial region. Bonnemain and Bourbouloux (1973) also concluded that the cambial zone and proto-xylem and proto-phloem parenchyma are primary paths of auxin transportation. This polarity may be a principal factor in auxin being of importance in correlative growth control, since it could be a mechanism that controls availability of auxin to the various plant parts and processes (Wareing, 1977).

Auxin levels are generally lower in dwarfing rootstocks compared to that of more vigorous types. The bark of dwarfing apple rootstocks is known to destroy auxin, perhaps through oxidation, which may account for the lower levels found in these trees (Lockard and Schneider, 1981). Faust (1987) however stated that low vigour seedlings had excessive level of auxin and gibberellins in relation to their low growth ability. A lack of auxin metabolism may cause its accumulation to the level, which negatively affects shoot elongation. They felt that the lack of growth in the low vigour seedlings may be the result of the production of a growth inhibitor in these plants. Such an inhibitor might directly

counteract the action of hormones or affect hormonal balance via inhibition of the hormone metabolising systems.

2.4.1.2 Polar transport of auxin

Polar transport of auxin is believed to occur by a chemiosmotic process that involves two steps. The first step is the uptake of undissociated auxin from the cell wall by diffusion and/or H^+/IAA- symport carrier and, secondly, the preferential exit of dissociated IAA through a saturable protein carrier (efflux carrier) distributed asymmetrically at the basal ends of transporting cells (Rubery, 1974; Morris and Johnson, 1990).

Soumelidou et al. (1994) and Kamboj (1997) reported that shoot segments from the dwarfing M9 rootstock have a lower capacity for auxin transport than shoot segments from the vigorous rootstock MM111. This also supports the role for auxin transport in the dwarfing effect. The total amount of IAA uptake by these two rootstocks is, however, the same and, therefore, it is unlikely that the failure in polar auxin transport in M9 is due to the level of the auxin symport carrier, the means by which auxin enters the cell. Therefore, Soumelidou et al. (1994) propose that reduction in M9 lies within the mechanism of auxin efflux from the cells and the proposal is supported by the inhibitory effect of TIBA, which is known to be active against the auxin efflux carrier.

Kamboj et al. (1997) however found in a similar study that rootstocks do differ in the uptake characteristics as well as in the transport of auxin to a distal part of the shoot segment. They also suggest that the differences in polar auxin transport between rootstocks could be at the influx to or efflux from the cell.

According to Goldsmith (1992) endogenous auxin levels appear to be important in the maintenance of polar movement, since auxin stimulates its own transport. It is therefore, possible that low endogenous auxin levels in the M9 rootstock limit its capacity to support polar auxin transport. ABA has been shown to influence polar auxin transport; greater levels of ABA may reduce transport, although a mechanism has not been

identified (Basler and McBride, 1977). Kamboj *et al.* (1997) speculated that a role could be envisaged for ABA in the control of uptake or efflux of auxin from the cell as ABA is higher in the bark of dwarfing rootstocks than in vigorous rootstocks.

Polar auxin transport is also involved in graft union formation between apple scion and rootstocks. Because dwarfing rootstocks transport less auxin, they do not fully utilize auxin supplies from the scion for adequate vascular differentiation. According to Soumelidou *et al.* (1994), this leads to an accumulation of auxin just above the union and consequently the abnormal union formation seen with a dwarfing rootstock like M9.

2.4.1.3   Auxin cytokinin interaction

Cytokinin movement in the plant is influenced by auxin, apparently by the establishment of sinks rather than by a direct effect on the transport system itself. IAA polarises cytokinin movement. Thus a reduction of auxin level reaching the roots (main centre of cytokinin synthesis) because of inherent lower levels of IAA, the rootstock or interstock could reduce scion vigour indirectly by its effect on the quantity cytokinin allocated to the scion (Lockhard, 1976). Thus the amount of auxin reaching the root determines the activity of the cytokinin that reaches the shoot, maintaining a rather constant scion to root ratio in plants. Cutting and Lyne, (1993) also concluded from their girdling trials that they support the hypothesis that reduced shoot growth is caused by reduced xylem transported, root supplied, promotive growth substances.

2.4.1.4   Auxin and root growth

Shoot produced auxin apparently plays a role in development of the root system, because auxin supplied to the root via the shoot promotes root growth (Goodwin, Gallnow and Letham, 1978). In addition, shoot-produced auxin may have a more direct role in regulating root growth. McDavid, Marshhall, and Sagar (1973) concluded that cessation of root growth of etiolated pea seedlings was due to reduction of auxin supply from shoot to root rather than due to a lack of sucrose.

Transport of abscisic acid (ABA), synthesised in root tips and apparently involved in growth control of roots, appears to be controlled by IAA (Pilet, 1977). He concluded that IAA from the shoots moved acropetally towards root tips and that these two compounds controlled growth of corn roots.

2.4.1.5 Phenolic influence on IAA

Phenolic compounds not only inhibit growth of plant stems, hypocotyls and roots, but also inhibit mitoses, cell division and cell elongation (Svensson, 1971). The level of phenol required to induce growth inhibition varies with the type of phenol and the plant tissue (Kefeli, 1978). However, phenols also stimulate rooting and at low concentrations it may stimulate growth (Poapst *et al.,* 1970; Thimann *et al.*, 1962). When stimulating growth it acts synergistically with auxin. Phenolic acids that inhibit growth enhance oxidative decarboxylation of auxin. Phenolic acids that promote growth suppress decarboxylation of auxin (Zenk and Muller, 1963).

Monophenols contain a single hydroxyl group and act as a cofactor of auxin oxidase and inhibit growth. Polyphenols with two or more hydroxyl groups inhibit auxin oxidase and tend to enhance growth (Schneider and Wightman, 1974). Poly- and monophenols act both synergistically with IAA.

Many phenols promote growth at very low concentrations, an effect that may be related to ready interconversion of the mono- to the polyphenols (Audus, 1972). Apple bark phenols have been reported to be synergistic or antagonistic to IAA.

Ferulic acid at low levels stimulates IAA oxidase activity but at higher levels it is a powerful enzyme inhibitor (Zenk and Muller, 1963). Phloretin reportedly stimulates wheat root growth, especially in the presence of auxin; however, its glycoside, phloridzin, is a potent stimulator of IAA oxidase (Stenlid, 1968). This could be an important fact with regard to growth of apple trees, because phloridzin is present in large amounts in the

bark. A test for free phenols in MM111 rootstock bark revealed the presence of only phloretin. Sarapuu (1965) reports that under the influence of low temperatures, phloridzin is partially converted to phenolic growth stimulators. This process is of great significance in the emergence of the plant from dormancy.

Phenols are not translocated but are synthesised in the cells in which they occur (Bate-Smith, 1962). However, the precursors for phenolic synthesis are translocated. Phenol synthesis requires light and evidence shows that phenols levels in older leaves, collected from the shady side of trees were much lower when compared with those collected from the sunny side (Hillis and Swain, 1959).

Van Sumere et al., (1975) reported that phloridzin inhibits transport of sugars in plants. Ferulic acid increased the polarity of transport of IAA and stimulated basipetal transport, whereas coumarin enhanced acropetal translocation of auxin (Basler and McBride, 1977). Some phenols increase amylase activity (presumably starch synthesis) which could account for accumulation of starch in the more dwarfing apple rootstocks.

Phenols are concentrated mainly in the bark of an apple tree. Miller (1973) reported the amount of phloridzin in the bark of an apple tree to be as high as 12% of the dry weight, whereas in the leaves, it can be 1% of the fresh weight. Lockard and Schneider (1981) found that in one-year-old apple stem bark, phloridzin was as high as 9.2% and 7.7% of dry weight for MM111 and M26, respectively. In the new roots, it was as high as 6.6% and 5.1% of dry weight for MM111 and M26, respectively. Levels of other phenols were much lower. The total amount of phenols in the stem bark of 1-year-old apple trees was 23.8% and 20.4% of the dry weight in MM 111 and M 26, respectively.

2.4.2 Cytokinin

3.4.2.1 Role of cytokinin

Cytokinins are synthesised primarily in the roots and transported via the xylem to other plant parts, where it stimulates shoot growth (cell division). Those cytokinins, which are

synthesised in immature fruits or seeds, are probably less important in apple tree growth (Lockard and Schneider, 1981) and will not be included in this discussion. Many root effects on shoot growth can be replaced by cytokinins. For example, the application of benzyl-adenine (BA) relieved most of the symptoms of flooding injury on tomatoes and water stress symptoms on sugar beets (Railton and Reid, 1973). Research on pea plants show that lateral buds on decapitated pea plant do not grow if roots are excised but they do grow when cytokinin is applied (Briusma, 1979). Cytokinins simulate the effects of roots in promoting normal branching of inflorescence on cultured ex-plants and promote the retention and development of inflorescence on unrooted single node cuttings of grape (Mullins, 1967). This indicates the importance of root produced cytokinin to the development of the canopy of the plant.

The synthesis of cytokinins in plant roots and their allocation to the shoot tips explains the influence of roots on shoot growth (Sachs and Thimann, 1967). The cytokinins found in xylem sap were usually zeatin and its nucleotide, and is considered to be the most common cytokinin in the xylem sap (Goodwin *et al.* 1978). Cytokinin is allocated to the shoot tip where it is utilised or re-exported to the older leaves where, if it is in the free form, converted to the glucoside and re-exported to other parts of the plant via the phloem tissue (Vonk 1978).

Jones (1984) concluded that in dwarfing apple rootstocks cytokinin concentration in the xylem sap below the graft union is at least fourfold higher than above the graft union. This indicates that the graft union has a not yet clearly defined role to limit the transport of solutes, including cytokinins, in the xylem sap (Faust, 1989). The downward translocation seems also to be limited by the graft union as Soumelidou *et al.* (1994) stated that auxin accumulated in the phloem above the graft union in dwarf rootstocks.

Cytokinin reaching the shoot tip functions in a number of ways: it enhances the "sink" effect of the tissue to make it a better competitor for carbohydrates and amino acids (Morris and Winfield, 1972); it effects cell membrane integrity and facilitates movement of compounds in the tip region (Turvey and Patrick, 1979); it promotes cell division and

probably its main contribution to shoot tip growth, is to increase DNA, RNA and proteins in plant tissues (Leshem, 1973).

Auxins regulate both distribution and metabolism of cytokinins (Lethan, 1978). Lethan also concluded that growth and auxin production in coleoptile tips depends on supply of root-produced cytokinin and that cytokinins are partially capable of regulating auxin status of the shoot as cytokinin stimulate cell divisions and auxin is then produced by this actively growing meristems.

3.4.2.1 Cytokinin interaction

Auxin and cytokinin interact on the release of buds from apical dominance indicating that the endogenous cytokinin supply may be involved in this process. Auxin induces vascular strand formation, but cytokinin is needed to convert these to functional xylem units (Sachs and Thimann, 1966). The cytokinin supply to the lateral buds may be controlled by auxin from the apical bud (Phillips, 1975). Cytokinins also appear to interact with gibberellin in the control of shoot growth. Railton and Reid (1973) found that endogenous cytokinins normally have some controlling influence over endogenous gibberellin levels and stem growth. Thus, any root stress reduces the amount of cytokinin produced by the roots (Torrey, 1968) and consequently influencing vigour negatively through the cytokinin/auxin interaction.

2.4.3 Abscisic Acid (ABA)

3.4.3.1 Function of ABA

ABA-like substances were found in considerably high levels in dwarfing apple rootstocks in contrast with a much lower level in vigorous rootstocks (Robitaille and Carlson 1976). Olien and Lakso (1984) found that dwarfing rootstocks often have lower water potential, which could cause the observed differences in ABA levels between the dwarf and vigorous trees. Faust (1989) concluded in his study that it is unlikely that ABA plays a major direct role in rootstock-induced dwarfing.

However, ABA has commonly been shown to counteract or inhibit several GA-induced physiological responses. Robitaille and Carlson (1971) found that single stem trees stopped elongating and set terminal buds when injected with 100mg/l of ABA. Kim *et al.* (1984) showed that application of ABA led to a reduction in shoot size in apple trees with dwarfing rootstocks more responsive than vigorous rootstocks. That shoot growth of apple is sensitive to ABA applied exogenously would lend support to the view that ABA is a cause rather than an effect of dwarfing in apple. However, at very low concentrations ABA produced a synergistic effect with GA_3.

ABA has been reported to inhibit root growth (Pilet, 1977) and stem elongation (Robitaille and Carlson, 1971), perhaps by inhibiting cell elongation and increasing the ethylene production. Lieberman and Kunishi (1971), however, reported that ABA decreased ethylene evolution and induce resting of buds. ABA also inhibit response to some growth promoters, especially gibberellin, perhaps by inhibiting the assimilation of the amylase involvement in starch metabolism. (Robitaille and Carlson, 1971). Other possible mechanisms for ABA influence in growth could be its effect on allocation of growth substances. Bellandi and Dorffling (1974) reported that ABA did not affect transport of IAA, while Basler and McBride (1977) reported an inhibition of auxin allocation by ABA. The higher levels of ABA in the bark of dwarfing stocks may contribute to the findings of Basler and McBride (1977). Exogenous ABA increased sugar transport from shoot to root in bean (Karmaker and Van Stevenind, 1979), but it is not known if this factor is involved in the higher starch levels found in dwarfing apple stocks.

2.4.4 Gibberelins (GA)

2.4.4.1 Role of gibberelins

According to Looney and Lane (1984) gibberelins influence elongation growth in plants, and severe spurriness in apple trees coincides with less GA-like activity. They also

reported that the dwarfing component of the spur-type habit might be due to gibberellin control. However, Yadava and Lochard (1977) found no clear confirmation that a lack of GA may be responsible for dwarfing in three un-grafted apple rootstocks. They found that the GA_{4-7} like compounds were at the lowest level in the roots of the most dwarfing rootstock M.9 and highest in roots, shoots and leaves of the least dwarfing rootstock MM111, but GA_3 like substances were reversed in order.

Gibberellins are synthesised in the shoots and root tips. However it is not very clear how gibberellins contribute to dwarfing in apple trees. No consistent relationship between dwarfism and gibberellin content has been found in higher plants and there was, until 1968, no evidence that shoot growth is dependent on root-synthesised gibberellins (Lockard and Schneider 1981).

Rootstocks may be able to convert gibberellins into a more active or less active form. Working on maize, Davies and Rappaport (1975) found that plants could metabolise gibberellins when they are applied endogenously. Crozier and Reid (1971) consider that shoot synthesised gibberellin may be allocated to the roots where it is converted to another gibberellin and then re-circulated to the shoot tip. The gibberellin may then act in shoot metabolism, but the root conversion may alter the efficacy of the hormone. Lockard and Scheider (1981) and Robitaille (1971), however, agree that there is little evidence to support a role for gibberellin in the rootstock effect. However, Grochowska et al., (1984) assigned the GA effect on vigour to the top of the tree as paclobutrazol (a GA inhibitor and growth retardant) is only transported upward in the tree when applied to the trunk of a tree.

Richards (1986) reported differences in the transport and metabolism of exogenously applied GA in interstocks of dwarfing and vigorous rootstocks. He found that a dwarfing interstock (M9) transported smaller amounts of GA and metabolised applied GAs to free GAs to a greater extent than the vigorous (MM115) interstock. Dwarfing apple rootstock stems, when used as interstock in an otherwise vigorous combination, impart dwarfing, suggesting that transport and metabolism are important factors in the physiology of dwarfing influences of these rootstocks (Richards, 1986).

Kamboj (1996) found that the reduced capacity of dwarfing rootstocks to provide growth hormones, such as gibberellin, to the shoot as a hypothesis to explain dwarfing effects of rootstocks. He suggests that the reason for the reduced capacity of a dwarfing rootstock to provide gibberillin may be because of: a) their low production of GAs, b) reduced transport, or c) altered metabolism of GAs in the rootstock while these are translocated form the roots to the shoots.

2.4.4.2   Metabolic block in gibberelin synthesis

The major GA in the vegetative tissue of apple is GA_{19}, and was never identified in seed of fruit. GA_4 and GA_7 were the major GA's identified in seeds and in immature seeds large amounts of GA_3 and a lesser amount of GA_1 were found (Faust 1989). This points to the fact that by determining seed produced GA's, one can not generalise to the GA's of the vegetative tissues. In dwarf types of peas, rice, wheat, maize, beans and curcurbits the biosynthetic pathway is blocked either in the early steps of the pathway soon after GA_7-12-aldehyde or just before GA_1 (MacMillan, 1987). GA_1 is considered to be the active GA in these dwarfed plants. Unfortunately, this type of work has not been done in fruit trees. Faust (1989) speculates that the extreme dwarfs have a metabolic block in their GA biosynthesis, and this is the reason for the short internodes. GA_1 has been identified in apple and since GA_1 can be converted from GA_4, GA_1 might be the central active GA in apple causing dwarfing also.

Apples accumulate ten times the level of various GA's during the time growth slows and internodes become shorter, and do not respond to GA sprays. This supports the theory that there is a block in the synthesis of GA's, close to the active GA; perhaps GA_1 and other inactive GA's accumulate. During summer, accumulation of GA in dwarfing trees could be explained by the metabolic block theory, but the accumulation in normal trees cannot happen unless a metabolic block is sensitive to temperature (Grochowska *et al.*, 1984).

The xylem GA, supposedly produced by the roots, decreases to a very low level at the same time that internodes shorten. This raises another possibility that root GA's are involved in internode elongation in fruit trees (Grochowska *et al.*, 1984). Grafting experiments (dwarf apple on normal root also produces longer internodes than dwarf apple on dwarfing roots) also indicate that the root has some involvement in determining internode length (Faust, 1989).

2.4.4.3 Gibberelin biosynthesis inhibitors

Paclobutrazol (PB), {(2RS, 3RS) -1-(4chlorophenyl) -4, 4-dimethyl-2-(1H-1,2,4-triazol-1-yl) pentan-3-ol} is a growth retardant which gives long-lasting control of tree growth with little or no adverse effect on fruit yield or quality. Quinlan and Richardson (1986) found that when PB is applied to apple shoots, the treatment site influences the effect on shoot elongation. Application to the shoot stem and/or shoot tip causes a greater reduction in shoot growth than application of the chemical to expanded leaves or to the woody stem. Quinlan and Richardson (1986) also confirmed that the mode of action of PB is to inhibit the biosynthesis of gibberellins. This was confirmed when a GA_3-application, cancelled the effect of a PB-treatment.

PB has been found to be almost exclusively xylem mobile so that it is readily translocated upwards via the roots from soil applications (Steffens and Wang, 1984). They also found when studying the physiological changes induced by PB that in trees with lowered GA content, assimilate partitioning is shifted from leaves to roots and carbohydrate

concentration is increased in all parts of the tree. The change in partitioning is obviously a secondary effect, a reaction to the elimination of the shoot as a sink. Also the chlorophyll content on a leaf area basis increased in PB-treated leaves. The higher chlorophyll content in PB-treated plants is very similar to the higher chlorophyll in leaves of genetic dwarf trees that are also possibly low in GA (Steffens and Wang, 1986).

A cyanide-resistant alternate respiratory pathway exists in apple root tissue but does not normally contribute to overall root respiration (Steffens and Wang, 1984). They found that 67% of the total respiration of PB-treated roots was via the alternate path. As previously indicated carbohydrate levels in roots from PB-treated shoots were considerably higher than in control plants. Since the alternate path does not usually function unless the cytochrome path is restricted or saturated, increased carbohydrates in roots from PB-treated shoots may have been responsible for the engagement of the alternate respiratory pathway. Due to growth restrictions of the shoot imposed by PB (GA synthesis inhibitor), less carbohydrates (less energy) may be required by PB-treated shoots that may have caused carbohydrates to especially build-up in the roots. This indicates that less energy was utilised on a per unit fresh weight basis by PB-treated plants for dark respiration which may be related to the less actively growing shoots of treated plants. Also this may partially account for carbohydrate build-up in PB-treated plants (Steffens and Wang 1984).

Paclobutrazol is a potent plant growth retardant that is active on a broad range of plant species. It inhibits specifically the three steps in the oxidation of the GA precursor ent-kaurene to ent-kaurenoic acid in cell-free extract of plants including apple (Steffens and Wang, 1984).

Paclobutrazol treatments reduce shoot elongation and leaf expansion more than leaf or node number in apple. Foliar applications of GA_3 are able to restore leaf area expansion more effectively than shoot growth (Steffens and Wang, 1986).

Examining the growth curves of fruit trees treated with paclobutrazol it is evident that there is a double effect of this chemical on shoot growth. The early spring growth is slowed as a result of inhibiting GA synthesis, perhaps the result of shorter internodes. In addition to spring growth effects, the ceasing of summer growth commences much earlier on treated trees than on control trees (Sansavini *et al.* 1986).

2.6 Conclusion

There is ample evidence presented to show that there is an interrelationship between shoot and root growth in plants. The messenger from the shoot and young leaves to the root is the auxin synthesised in these organs. Auxin flows basipetally through phloem and cambial cells of the tree to the roots. Some of the auxin is degraded in bark and the concentration decreases as it proceeds down the bark. The amount of degradation depends on the amount of IAA oxidase, peroxidase and phenols present in the phloem,

These levels are genetically controlled and may vary among species. The level of active auxin that reaches the roots influences root growth and metabolism, as well as the synthesis of cytokinin. The amount and kind of cytokinin translocated acropetally in the plant via the xylem would reflect the amount of shoot synthesised auxin reaching the roots. The cytokinins arriving at the shoot tip would then influence shoot growth, which would influence the synthesis of auxin, and again the amount translocated to the roots. Thus, the manner in which a dwarfing apple rootstock or interstock may affect this growth is by controlling the auxin passing through the bark of the rootstock or interstock.

Bark of different genetic composition will permit deferent amounts of unchanged auxin to pass through it. This affects root growth, followed by cytokinin synthesis, and then shoot growth, which result in a small or large tree, depending on the bark or type of interstock. The evidence that insertion of bark from a dwarfing rootstock (M26) on a tree with a vigorous MM111 rootstock resulted in a dwarfed tree, supports this theory. Insertion of inverted bark from a vigorous rootstock on the same rootstock also gave a

dwarfing effect, confirming the difficulty of translocation of IAA when bark is grafted inversely or when dwarfing bark is grafted as interstem.

Phenols also contribute to dwarfism of apple trees, although the precise role is unknown. Some phenols enhance the degradation of auxin by functioning synergistic with IAA oxidase while others inhibits translocation of sugars and auxin. This is, however, complicated because there is sometimes higher concentrations of total phenols in vigorous than dwarfing apple rootstocks. This is because of phloridzin, which comprises nearly half of the phenols in the bark, and in vigorous rootstocks it is the most commonly found phenol.

The bark from dwarfing rootstocks is thicker than from non-dwarfing stocks. This results in greater total amount of phenols in the bark with a greater area for interaction between auxin and phenols. The precise function of phenols in reducing vigour is however currently unknown.

The fact that shoot growth of apple is sensitive to ABA applied exogenously, lends support to the view that ABA is a cause rather than an effect of dwarfing in apple. Also the findings that ABA affects IAA movement implicates that the higher levels of ABA in bark of dwarfing rootstocks might influence polar auxin transport negatively. This might influence the IAA/cytokinin interaction causing less vigour in the scion.

Gibberellins also play a central role in vigour. It seems that the xylem of dwarfing rootstocks transported smaller amounts of GA and metabolises applied GA to free GA, to a greater extent than the vigorous rootstocks. Work that has been done on dwarf plants (peas, rice, wheat, maize, and beans) showed that the biosynthetic pathway is blocked either in the early steps of the pathway, soon after GA_{7-12} -aldehyde or just before GA_1, and GA_1 is considered to be the active GA in those plants. This work has unfortunately not been done on fruit trees, but the possibility that the low vigour rootstocks also have a metabolic block in their GA biosynthesis, is possible.

The interaction between IAA and cytokinin in the root to shoot ration is strong evidence that auxin is the most important hormone in controlling vigour. This is also confirmed by the enhanced degradation of auxin by higher levels of phenols, and the influence of higher ABA levels on the polar transport of auxin in dwarfing rootstocks.

2.7 References

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Paper 1: Chilling period influences the progression of bud dormancy more than temperature in 'Granny Smith' apple and 'Doyenne du Comice' pear shoots.

Abstract

One-year-old, ca. 50 cm long shoots of 'Doyenne Du Comice' pear and 'Granny Smith' apple were selected randomly from commercial orchards in either Elgin (34°S, 320 m) or in Somerset West (34°S, 80 m), South Africa. Shoots were cold stored at 1, 4, 7 or 10°C for periods of 0, 1, 2 or 3 months after a 12/12 h freezing temperature pre-treatment of -1/13°C (supposedly non-chilling temperatures) for periods of 0, 1, 2 or 3 weeks. After the different treatments the shoots were forced to budburst at 25°C with continuous illumination. The rate of budburst, final percentage budburst, and the synchronisation of budburst between shoots were used to determine the progression of bud dormancy. In all the trials the storage period was the most important factor influencing the progression of dormancy. While in some cases the storage temperature and the freeze treatment effects were significant, the contribution to differences in the progression of dormancy was negligible. Our findings indicate that chilling models currently used in South Africa should emphasise the time of exposure to low temperatures more than the difference in temperatures between 1 to 13°C.

Keywords. Bud dormancy, chilling temperatures, Malus ×domestica Borkh., Pyrus communis L.

Introduction

Delayed foliation is commonly observed in apple and pear producing countries with warm and/or short winter climates. This leads to the less synchronised budburst, of fewer buds and reduced yield. However, with the correct timing and application of rest-breaking agents the symptoms of delayed foliation are diminished and yields are

improved. Different models were developed to predict the end of bud dormancy (Erez and Lavee, 1971; Richardson *et al.*, 1974; Shaltout and Unrath, 1983; Fishman *et al.*, 1987). These models assume an optimum temperature between 6 and 8°C for chilling. Temperatures of 1.5 and 10°C were assumed to be half as effective as the optimum temperature range and temperatures below 1.4°C and above 12.5°C were assumed to be ineffective for accumulation of chill units (Richardson *et al.*, 1974). Scalabrelli and Couvillon (1986), however, found no difference in percentage budburst for terminal buds of 'Redhaven' peach cuttings when treated at 2, 3 or 7°C. High temperatures were found in several studies to deplete the chilling that was already received (Erez and Lavee, 1971; Richardson *et al.*, 1974; Erez *et al.*, 1979; Shaltout and Unrath, 1983). Erez and Couvillon (1987) found that chilling rooted hardwood 'Redhaven' peach cuttings at 0°C cycled with 8 h at 15°C had the same effect as constant chilling at 6°C.

Cook and Jacobs (2000) found that 'Granny Smith' shoots reached maximum dormancy after only 100 Utah Chill Units (CU) in a cold area while those from a warmer area reached maximum dormancy after 600 CU. They speculated that temperatures other than those used to calculate chill units, possibly freezing temperatures, may enhance the progression of dormancy. The possible role of freezing temperatures in the induction of dormancy was investigated.

Material and Methods

'Granny Smith' apple and 'Doyenne du Comice' pear shoots were harvested from trees on vigorous and dwarfing rootstocks (M793 and MM106 for apples, BP3 and QuinceA for pears). Shoots were harvested in late autumn (24 and 31 May 1999 for pears and apples, respectively) from two adjacent pear orchards in Elgin (828 CU net for May, June, July, and Aug. 1999, 34°S, 320m), and two adjacent apple orchards in Somerset West (190 CU net for May, June, July, and Aug. 1999, 34°S, 80m) in the Western Cape, South Africa. Due to the low chilling received in the apple orchards, the trial was repeated in winter (3 Aug. 1999) with shoots from the same 'Granny Smith' orchard on M793 rootstock.

At harvest the shoots were defoliated and cut to a length of 50 cm, wrapped in moist paper and placed in plastic bags, and stored upright during cold storage. The shoots were cold stored at 1, 4, 7, or 10 °C, for 0, 1, 2 or 3 months following a pre-treatment of 0, 1, 2, or 3 weeks of a 12/12 h freeze treatment at -1°C night and 13°C day temperatures. The trial with the 'Granny Smith' apple shoots harvested 3 Aug. differed. These shoots were cold stored at 1, 4, 7, or 10 °C, for 0, 1, or 2 months following the above freeze treatment for 0, 1, or 2 weeks. Buds from the bottom 10 cm of all the shoots were removed with a scalpel prior to forcing. 24 shoots per treatment were bundled in 3 replicate bundles of 8 shoots. The bundles were then placed at random in 5 L buckets with their bases in ≈1 L of water containing 5 mL·L^{-1} household bleach (5% sodium hipochlorite), and forced at 25°C with continuous illumination (215 μmol·m^{-2}·s^{-1} photosynthetically active radiation). The water in the buckets was replaced 3 times a week, removing the bottom 5 mm of each shoot weekly.

During forcing the shoots were checked three times a week for budburst, which was considered at the first visible signs of green expanding leaves, i.e., green tip. The rate of budburst was determined from the inverse of the time (d) for budburst to occur on four shoots per bundle, i.e., 1/(days to 50% budburst) (Cannell, 1989). The number of days between budburst on the first and the fourth shoot in each bundle was calculated as an indication of the synchronisation of budburst. The shoots were maintained in the buckets until buds no longer burst. Finally, on each shoot the number of dormant and burst buds was counted and the final % budburst calculated. Each month during winter additional shoots were cut and forced as above from the same orchards to compare the progression of dormancy in the field with that of the shoots in cold storage.

The experimental design was a completely randomised design with three factors, i.e., freeze treatment period, cold storage period, and cold storage temperature. Each treatment consisted of three replicate bundles of eight shoots. The data were analysed using the General Linear Models (GLM) procedure of SAS$^®$ release 6.12 (SAS Institute, Cary, NC).

Results and Discussion

Initially only the data from shoots not receiving a freeze treatment were analysed to test for storage temperature by storage period interaction. The rate of budburst increased significantly with storage period in all five trials (Fig. 1, Table II). While temperature effects were sometimes observed ('Doyenne du Comice' on BP3, 'Granny Smith' on M793), these effects were inconsistent and small and did not greatly influence the progression of bud dormancy in terms of the rate of budburst. Similar to the rate of budburst the final %budburst increased with storage period (Fig. 1, Table II). Again significant temperature effects were sometimes evident but not consistently. As storage period increased budburst was more synchronised between shoots (Fig. 1). Temperature effects were sometime significant but were not consistent.

This inconsistency in temperature effects was observed within each freeze treatment period regime when analysed separately (data not presented). Temperature differences between 1 and 10°C were, thus, assumed to be negligible, and were consequently pooled to give 12 replications instead of three (Table III). Freeze treatment period by cold storage period interaction was tested. The autumn harvested 'Granny Smith' shoots that been exposed to the freeze treatment showed considerable die back after two weeks of forcing. The shoots may not have hardened off at the time of harvest, resulting in freeze injury. When the trial was repeated two months later none of the shoots died back. The pear shoots showed no signs of injury.

The freeze treatment had an effect on the rate of budburst in all three trials, but it was small and inconsistant (Fig. 2, Table IV). The final % budburst was significantly influenced by the freeze treatment, mostly so in the case of 'Doyenne du Comice' on BP3 where the highest increase in % budburst occurred with three weeks of pre-treatment (Fig. 2, Table III). It would appear that three weeks at -1/13°C contributed to chilling in these pear shoots. The synchrony of budburst was not consistently influenced by the freeze treatment (Fig. 2, Table III).

In all trials the effect of cold storage period outweighed any effects due to cold storage temperature or freeze treatment period in terms of the rate of budburst, final % budburst, and the synchrony of budburst. These results agree with the general understanding that dormancy progresses more rapidly with chilling (Shaltout and Unrath, 1983, Couvillon and Erez, 1985), but not with differences ascribed to temperatures between 1 and 10°C in other studies which show that the effectivity of temperature in dormancy release is normally distributed around an optimum temperature of 6 to 8°C (Erez and Lavee, 1971; Richardson *et al.*, 1974; Gilreath and Buchanan, 1981; Shaltout and Unrath, 1983; Erez and Couvillon, 1987). Erez and Couvillon (1987), however, found that cycling 0°C for 16 h with 15°C for 8 h was as efficient as continuous chilling at 6°C despite the perception that 0°C is inefficient as a chilling temperature. Our findings with apple shoots support the findings of Scalabrelli and Couvillon (1986) who found a similar response of terminal vegetative buds of 'Redhaven' peach shoots to temperatures of 2, 3 or 7°C. They, however, also found differences between these temperatures for the dormancy release of lateral vegetative and reproductive buds. It should be noted that the Utah model (Richardson *et al.*, 1974; Shaltout and Unrath, 1983) describes the progression of bud dormancy in terms of an increase in the number of bursting buds, thereby, taking into account correlative influences active between buds during dormancy (Cook *et al.*, 1998). By working with the rate of budburst of terminal buds this problem is avoided. While not clearly supported in these data, previous work that used the % budburst may emphasise temperature effects on these correlative phenomena (paradormancy) rather than endormancy within the buds.

This raises the question of whether the Utah model over emphasises the effect of temperature relative to chilling period. According to Richardson *et al.* (1974) no chilling accumulates below1.4°C or above 12.4 °C. Our freeze treatment of -1/13°C should not contribute to the accumulation of chilling, yet in these data -1/13°C appears to contribute to chilling, particularly after one month of storage. As a result, we plotted our budburst rate data against chill accumulation according to four different models, i.e., Utah chill units (Richardson *et al.*, 1974), positive chill units (based on the Utah model without

chilling negation carried from one day to the next), the number of hours below 7°C, and the hours equal to and below 13°C (Fig. 3). It is clear that the Utah model, the positive chill unit model or the hours below 7°C poorly describe the accumulation of chilling in our treatments. In numerous treatments buds exit dormancy with equal efficiency at temperatures not accounted for by the chilling model. When chilling was calculated as hours below 13°C we assume all our chilling temperatures to be equally efficient. With this model the progression in rate of budburst was best described. It is also interesting to note that data collected from shoots chilled in the field best fitted this model. This research continues.

In conclusion, the length of the chilling period was the most important factor determining bud growth potential. Temperatures between 1 and 10°C were equally efficient in releasing dormancy, which may explain why previous chill unit models were not able to accurately estimate the progression. When chill accumulation in our data was calculated by simply adding hours below 13°C, the progression of dormancy is more accurately described than with previous models. The effect of chilling negation at higher temperatures, however, needs to be evaluated. Freezing temperatures used in our experiment did not appear to further induce dormancy, as our buds may have already been dormant at the time the shoots were harvested. The pre-treatment at freezing temperatures appeared to contribute to dormancy release rather than intensify it.

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Table I. Plant material, origin, and harvest date of shoots used in chilling trials.

	Cultivar	Rootstock	Origin	Date of shoot harvest
Pear	Doyenne du Comice	QuinceA	Elgin	24 May 1999
	Doyenne du Comice	BP3	Elgin	24 May 1999
Apple	Granny Smith	M793	Somerset West	31 May 1999
	Granny Smith	MM106	Somerset West	31 May 1999
	Granny Smith	M793b	Somerset West	3 Aug. 1999

Table II. The significance levels (Pr > F) of chilling period by temperature effects for the change in the rate of budburst, final % budburst and synchrony of budburst.

	Doyenne du Comice			Granny Smith	
	Quince A	BP 3	M793	MM 106	M793b
Rate of budburst [1 (d to 50% budburst)]					
Storage period	0.0001	0.0001	0.0001	0.0001	0.0001
Temperature	0.3456	0.0121	0.0656	0.1617	0.1159
Storage period by temperature interaction	0.6969	0.1975	0.0508	0.2814	0.0536
Final % budburst					
Storage period	0.0001	0.0001	0.0001	0.0001	0.0001
Temperature	0.0413	0.0001	0.0099	0.4748	0.0587
Storage period by temperature interaction	0.0169	0.0031	0.0189	0.2868	0.3782
Synchrony of budburst (d)					
Storage period	0.0001	0.0001	0.0005	0.0012	0.0012
Temperature	0.6908	0.2174	0.0254	0.5610	0.0073
Storage period by temperature interaction	0.6178	0.0396	0.4909	0.5030	0.0112

Table III. The significance levels (Pr > F) of chilling period by freeze treatment effects for the change in the rate of budburst, final % budburst and synchrony of budburst

	Doyenne du Comice		Granny Smith
	Quinc A	BP3	M793b
Rate of budburst [1 (d to 50% budburst)]			
Storage period	0.0001	0.0001	0.0001
Freeze treatment	0.0001	0.0629	0.0306
Storage period by freeze treatment interaction	0.0434	0.0001	0.0001
Final % budburst			
Storage period	0.0001	0.0001	0.0001
Freeze treatment	0.0001	0.0001	0.0001
Storage period by freeze treatment interaction	0.0752	0.0001	0.0001
Synchrony of budburst (d)			
Storage period	0.0001	0.0001	0.0001
Freeze treatment	0.0342	0.7238	0.2875
Storage period by freeze treatment interaction	0.0014	0.4246	0.0084

Fig. 1

The change in rate of budburst, final % budburst and the synchrony of budburst after 0, 1, 2,or 3 months of cold storage at 1($\square$), 4($\triangle$), 7($\bigcirc$) and 10°C($\times$) of 'Doyenne du Comice' pear and 'Granny Smith' apple shoots.

Fig. 2

The change in rate of budburst, final % budburst and the synchrony of budburst after 0, 1, 2, or 3 months of cold storage following a 12/12h pre-treatment of -1/13°C for 0($\square$), 1($\triangle$), 2($\bigcirc$), or 3($\times$) weeks of 'Doyenne du Comice' pear and 'Granny Smith' apple shoots.

Fig. 3

The change of rate of budburst of 'Doyenne du Comice' pear and 'Granny Smith' apple shoots. Chill units were calculated as Utah chill units, positive chill units, hours below 7°C, or hours below or equal to 13°C ($\square$ = no cold storage, $\triangle$ = 1 month of cold storage, $\bigcirc$ = 2 months of cold storage, and $\times$ = 3 months of cold storage). Control shoots ($\bullet$) were harvested monthly during winter to quantify the progression of dormancy in the field

Figure 1

Figure 2

Figure 3

Rate of budburst [1 / (d to 50% budburst)]
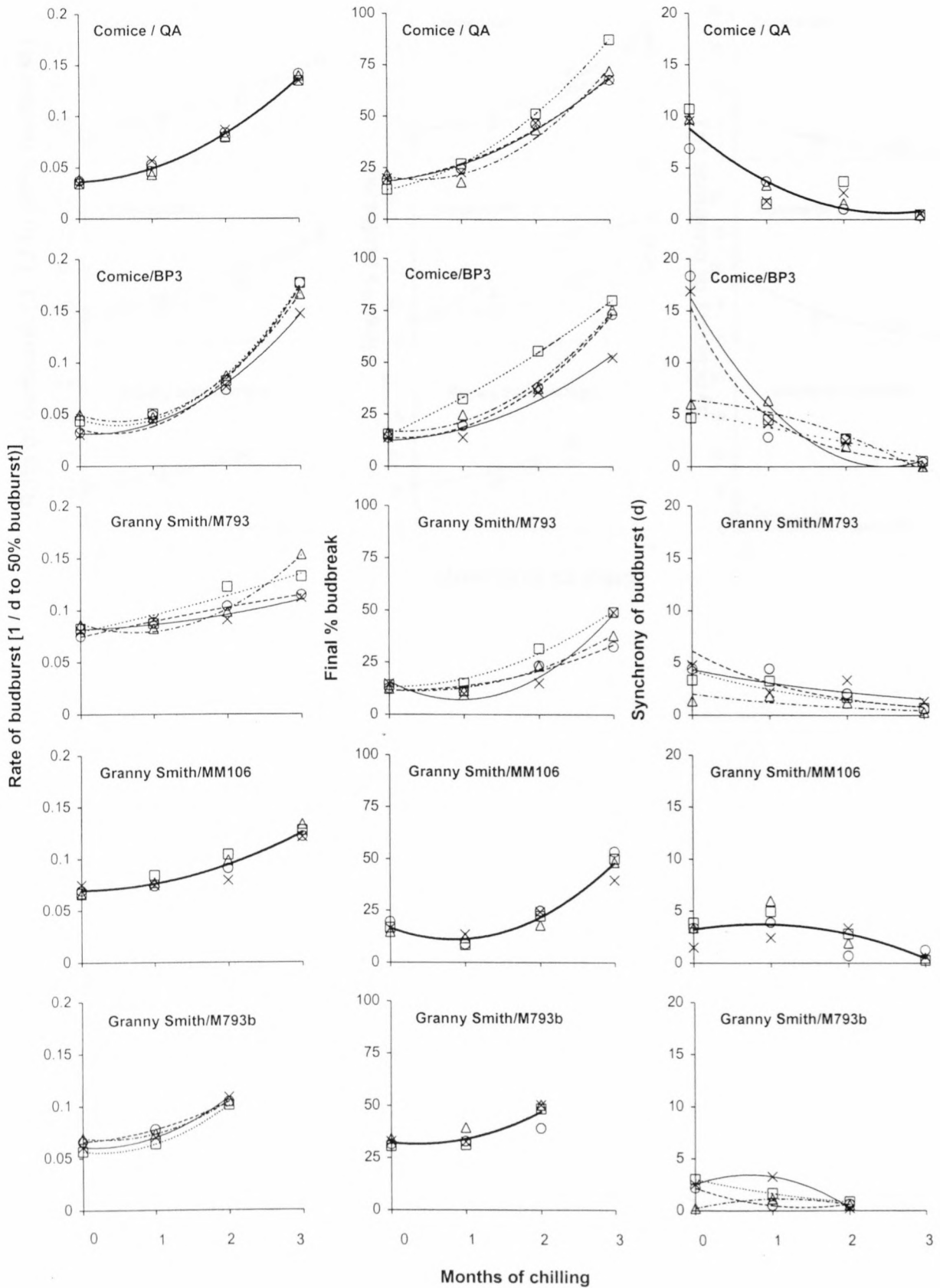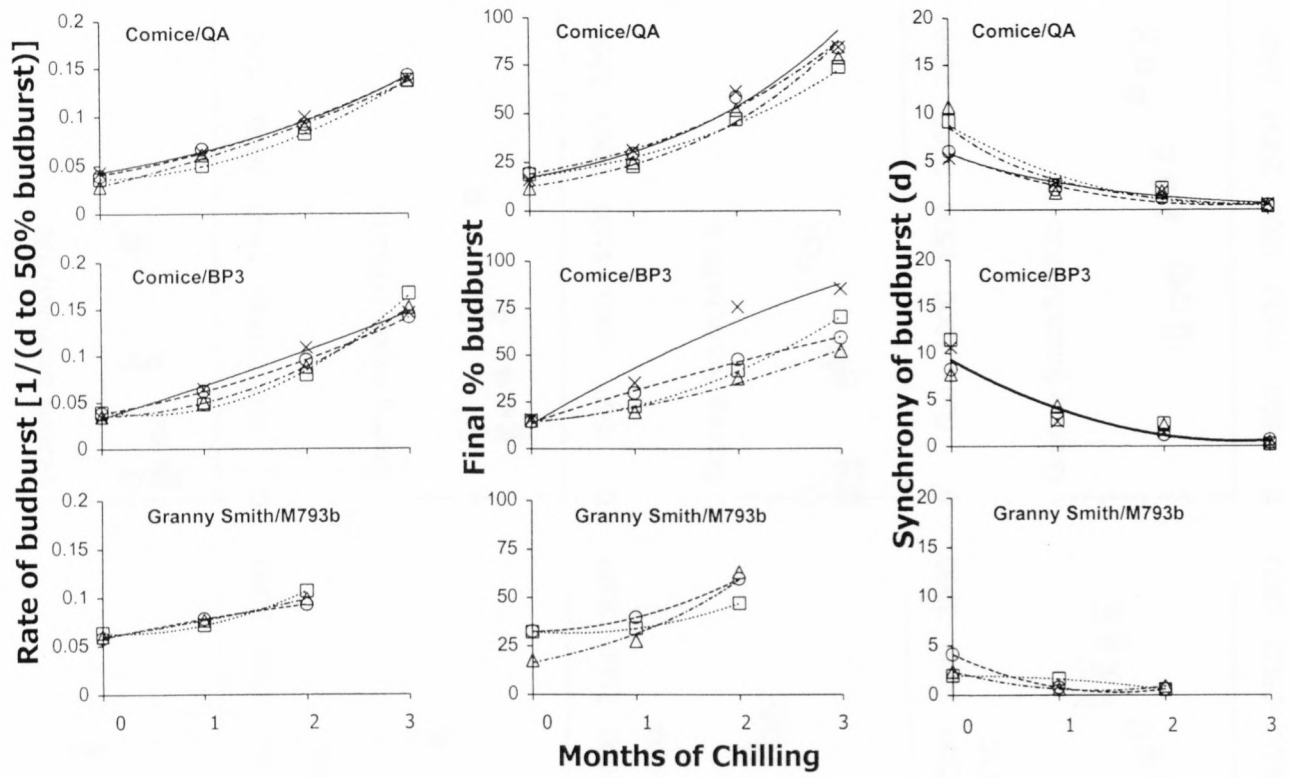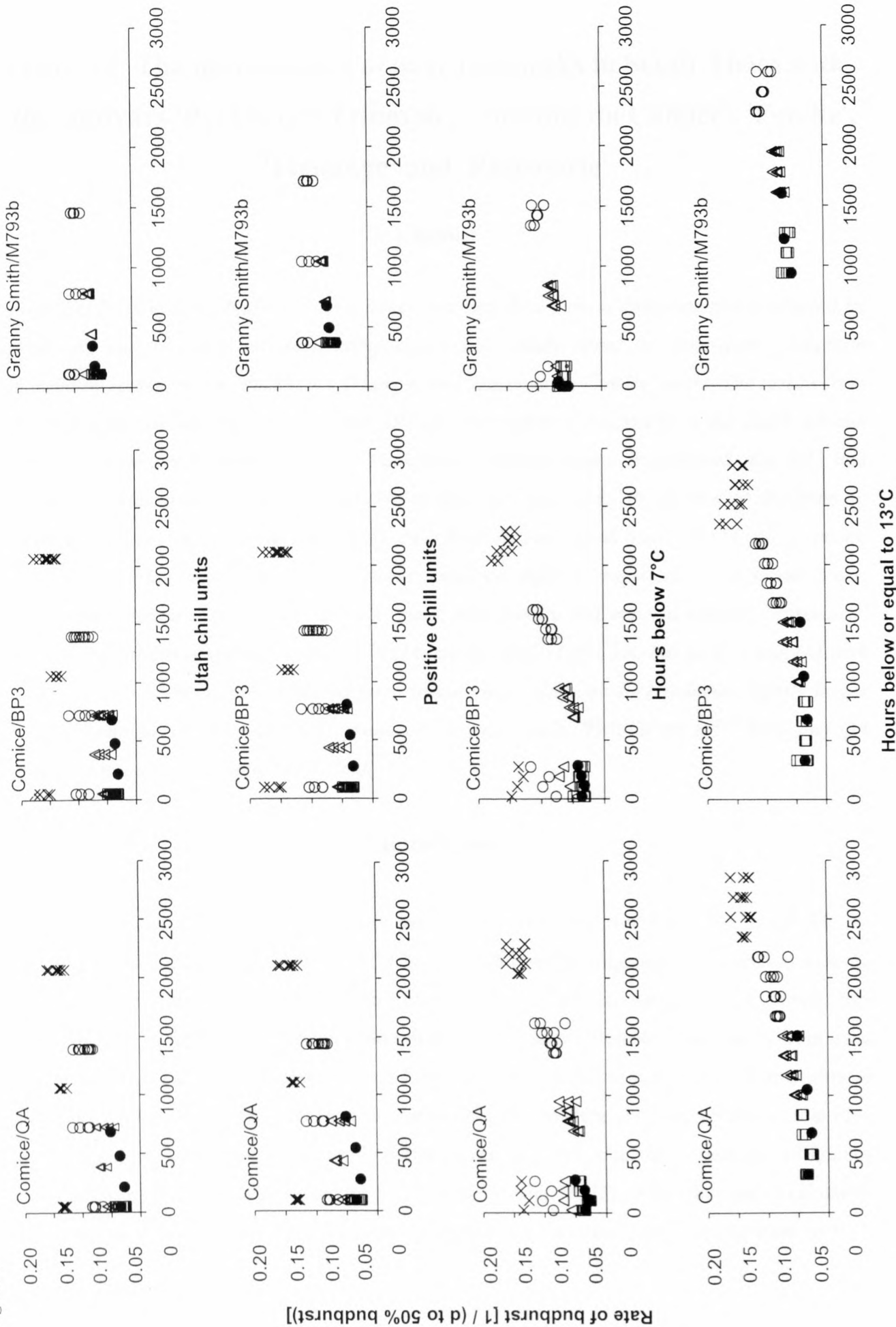
Paper 2: The performance of pear rootstocks in South Africa with the cultivars 'Packham's Triumph', 'Doyenne du Comice', 'Forelle', 'Flamingo' and 'Rosemarie'

Abstract

From production data obtained from a packhouse and data from a questionnaire completed by producers and technical advisors, comparisons were made about the long-term production induced by rootstocks on 'Packham's Triumph' and 'Doyenne du Comice' pears. The results from the questionnaire indicate that BP1 and BP3 are the preferred rootstocks in the South African industry. From production records of 'Packham's Triumph' pears, it appeared that BP3 and OHxF97 produced the best yields compared to the other rootstocks. Production of 'Doyenne du Comice' was the best on QuinceA (QA) and BP3. In replicated trials the bi-colour pears, 'Rosemarie', 'Flamingo', and 'Forelle', were tested on different rootstocks in different areas. Parameters measured were trunk growth, yield, fruit quality and mineral content. 'Rosemarie' showed indications of incompatibility with QA and QuinceC51 (QC51), but on BP1 and QA with a 'Beurre Hardy' interstock produced good initial yields although BP1 induced slightly larger trees. 'Flamingo' on QA and QC51 produced the best yields. 'Forelle' on BP1, BP3, and QA produced similar yields up to the 4th leaf.

Introduction

In 1928, Prof. A. F. de Wet started the search for better pear rootstocks for South African conditions. He collected material only if it held possibilities for vegetative propagation so as to develop clonal rootstocks. Trees on seedling rootstocks showed variation that complicated practices such as fertilisation, pruning and thinning. The material selected was mostly from local origin, although some were imported from England. Some clones selected were from deliberate crossings while others were selected from large trees that made a good impression at that time and of which the genetic origin was only partly known. De Wet collected 39 pear and 17 Quince varieties as potential clonal rootstocks (Stadler & Allison, 1972). After thorough evaluation, seven pear and two Quince rootstocks were regarded as promising. They were labelled as B11,

B12, B13, B14, B18, B33 and B27 as well as QA, and Quince B. Out of these rootstocks B13 and B12 were released in the industry in 1973, and named Bien Donné pear 1 (BP1) and Bien Donné pear 2 (BP2) respectively. Six years later when the technique of rooting by means of hardwood cuttings was developed, clone B14 was released and named Bien Donné pear 3 (BP3) (Van Zyl, 1979).

Van Huyssteen (1984) found BP3 to be the most vigorous rootstock, followed by seedling, BP2, BP1 and QA. As the difference between BP2 and BP3 in terms of vigour and production characteristics was not large enough to justify the use of both in the industry, BP2 was discarded. QA was considered too dwarfing for 'Packham's Triumph' and 'Bon Chretien' pears, which resulted in smaller fruit which were more prone to russeting (Van Huyssteen, 1984). Stadler (1973) mentioned that incompatibility was a problem with Quince rootstocks and that an interstock of at least 23cm long from 'Beurré Hardy' or 'Doyenne du Comice' should be used. QC51 was imported from East Malling in England in the early seventies and after being handed over in 1977, it was released, virus free thirteen years later, by the Fruit and Fruit Technology Research Institute (FFTRI) for commercial use in South Africa. QC51 induced a tree slightly smaller in size than QA when used for 'Packham's Triumph', with cumulative production similar to that of BP1 and BP2 but slightly less than BP3 (Van Huyssteen and Van Zyl, 1992). QC51 and BP1 were the most yield efficient in these data.

Although they were known to be difficult to root, *Pyrus calleryana* and *Pyrus betulaefolia* and a series of Old Home x Farmingdale (OHxF) were imported for evaluation (Van Huyssteen, 1984). Seedlings from these clones were used in some of the evaluations planted in the early 80's. To date no results from these plantings have been published.

In South Africa sunburn is a problem, particularly with green pears, when dwarfing rootstocks are used on poor soils and insufficient leaf surface develops to protect the fruit. As a result Quince rootstocks are infrequently used in the South African industry. However, with the recent interest in bi-coloured pears where optimal light distribution is essential for red colour development, interest in the use of Quince rootstocks rather than the vigorous BP series has renewed. Recent work done by Du Plooy (2000) showed that 'Forelle' trees on QA rootstock

were more productive in the early years than BP1 and BP3 rootstocks. He also stated that QA significantly increased fruit mass, blush development and total soluble solids compared to BP1 and BP3.

We aimed to quantify the field performance of locally available pear rootstocks, in particular from data outside of previously reported local trials. Preliminary findings from statistically replicated rootstock trials of the bicolour cultivars 'Rosemarie', 'Flamingo' and 'Forelle' are presented.

Materials and Methods

Industry preference

To assess current preferences for pear rootstocks in South Africa, eleven producers and six technical advisors completed a questionnaire. Firstly, they had to comment on their experience with different rootstocks, and secondly they had to mark their first and second choice rootstocks for each of a number of cultivars. A value of two or one was then allocated for a first or second choice, respectively. The relative popularity of the different rootstocks was then calculated, as a percentage of points given to each rootstock, relative to the total points given to all rootstocks, within each cultivar.

Commercial data

Production records were collected from commercial orchards and trails. Yield data of 'Doyenne du Comice' and 'Packham's Triumph' pear orchards are presented.

Statistically replicated bi-coloured pear trails

Rootstocks:

Five statistically replicated trials with 'Forelle', 'Rosemarie', and 'Flamingo' bi-colour pear cultivars, were planted in three different areas (Vyeboom, Ceres, and Koue Bokkeveld) in the Western Cape South Africa (Table 1). In winter 1996 'Forelle' and 'Rosemarie' on QuinceA, BP1 and BP3 rootstocks were planted at the same site in Vyeboom (34 °S, 400m). The other trials were all planted in 1997 with 'Rosemarie' and 'Flamingo' on rootstocks QuinceA (QA),

QuinceC51 (QC51), BP1 and QuinceA with a 'Beurre Hardy' interstock (QAis). 'Rosemarie' was planted in Ceres (34° S, 450m) and in the Koue Bokkeveld (34° S, 900m), while 'Flamingo' was only planted in the Koue Bokkeveld.

The rootstocks were replicated three times in a completely randomised block design in each trial. The trials were planted as part of commercial orchards and received the same production practices used for the orchard. The tree spacing was 4m x 1m in all trails.

Parameters measured at harvest:

Data collected included: a)trunk circumference measured 20 cm above the graft union; b) yield in terms of weight and number of fruit per tree; c) fruit size as weight and diameter (diameter measured using a Cranston gauge); d) fruit firmness measured with a penetrometer using an 8mm plunger; and e) fruit colour according to the Unifruco colour charts, P16 for 'Flamingo' and P26 for 'Rosemarie' (1 = red, 12 = green). The percentage poor-coloured fruit and small fruit (<55mm) were determined using the minimum standards for export. Yield efficiencies were calculated as kg fruit produced per cm trunk circumference.

Parameters measured postharvest:

At harvest of the 'Flamingo' trial in the Koue Bokkeveld, 15 fruit per replicate were sampled at random for mineral analysis. Maturity parameters of the remaining fruit was evaluated at harvest and then after storage at -0.5°C in air for twelve weeks. Maturity parameters included: a) background colour indexing according to the Unifruco colour chart for apples and pears (0.5 = green and 5.0 = yellow); b) firmness measured using a penetrometer with an 8 mm plunger; c) the percentage titratable soluble solids (%TSS); and d) the percentage acid (%Acid). After twelve weeks of storage and one week of shelf life (12 +1 weeks) colour and firmness were again measured. The fruit were also inspected for any physiological disorders that might have developed during storage.

Statistical analysis:

The data were analysed using the general linear models (GLM) procedure of SAS[®] release 6.12 (SAS Institute, Cary, NC.).

Results and Discussion

Industry preference

BP1, is the preferred rootstock in South Africa. It seems, from the results in Table 2 that the producers and technical advisors consulted were content to use BP1 as a general rootstock for all pear cultivars. However, with the bi-colour pears there seems to be a trend towards a preference for less vigorous rootstocks such as the Quince series. This, despite the fact that few producers and advisors had long term experience with bi-colour pears on Quince rootstocks.

A few producers with experience with 'Packham's Triumph' on OHxF97 were pleased with the precocity and production of the rootstock. They felt OHxF97 performed similar to BP3 in terms of vigour and production, and although more vigorous, OHxF97 is more precocious than BP1.

Some producers had 'Doyenne du Comice' on QA and were very pleased with its performance, supporting what Mielke (1993) found in his rootstock studies. All producers and advisors found seedling rootstock to be too vigorous, prone to suckering, susceptible to Fusarium, and uneven in tree size, and thus unacceptable. These problems are common with seedling rootstock (Stadler & Allison, 1972; Stadler, 1973; Van Huyssteen, 1984; Lombard & Westwood, 1987).

Commercial data

'Doyenne du Comice' orchards planted between 1972 and 1975 on QA rootstock produced annually 23 t/ha more over the last ten years than on seedling rootstock (Figure 1). Unfortunately the first ten years' early production records of these old orchards were not available to compare with the early production records of the later plantings (1985-1990) where BP1, BP3 and seedling rootstocks were used (Figure 2). After ten years, cumulative yield on BP3 was 48 t/ha, considerably higher yields than seedling and BP1 that produced 27 and 15 t/ha, respectively.

Production of 'Packham's Triumph' pears on a broader spectrum of rootstocks is shown in Table 3. Seedling, BP3 and BP1 were used more often than QA for 'Packham's Triumph'. The use of QA on 'Packham's Triumph' was restricted as a result of recommendations from earlier work

done by Stadler (1973). Results from Figure 3 indicate that the mean yield of the last five years of full bearing 'Packham's Triumph' trees were similar on BP1 and BP3 (≈50 ton/ha). The mean cumulative yield for the first nine years from planting, was the highest with BP3 (130 t/ha), followed by seedling (118 t/ha), QA (109 t/ha), and BP1 (86 t/ha). The lower yields of 'Packhams Triumph' on seedling and QA shown here confirm the results of Van Huyssteen (1984).

Previously unpublished data from commercial trials with 'Packhams Triumph' are shown in Table 3. BP3 generally performed well and in only one site did OHxF97 produce higher yields. In the trials where OHxF97 was planted it produced high cumulative yields. BP2 planted in one site produced 280 t/ha, only slightly less than OHxF97 at 282 t/ha. Seedling rootstock with a BP3 interstock produced higher yields than the seedling rootstock without an interstock, but not as high as on BP3 rootstock. BP1, seedling and P. calleryana rootstocks performed worst.

Statistically replicated trials

In Table 4, tree vigour in terms of trunk growth of pear trees on different rootstocks at five Western Cape sites are presented. BP1 and BP3 rootstocks induced, in most trials, the largest trees. Vigour of 'Rosemarie' trees in Vyeboom showed no significant difference between rootstocks BP1, BP3 and QA. These trials indicate that BP1 and BP3 induce similar vigour in terms of trunk growth in the early years, which contradicts previous findings. Both Stadler and Allison, (1972) and Van Huyssteen and Van Zyl (1992) found BP1 more dwarfing than BP3.

'Rosemarie' scions on QA and QC51 showed symptoms of incompatibility in Ceres and the Koue Bokkeveld, but not in Vyeboom. 'Flamingo', which has the same parents as 'Rosemarie' showed no incompatibility on Quince rootstocks. 'Flamingo' scions on Quince with a 'Beurre Hardy' interstock had a smaller trunk circumference than the scions without the interstock, but did not differ in terms of trunk growth (Table 4). With 'Rosemarie' the opposite was evident; scions on QAis showed more growth than scions without an interstock. The interstocks used in these trials were only 5cm long; according to Stadler (1973) a 'Beurre Hardy' or 'Doyenne du Comice' interstock of at least 23 cm long should be used.

'Rosemarie' in Ceres and Koue Bokkeveld on BP1 and QAis rootstocks produced higher yields than the QA and QC51 rootstocks, but not in Vyeboom (Table 5). The apparent incompatibility of 'Rosemarie' on QA and QC51 may account for these lower yields. However, in Vyeboom the QA rootstock was cumulatively more yield efficient than the BP1 and BP3 rootstocks (P = 0.0193).

With 'Flamingo' in the Koue Bokkeveld area, both QA and QC51, produced significantly higher yields (P = 0.0037), and were more yield efficient (P = 0.0049), than the BP1 and QAis rootstocks. There was no significant differences in yield and yield efficiency between the three rootstocks used in the 'Forelle' trial in Vyeboom, yet QA produced significantly less fruit in fourth leaf (P = 0.0184).

In all trials, fruit produced from Quince rootstocks were larger in size, yet only significantly in 'Rosemarie' in the Koue Bokkeveld and 'Forelle' in Vyeboom (Table 6). This is in contrast with the results of Van Huyssteen (1984) which stated that fruit of 'Packham's Triumph' were smaller on QA than on BP1, BP3 and seedling. However, in later work Van Huyssteen (1992) found no difference in fruit size between BP1, BP3, QA and QC 51.

Only in 'Rosemarie' on BP1 in the Koue Bokkeveld was the % poor coloured fruit significantly higher (P = 0.0081). This correlates well with the more vigorous BP1 trees. There were no statistical differences in poor coloured fruit in the other trials (Table 6).

Stadler (1973) found that fruit produced from trees on Quince rootstock ripen slightly earlier than those on seedling rootstock. In these trials however, maturity of fruit from different rootstocks did not follow any specific trend, although some significant differences occurred. These differences were inconsistent and contradictory (Table 7). According to Stadler and Allison (1972), pears from dwarfing rootstocks show a tendency to stay firm longer after storage. We observed no significant difference between fruit from different rootstocks in terms of firmness, background colour, % TSS and % acid after 12 weeks of storage at –0.5 °C and 1 week of shelf life (Table 7).

There was no significant differences between rootstocks for all the minerals tested (Table 8), except for Boron (B) which was higher in fruit from the BP1 rootstock (P = 0.0045). These fruit from the more vigorous BP1 rootstock had 2 ppm B compared to the 1.3, 1.2 and 1.3 ppm in fruit from QC51, QA and QAis rootstocks, respectively. According to Lombard and Westwood (1987), the *Pyrus* species (Pears), have higher uptake of B than *Cydonia oblonga* (Quince).

Conclusion

BP1 and BP3 rootstocks have clearly been adopted by our industry as universal rootstocks for pears in South Africa. Although the industry has little experience in using Quince rootstocks there seems to be a need for more dwarfing rootstocks, for example the QA and QC51, particularly in the case of the bi-colour pears.

From the commercial data one can conclude that BP3 and OHxF97 produce the highest yields on 'Packham's Triumph' pears under local conditions. Higher yields of 'Doyenne du Comice' were obtained with QA and BP3 rootstocks. QA should perform well in high density plantings and BP3 in lower density plantings of 'Doyenne du Comice'.

Early data from statistically replicated trials on the bi-colour pears, indicate that BP1 and BP3 are the most vigorous as measured by trunk growth. In general the 'Rosemarie' trials produced higher yields on BP1 and Qais, than on QA and QC51, possibly because of incompatibility. BP1 tends to produce trees slightly larger than QAis and, therefore, will be recommended at a wider spacing than QAis. At this early stage a final recommendation on spacing and rootstock would not be accurate and must still be determined. With 'Flamingo', incompatibility with Quince rootstocks does not seem to be as big a problem as with 'Rosemarie', but it is still too early to draw this conclusion. QA and QC51 produced higher yields in the 3rd leaf compared to BP1 and QAis. For 'Forelle', incompatibility with the QA rootstock is not evident at this stage, and at the same density produced similar yields to BP1 and BP3, but with bigger fruit, confirming the findings of Du Plooy and Van Huyssteen (2000). These are only preliminary conclusions, and the continuation of these trials will confirm differences between rootstocks in terms of tree size, yield, fruit size and fruit quality.

References

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Figure 1: Mean yield of 'Doyenne du Comice' pear orchards planted between 1972 and 1975 on different rootstocks for the first period 1989 to 1998.

Figure 2: Mean cumulative yield for the first ten years from planting of 'Doyenne du Comice' pear orchards planted between 1985 and 1990 on different rootstocks.

Figure 3: Mean annual yield over the period 1995 to 2000 of full bearing 'Packham's Triumph' pear orchards on different rootstocks.

Fig. 1

Fig. 2

Fig. 3
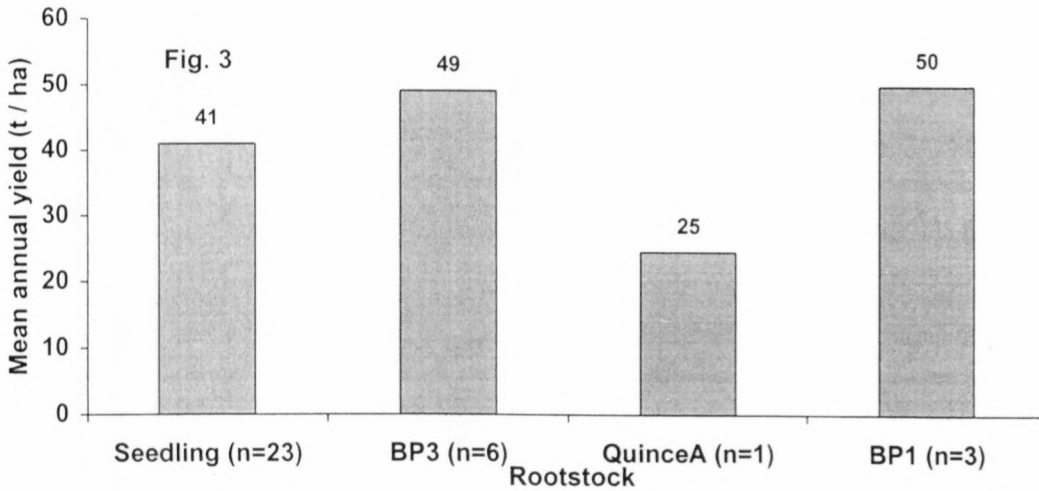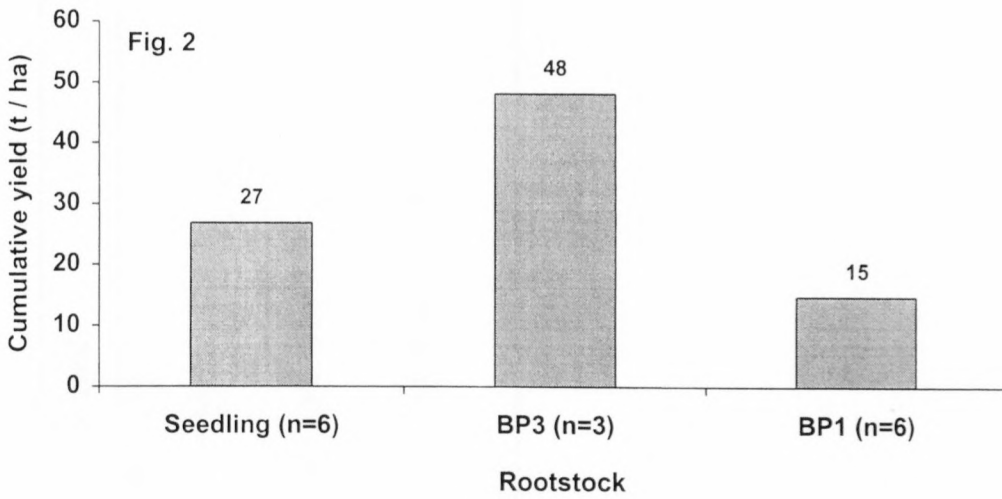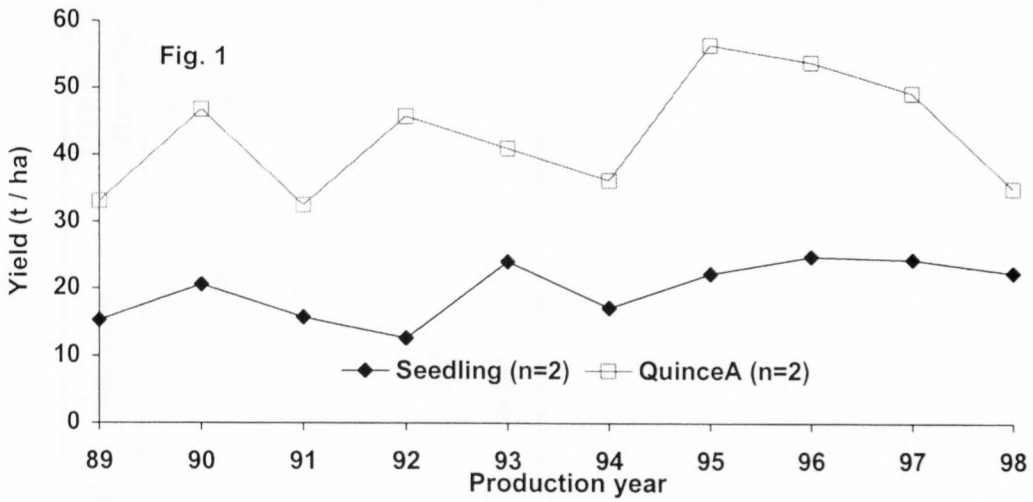
Table 1. Details of the different statistically replicated trials performed in various production regions in the Western Cape.

Production region	Cultivar	Rootstocks used	Year planted	Soil type	Tree density (trees/ha)
Vyeboom	Rosemarie	BP1, BP3, QA	1996	Loamy clay	2500
	Forelle	BP1, BP3, QA	1996	Loamy clay	2500
Ceres	Rosemarie	BP1, BP3, QA, QAis	1997	Loam	2500
Koue Bokkeveld	Flamingo	BP1, BP3, QA, QAis BP1, BP3, QA	1997	Sand	2500
	Rosemarie	QAis	1997	Sand	2500

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Table 2. Results of a questionnaire completed by 11 producers and 6 technical advisors asked to mark their first and second choice rootstocks for each cultivar. A value of two or one was allocated for a first or second choice respectively. The relative popularity of the different rootstocks was calculated, as a percentage of points given to each rootstock, relative to the total points given to all the rootstocks, within each cultivar.

Scion cultivar	Rootstock						
	QC51	QA	BP1	BP3	Calleryana	OHxF97	Seedling
Rosemarie	10	11	50	24	0	5	0
Forelle	13	17	46	22	0	4	0
Flamingo	10	6	58	22	0	4	0
Doyenne du Comice	12	24	36	24	0	4	0
Packham's Triumph	0	2	45	45	0	8	0
Bon Chretien	0	2	42	47	0	9	0
Beurre Bosc	0	2	64	30	0	4	0
Beurre Hardy	0	2	62	31	0	5	0
Early Bon Chretien	0	0	62	34	0	4	0

Table 3. Cumulative yield for the first nine years from planting of 'Packham's Triumph' pear orchards in different production regions on different rootstocks.

Production region	Rootstock	Year planted	n [z]	Cumulative Yield (t / ha)
Commercial orchards				
Vyeboom/Grabouw	Seedling	1983-1986	23	118
	BP3	1983-1986	6	130
	QA	1984	1	109
	BP1	1986-1987	3	86
Commercial trials				
Somerset West	'Winter Nelis' seedling	1984	1	110
	'Bon Cretien' seedling	1984	1	145
	'P. calleryana' seedling	1984	1	95
	BP3	1984	1	245
	'Bon Cretien' seedling/BP3 interstock	1984	1	176
	BP1	1984	1	117
Somerset West	OHxF97	1987	1	157
	Calleryana	1987	1	119
Tulbagh	OHxF97	1987	1	201
	BP3	1987	1	173
Stellenbocsh	OHxF97	1987	1	195
	BP3	1987	1	201
Viliersdorp	OHxF97	1987	1	282
	Calleryana	1987	1	202
	BP2	1987	1	280
Ceres	OHxF97	1983	1	273
	'Winter Nelis' seedling	1983	1	207

[z] Number of orchards used to determine mean cumulative yield.

Table 4. Initial trunk growth (cm) of bi-colour pear trees on different rootstocks at five Western Cape sites.

| | Rootstock | | | | | |
---	QC51	QA	QA(IS)	BP1	BP3	Pr >F
'Rosemarie' in Ceres						
Trunk circumference 2nd leaf	9.4 b^z	8.7 b	13.3 a	14.8 a	-	0.0001
Trunk circumference 3rd leaf	13.5 b	13.1 b	20.6 a	22.7 a	-	0.0003
Increase	4.2 b	4.4 b	7.4 a	8.0 a	-	0.0063
'Rosemarie' in Koue Bokkeveld						
Trunk circumference 2nd leaf	8.7 b	9.1 b	9.0 b	11.3 a	-	0.0102
Trunk circumference 3rd leaf	10.6 b	10.8 b	11.5 b	14.7 a	-	0.0092
Increase	2.0 b	1.7 b	2.5 ab	3.4 a	-	0.0212
'Rosemarie' in Vyeboom						
Trunk circumference 3rd leaf	-	12.2 a	-	18.5 a	18.1 a	0.0518
Trunk circumference 4th leaf	-	14.1 a	-	20.9 a	20.5 a	0.0771
Increase	-	1.9 a	-	2.5 a	2.4 a	0.5062
'Flamingo' in Koue Bokkeveld						
Trunk circumference 2nd leaf	9.4 ab	9.1 b	6.7 c	9.9 a	-	0.0001
Trunk circumference 3rd leaf	11.6 ab	10.8 b	9.1 c	12.7 a	-	0.0002
Increase	2.2 ab	1.7 b	2.3 ab	2.9 a	-	0.0113
'Forelle' in Vyeboom						
Trunk circumference 3rd leaf	-	12.3 b	-	17.5 a	18.1 a	0.0020
Trunk circumference 4th leaf	-	16.3 b	-	21.9 a	22.2 a	0.0006
Increase	-	3.9 a	-	4.5 a	4.1 a	0.2311

^{z} Means seperation by Tukey's Studentized Range Test (5%).

Table 5. Initial production of bi-colour pear trees on different rootstocks at five Western Cape sites.

| | Rootstock | | | | | |
	QC51	QA	QAis	BP1	BP3	Pr >F
'Rosemarie' in Ceres						
Yield (kg/tree) 3rd leaf	2.1 b[y]	1.9 b	4.9 a	4.9 a	-	0.0024
Yield efficiency (kg/cm) 3rd leaf	0.15 a	0.14 a	0.24 a	0.21 a	-	0.0811
Number of fruit 3rd leaf	14.9 b	14.4 b	32.9 a	36.0 a	-	0.0069
'Rosemarie' in Koue Bokkeveld						
Yield (kg/tree) 3rd leaf	1.1 c	1.9 bc	2.7 b	4.4 a	-	0.0011
Yield efficiency (kg/cm) 3rd leaf	0.10 a	0.14 a	0.23 a	0.30 a	-	0.0456
Number of fruit 3rd leaf	8.5 c	11.9 b	21.6 ab	34.7 a	-	0.0020
'Rosemarie' in Vyeboom						
Yield (kg/tree) 3rd leaf	-	3.8 a	-	2.5 a	3.7 a	0.1450
Yield (kg/tree) 4th leaf	-	6.6 a	-	6.8 a	4.5 a	0.0871
Cumulative yield efficiency (kg/cm)[z]	-	0.75 a	-	0.45 b	0.40 b	0.0193
Number of fruit 3rd leaf	-	27.4 a	-	20.4 a	29.5 a	0.3717
Number of fruit 4th leaf	-	57.5 ab	-	58.5 a	35.4 b	0.0502
'Flamingo' in Koue Bokkeveld						
Yield (kg/tree) 3rd leaf	4.8 a	5.0 a	1.1 b	2.2 b	-	0.0037
Yield efficiency (kg/cm) 3rd leaf	0.41 a	0.46 a	0.13 b	0.18 b	-	0.0049
Number of fruit 3rd leaf	20.3 bc	36.9 a	7.1 c	28.0 ab	-	0.0026
'Forelle' in Vyeboom						
Yield (kg/tree) 3rd leaf	-	0.7 a	-	0.3 a	0.5 a	0.2989
Yield (kg/tree) 4th leaf	-	3.6 b	-	4.2 ab	4.4 a	0.1193
Cumulative yield efficiency (kg/cm)	-	0.262 a	-	0.202 a	0.217 a	0.0870
Number of fruit 3rd leaf	-	4.4 a	-	2.7 a	3.5 a	0.5239
Number of fruit 4th leaf	-	27.2 b	-	41.6 a	43.1 a	0.0184

[y] Means seperation by Tukey's Studentized Range Test (5%).
[z] Cumulative yield efficiency calculated from the sum of yield (kg) for the 3rd and 4th leaf, divided by the 4th leaf trunk circumference (cm).

Table 6. Fruit quality of bi-colour pears from different rootstock trials during the first two years of production.

	Rootstock					
	QC51	QA	QAis	BP1	BP3	Pr >F
'Rosemarie' in Ceres						
Fruit diameter (mm) 3rd leaf	62.5 a[z]	62.2 a	61.9 a	60.2 a	-	0.3703
% Fruit <55mm	8.0 a	11.4 a	11.2 a	24.1 a	-	0.1464
% Poor coloured fruit	25.8 a	10.1 a	12.6 a	10.5 a	-	0.1670
'Rosemarie' in Koue Bokkeveld						
Fruit diameter (mm) 3rd leaf	63.9 a	64.5 a	59.2 b	59.2 b	-	0.0081
% Fruit <55mm	15.6 a	3.9 a	16.1 a	17.6 a	-	0.5056
% Poor coloured fruit	7.5 b	3.9 b	7.9 b	20.0 a	-	0.0018
'Rosemarie' in Vyeboom						
Fruit weight (g) 3rd leaf	-	142.5 a	-	116.7 a	127.8 a	0.1250
Fruit weight (g) 4th leaf	-	114.6 a	-	117.6 a	127.3 a	0.4973
'Flamingo' in Koue Bokkeveld						
Fruit diameter (mm) 3rd leaf	62.9 a	62.7 a	62.5 a	61.6 a	-	0.5319
% Fruit <55mm	9.1 a	3.6 ab	2.0 b	3.4 ab	-	0.0478
% Poor coloured fruit	6.2 a	4.2 a	0.6 a	6.6 a	-	0.1900
'Forelle' in Vyeboom						
Fruit weight (g) 3rd leaf	-	169.6 a	-	124.6 a	129.5 a	0.0540
Fruit weight (g) 4th leaf	-	133.9 a	-	100.8 b	104.6 b	0.0034

[z] Means seperation by Tukey's Studentized Range Test (5%).

Table 7. Maturity parameters of bi-colour pear fruit harvested from five rootstock trials during early production years.

	Rootstock					
	QC51	QA	QAis	BP1	BP3	Pr >F
'Rosemarie' in Ceres						
Firmness at harvest (kg) 3rd leaf	7.0 a^z	7.1 a	7.2 a	7.3 a	-	0.1268
'Rosemarie' in Koue Bokkeveld						
Firmness at harvest (kg) 3rd leaf	6.8 b	6.8 b	6.9 b	7.3 a	-	0.0016
'Rosemarie' in Vyeboom						
Firmness at harvest (kg) 4th leaf	-	5.7 a	-	5.5 a	5.5 a	0.0947
'Forelle' in Vyeboom						
Firmness at harvest (kg) 4th leaf	-	7.0 a	-	6.6 b	6.6 b	0.0146
'Flamingo' in Koue Bokkeveld						
Firmness at harvest 3rd leaf (kg)	6.7 ab	6.8 b	7.2 a	6.6 b	-	0.0414
Background colour (0.5-5.0) at harvest	2.0 a	1.8 a	1.6 a	1.7 a	-	0.1220
%TSS at harvest	11.6 a	11.6 a	11.8 a	12.1 a	-	0.1075
%Acid at harvest	0.37 ab	0.33 b	0.43 a	0.37 ab	-	0.0413
Firmness after 12 weeks (kg)	5.1 a	5.3 a	5.3 a	4.9 a	-	0.4292
Firmness after 12 +1 weeks (kg)	2.0 a	2.0 a	2.0 a	2.0 a	-	0.4607
Background colour (12 weeks)	3.1 a	3.3 a	3.0 a	3.0 a	-	0.7867
Background colour (12 +1 weeks)	4.6 a	4.9 a	4.8 a	4.2 a	-	0.0276
%TSS (12 weeks)	14.1 a	13.9 a	14.1 a	13.6 a	-	0.3398
%Acid (12 weeks)	0.42 a	0.42 a	0.42 a	0.42 a	-	0.9934

^{z} Means seperation by Tukey's Studentized Range Test (5%).

Table 8. Mineral analysis of 'Flamingo' pears harvested in 2000 form different rootstocks in the Koue Bokkeveld.

'Flamingo' in Koue Bokkeveld	Rootstock						
	QC51	QA	QAis	BP1	BP3	Pr >F
N (mg/100g fresh mass)	50.3 a ^{z}	53.7 a	63.7 a	62.3 a	-	0.6756
P (mg/100g fresh mass)	9.1 a	10.0 a	11.8 a	12.9 a	-	0.2295
K (mg/100g fresh mass)	138.3 a	134.3 a	160.4 a	143.1 a	-	0.4377
Ca (mg/100g fresh mass)	10.8 a	7.9 a	11.5 a	10.7 a	-	0.4551
Mg (mg/100g fresh mass)	8.4 a	8.4 a	10.0 a	8.5 a	-	0.0950
Na (mg/kg fresh mass)	19.4 a	18.7 a	22.5 a	19.4 a	-	0.4756
Mn (mg/kg fresh mass)	1.1 a	1.2 a	1.5 a	1.2 a	-	0.1690
Fe (mg/kg fresh mass)	2.7 a	1.5 a	1.7 a	1.5 a	-	0.1152
Cu (mg/kg fresh mass)	2.5 a	0.3 a	0.4 a	0.3 a	-	0.4502
B (mg/kg fresh mass)	1.3 b	1.2 b	1.3 b	2.0 a	-	0.0045
Zn (mg/kg fresh mass)	1.5 a	1.8 a	1.8 a	1.6 a	-	0.8326

^{z} Means seperation by Tukey's Studentized Range Test (5%).

Paper 3: The performance of apple rootstocks in South Africa with the cultivars 'Granny Smith', 'Golden Delicious', and 'Cripps' Pink'

Abstract

From production data obtained from a packhouse and data from a questionnaire completed by producers and technical advisors, comparisons were made about the long-term production of 'Golden Delicious' and 'Granny Smith' apples induced by different rootstocks. The results from the questionnaire indicate that M793 is the preferred rootstock in the South African industry. From production records of 'Golden Delicious' and 'Granny Smith' apples, it appeared that M793 and MM106 produced the best yields when compared to seedling rootstock. In a statistically replicated trial with 'Cripps' Pink', trunk growth, yield, fruit quality and mineral content were followed for the first years of production. MM109, M793 and M25 were more vigorous than M7, MM111 and MM106. MM106 was cumulatively, over four years from planting, the most yield efficient. No consistent trend regarding fruit quality was observed between the rootstocks evaluated.

Introduction

Dense plantings of apple orchards on dwarfing and fertile clonal rootstocks have already been established successfully in Europe for the past 40 years. De Wet started an extensive evaluation programme for apple rootstocks in 1940. Further imports of apple rootstocks followed on an ongoing basis and additional evaluation plots were established during 1966 and again in 1972. All the rootstocks imported originated from East Malling and included the Merton (M778-M793), East Malling (M7-M26) and Malling Merton series (MM101-MM115). These rootstock series were developed through crossings with Northern Spy to gain resistance against woolly aphid and to provide a series with varied vigour. In collaboration with researchers of East Malling, 19 of these rootstocks were identified for local evaluation. Berg (1992) identified seven rootstocks that showed promise during evaluation and gave a

short description of their performance. In sequence of increasing vigour they were M26, M7, MM106, MM111, M793, M25 and MM109. Ferree and Carlson (1987) described the origin and disease susceptibility of these and other rootstocks.

M26 has a serious dwarfing effect under South African conditions; it is poorly anchored and produces a tree approximately half the size compared to M7. As a result of its dwarfing characteristic it was not recommended for commercial orchards (Bergh, 1992). Wertheim (1991) also stated that dwarfing rootstocks like M9 and M26 don't thrive in warmer apple producing areas like South Africa and that stronger rootstocks must inevitably be used to supply a better leaf area index for adequate light interception and protection of fruit against sunburn. Van Zyl (1979) found that 'Golden Delicious' on MM106 and M793 yielded well. Yet difficulties with propagation delayed the use of clonal rootstocks, and many producers were not convinced that they would benefit by paying more for trees on clonal rootstocks. As the trend towards higher density plantings became more imperative because of high input costs and interest rates, plantings of 1500 trees per hectare became common. Fortunately, good results obtained with 'Golden Delicious' and 'Granny Smith' on M793 rootstock made it the most commonly used rootstock in the South African apple industry (Van Zyl, 1979; Bergh, 1992).

In some situations the M793 rootstock is still too vigorous and producers have to fight the vigour of the tree continually, compromising production efficiency (Cook, N.C. pers. comm., Department of Horticulture, University of Stellenbosch, Stellenbosch, RSA.). Rootstocks with varied vigour are locally available. In this study we aimed to quantify the field performance of locally available apple rootstocks, in particularly from data outside of previously reported local trials. Preliminary findings from a statistically replicated rootstock trial and four non-replicated trials with 'Cripps' Pink' apples are presented.

Materials and Methods

Industry situation

In an attempt to assess current preference of apple rootstocks in South Africa, a questionnaire was sent out to producers and technical advisors. Firstly, they had to comment on their experience in the industry with different rootstocks and, secondly, they had to mark their first and second choice rootstocks. A value of two or one was allocated for a first or second choice, respectively. The relative popularity of the different rootstocks was then calculated as the percentage of points given to a rootstock relative to the total points given to all rootstocks.

Commercial data

Commercial production records from different rootstocks used in the industry were gathered from a pack house in Grabouw (Two-a-Day Group Limited). Production data for the last 13 years of production from full-grown Granny Smith orchards, planted between 1973 and 1977, and Golden Delicious orchards, planted between 1970 and 1975, were compared. The cumulative yield of younger 'Granny Smith' (12-years-old) and 'Golden Delicious' (13-years-old) were compared.

Trials

With the new apple cultivar 'Cripps' Pink' emerging in South Africa, trials with currently available rootstocks in the industry, have been planted. Five trials of 'Cripps' Pink' trees grafted on M7, MM106, MM111, M25, M793 and MM109 were planted in 1996 in Somerset West (34 °S, 80m), Elgin (34 °S, 320m), and Vyeboom (34 °S, 400m) areas in South Africa. Only the one trial planted in Somerset West was statistically replicated. This trial consists of six rootstocks, replicated four times with three trees per plot, in a randomised complete block design.

For all five trials data collected included: a) trunk circumference measured 20 cm above the graft union; b) yield in terms of weight and number of fruit per tree; and c) fruit size as weight and diameter (measured using a Cranston gauge). Yield efficiency was calculated as kg fruit produced per cm trunk circumference.

At harvest 15 fruit per replication were sampled at random for mineral analysis. Maturity parameters of the remaining fruit was evaluated, at harvest and then after storage at -0.5°C in air for twelve weeks, as follows: a) red colour according to a preliminary colour chart for 'Cripps' Pink' (1 = well blushed; 15 = no blush development); b) background colour indexing according to the Unifruco colour chart for apples and pears (0.5 = green; 5.0 = yellow); c) firmness measured using a penetrometer with an 11 mm plunger; d) the percentage titratable soluble solids (%TSS); e) the percentage acid (% Acid); and f) the percentage starch breakdown. After twelve weeks of storage and after another week of shelf life (12 +1 weeks) colour and firmness were again measured. The fruit were also inspected for any physiological disorders that might have developed during storage. The percentage fruit with sunburn, ridging and hammering were calculated. The percentage poor-coloured fruit and small fruit (<55 mm) were determined based on the minimum standard for export. The data were analysed using the general linear models (GLM) procedure SAS® release 6.12 (SAS Institute, Cary, NC.).

Results and Discussion

Results from the questionnaire indicate that M793 is the most popular rootstock used in the South African apple industry (Table 1). MM111 and M25 rootstocks were not popular among the participants. This may be the result of limited experience with MM111. M25 and MM106 however, were experienced to be susceptible to Phytophtera, which is in accordance with the findings of Browne & Mircetich (1993) and Ferree & Carlson (1987). M7, MM106 and MM109 have been used successfully and should not be discarded.

Commercial data of 'Granny Smith' and 'Golden Delicious' planted in the early seventies indicate that M793 produced consistently higher yields than seedling rootstock over a long period (Figures 1 and 2). Over the past 13 years 'Granny Smith' trees on seedling rootstock produced 52 T/ha compare to 61 t/ha on M793, which agrees with previous findings of Van Zyl (1979) and Berg (1992).

The cumulative yield over 12 years from planting for 'Granny Smith' orchards was 213, 319 and 307 t/ha for seedling, MM106, and M793 respectively (Figure 3). 'Golden Delicious' on seedling, MM106 and M793, respectively, produced 284, 312 and 331 t/ha cumulatively over 13 years (Figure 4).

Within the statistically replicated trial with 'Cripps' Pink' in Somerset West the vigour of the rootstocks expressed as trunk circumference was clearly separated in two groups, with MM109, M793 and M25 more vigorous than M7, and MM106 (Table 2). MM111 was intermediate between the two groups. The two vigour groups concur with the findings of Berg (1992). These trees produced well in third leaf, varying between 6 and 9 kg per tree (Table 2). Although not significant in the 3rd leaf, M793 and M25 produced significantly lower yields than MM106 and MM109 rootstocks in the 4th leaf. The generally lower production during 4th leaf from the orchard was probably due to insufficient winter chilling that resulted in severe delayed foliation. MM106 was the most efficient (0.73 kg/cm), but only differed significantly from M25 (Table 2). In both years M25 produced the smallest and M7 the largest fruit, however, only significantly in the 4th leaf (Table 2).

Rootstock generally did not influence red colour, harvest maturity, post-harvest quality, or the fruit mineral status of 'Cripps' Pink' apples in Somerset West (Tables 3, 4, and 5). However, after 12 weeks of storage and a week shelf life, the background colour was significantly greener for M7 than M25 (Table 4). Fruit from trees on M7 had lower Boron (B) content in the 3rd leaf (Table 5).

In the four non-replicated trials M7 and MM106 tended to be the most dwarfed with MM109 and M25 the most vigorous (Table 6). Yield efficiency differed at each site with M793 (0.57 kg/cm), MM109 (0.65 kg/cm), MM106 (0.85 kg/cm) and M7 (0.89 kg/cm) the most efficient rootstocks at Oakvalley, Moreson, Greamead and Elgin Orchards, respectively. No clear trend was observed for fruit size or firmness.

To conclude, the results from the questionnaire indicate that M793 is the most popular used rootstock in the South African apple industry although other rootstocks like M7, MM106 and

MM109 have been used successfully. Commercial data confirm that 'Granny Smith' and 'Golden Delicious' on M793 performed better than on seedling rootstock over a long period. In a replicated trial with 'Cripps' Pink' trial, the rootstocks could be divided in two groups. MM109, M793 and M25 were the most vigorous rootstocks compared to the less vigorous MM111, M7, and MM106. M7 tended to produce the largest fruit in the Somerset West trial, but these results were not confirmed in the non-replicated commercial trials where no consistent trend regarding fruit size was evident. Rootstock generally did not influence red colour, harvest maturity, post-harvest quality, or the fruit mineral status of 'Cripps' Pink' apples.

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Figure 1: Mean annual yield of 'Granny Smith' apple orchards planted between 1973 and 1977 on different rootstocks in the Grabouw and Vyeboom area.

Figure 2: Mean annual yield of 'Golden Delicious' apple orchards planted between 1970 and 1975 on different rootstocks in the Grabouw and Vyeboom area.

Figure 3: Mean cumulative yield over a 12 year period of 'Granny Smith' apple orchards planted between 1981 and 1985 on different rootstocks in the Grabouw and Vyeboom area.

Figure 4: Mean cumulative yield over a 13 year period of 'Golden Delicious' apple orchards planted between 1982 and 1986 on different rootstocks in the Grabouw and Vyeboom area.

Fig. 1.

Fig. 2.

Fig. 3.

Fig. 4.
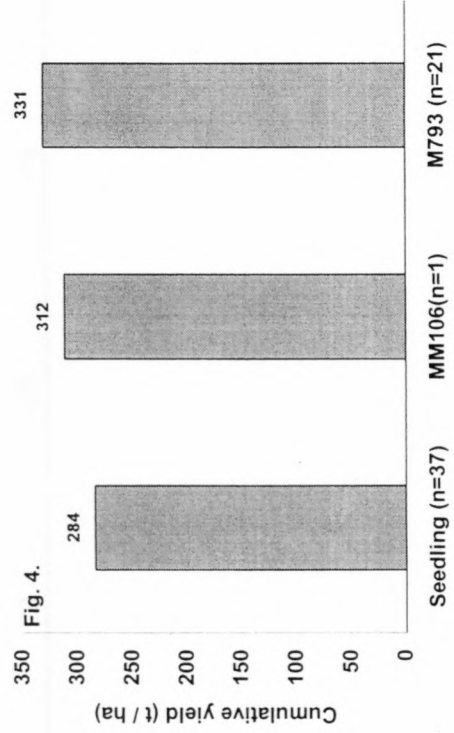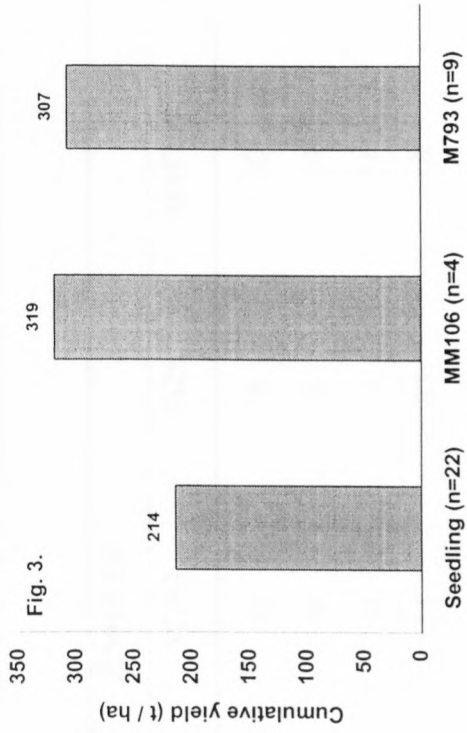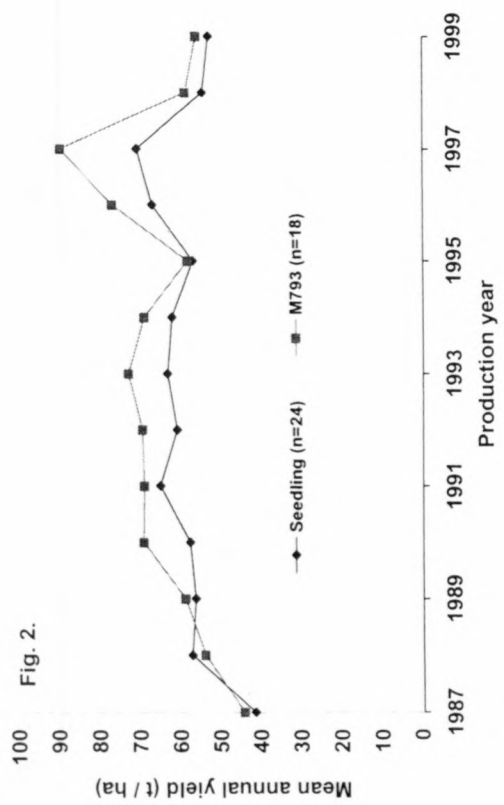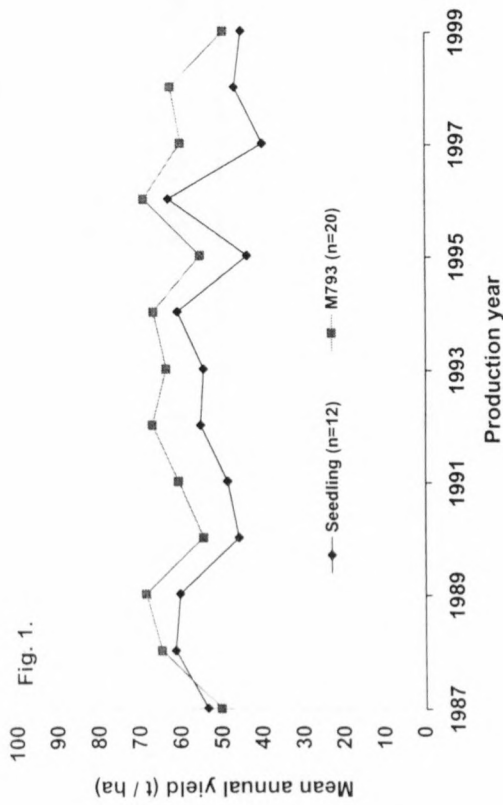
Table 1. Results of a questionnaire completed by 11 producers and 6 technical advisors asked to mark their first and second choice rootstocks for each cultivar. A value of two or one was allocated for a first or second choice, respectively. The relative popularity of the different rootstocks was calculated, as a percentage of points given to each rootstock, relative to the total points given to all the rootstocks, within each cultivar.

Scion cultivar	Rootstock						
	M7	MM106	MM111	M793	M25	MM109	Seedling
Golden Delicious	3	19	3	46	5	20	5
Granny Smith	16	14	0	40	2	24	4
Fuji	41	15	0	34	0	11	0
Braeburn	9	12	0	34	23	18	5
Royal Gala	30	17	2	26	0	24	0
Topred	9	7	0	43	16	25	0
Cripps' Pink	19	35	0	32	0	13	0
Spur-type apples	0	0	0	20	25	49	6

Table 2: Yield, fruit size and fruit quality of 'Cripp's Pink' apples grown on six rootstocks in a statistically replicated trial in Somerset West for the first two years of production.

	Rootstock						
	M7	MM106	MM111	M25	M793	MM109	Pr >F
Trunk circumference							
Trunk circumference (cm) 3rd leaf	17.6 bc [y]	15.9 c	17.5 bc	19.1 abc	19.8 ab	21.0 a	0.0021
Trunk circumference (cm) 4th leaf	21.8 ab	18.4 b	20.8 ab	22.6 a	23.5 a	23.6 a	0.0068
Production performance							
Yield (kg/tree) 3rd leaf	6.4 a	8.5 a	7.9 a	6.9 a	8.2 a	9.0 a	0.4145
Yield (kg/tree) 4th leaf	4.4 ab	5.1 a	4.6 ab	2.8 b	2.8 b	4.9 a	0.0825
Cumulative yield efficiency (kg/cm) [z]	0.49 ab	0.73 a	0.60 ab	0.43 b	0.47 ab	0.60 ab	0.0277
Fruit quality							
Fruit diameter (mm) 3rd leaf	67.0 a	66.1 a	66.1 a	65.3 a	65.6 a	66.6 a	0.1037
Fruit diameter (mm) 4th leaf	67.8 a	66.3 ab	67.1 ab	65.8 b	67.1 ab	67.1 ab	0.0520
% Small fruit (<65 mm) 3rd leaf	26.6 a	34.7 a	32.9 a	38.2 a	36.1 a	27.6 a	0.4359
% Small fruit (<65 mm) 4th leaf	15.3 a	30.9 a	18.9 a	36.8 a	19.8 a	21.9 a	0.0741
Number of fruit per tree 3rd leaf	50.0 a	67.0 a	61.8 a	54.5 a	60.8 a	71.5 a	0.3221
Number of fruit per tree 4th leaf	32.3 a	40.3 a	32.0 a	22.3 a	20.8 a	36.5 a	0.0880
% Fruit with sunburn 3rd leaf	18.4 a	14.7 a	17.0 a	16.8 a	16.7 a	14.3 a	0.5611
% Fruit with sunburn 4th leaf	50.7 a	50.0 a	60.7 a	58.0 a	42.0 a	56.7 a	0.2575
% Fruit with ridging 3rd leaf	52.5 a	39.4 a	44.1 a	42.7 a	41.7 a	37.9 a	0.3921
% Fruit with ridging 4th leaf	46.0 a	43.3 a	60.7 a	33.8 a	54.6 a	44.1 a	0.2532
% Fruit with hammering 3rd leaf	18.5 a	6.6 a	7.2 a	9.9 a	6.5 a	12.0 a	0.2159
% Fruit with hammering 4th leaf	9.2 a	2.5 a	3.2 a	4.2 a	6.6 a	1.7 a	0.4549
% Poor coloured fruit 3rd leaf	24.2 a	14.5 a	19.6 a	22.9 a	26.7 a	24.2 a	0.4412
% Poor coloured fruit 4th leaf	44.9 a	23.2 a	43.5 a	39.6 a	47.1 a	47.9 a	0.1440

[y] Means seperation by Tukey's Studentized Range Test (5%).

[z] Cumulative yield efficiency is calculated by dividing the sum of yield (kg) during the 3rd and 4th leaf, by the mean 4th leaf trunk circumference (cm).

Table 3: Maturity parameters at harvest of 'Cripp's Pink' fruit harvested from trees on six different rootstocks in the Somerset West trial during the first two years of production.

| | Rootstock | | | | | | |
	M7	MM106	MM111	M25	M793	MM109	Pr >F
Maturity 1st pick 3rd leaf							
Background colour [x]	2.00 a [y]	2.14 a	2.13 a	1.99 a	2.01 a	2.09 a	0.1485
Firmness (kg)	8.8 a	8.8 a	8.6 a	8.5 a	8.6 a	8.6 a	0.3592
Seed colour [z]	5.79 a	5.81 a	5.76 a	5.74 a	5.85 a	5.77 a	0.6776
%TSS	13.5 a	13.9 a	13.8 a	13.7 a	13.3 a	13.4 a	0.4515
% Acid	0.61 a	0.61 a	0.60 a	0.61 a	0.62 a	0.66 a	0.8118
% Starch breakdown	68.9 a	67.4 a	66.9 a	60.8 a	60.5 a	69.7 a	0.7168
Maturity 2nd pick 3rd leaf							
Background colour	2.01 a	2.15 a	1.96 a	2.05 a	1.88 a	1.98 a	0.1073
Firmness (kg)	8.6 a	8.2 a	8.5 a	8.5 a	8.5 a	8.4 a	0.5911
Seed colour	5.88 a	5.90 a	5.83 a	5.87 a	5.75 a	5.84 a	0.2989
%TSS	13.2 a	13.6 a	13.3 a	13.6 a	13.4 a	13.4 a	0.8016
% Acid	0.61 a	0.56 a	0.56 a	0.58 a	0.63 a	0.63 a	0.1722
% Starch breakdown	69.6 a	65.2 a	56.0 a	64.9 a	52.1 a	54.6 a	0.1799
Maturity 4th leaf							
Background colour	2.6 a	2.7 a	2.7 a	2.6 a	2.5 a	2.4 a	0.2038
Firmness (kg)	7.8 a	7.8 a	7.8 a	7.6 a	7.6 a	7.6 a	0.2742
Seed colour	5.7 a	5.8 a	5.6 a	5.7 a	5.7 a	5.7 a	0.2637
%TSS	16.2 a	15.8 a	15.8 a	15.1 a	15.1 a	15.3 a	0.2893
% Acid	0.80 a	0.80 a	0.82 a	0.79 a	0.83 a	0.82 a	0.8252
% Starch breakdown	63.9 a	65.1 a	54.4 a	52.3 a	46.5 a	54.0 a	0.0810

[x] According to Unifruco research services (Pty.) Ltd. colour chart for apples and pears (0.5 = green; 5.0 = yellow)

[y] Means seperation by Tukey's Studentized Range Test (5%).

[z] According to Unifruco research services (Pty.) Ltd. seed colour chart (1 = white; 6 = black).

Table 4: Postharvest quality of 'Cripp's Pink' fruit harvested from trees on six different rootstocks in the Somerset West site during the first two years of production.

| | Rootstock | | | | | | |
	M7	MM106	MM111	M25	M793	MM109	Pr >F
Post harvest analysis 3rd leaf							
Background colour (12 weeks) [y]	3.3 b [z]	3.6 a	3.5 ab	3.5 ab	3.4 ab	3.4 ab	0.0816
Firmness (12 weeks) (kg)	6.8 a	6.5 a	6.8 a	6.5 a	6.7 a	6.6 a	0.2357
%TSS (12 weeks)	13.9 a	14.3 a	13.7 a	13.9 a	13.7 a	13.6 a	0.4494
%Acid (12 weeks)	0.48 a	0.43 a	0.43 a	0.45 a	0.46 a	0.46 a	0.8560
Background colour (12 + 1 weeks)	3.5 a	3.8 a	3.7 a	3.6 a	3.5 a	3.6 a	0.2036
Firmness (12 + 1 weeks) (kg)	6.4 a	6.4 a	6.4 a	6.3 a	6.4 a	6.4 a	0.8163
Bitterpit 1999	3.5 a	1.8 a	1.2 a	2.6 a	1.0 a	0.6 a	0.2119
Superficial scald 1999	24.9 a	17.2 a	22.0 a	38.1 a	34.4 a	43.6 a	0.0858
Post harvest analysis 4th leaf							
Background colour (12 weeks)	2.8 a	2.9 a	2.9 a	2.8 a	2.8 a	2.8 a	0.8194
Firmness (12 weeks) (kg)	6.7 a	7.1 a	6.7 a	7.0 a	6.9 a	6.9 a	0.3379
%TSS (12 weeks)	14.2 b	15.1 a	14.3 b	14.6 ab	14.3 b	14.3 b	0.1552
%Acid (12 weeks)	0.47 a	0.50 a	0.50 a	0.50 a	0.52 a	0.53 a	0.6714
Background colour (12 + 1 weeks)	3.3 b	3.7 ab	3.8 ab	3.9 a	3.6 ab	3.6 ab	0.0450
Firmness (12 + 1 weeks) (kg)	6.8 a	6.9 a	7.0 a	6.8 a	6.7 a	6.8 a	0.4905

[y] According to Unifruco research services (Pty.) Ltd. colour chart for apples and pears (0.5 = green; 5.0 = yellow).

[z] Means seperation by Tukey's Studentized Range Test (5%).

Table 5: Mineral analysis of 'Cripp's Pink' apples harvested in 1999 and 2000 from six different rootstocks the Somerset West trial.

	Rootstock						
	M7	MM106	MM111	M25	M793	MM109	Pr >F
Mineral analysis 3rd leaf							
N (mg/100g fresh mass)	30.8 a z	26.0 a	26.0 a	25.8 a	27.0 a	28.0 a	0.4835
P (mg/100g fresh mass)	3.6 a	3.7 a	3.3 a	3.2 a	3.5 a	3.5 a	0.4196
K (mg/100g fresh mass)	131.5 a	111.3 a	116.0 a	113.8 a	125.3 a	127.3 a	0.3608
Ca (mg/100g fresh mass)	6.0 a	6.0 a	5.5 a	5.4 a	5.6 a	5.3 a	0.6119
Mg (mg/100g fresh mass)	5.9 a	5.6 a	5.4 a	5.5 a	5.9 a	5.6 a	0.6898
Na (mg/kg fresh mass)	16.5 a	12.3 a	12.2 a	15.6 a	9.5 a	15.7 a	0.1747
Mn (mg/kg fresh mass)	0.53 a	0.50 a	0.58 a	0.50 a	0.55 a	0.50 a	0.8217
Fe (mg/kg fresh mass)	3.6 a	3.1 a	2.4 a	3.0 a	2.6 a	4.3 a	0.3987
Cu (mg/kg fresh mass)	0.83 a	0.48 a	0.38 a	0.43 a	0.43 a	5.48 a	0.4656
B (mg/kg fresh mass)	2.2 b	3.1 a	3.2 a	2.7 ab	2.7 ab	3.2 a	0.0015
Zn (mg/kg fresh mass)	1.6 a	0.9 a	2.3 a	2.4 a	1.1 a	1.1 a	0.5198
Mineral analysis 4th leaf							
N (mg/100g fresh mass)	39.0 a	28.3 ab	37.3 a	23 b	29.5 ab	30.5 ab	0.0464
P (mg/100g fresh mass)	8.4 a	7.8 a	8.2 a	6.2 a	7.5 a	7.1 a	0.1009
K (mg/100g fresh mass)	152.5 a	127.8 a	138.0 a	124 a	141.3 a	143.8 a	0.0938
Ca (mg/100g fresh mass)	6.0 a	7.5 a	7.0 a	7.2 a	6.3 a	6.6 a	0.3027
Mg (mg/100g fresh mass)	6.9 a	6.7 a	7.0 a	6.8 a	7.3 a	6.7 a	0.8589
Na (mg/kg fresh mass)	5.6 a	5.4 a	5.4 a	6.4 a	6.1 a	6.8 a	0.0840
Mn (mg/kg fresh mass)	1.2 a	1.2 a	1.5 a	1.6 a	1.6 a	1.2 a	0.5199
Fe (mg/kg fresh mass)	7.1 a	7.4 a	11.2 a	9.2 a	8.8 a	7.5 a	0.3024
Cu (mg/kg fresh mass)	0.6 a	0.5 a	0.4 a	1.7 a	0.4 a	0.3 a	0.4211
B (mg/kg fresh mass)	8.5 a	10.4 a	10.8 a	9.2 a	9.3 a	9.1 a	0.3721
Zn (mg/kg fresh mass)	3.6 a	3.7 a	3.0 a	4.3 a	4.8 a	2.8 a	0.5469

z Means seperation by Tukey's Studentized Range Test (5%).

Table 6: Production performance of 'Cripp's Pink' apple in four different non-replicated rootstock trials in the Vyeboom and Grabouw area during the 1999 and 2000.

	Rootstock					
	M7	MM106	MM111	M25	M793	MM109
Oakvalley (Grabouw)						
Trunk circumference (cm) 3rd leaf	16.3	-	16.5	17.9	18.7	18.1
Trunk circumference (cm) 4th leaf	19.1	-	18.4	20.4	21.1	20.3
Yield (kg/tree) 4th leaf	10.3	-	10.1	10.9	11.9	7.5
Yield efficiency (kg/cm) [z]	0.54	-	0.55	0.53	0.57	0.37
Fruit weight (g) 4th leaf	141	-	139	147	122	118
Fruit firmness (kg)	9.5	-	9.3	9.8	10.0	10.0
More-Son (Vyeboom)						
Trunk circumference (cm) 3rd leaf	12.6	12.5	13.9	15.9	13.7	17.9
Trunk circumference (cm) 4th leaf	15.8	15.3	16.6	19.0	17.2	21.7
Yield (kg/tree) 4th leaf	8.4	8.0	8.0	8.8	8.6	12.1
Yield efficiency (kg/cm)	0.53	0.52	0.49	0.47	0.50	0.65
Fruit weight (g) 4th leaf	138	126	125	139	122	131
Fruit firmness (kg)	9.0	9.5	9.3	9.6	9.3	9.5
Greamead (Vyeboom)						
Trunk circumference (cm) 3rd leaf	15.7	16.8	17.2	19.4	15.9	20.6
Trunk circumference (cm) 4th leaf	20.3	21.1	20.8	23.9	20.1	25.8
Yield (kg/tree) 4th leaf	15.0	18.1	16.7	18.4	14.3	17.0
Yield efficiency (kg/cm)	0.73	0.85	0.80	0.76	0.71	0.66
Fruit firmness (kg)	9.0	9.2	9.0	9.0	9.1	9.2
Elgin orchards (Grabouw)						
Trunk circumference (cm) 3rd leaf	13.0	15.2	15.3	15.6	13.2	17.8
Trunk circumference (cm) 4th leaf	16.4	19.3	19.0	19.6	17.1	21.6
Yield (kg/tree) 3rd leaf	2.1	6.1	3.5	3.6	4.1	4.3
Yield (kg/tree) 4th leaf	14.8	12.2	10.9	11.9	14.0	15.3
Yield efficiency (kg/cm)	0.89	0.64	0.58	0.61	0.82	0.71
Fruit weight (g) 4th leaf	173	172	180	174	177	159
Fruit firmness (kg)	9.6	9.3	9.3	9.5	9.0	9.2

[z] Yield efficiency is calculated by dividing the yield (kg) during the trunk circumference (cm).

6. Conclusion

Chilling models currently used in South Africa are unsatisfactory in predicting the progression of bud dormancy. The Utah chilling models were adapted for our climate and the Positive Utah chill unit was established. However, this model, primarily developed in Utah where winter chilling is abundant, is based on assumption of an optimum chilling temperature between 6 and 8°C. Temperatures of 1.5 and 10°C are assumed to be half as effective as the optimum temperature range and temperatures below 1.4°C and above 12.5°C are assumed to be ineffective for accumulation of chill units. To understand why currently used chill models do not accurately predict the development of dormancy in warmer apple and pear production areas, the efficiency of chilling at temperatures between 1 and 10°C was revisited. In our study we found that the length of the chilling period was the most important factor determining bud growth potential and that temperatures between 1 and 10°C were equally efficient in releasing dormancy. This may partially explain why previous chill unit models poorly estimate the progression of dormancy for South African conditions. When chill accumulation in our data was calculated by simply adding hours below 13°C, the progression of dormancy is more accurately described than with previous models. As trees in a colder climate where autumn frost occurs frequently reach maximum dormancy sooner than trees planted in warmer climates, the possible role of freezing temperatures in the induction of dormancy was investigated. In our study, freezing temperatures used did not appear to further induce dormancy. Our buds may have already been dormant at the time the shoots were harvested. The pre-treatment with freezing temperatures however appeared to contribute to dormancy release rather than intensify it. Further research needs to be done, investigating the possible role of freezing temperatures in the induction of dormancy. The effect of chilling negation at higher temperatures, however, was not addressed in this study and also needs to be evaluated in future studies.

The South African apple and pear industry made good progress in moving towards high density plantings, but large variation in soil types, sub-optimal growing conditions, replant situations, and a lack experience with dwarfing rootstocks limited further

development. However, there is still an urgency to obtain higher early yields of good quality fruit. We aimed to quantify the field performance of locally available apple and pear rootstocks, in particular from data outside of previously reported local trials, as well as early production of newly planted trials.

The search for a suitable pear rootstock in South Africa was started in 1928 by Prof. A.F. de Wet. The five pear rootstocks released by the FFTRI are BP1, BP2, BP3, QA, and QC51 although rootstocks OHxF97 and *P. calleryana* were also evaluated. With the recent interest in bi-coloured pears where optimal light distribution is essential for red colour development, interest in the use of dwarfing Quince rootstocks rather than the vigorous BP series has renewed. These rootstocks were tested in trials with the bicolour cultivars 'Rosemarie', 'Flamingo', and 'Forelle'. Our findings were that BP1 and BP3 rootstocks have been adopted by our industry as universal rootstocks for green pears and that Quince rootstocks although infrequently used in the South African industry, are in demand for the bi-coloured pear cultivars. From the commercial data one can conclude that BP3 and OHxF97 produce the highest yields on 'Packham's Triumph' pears under local conditions. Higher yields of 'Doyenne du Comice' were obtained with QA rootstock. Early data from trials on the bi-colour pears, indicate that BP1 and BP3 are the most vigorous as measured by trunk growth. In general 'Rosemarie' produced higher yields on BP1 and QAis than on QA and QC51, possibly because of incompatibility. With 'Flamingo', incompatibility with Quince rootstocks does not seem to be a problem, but it is still too early to draw this conclusion. 'Flamingo' on QA and QC51 produced higher yields in the 3rd leaf compared to BP1 and QAis. 'Forelle' on QA rootstock at the same density produced similar yields to BP1 and BP3, but with bigger fruit. 'Forelle' is compatible with Quince. These are only preliminary conclusions, but of utmost importance for the industry in the general movement to higher density plantings for increased production efficiency. The continuation of these trials is important.

For apples M793 seems to be the preferred rootstock in the South African industry. From long term production records of 'Golden Delicious' and 'Granny Smith' apples, it appeared that M793 and MM106 produced the best yields when compared to seedling

rootstock. With 'Cripps' Pink', MM109, M793 and M25 were more vigorous than M7, MM111 and MM106. MM106 was cumulatively, over four years from planting, the most yield efficient, although no consistent trend regarding fruit quality was observed between the rootstocks evaluated. Our findings show that there are two distinct vigour groups, but no clear difference between yield and fruit quality amongst rootstocks.