35 Years of the SAAGA Yearbook: A Review[1]

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Foreword

This review includes the SAAGA Yearbooks from 1977 to 2012 – 35 yearbooks in total (there was no volume in 1980). The annual SAAGA Research Symposium is held in the first quarter of the year for the presentation of the preceding year's research results. The objectives of this review were: (i) to consolidate and summarise the more important information in the yearbooks for the benefit of researchers and growers, and (ii) to translate the articles written in Afrikaans into English to make this information available to a wider audience. Multi-year projects have been combined. Many research projects are multi- or cross-disciplinary, necessitating cross-referencing. We recommend that you use the search function in an electronic copy of the review if you are searching for a specific topic.

This manuscript does not report on or imply current best practice. Similarly, South African research published in journals, booklets, bulletins or newsletters other than the SAAGA Yearbook is not included. For a broader overview of international avocado research and production, please refer to the second edition of "The Avocado: Botany, Production and Uses" by Schaffer *et al.* (2013). The original SAAGA Yearbook articles are available online at www.avocadosource.com courtesy of the Hofshi Foundation.

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Introduction

This introduction gives an overview of the South African avocado industry, mostly from the viewpoint of the SAAGA chairman at the time, but also with views from other leaders in industry and research.

SAAGA's functions are to provide: co-ordination of funded avocado research, generic promotions, industry statistics, extension services, and export volume co-ordination. Much has changed since the founding of SAAGA in the 1970s, where competition in our established export marketing window from other countries was not considered a serious threat, but in some ways, some things have not changed. Growers are still looking to improve on production per hectare, improve co-operation, and increase promotions (Lourens, 1979). One of the strengths of SAAGA is the association's attitude to research, which has always been commendable and has benefited the global avocado industry, especially in the 1980s and 1990s.

There were infrequent reports from the SAAGA chairmen until the mid-1990s, and as such the information in the SAAGA Yearbooks is scant. Between **1969** and **1979**, production increased from 8 000t to 18 000t (Grobler, 1979). In **1970** the export volume was about 370 000 cartons and increased to 2.8 million cartons in **1982** (Bredell, 1983). Export volumes increased by an average of 23% per annum between **1970** and **1980**, reaching the record of 2.9 million cartons. The volume of export cartons then declined between **1980** and **1984** (WIlliams, 1984). The number of commercial avocado trees in South Africa doubled between **1973** and **1981**, from 500 000 to 1 million trees (Milne, 1982). When those trees came into bearing, the **1985** season was a (then) record year, with 4.127 million cartons being exported. The outlook for **1986** was challenging because of lower prices in the local and export market due to increased competition from Israel, California, and Spain, along with the strengthening of the Rand at that time, and the growing anti-South African sentiment abroad (Kay, 1986). The volume of export fruit continued to rise, reaching 8.9 million cartons in **1989** and 8.1 million cartons in **1991**. The production volume in **1993** season was severely reduced because of the impact of a severe three-year long drought, with exports of only 5.6 million cartons. The **1994** export crop was estimated at 8 million cartons and the actual volume was 9.3 million cartons. The total production in **2000** was projected to reach 20 million carton equivalents, but this was already exceeded in **1998**, when the current record of 29.7 million carton equivalents (118 709t) was produced (Toerien, 1994a).

During the early 1990s producers were under strain because of reduced production, rising costs, and a stagnant market. SAAGA's long-serving research manager, Prof. Kotzé, urged greater market research and co-operation in advertising and promotions, and also greater involvement and investment by the avocado growers (Kotzé, 1993). By 1994, 17 years had passed since the inaugural SAAGA Yearbook and the two stand-out achievements were trunk injections for PRR control and postharvest temperature control. Some of the students had become industry leaders, such as Louis Vorster, Joe Darvas, Martin Slabbert, and André Ernst. Once again, the importance of market research was stressed (Kotzé, 1994). Prof. Kotzé was thanked for his 17 years of service to SAAGA's research co-ordinator (Toerien, 1994a).

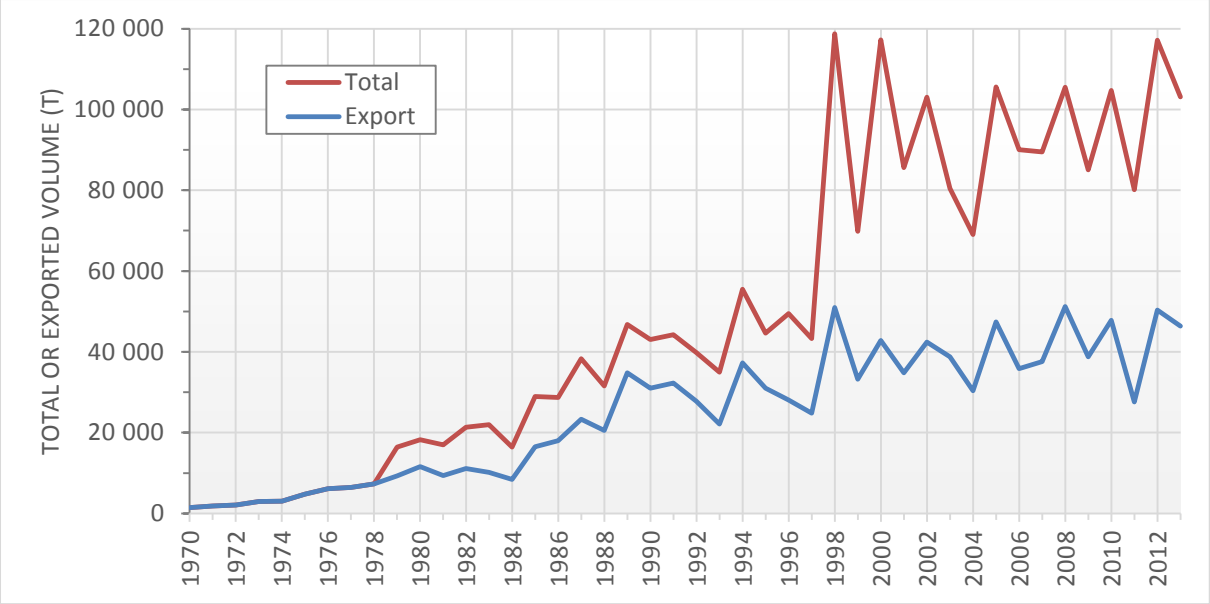

Figure 1: Total and export volumes of avocados produced in South Africa between 1970 and 2013. Note, volumes after 1979 are more reliable than those between 1970 and 1978.

Toerien (1994b) outlined what SAAGA had achieved, and what still needed to be done to increase demand and/or increase price, and likely future challenges. In summary he reported:

Achievements

1. Control of Phytophthora root rot (PRR) with better rootstocks, better nurseries, improved cultural practices, and trunk injections of phosphonates.
2. Control of most pre- and post-harvest diseases solved.
3. Standardised carton design, quality control and ventilation.
4. Developed temperature regimes for shipping to Europe.
5. Consensus with Perishable Products Export Control Board (PPECB) regarding daily temperature monitoring.
6. Co-ordination of shipment volumes.
7. Industry communication, via newsletter.
8. Global production and consumption data.
9. Hosted the First World Avocado Congress at Pretoria in 1987.

Required

1. Successful advertising campaign for:
    a. Promoting the nutritional and health advantages of avocado fruit.
    b. Promoting avocado as a salad fruit.
    c. Promoting avocado as a baby food.
    d. Launching a meaningful ready-to-eat programme.
2. Start a joint generic advertising campaign with another industry (e.g. Israel).
3. Co-ordination in Europe.

Future Challenges

1. Increase average production to 20-30 t/ha using research results and improved cultural practices.
2. Keep research as the basis of the industry for stability and addressing economically important problems.
3. Grower involvement in SAAGA, so it can remain the mouthpiece of the industry.
4. Greater industry orientation amongst exporting and importing agents, with greater grower interest in their fruit in Europe.
5. More effective advertising in Europe.

Although **1994** was a dry year and hail resulted in severe fruit damage for some growers, the fruit set was good and record number of 9.3 million cartons was exported. This was despite logistical challenges. A new container terminal at Cape Town harbour was opened in March 1995, to be managed by PPECB and open to all producers. Negotiations on reduced import tariffs were underway, as they were a substantial cost at R10 million per year (Ernst, 1995).

By **1995**, the South African avocado industry had "come of age", with more than 10 000ha planted and new Hass plantings greater than Fuerte, but the cost/price squeeze was still affecting profitability for growers (Partridge, 1995). The four year drought ended in spring 1995, but a tremendous flowering and fruit set was followed by a heavy fruit drop (Partridge, 1996). Although 7.7 million cartons were exported in **1995**, it was a difficult season, with wind and hail reducing and damaging the crop, and severe congestion at the Cape Town harbour affecting shipping and fruit quality. Due to the congestion, break bulk shipping was used to prevent shipping delays. The temperature committee managed to land old fruit in acceptable condition but marketing these fruit proved difficult resulting in poor prices abroad. The use of break bulk shipping also meant more than 30% of pallets collapsed. Negotiations on EU tariffs resulted in reduced tariffs that benefitted the growers by R3.5 million. In **1995**, 10,774ha were planted to avocados in South Africa, with Fuerte 47.5%, Hass 31.3%, Ryan 10%, Pinkerton 5.2%, Edranol 4.5% and other cultivars making up 1% (Ernst, 1996).

The **1996** season was marred by wind and hail reducing and damaging the crop (7.0 million cartons exported). The shift in preference from count 18-20 per 4kg carton to smaller counts (*i.e.* larger fruit) was noted in 1996. An additional 250 40ft integral containers were made available and 100 plug points per ship were installed for CA integral containers. A reduction in freight rates saved the industry R2.7 million in the 1996 season. The surcharge on CA was reduced to $500, saving R2 390 per container at the time. Greater effort was given to accessing the USA and Japan markets (Ernst, 1997).

The **1997** season was an "off year" and also affected by wind and hail, particularly in the Levubu and Letaba regions, resulting in only 6.2 million cartons being exported. The withdrawal of government subsidies to universities and research institutions meant these bodies were under financial strain. It was recommended that they should be more carefully scrutinised before being awarded SAAGA funding, and a more global approach should be taken with research to prevent the duplication of research done elsewhere. A further reduction in freight rates was achieved in 1997, which in itself recovered the cost of SAAGA levies. A record export crop in **1998** (12.75 million cartons) required excellent co-ordination and a controlled, spread-out harvest to prevent an over-supply in the market (Blanden, 1998). In the **1998** season, the UK promotion had doubled the consumption of avocados from 200g to 400g per capita in three years. The promotion in France was however insufficient to

increase consumption and was put on hold until sufficient money was available for a bigger promotion (Blanden, 1999).

Volume co-ordination was a major problem in the **1999** season and greater co-operation in the industry was needed (Vorster, 2000). Although fruit quality was excellent in a potentially troublesome year, volume co-ordination early in the **2000** season was poor and cost the industry millions of rand. A tougher trading environment for fresh produce in the new millennium was expected, and Vorster stressed the importance of growers taking greater responsibility in market supply by following the export plan. Market development in the UK and the local market was a success. Market development in France depended on a consistent supply of fruit, and convincing supermarkets that ripened avocados will increase sales. The demand for green-skin cultivars was declining, with a price premium being paid for Hass (Vorster, 2001).

The **2001** season was one of extremes, with good prices in the early season, but poor prices mid-season when quality problems began to manifest. A total of 8.7 million cartons was exported, with Hass predominating (Reay, 2002). Volume co-ordination was much improved in the **2002** season, resulting in good returns for growers. The multinational supply forecast was implemented in 2001/2, to co-ordinate volumes from South Africa, Kenya, Spain, Israel, Mexico, Chile, and Argentina to smooth the supply of avocados on the European market (Reay, 2002). Despite high volumes of fruit being supplied into the European market in **2002**, multinational supply co-ordination meant that there was over-supply in only one week of the season and this was corrected the following week (Reay, 2003).

Market co-ordination in **2003** was lacking in mid-season, linked to Peru's increasing supply of Hass into the European market in direct competition with South Africa, and the supply of small Hass fruit from South Africa. EurepGAP (now GlobalGAP) was implemented in the mid-2000s. 17% of growers had resigned from SAAGA by 2003, and growers were urged to encourage these former members to re-join SAAGA. Local market consumption and prices were very good in **2003** (Seele, 2004).

The **2005** season was a good season for South African avocado producers. This was despite a record volume of avocados traded in the European market, and a near-record South African export crop (11.85 million cartons), and growing exports from Peru, Kenya, and Chile. The European market did not crash at levels of 1 million cartons per week because of good market co-ordination among exporters. Issues emerging at that time, requiring SAAGA assistance to growers were land claims, and black economic empowerment and training. The SAAGA board was given a mandate to approach the other subtropical grower associations (mango, litchi, and macadamia) to form the Subtropical Fruit Growers' Association (Subtrop). The local market continued to grow and local promotions were very successful. Membership decline had been addressed and membership increased from 435 to 442 in **2005** (Lippert, 2006). The exported volume of fruit in the **2006** season was 8.96 million cartons. Weekly volumes and prices were stable due to the co-ordinated volumes supplied to Europe. Subtrop was established in 2006. Spending on market access and development and research was increased again in **2006** to R2.25 million and R1.25 million, respectively (Lippert, 2007).

Export (9.4 million cartons) and local markets sales (3.37 million cartons) continued to grow in **2007** with good returns achieved from advertising and promotions. Prices remained at profitable levels at weekly volumes of 1.0 to 1.2 million cartons on the European market. This is in contrast to a few years earlier when volumes of more than 700 000 would crash that market. The frost damage in late May 2007 resulted in losses of 500 000 to 600 000 cartons (Westcott, 2008).

The **2009** season was a good season for the South African avocado industry, with 9.68 million cartons exported. This followed a record crop in **2008** (12.8 million cartons exported). A growing industry, with better management practices, as well as good market co-ordination and development both contributed to these impressive volumes. It was decided to shift the focus on market development from the UK and France to Scandinavia. The success of the campaign against immature fruit on the local market was limited because there was little action against sending immature fruit to the local market and prices, even for marked immature fruit were high enough to warrant the practice (Muller, 2010). The **2010** season was another good year for the industry, with 11.95 million cartons being exported and 5.6 million cartons sold on the local market and 1.3 million cartons directly to retailers (Muller, 2011).

The **2011** season was the lowest volume year since 1997 (6.91 million cartons exported, total production of 80,142t) because of extreme weather, especially in the Letaba area. The weekly supply to the European market had doubled in the previous decade from about 600 000 cartons/week to more than 1.2 million cartons/week. This was due to concerted marketing, promotions and volume co-ordination efforts. SAAGA's main research objectives were identified as (i) enhancement of on-farm profitability, (ii) decreased packing and logistics costs, (iii) enhanced quality and consistency of quality in the market, and (iv) threats to industry profitability. The research budget was R2.0-R2.5 million annually (Smith, 2012). Volumes recovered in **2012**, with a near-record 12.58 million cartons being exported and 11.60 million cartons exported in **2013**.

The Golden Avocado

The Golden Avocado is SAAGA's highest recognition for a person who has made an exceptional contribution to the South African avocado industry. As of 2013, fifteen people had been granted this prestigious award, with Bill Blanden the latest recipient in 2006 (Table 1).

Table 1: List of Golden Avocado recipients until 2013.

Year	**Recipient**
1985	Gerald A. Cresswell
1986	Joe Darvas
1987	Prof. J.M. Kotzé
1988	Jan Toerien
1989	Frikkie Lourens
1993	Robbie Maddison
1995	Jurg Bezuidenhout & Gawie Eksteen
1997	Lindsey Milne
1998	Nigel Wolstenholme
2000	Werner Seele & Alan Whyte
2001	Nino Burelli
2002	Stefan Köhne
2006	Bill Blanden

1. International Production

From time to time international guests give insights on avocado production in their countries. A summary from each country is given in this section, but because of its sporadic nature it is by no means comprehensive nor is it up-to-date information for each country. The countries are given in alphabetical order.

1.1. Australia

Australian avocado production, in the main growing areas in coastal south-east and central Queensland and northern New South Wales, is similar to South Africa in many respects: high summer rainfall, (usually) deep red soils, zinc and boron deficiencies, *Phytophthora cinnamomi* root rot (PRR), and anthracnose fruit rot, etc. Major cultivars were Fuerte (early), Sharwil (mid-season), and Hass (late season), with Shepard, Pinkerton, and Reed produced in smaller volumes. The industry was served by the Australian Avocado Growers' Federation which co-ordinated marketing and gave national representation. Already at that stage, a cost-price squeeze was challenging growers to produce fruit more efficiently (Whiley, 1987). This has only increased since then, and not only in Australia.

1.2. Brazil

Despite producing a large volume of avocados (22 155 ha in 1986), two major limiting factors were identified in Brazil: (i) a lack research and extension, resulting in an inefficient use of technology, low intensity cultural practices, and fruit quality loss, and (ii) no central organisation for marketing fruit locally and abroad. PRR was increasingly becoming a problem in Brazil by 1986. Cultivars were pure West Indian and West Indian-Guatemalan hybrids. Pollock, Fuchs, Simmonds, Prince, Linda, Wagner, Geada, Fortuna, Quintal, Ouro Verde and Solano made up 70% of annual production. Newer selections were Imperador, Dourado, and Margarida (Donadio, 1987). [T*he Brazilian avocado industry was more "tropical" than "subtropical" at the time. At the present time there are increasing plantings of Hass for the export market – Ed.*].

1.3. Israel

In Israel, particular attention is paid to irrigation, using daily drip or micro-jet irrigation, the control of vigour by GA-inhibitors (paclobutrazol or uniconazole), and intensive pruning to increase average yields from 6-7t/ha to 15-18t/ha (Gafni, 1998).

1.4. Mexico

In Mexico, the main fungal pathogens affecting fruit were identified as *Phythophthora citricola*, *Sphaceloma perseae*, *Cercospora purpurea*, *C. gloeosporioides*, and a *Diplodia* sp. Bacterial pathogens were *Pseudomonas syringae pv syringae* and *Erwinia herbicola* to a lesser degree. The viroid ASBVd had been recorded at a low incidence; ring-neck was a problem with an unidentified cause [*now known to be water-stress related – Ed.*] (Fucikovsky & Luna, 1987).

Aguilera-Montañez & Salazar-García (1991) gave a brief overview of the Mexican avocado industry at the time. In 1989, about 90 000ha were planted to avocado in Mexico, mostly in Michoacán state.

1.5. New Zealand

The chairman of the New Zealand Avocado Growers' Association, Ron Bailey visited South Africa in 1994, to explore areas of mutual benefit in research, marketing, and industry structures. At that time the New Zealand industry had 900 growers and 1 000ha of orchards. They were mainly exporting to

Australia and were looking to supply Asia, in conjunction with South Africa (Bailey, 1994). The New Zealand industry (at the time) was funded by the Avocado Growers' Association, Avocado Export Council, and government, with 40% of the NZ$300 000 annual budget being provided by the industry. Major projects included: cultivar and rootstock selection and evaluation, tree size and phenology, integrated pest management, postharvest handling, postharvest disease control, postharvest disinfestation, and PRR control (Hale, 1994).

1.6. Spain

The Spanish industry grew tremendously from 1976 to 1986 but was under strain because of competition from Israel and South Africa. An advantage is that Spanish fruit are produced close to the main European market hubs. It was anticipated that average yields would stabilise at 8-12 t/ha, comprising mostly Hass with lower volumes of Fuerte, Bacon and small volumes of Reed. Soil and water management are critical in the Costa del Sol in Spain because, although leaf phosphorus is adequate, zinc, potassium and iron are deficient and waterlogging is a risk (Farré & Pliego, 1987). A financial analysis based on internal profitability rate (IPR) in Spain was presented. It predicted that avocado production on the Spanish Mediterranean coast would stabilise at 6 000ha (60 000 – 80 000t), based on a number of cost and income hypotheses. It was suggested that alternative crops, such as cherimoya, mango, feijoas and litchis, medlars and some citrus, and early deciduous fruit be considered as alternatives to avocado in Spain beyond the 1990s (Calatrava & Garcia, 1987).

The major avocado diseases in Spain are PRR (*Phytophthora cinnamomi*) and white root rot (WRR, *Rosellinia nectrix*) with 35% and 39% incidence, respectively, in Andalucía in southern Spain. Soil solarisation using 75µm transparent polyethylene for 8 weeks in existing avocado orchards was effective in controlling *P. cinnamomi* for 14 months after treatment without affecting tree growth. Phosetyl-Al injection, foliar phosphorous acid and ethyl phosphite injection were the most promising chemical control methods for PRR and benzimidazoles were promising for WRR control (Pérez Jiménez *et al.*, 2005).

1.7. United States

Arpaia (1987) gave a brief overview of the Californian avocado industry. Hass was already the predominant cultivar in 1986, accounting for 66% of the state's production because of a price-premium over the green-skinned cultivars (Fuerte, Bacon, and Zutano made up another 29%). San Diego county accounted for 48% of the state's production with Ventura (22%), Riverside (11%), Santa Barbara (10%), San Joaquin Valley (3.2%), and other Southern areas of California (4%) making up the rest. The Californian Avocado Commission (CAC) manages trade promotion and advertising programmes. At the time, 80% of the California crop was consumed west of the Mississippi and only 4% of the crop was exported – mostly to Japan. The Florida avocado industry made up only 13% of avocado production in the United States in 1986 and was based on West Indian and West Indian-Guatemalan hybrid cultivars [*due to the semi-tropical nature of the climate in Florida – Ed.*].

2. Orchard Management

A comparison was made between Fuerte, Hass, and Rinton planted at 7m x 7m on a farm outside Pietermaritzburg. Hass was the most precocious and reached 20t/ha in year 6, and then averaged 22.5t/ha. Rinton yielded an average of 25t/ha but was highly alternate bearing. Fuerte required 7-8 years to reach 20t/ha and this was thought to be a reasonable estimate of average yield [*however the average yield at the farm is lower at the time of writing – Ed.*]. It was suggested that "ultra-intensive" (at the time) plantings at 400 - 800 trees/ha would hasten the time to 20-25t/ha and would require earlier pruning and/or tree thinning (Wolstenholme *et al.*, 1991).

Westfalia Estates' production team provided a good overview of harvest preparation. It included an overview of a crop estimate method, how to decide when to harvest (orchards with high fungal disease pressure, high PRR pressure, high yield, and those farmed dry land should be picked first) [*orchards with a risk of frost should also be picked as soon as possible – Ed.*]. Roads need to be in good condition before harvest to prevent fruit damage. Picking equipment, including lug boxes, scissors, ropes and ladders need to be in good condition. Pickers should be taught, or reminded, how to properly pick avocados. Guidelines for selective picking and monitoring of picking were included. The importance of protecting fruit from sun damage once picked, and the need to get fruit to the packhouse as quickly as possible was stressed (Anonymous, 1991).

Shadow® (kaolin clay formulation) reduced the incidence of sunburn by 20% when compared to the unsprayed control. However, residues and increased insect damage only slightly increased the export grade percentage. Shadow® was not recommended for Hass, but further testing was warranted on smooth skin cultivars like Fuerte [*and on the foliage before fruit set to reduce tree stress – Ed.*] (Rossouw, 2002).

2.1. Soil

A survey of soils at H.L. Halls & Sons' farms in the Nelspruit area revealed a number of edaphic (soil) factors affecting orchard performance (Mitchell, 1977b):

i. Not blocking orchards according to soil type will increase variability, e.g. including a Hutton soil (red, deep, well drained) and Longlands soil (grey, sandy, gravelly, poorly drained) in the same block.
ii. Variability in the soil due to granite outcrops – even in a deep Hutton – will cause orchard variability.
iii. A compaction layer at the boundary between the A and B horizons (top- and subsoil), can cause a perched water table which limits drainage and can increase the severity of PRR and restrict plant growth.
iv. Sand lines, such as sand lenses, can cause a perched water table.
v. The importance of conducting a detailed soil survey before planting was shown.
vi. Correcting soil pH, increasing soil calcium and reducing soil exchangeable Al were facilitated by a detailed soil survey.

A high soil bulk density of 1.7g/cm^3 restricted avocado root growth, and a marked change in soil texture down the profile restricted root penetration into the lower layer; feeder roots tend to increase from the stem to the drip-line of the tree (Durand & Claassens, 1987).

Some basic soil characteristics (colour, texture, structure, staining, stoniness, depth) were discussed in terms of their significance for general crop production, and then specifically for avocado production by Nel (1982). Soil series commonly found in avocado producing areas in South Africa are categorised for suitability for avocado production in Table 2. He concluded that in all circumstances it is undesirable to plant avocados if the clay content is higher than 40%. [*However, with appropriate amelioration, e.g. ridging or mounding, and careful irrigation, there are many examples of successful orchards on such heavy soils in suitable soil series – today called forms and families – Ed.*].

Table 2: The suitability of certain soil series, commonly found in avocado production areas, for the cultivation of the crop – taken from (Nel, 1982)

Suitability	**Soil Series**	**Description**
Very Suitable	Hutton, Farningham, Msinga, Doveton, Fountainhill, Inanda	Red and red-brown, good drainage, structure-less soil sometimes with humus-rich humus topsoil
Suitable	Oatsdale, Clovelly, Newport, Griffin	Yellow-brown, good drainage, structure-less soil sometimes with humus-rich humus topsoil
Marginal	Argent, Glendale, Elysium, Lonetree, Leeufontein, Jozini, Brontberg, Clansthal, Balmoral, Balgowan	Red-brown, yellow-brown or brown, good drainage, moderately structured or slightly blemished or unconsolidated, or very sandy or clayey subsoil
Relatively unsuitable	Series in the Swartland, Valsrivier, Fernwood, and Glenrosa forms	Light to dark brown, well and moderately poorly drained soils or strong structured, or a gravelly or extremely quickly drained soil
Totally unsuitable	Series in the Rensburg, Bonheim, Estcourt, Kroonstad, Arcadia, Westleigh, and Avalon forms	Light and dark, sandy and stony soil often with a layer that limits drainage

[*A more recent evaluation than Table 3 of soil form and family for avocados according to the revised soil classification system for South Africa was given by Wolstenholme and Sheard (2011a; b) – Ed.*].

The importance of considering soil depth in orchard management was illustrated by Barnard & Slabbert (1988) who showed that the subsoil (>15cm below surface) was often markedly different to the topsoil (0-15cm), with some orchards having very poor subsoil conditions while the topsoil was satisfactory.

Soil strength is a function of bulk density, ground water content, soil texture, and soil organic matter content. Roots generally do not grow in a soil with a soil strength of 2-3MPa. Increased soil strength and reduced bulk density have a detrimental effect on water content of a soil (Broekman, 1993).

2.2. Site Selection & Preparation

Solarisation using clear polyethylene plastic reduced pathogen propagules before planting. *P. cinnamomi* was eliminated after heating to 55°C for 5min [*depth not specified – Ed.*]. Guidelines for the use of solarisation include: 1) soil must be covered in the summer months, 2) sufficient water must be maintained in the soil, 3) existing trees should be stag-horned, 4) weeds must be controlled, and

5) the temperature of the soil must fluctuate from high to moderate to kill the pathogen propagules (Wehner & Kotzé, 1985). [*However, solarisation has not become standard practice – Ed.*].

An interesting model for site selection was developed by Human & De Jager (1987), including altitude, latitude, longitude, distance from the ocean, and nine climatic factors (temperature, relative humidity, and evaporation). Altitude had a greater effect than the other three geographic factors on temperature.

Planting on mounds (0.5m high, 0.2m diameter) in California enabled trees in replanted orchards to grow faster under PRR pressure, but integrated disease control is necessary for the orchard to survive. Mounds were deemed unnecessary if the slope of the orchard was more than 30°, or if the soil was not clayey (Goodall *et al.*, 1987a).

The negative effect of Eucalyptus plantations on avocado yield was shown to extend to about 21m into the orchard (Köhne & Kremling, 1988). Trees planted 14m away showed a 66% reduction, and those 21m away a 33% reduction in yield compared to trees 28-70m away (average yield of these tree was about 82kg/tree) in one season.

Wind-breaks at Everdon Estate reduced fruit wind damage by 26%, increased the monthly maximum air temperature by about 0.5°C, and increased the relative humidity by about 5%. However, yields may well be reduced because of increased competition for light, nutrients and water, shading, and reduced area for avocado trees (Holmes & Farrell, 1993). [*The number of windbreaks in this hilly, windy area was drastically reduced as orchards matured – Ed.*].

2.3. Orchard Floor Management

A review of the use of herbicides was given by Jordan & Jordan (1987). Rather than repeating their summary, the reader is referred to original article for further details on herbicide use for avocados.

Avocado roots do not grow well in compacted soil. Roots extended 330cm in good soil, and feeder roots were present near and outside the tree drip zone (Figure 2) (Rowell, 1979). In the soil under investigation (Hutton Form, Doveton series, clay content above 35%), there was little available water for young avocado trees, with a limited mulch layer present, especially in the top 30cm of soil. Inserting plastic mulch just below the soil surface resulted in 24% less water loss. Organic mulch would achieve similar results. Mature avocado trees lost little water, when a good leaf mulch had developed, with a crop pan factor as low as 0.2 compared to 0.63 for young trees with no mulch. The results here show the importance of a uniform orchard, in that young and mature trees have markedly different rates of water loss. Mature trees required irrigation every 60 - 70 days during winter – depending on summer rainfall and weather conditions. Soil water should be monitored using tensiometers to avoid over- or under-irrigation.

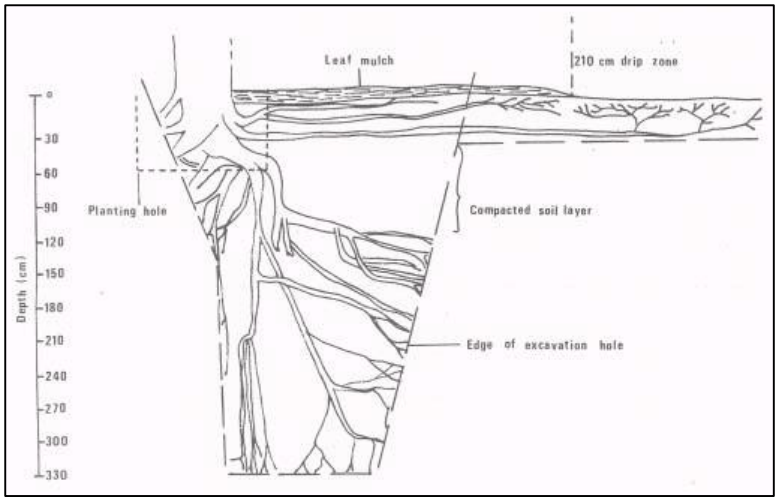

Figure 2: Root system of an 8 year old Fuerte avocado tree in Hutton Form, Doveton series (clay content above 35%) soil - taken from Smail (1971) cited by Rowell (1979).

Arachis glabrata (perennial forage peanut), *Polygonum capitatum* (knotweed), and *Lippia canescens* were compared as ground covers at Everdon Estate in the KZN midlands. *L. canescens* had the most potential as a ground cover because of a strong growth rate, but competed with the avocado trees for nitrogen. The growth rate of the other two species was too low, but *A. glabrata* increased the leaf nitrogen content. The cost of establishment for the groundcover was high but weed control and labour requirement were reduced in the second year onwards. More work was needed to find a suitable ground cover. The adjustment of the fertiliser programme to account for the ground cover, and the effect of bee activity on avocado flowers if the ground cover flowers at the same time also needed attention (Mans & Hattingh, 1992) .

Preliminary results showed that a mulch of coarse composted pine bark (15cm deep) with 500g of calcium acetate crystals per tree fortnightly resulted in better root growth and increased fruit growth (Moore-Gordon *et al.*, 1994; Allwood & Wolstenholme, 1995). The following year, the mulch treatment resulted in prolonged and more extensive root growth, increased fruit number (6%), fruit mass (11.8%), and subsequently yield (18.5%) compared to trees with no mulch (Moore-Gordon *et al.*, 1995). Second year results showed that the mulch treatment increased both fruit mass and fruit set, with an overall increase in yield of 30%. The treatment also reduced symptoms of water stress: seed coat abortion and fruit stalk ring-neck, increased the intensity and duration of the root flushes, and reduced the canopy temperature by 0.5°C during the dry season (Moore-Gordon & Wolstenholme, 1996). Final results showed that the mulching treatment increased yield by 22.6% and fruit mass by 6.6% and also increased pack-out percentage. The cost of the pine-bark was off-set in two seasons and had a half-life of 5 years so mulching offers a practical means to increase the profitability of avocado production

An excellent review on mulching was provided by Wolstenholme *et al.* (1996). In summary, mulching is an effective tool to improve the soil environment, tree health, yield and fruit size, and ultimately profit as it simulated the rainforest floor from where avocado naturally occurs. The type of material that is used is important. It must have C:N ratio between 25:1 and 100:1, break down slowly, and not produce an anaerobic environment during decomposition, and should preferably be composted before application. Mulch should be applied in autumn, after the summer rains. The tree nutrient status and soil moisture should be monitored because these will both change after mulching. The

removal of any vegetative material from the orchard was discouraged. Mulch should not be applied up against the tree trunk.

The use of composted sugarcane filter press (100mm thick) on a KwaZulu-Natal midlands farm was an effective mulch and organic fertiliser for avocados with regard to fruit size, pack-out and yield. The addition of 2.5kg potassium (alternating KCl and K_2SO_4) per tree also improved fruit size distribution. Pine bark was not effective, probably because of the dry conditions at the time of the experiment which resulted in a very dry mulch and reduced feeder root growth (van Niekerk *et al.*, 1999).

Cured kraal (cattle) manure applied in the drip line at 2 or 5kg/m^2 in June over three seasons significantly increased average fruit mass compared to the control, but did not increase fruit number; the differences between the two treatments were not significant (Erasmus *et al.*, 1999).

In a pot trial, the addition of gypsum, pine bark + antagonist, eucalyptus wood chips, or composted pine bark improved root health. Cattle manure was deleterious to tree health but trees did recover after 6 months. In field trials, avocado wood chips and Eucalyptus wood chips reduced the *P. cinnamomi* population because the cellulase enzymes secreted by soil microbes combat the *P. cinnamomi.* Compost tea + cattle manure resulted in increased *P. cinnamomi* growth because of the increased nutrition available for the pathogen. Incomplete decomposition of a mulch can result in nitrogen drawdown as it is decomposed in the field. Irrigation scheduling needs to be modified according to the mulch because the mulch material affects the water movement in the soil (Mavuso & Willis, 2007). The following year, avocado wood chips alone or in combination with gypsum, again resulted in the lowest *P. cinnamomi* levels. The use of 50% mature compost resulted in the least decline in tree health and increased yield compared to the untreated control. The combination treatment would be investigated (Mavuso, 2008; 2009).

Baseline soil health measurements for a three year mulch trial (comparing grass, eucalyptus chips, composted eucalyptus chips and an untreated control) at Politsi and Mooketsi differed by 10% in the Cornel soil health ratings; further data would follow in subsequent Yearbooks (Nzanza & Pieterse, 2011). Twelve months after the mulch application mulching with composed wood chips increased soil pH, P and Mg and the Politsi site, and soil K and active carbon at both sites. Grass and wood chips decreased active carbon in both locations. While the number and groups of nematodes were not affected, the plant parasitic nematodes tended to decline after mulch application. There was also a trend of increasing fruit Zn, K, and P concentrations after mulching (Nzanza & Pieterse, 2012).

2.4. Irrigation

In an irrigation trial at Burgershall Research Farm, the fruit water potential had an effect on the rate of ripening. Fruit with a highly negative water potential ripened faster in a curvilinear manner (Bower, 1984). Furthermore, fruit water potential was affected by long term soil water potential. Fruit water potential was optimal at a soil water tension of 35-55kPa. A high soil water tension would also have a negative effect on fruit quality by reducing the accumulation of calcium and other mineral nutrients in the fruit. Following on from this research, with sub- and supra-optimal irrigation (80kPa and 35kPa thresholds, respectively, compared to a control treatment threshold of 55kPa) both negatively impacted calcium accumulation in the first 16 weeks after fruit set (Bower, 1985). Calcium is required for cell wall and cell membrane stability, among many other physiological roles, so this research

highlighted the importance of correct irrigation practices, particularly at the time of flowering and the four subsequent months, on fruit size, quality, and ripening (paragraph repeated in §6.4 (Ripening)).

The use of tensiometers to schedule irrigation was superior to an evaporation pan for avocados (Slabbert, 1987), because an evaporation pan indicated that more irrigation rounds were needed, and the pan factor is highly variable and therefore unworkable. The variation in soil conditions cannot practically be taken into account using an evaporation pan, so this method does not give a true reflection of the soil water dynamics. The correct location of the 300mm and 600mm units to give a representative result for the orchard, and their maintenance, are critical for tensiometers.

In Israel, the addition of nitrate to saline irrigation water reduced the chloride uptake in seedling Mexican and West Indian rootstocks (Bar *et al.*, 1987a).

The important irrigation scheduling factors for avocados are to prevent over- or under-irrigation because over-irrigation can cause root hypoxia and the spread of PRR, and under-irrigation can lead to excessive fruit drop. The important factors are (i) the tree itself, *i.e.* root depth, tree age, phenological stage, (ii) the soil, because soil texture (clay percentage and organic matter content) will determine the water holding capacity of the soil, and the allowable depletion of easily available water, and (iii) measuring equipment, *i.e.* tensiometer or evaporation pan. It was recommended that in South African soils, not more than 50-60% of the easily available water should be allowed to be depleted, which corresponds to a soil matric potential of about -50kPa for clayey soil, and -30kPa for sandy soil at 300mm. Tensiometers were recommended over evaporation pans (Du Plessis, 1991).

In terms of yield, count distribution, and percentage exportable fruit, the rewetting of soil planted with 6 year old Hass on Duke 7 trees to field capacity (-15cb) at 300mm depth was better than rewetting to -55cb (commercial control), -40cb, and between -30 and -50cb depending on phenological development (van Eyk, 1994).

Avocado trees were able to maintain leaf metabolism at transpiration rates that would cause partial wilting in citrus (Sharon, 1999). Further research showed that avocado trees were able to keep stomata open despite significant water loss because avocado roots [*rootstock not specified – Ed.*] were able to supply the canopy with water at a rate very similar to transpiration losses if soil was close to field capacity (Sharon *et al.*, 2001).

Kalala *et al.* (2005) suggested that seed water potential (Ψ_w) could be used as an indicator for irrigation scheduling in conjunction with tensiometer readings. Differences were noted between cultivars and better management of water potential could reduce physiological disorders in fruit. Young Hass fruit had a more negative Ψ_w compared to young Fuerte fruit, indicating that Hass trees have a higher water requirement to compensate for higher transpiration rate. In mature fruit, Fuerte fruit have a more negative Ψ_w, providing a physiological explanation for the increased physiological disorders in Fuerte.

Soil moisture content at the time of harvest had an effect on ripening, and variable ripening may be linked to inefficient irrigation, especially during dry seasons (Kruger & Magwaza, 2012).

Preliminary results indicated that a moderate to severe water stress was existed in orchards during early fruit development – which may well result in reduced fruit size, fruit number, and yield. Further research, including the optimisation of irrigation scheduling using midday stem xylem water potential would continue (Roets *et al.*, 2012).

2.5. Nutrition & Fertilisation

Fertilisation guidelines for avocados were given by Köhne *et al.* (1990). The integration of the phenological cycle and fertilisation events are now integrated into the SAAGA Avocado Management Chart which is readily available. The norms for leaf and soil are given below.

Table 4: Soil and Leaf analysis norms from summer flush (March/April) on non-fruiting branches (Köhne *et al.*, 1990)

Element	Shortage	Below Normal			Normal			Above Normal			Excess	Units
					Soil Norms							
P (Bray 1)	20	21	–	29	30	–	90	91	–	129	130	mg/kg soil
P (Hars)	2	3	–	7	8	–	27	28	–	45	46	
K	100	101	–	149	150	–	250	251	–	499	500	
Ca	250	251	–	749	750	–	1000	1000				
Mg	50	51	–	99	100	–	300					
Al					0	–	30					
pH (water)	4.5	4.6	–	5.4	5.5	–	6.5	6.6	–	7.5	7.6	
Resistance					> 500							Ohms (Ω)
Ca:Mg					2.5	–	5					
(Ca+Mg):K					5	–	10					
					Leaf Norms							
N (Hass)	1.40	1.41	–	2.19	2.20	–	2.40	2.41	–	2.69	2.70	% DM
N (Fuerte)	1.30	1.31	–	1.69	1.70	–	2.00	2.01	–	2.49	2.50	
N (Other)	1.30	1.31	–	1.89	1.90	–	2.20	2.21	–	2.49	2.50	
P	0.05	0.06	–	0.07	0.08	–	0.15	0.16	–	0.24	0.25	
K	0.35	0.36	–	0.74	0.75	–	1.25	1.26	–	2.24	2.25	
Ca	0.50	0.51	–	0.99	1.00	–	2.00	2.01	–	2.99	3.00	
Mg	0.25	0.26	–	0.39	0.40	–	0.80	0.81	–	0.99	1.00	
Na					0.01	–	0.06	0.06	–	0.24	0.25	
S	0.05	0.06	–	0.19	0.20	–	0.60	0.61	–	0.99	1.00	
Cl					0.07	–	0.23		–		0.25	
Cu	3		4		5	–	15	16	–	24	25	mg/kg DM
Fe	40	41	–	49	50	–	150	151	–	249	250	
Mn	19	20	–	49	50	–	250	251	–	749	750	
Mo	0.01	0.02	–	0.04	0.05	–	1.00		–			
Zn	20	21	–	24	25	–	100	101	–	299	300	
B	14	15	–	49	50	–	80	81	–	149	150	

Fruit nutrition status was a major determinant of fruit quality after extended cold storage. Stem end rot was correlated to flesh Ca, S, and Fe content, and negatively correlated with Mn and Zn (Oosthuyse & Donkin, 2001).

2.5.1. Nutrient deficiencies

A major study on the selective elimination of individual nutrients to induce leaf deficiency symptoms was initiated in 1987, and the first progress report outlined difficulties in growing avocados (Hass on Duke 7 or Hass on G755) in the greenhouse (Barnard, 1988). Growing the trees in quartz sand resulted in better tree condition and allowed the development of individual nutrient deficiency symptoms (Barnard, 1990). The following year, they were able to photographically catalogue deficiency symptoms for calcium, copper, iron, magnesium, manganese, nitrogen, potassium, sulphur, and zinc (Barnard *et al.*, 1991). Readers are referred to the original article for these photographs. Additionally, Barnard's study permitted a study on the interactions between macro-elements in avocados. Leaf

calcium concentrations could be increased by reducing potassium and applying moderate amounts of magnesium. The elimination of nitrogen resulted in low concentrations of N, P, K, Mg, and Ca but very high levels of Mn and Zn (Barnard, 1991).

2.5.2. Micro-nutrients

2.5.2.1. Boron

Although a relationship between pollen germination and boron uptake of excised flowers in agar could not be found, there was a clear correlation between boron uptake and the percentage of pollen tubes that reached the ovule (Robbertse & Coetzer, 1988).

The application of boron as a foliar spray or soil application was examined. Although both application methods increased leaf and flower boron content, it was still well below the 50ppm recommended for good pollination and fruit set (Robbertse *et al.*, 1989). Boron uptake by avocado leaves after foliar application was mainly through the abaxial surface and uptake is higher in immature leaves than mature leaves (Robbertse & Coetzer, 1990).

An experiment into the role of boron on fruit set was confounded by tree position on the slope, and leaf nitrogen concentration, and no significant differences were observed between treatments (Robbertse *et al.*, 1991).

The application of Solubor® (3g/L) had the highest increase in leaf boron content, and trebled fruit set. The uptake of boron was limited but greater from foliar application than soil application and mainly occurred through the abaxial leaf surface [*later findings found that foliar applications were insufficient – Ed.*] (Robbertse *et al.*, 1992).

Coetzer *et al.* (1993) summarised their findings on boron after four seasons or research. It was concluded that the optimal concentration of boron in the leaves is approximately 70 mg/kg in mature leaves and approximately 50 mg/kg in inflorescences for optimal pollen tube growth. Soil application was ineffective due to very low uptake of boron through the roots, therefore foliar spray was recommended at least a month before flowering [*Subsequent research in Australia and South Africa has shown the importance of soil applications to remedy previously unrecognised boron deficiencies in the whole trees – Ed.*]. The accumulation of boron in the soil should be minimised because it can quickly reach toxic levels. The concentration of free boron in mature leaves is the important metric (rather than total or bound boron) that will determine the concentration of boron in the inflorescences. Boron is predominantly absorbed through the abaxial (lower) surface of the leaf. Because boron is utilised in the cell wall and cellular metabolism and young leaves have a high demand for boron, *i.e.* little free boron, one should focus on increasing the concentration of boron in mature leaves to ensure the boron is translocated to the inflorescences. Leaf sampling, with sufficient time for corrective action, should be done on the youngest mature leaves – the closer to the onset of flowering, the more accurate. Later, Coetzer *et al.* (1994) reported that avocado roots are highly sensitive to boron, and only require about 5 mg B/kg soil (warm water extraction) and should rather use foliar-applied boron.

Whiley *et al.* (1996) provided a good discussion on the effects of boron deficiency on tree health, fruit set and fruit quality. They detailed the symptoms of boron deficiency: shot-holes in spring flush leaves with yellow halo around shot-hole, crescent-shaped leaves, reduced tree vigour, nodal swelling, and

loss of geotropism. In severe cases of deficiency there is leaf yellowing, loss of feeder roots, earlier flowering, and defoliation during flowering, resulting in sunburn of branches. Since boron is transported via xylem, the use of foliar sprays alone is not recommended because the roots will not receive any of this boron. The soil application of boron must be done with care to avoid toxicity, and it is better to apply low doses multiple times. Regarding leaf sampling, only leaves that have not been sprayed with foliar boron should be tested because the results can otherwise be artificially high due to boron being held in the cuticle.

The soil application of boron was tested at two sites in KZN (Everdon and Cooling). Early results showed that younger trees showed a greater response than older trees with a greater boron concentration in the leaves. This was probably due to chronic boron deficiency in the older trees restricting the boron to the roots rather than translocating it to the leaves. In the second year, boron uptake increased dramatically and these sites (soil with >35% clay), a dose of 10-15g borax/m^2/year in three applications was suitable to correct boron deficiency, reducing to 5g borax/m^2/year for maintenance or small trees. A level of 50mg B/kg soil is recommended as being sufficient. Fruit size increased by 4% and yield by 10% (Bard & Wolstenholme, 1996; 1997; 1998).

2.5.2.2. Calcium

Various Ca-based soil ameliorants were tested in pot trials by Barnard & Mentz (1992). Ca-acetate and Ca-fulvate (20t/ha calcite equivalent for both) resulted in the best vegetative growth in the first year but there were differences in the response of trees when planted in different soils (sourced from Westfalia and Everdon).

The application of a foliar fertiliser (3:1:6 with micronutrients; commercial name: Supafeed®) (4.5L/tree) at flowering increased yield if sprayed when the first flowers opened. The trees used in this study were deficient in N and B (Mans, 1996a).

The application of Calcimax® (chelated calcium (8%) and boron (0.5%)) at 0.5% and 1%, 3 weeks after fruit set did not significantly increase the concentration of calcium in fruit but reduced the incidence of grey pulp and vascular browning appreciably (Penter & Stassen, 1999). Calcimax® and Caltrac® (both chelated Ca products) reduced grey pulp, black cold damage, anthracnose and softening, and the effect was more noticeable when applied early (three sprays at full flower, fruit set, and 2 weeks later) and on earlier set fruit (Pinkerton). A 10min postharvest bath in the chelated Ca, particularly Basfoliar Ca® (155.7mL/100L) significantly reduced softening, grey pulp, lenticel damage, and anthracnose (Penter & Stassen, 2000).

2.5.2.3. Iron

Iron concentration in the fruit flesh was negatively correlated to black cold injury in Hass and Fuerte (Kruger *et al.*, 2004). A benchmark iron concentration in the flesh of 60ppm Fe in March was recommended to reduce the risk of external chilling injury development (Magwaza *et al.*, 2008). Clear results in the second season were not repeatable, and although external chilling injury was lower in the iron treatments these differences were not significant. The manipulation of fruit iron concentrations to reduce chilling injury was concluded to be futile but the monitoring of fruit iron concentration to predict chilling injury was proposed (Magwaza *et al.*, 2009b).

2.5.3. Macro-nutrients

Preliminary results from long term fertiliser trials by the then CSFRI in Nelspruit were reported, but further work was needed to improve leaf sampling, so that fertiliser norms could be established. Zinc nitrate (NZN®), used on pecan nuts, increased the leaf zinc content but was phytotoxic to avocado trees. 65% of samples from growers were too high in nitrogen, 60% were deficient in zinc and boron, and 60% had excess manganese – due to low soil pH (Langenegger & Koen, 1978). It was later concluded that fertilisation at the trial site did not significantly improve yield, and in some instances reduced yield. Attention was paid to leaf and soil sampling, and fertilisation. In one year, the percentage of orchards with excess nitrogen dropped from 65 to 47%, and a reduction in highly acidic soils from 95% to 65% (Langenegger & Koen, 1979).

The potassium content in leaves and soil was positively correlated, and calcium and magnesium negatively correlated to the severity of grey pulp development. Calcium and magnesium, and the (Ca+Mg)/K ratio were positively correlated to the incidence of pulp spot and vascular browning. It was concluded that a potassium deficiency in the soil was probably responsible for the development of pulp spot and vascular browning (Koen *et al.*, 1989).

The application of K to soils with a low K content did not increase fruit yield or fruit quality. Application of N reduced yield and fruit quality, but the addition of K and Mg with the N counteracted this negative effect (Köhne *et al.*, 1993).

Stassen *et al.* (1997) recommended nutrient replenishment based on soil and leaf analyses, and tree condition to prevent nutrient imbalances and excessive nitrogen which will cause vigorous growth and fruit quality problems.

Snijder & Stassen (2000) found that yield per tree peaked at nine years of age if trees were not pruned [*spacing not provided – Ed.*] and a tree management plan must be implemented well before that. The nutrient accumulation in trees (3-11 years of age) was potassium > nitrogen > magnesium > phosphorus. Large amounts of macro-nutrients went to the vegetative parts of the tree. The bark, wood and shoots fixed most of the nitrogen. Phosphorus and potassium was evenly spread throughout the plant parts. Most of the magnesium was fixed in leaves, shoots and wood. Most calcium was found in leaves, shoots and wood, with very little in fruit. Nitrogen should be applied in small amounts frequently, with little or no nitrogen applied in summer to limit water shoot growth. Calcium should be applied in the post-harvest winter period, and again 3-6 weeks before harvest. Phosphorus can be applied once in the post-harvest winter period. Potassium applications will depend on the soil clay percentage. It is also important to keep the Ca, Mg, and K ratio, and soil pH in mind.

Wolstenholme (2004) provided an in-depth mini-review of the nitrogen cycle, how to manage nitrogen on different soils in South Africa for avocado production, sampling and interpreting leaf analyses for nitrogen, timing of nitrogen fertilisation, and the relationship between N and fruit quality. He recommended research on N budgets and cycling in South African avocado orchards with various soil properties, and the fine-tuning of leaf analysis standards for various orchard management systems.

2.5.4. Liming

Fouché (1981) provided the basic principles of acidic soils and the amelioration of these soils using lime in preparation for a long term liming experiment at Westfalia Estate. Eighteen months after treating with agricultural lime, gypsum, or lime + gypsum (red Oxisol soil), lime (6-12 t/ha) increased

the pH (water) of the top 15 cm of soil from 4.5 to 5.1-5.4 (15-30cm fraction was approximately 0.2 points lower), and increased the extractable calcium from 0.53 to 3.00 me/100g in the top 15 cm and from 0.32 to 2.30 me/100g in the 15-30cm fraction. As expected, gypsum was not effective in increasing the pH. The combination treatment had an additive effect on the extractable calcium but had a similar effect on pH as the lime treatment. Importantly, the estimated lime requirement was insufficient to raise the pH to 6.0, because of the high concentrations of amorphous aluminium and iron compounds in the soil buffering the effect of the lime (Fouché, 1985; 1986). After 12 years, high rates of lime (12 t/ha) and a combination of lime and gypsum (6 t/ha each) was effective in increasing soil Ca and pH but the effect does not last more than three years after application. Leaf Ca of young trees increased with lime while leaf K decreased (Fouché & du Sautoy, 1995).

In a liming experiment at two sites with heavy clay soils, calcium hydroxide ($Ca(OH)_2$) was the most effective in increasing the soil pH in the top 75mm (Rowell, 1981). Between 75mm and 450mm, the effect was variable between the sites and there was little difference between calcium oxide (CaO), calcium hydroxide, and calcium carbonate ($CaCO_3$). Calcium sulphate (gypsum – $CaSO_4$) had no effect on the soil pH in soil that was previously limed, but did reduce the pH of the topsoil in the other site. The effect on the concentration of available aluminium closely followed the results for pH – which is to be expected. At the applied doses, there was little effect of the different sources of calcium on raising the concentration of calcium in the soil. The importance of correcting the soil pH and calcium concentration before establishment was stressed.

Moderate (e.g. 4.7 t/ha of dolomitic lime) application of lime increased yield of Edranol because of the decrease in extractable Al in the topsoil. A strong negative correlation was found between topsoil extractable Al and yield. The change in pH after four years of liming was minimal so it was recommended that soils be limed to reduce extractable Al, rather than increase pH. The recommended maximum extractable Al in the topsoil is 20mg/kg. [*On highly buffered soils with low pH value, it is virtually impossible to raise the pH without massive lime applications which would be both uneconomic and unbalance the soil nutrients. Liming should be seen primarily as a tool to reduce Al toxicity in such soils and secondarily to raise soil Ca levels – Ed.*]. Gypsum increased the subsoil Ca considerably, but did not change topsoil or subsoil pH or extractable Al at all [*Gypsum is used commercially as a soluble calcium source and not to increase pH. It also acts as a mild fungicide for PRR when applied annually at a low rate, e.g. 0.5t/ha – Ed.*]. Calcium hydroxide effectively increased subsoil Ca. Dolomitic lime also increased subsoil Mg. Excessive lime reduced the potassium concentration in leaves and fruit (Du Plessis & Koen, 1987).

The addition of gypsum increased subsoil pH, but reduced Mg and K concentrations. It is advisable to include gypsum application with dolomitic lime. As it is difficult to raise the pH of soil without physical incorporation and mixing, it is imperative to correct soil acidification before planting and limit acidification thereafter (Barnard, 1989).

2.5.5. Leaf sampling

In Israel, leaf sampling was recommended in early autumn from spring flush leaves, because the N concentration in the spring flush stabilised in autumn and was lower than the summer flush; the Ca concentration of the spring flush was higher than the summer flush (Bar *et al.*, 1987b). Also, withholding N for two years resulted in an N deficiency two years later after N fertilisation was resumed.

The leaf sampling procedure used in California was unsuitable for South African conditions, and the use of the youngest leaves at the tip of a new spring flush was even less suitable. It was recommended that, under South African conditions, a leaf 6-8 months old attached to the base of a non-bearing secondary branch in the middle of the spring flush be used for leaf samples (Koen & Du Plessis, 1991).

[*Subsequent research in Australia has shown that under some conditions May sampling from summer flush leaves is preferable as these shoots are more likely to bear fruit the next season – Ed.*].

2.6. Growth Control

The points made by Köhne (1988) regarding methods to increase avocado production are still pertinent today. Even with growth retardants, pruning, and higher planting densities being utilised since then sound orchard practices will always be necessary to realise an orchard's yield potential. The control of PRR in areas with mesic climates and excellent soils resulted in vigorous trees with reduced yields and overcrowded orchards, so it was thought that a slight PRR infection (Ciba-Geigy tree health rating of 1-2) could be beneficial for vigour control and increased yield. The role of irrigation to control growth, and limit *P. cinnamomi* spread was highlighted. Fertilisation was discussed, emphasizing the need for leaf and soil analyses incorporated with crop take off values, and the necessity to supplement calcium, zinc, boron, and nitrogen under local conditions, but Köhne cautioned against the over-application of nitrogen which would increase vegetative growth at the expense of yield. In his continued investigation into chemical growth manipulation, he showed that paclobutrazol should be applied during active growth and can improve fruit set and reduce internode length. The clean cultivation of the orchard floor was strongly discouraged because a bare soil will increase erosion and decrease aeration [*and increase water loss – Ed.*]. Mulching under trees with lawn grass in the inter-row was promoted. The identification and monitoring of consistently high-yielding trees to identify potential high-yielding selections was advised. Late-hanging was again discouraged because of its negative effect on the following year's crop, but is an economic decision which be made by the producer. The point was made that the optimal rootstock with PRR tolerance/resistance that is dwarfing is "unlikely to be found soon", and new PRR tolerant rootstock selections were particularly vigorous to "outgrow" the *P. cinnamomi*. The use of dwarfing interstocks was still under investigation at that time. The use of new high-yielding scion cultivars was mentioned, particularly Californian selections Gwen and Whitsell. At that time the areas planted to Ryan and Pinkerton had increased, but the industry was still dominated by Fuerte and Hass.

An excellent overview of vegetative growth control, or the manipulation of the vegetative/reproductive balance was given by Wolstenholme & Whiley (1990). The control of the competition between vegetative and reproductive growth using nitrogen, physical manipulation (girdling, cincturing, training, and pruning), chemical control, rootstocks, and scion cultivars were all discussed, with a focus on the practices, rather than genetic resources.

The principles of high density plantings (556-1000 trees/ha) and the growth control strategies (pruning, chemical growth control, nitrogen manipulation, and water manipulation) were discussed by Stassen *et al.* (1995). The principles discussed are still very relevant at this time where greater productivity is needed in avocado production.

2.6.1. Pruning

2.6.1.1. Young Trees

For young trees, training and pruning to a central leader was recommended, and a step-by-step approach for the first three years was outlined (Snijder & Stassen, 1999b; Snijder *et al.*, 2000a). This involves training to a central leader, with frequent light pruning and water shoot removal to avoid tree encroachment. Pinkerton and Ryan need the least attention while Fuerte and Hass need the most attention with regard to regrowth control. The reader is referred to the original document for details.

Plantings at 4m x 1.5m resulted in yields of 13.6 t/ha for Hass and 5.33 t/h for Fuerte in 3.5 years after planting. Growth control can be achieved by cincturing (spiral), nitrogen management, growth inhibitors, but fruit set is the most effective growth control (Snijder *et al.*, 2000a). Early fruiting needs to be encouraged to reduce vegetative vigour. This can be done with cincturing or PGRs. Cincturing need not be done two years in a row on the main stem and is best done in autumn. [*The long term effects of these high density plantings need to be determined – Ed.*].

2.6.1.2. Large Trees

The effect of pruning and tree removal was investigated at Westfalia on 7-11 year old Fuerte trees (tree spacings of 7.4m x 7.4m or 6.1m x 6.1m) (Toerien, 1977d). Pruning in 1975 reduced yield from 16.4t/ha to 7.6t/ha. In the same orchards, alternate diagonal rows were stag-horned in 1976 and yield was restored to 15.8t/ha in 1977. [*Further monitoring of this experiment would have been necessary to determine the long term effect of the pruning and stag-horning on yield and to account for alternate bearing – Ed.*].

Preliminary results showed that the removal of the spring flush from indeterminate shoots increased fruit size, but not yield because of increased late summer fruit drop – and resulted in increased sunburn. In a separate trial in South Africa, the removal of this vegetative growth resulted in a higher concentration of P, K, Ca, and Mg in the fruit (Cutting & Bower, 1990).

Very important principles of pruning encroached were discussed by Snijder & Stassen (1995). In summary, the critical points for pruning large trees were:

1. Timing of pruning. It is best done just after harvest.
2. Summer pruning for re-growth control is imperative to have any benefit from pruning.
3. Minimum light penetration for optimal functioning of the tree is 30% of full sunlight.

Over-crowded orchards can be pruned with the above principles (Stassen & Snijder, 1996a; Snijder & Stassen, 1997b; 1999a). The reader is referred to the original article for a step-by-step guide to this method. After four years, the following conclusions were made regarding the pruning of young trees to a pyramidal shape:

1. Pruning to a central leader in a pyramidal shape is recommended. Edranol, Pinkerton, and Hass are easier to shape than Ryan and Fuerte.
2. Growth inhibition, using chemical growth regulators, and the judicious use of nitrogen and water is needed to prevent/delay over-crowding.
3. Unwanted growth needs to be controlled before it negates the positive effects of pruning. Follow-up pruning in spring and summer is a necessity.

Later, specific strategies for orchards without overcrowding, medium, and severe overcrowding were outlined. Although some yield loss may result in over-crowded orchards, it is necessary for the long-term productivity of the orchard (Snijder *et al.*, 2000b).

In Kiepersol, selective pruning significantly increased yields after pruning (almost doubling yield from 11.5 t/ha to 19.9-25.4 t/ha) but severe pruning of the whole tree slightly reduced yield (10.7 t/ha). In Mooketsi, pruning one side vs. the whole tree in an orchard with medium overcrowding were both beneficial (Snijder *et al.*, 2000c).

Köhne & Roe (1995) embarked on a pruning trial at Mooketsi and Westfalia but no results were available in 1995. Rejuvenated trees at Westfalia were root pruned one year after rejuvenation but root pruning at 80cm deep 3-5m around the trunk was expensive without offering growth control. At the tree removal stage, hedge-rowing, in comparison to lone trees maintenance, was more beneficial in Mooketsi (more arid environment) than Tzaneen (Roe & Köhne, 1996b).

2.6.1.3. Flower Pruning

From research in Spain, early heavy pre-bloom pruning of Hass trees coming out of an "off" season increased yield by up to 50% over three years (Farré & Hermoso, 1987). Heavy pruning involved removing the previous summer flush and some of the spring flush in the equivalent of South Africa's September (March in Spain).

In a Westfalia trial, flower pruning in a severe "on" year increased fruit size and pack-out (60 vs. 80%), greatly increasing returns for the grower. Flower pruning was only recommended on a tree by tree basis and should be done before full flower (Roe & Morudu, 1999b; 2000).

2.6.2. Phloem disruption

Phloem disruption includes cincturing (thin cut into the phloem) and girdling (relatively thicker cut into the phloem). Girdling is an ancient horticultural technique to reduce excessive tree vigour, thereby favouring reproductive growth – at the expense of root growth. It has a place in tree manipulation, provided that it is understood, and properly used.

A comparison on the effect on yield of tree thinning was conducted in 1978-79. Low ring barking of the trees to be removed was the only treatment that increased yield in the first year compared to the control. Other treatments included high ring barking, top pruning, stag-horning, cutting and killing trees with Roundup®, and removing trees (Toerien & Basson, 1979).

It was concluded that girdling the branches of trees the year before tree thinning was an excellent method to increase yield on those trees. Overall yield was increased by 60% compared to the untreated control (9.6 vs. 6.0 t/400 trees) and the export yield was 7.4 vs. 5.0 t/400 trees) (Köhne, 1992).

The disruption of phloem by removing 20mm of bark, loosening and rotating the bark 180°, removing and inverting the bark, or replacing Duke 7 bark with Ryan bark, in Hass was too severe and narrower rings would be tested going forward (Köhne & Schutte, 1993).

The cincturing of selected branches of Hass trees had positive results on fruit size with limited negative effects on the tree. Although the effect on fruit size was repeated with girdling, the severity of the wound from girdling is too severe. The treatments resulted in the accumulation of starch above the

wound, while chlorophyll content decreased and leaves turned chlorotic after 5 weeks. Girdled branches started flowering 6 - 7 weeks after wounding and the non-girdled branches started to flush. Root starvation was reduced by girdling only selected branches. Average fruit size increased from 103 to 139 g with both treatments (Davie *et al.*, 1995). Cincturing before flowering on young Hass trees increased yield by 40-50% and moderated alternate bearing if repeated annually while also affecting the root starch concentration. Cincturing in October/November may increase fruit retention. Fruit thinning was not effective in increasing yield the following year but did illustrate the effect of fruit load on alternate bearing and fruit size (Davie *et al.*, 1996; Davie & Stassen, 1997).

Trunk cincturing of two year old Hass trees on Everdon Estate in the KZN midlands in March or April resulted in severe tree decline, probably because carbohydrate flow to the roots before the root flush was interrupted. Cincturing between June and mid-November usually resulted in a significant increase in fruit/tree without negatively affecting tree condition and they recommended cincturing about 5 weeks after the second shoot flush of the season. Treatment in early July resulted in the spring flush being two weeks earlier (Hackney *et al.*, 1995).

In California, it was shown that girdling [*severity not specified – Ed.*] increased fruit set dramatically. Comparing girdled vs. non-girdled branches, girdling in November (May in Southern Hemisphere) was the most effective, but comparing tree vs. tree girdling in February (August in Southern Hemisphere) was the most effective in increasing fruit set (Francis, 1996a).

Cincturing during January was better than treating in May to induce flowering in strongly vegetative trees, and cincturing in August could be used for better fruit set (Stassen & Snijder, 1996b). Cincturing between late February and late May significantly increased yield but only at 400trees/ha density – not 800trees/ha (Snijder & Stassen, 1997a).

2.6.3. Chemical growth control

Methods to increase fruit set and control vegetative growth were (i) pruning and training of young trees to increase complexity and number of lateral branches, and (ii) hormonal manipulation using paclobutrazol (Bertling & Köhne, 1986; Köhne, 1986). A spray or injection of the anti-gibberellin paclobutrazol (Cultar®, 0.4% a.i.) significantly reduced shoot length by shortening internodes, and significantly increased fruit retention in Fuerte (Köhne & Kremer-Köhne, 1987). Uniconazole (Sunny®) and paclobutrazol both significantly limited shoot extension of potted avocado seedlings. Rates as low as 50 ppm a.i. were effective, but higher rates were recommended for field use (Köhne & Kremer-Köhne, 1989). High density plantings (HDP), 800 trees/ha either as a hedge or bed managed with paclobutrazol sprays, were shown to produce a cumulative 3.0 t/ha and 7.8t/ha more the standard 400 trees/ha in the first two years of production. The following year, the cumulative yield per ha was 95% higher in the HDP than the standard density planting (34.4 vs. 17.6t/ha over 3 seasons) although the yield/tree was slightly lower (2% or 1kg/tree) lower. The HDP produced a positive cash flow in year 5, while the SDP cash flow was still negative. Growth control was a major factor affecting the success of the HDP system (Köhne & Kremer-Köhne, 1990). Paclobutrazol applied at the early spring flush stage significantly increased yield and fruit quality when applied going into an “off year”. Furthermore, a carry-over effect was noticed over the two seasons. Ultra-low volume application at 12.5mL/tree was the most profitable (Kremer-Köhne *et al.*, 1991).

In a study in Australia and KZN, paclobutrazol (Cultar®) sprayed at full bloom (2.5 or 5 g/L) decreased the spring vegetative flush. The treatment resulted in significantly rounder fruit and larger seed size

in Fuerte and also increased fruit size but did not significantly increase yield because of high summer fruit drop. The provisional recommendation was a single spray at full bloom at 2500mg/L or lower (Wolstenholme *et al.*, 1988). Symons & Wolstenholme (1989) showed that paclobutrazol (1.25, 2.50, and 5.0 mL Cultar®/m^2 canopy) was effective in reducing vegetative growth in potted plants by shortening the internodes, and also increased the root:shoot ratio. They also noted that the leaves of treated plants had typical symptoms of reduced leaf area, abaxially curled midribs, darker green colour, and bubbled leaf blades, while the treated plants flowered. The next year, applications of 500, 1000, and 2000 mg/L paclobutrazol at 5L/tree, at either early spring flush elongation, full bloom, or 3 weeks after full bloom were made on commercial trees in Wartburg, KZN. Application at early spring flush elongation, at the higher dose was the most effective in increasing yield, but the later spray had the greatest effect on vegetative growth reduction (Symons & Wolstenholme, 1990).

2.6.4. Fruit size manipulation

Hand thinning was not effective in increasing fruit size, but CPPU (a cytokinin) was effective in increasing fruit size, particularly in small fruit (<182g) (Köhne & Schutte, 1991). However, it was later found that CPPU reduced cumulative yields and did not have a significant effect on fruit size (Köhne *et al.*, 1993).

The health of the seed coat is the paramount physiological consideration in determining fruit size. There was a relationship between the cytokinins, climate, and seed coat health which was still to be determined (Cutting, 1993).

The application of paclobutrazol (250 mg a.i./L) at full flowering increased total yield and fruit size in two seasons (Kremer-Köhne & Köhne, 1996).

A fruit thinning trial did not result in any effect on fruit size (Stassen & Snijder, 1996b; Snijder & Stassen, 1997a). Sunny®, Cultar®, Cycocel®, and Pix® were tested for growth control and fruit set, and a double Sunny® application at full bud and full flower and a standard paclobutrazol (Cultar®) spray reduced the vigour of the spring growth. Only the paclobutrazol spray increased fruit set (Snijder & Stassen, 1997b). Results in 1998 showed promise in controlling vegetative vigour and increasing fruit size, but the timing and concentration of the PGRs needed to be improved (Penter & Stassen, 1998). [*Cycocel is a QAC – Ed.*]. The timing of the inhibitor sprays was important, with the best results when the spring flush was sprayed rather than the flowers. Both Sunny® and Cycocel® increased fruit size but Sunny® resulted in a decrease in yield. Cultar® increased yield by increasing the size of small fruit (Penter & Stassen, 1999). Sunny® was recommended as the most effective growth inhibitor for avocados, but cheaper, more effective methods of applications needed to be found because of the cost of the product. It can be used in conjunction with pruning to increase yield further. The harvest interval/withholding period was 84 days (Penter *et al.*, 2000). Mineral oils were not an effective adjuvant for growth inhibitors. The effect on yield of growth inhibitors was greater in an “off year” but inhibitors always increased fruit size and were recommended when small fruit was expected (Penter & Snijder, 2001)

Uniconazole (Sunny® 50SC) with urea phosphate (UP50) sprayed at 1% a.i. at full bloom increased fruit size, with the peak increasing by two counts (count 18 to count 14), and resulted in rounder fruit (Erasmus & Brooks, 1998). [*It should be remembered that paclobutrazol and uniconazole are growth retardants. They are therefore most effective when tree vigour is excessive, e.g. in young trees grown in mesic climates on good soils, and during an “off” crop season – Ed.*].

2.7. Yield Estimation

A method for yield estimation was described where the average volume of the tree multiplied by the number of fruit observed in 10 fruit set density counts gives an estimate of the number of fruit per tree (Köhne, 1985b). A correction factor was required to increase the accuracy of the estimate. The error between estimates and actual yield was reduced the following season, and as users gained experience (Foldenauer & Köhne, 1986).

Using this formula in 1992 and 1993, the deviation was 15 and 6% respectively (Bezuidenhout, 1994). A yield estimation method was developed using single tree samples and the rating scale for tree yield of A to E where a tree rated A has a very high yield and E a very low yield. The formula was:

$$Yield = z.\sum_{i=A}^{E} n_i.x_i$$

Where:
n_i = number of trees with grade i (A to E)
x_i = fruit density of a tree with grade i (A to E)
z = spray for the orchard (kL)

3. Pathology

In an attempt to standardise the interpretation of symptoms of diseases and disorders, in both fruit and trees, Kotzé & Darvas (1985) presented a range of high quality photographs for Cercospora spot, Phomopsis spot, sooty blotch (*Akaropeltopsis* sp.), anthracnose, stem-end rot, zinc deficiency, chlorine toxicity, lenticel blossoming (physiological disorder caused by high relative humidity directly after harvest where callus tissue grows from the lenticels), thrips damage, sunburn, shrivel, and water deficiency (drought) symptoms. Readers are referred to the original document for more detailed information.

The selection criteria for fungicide selection and the economic benefit of applying a fungicide were discussed by De Wet (1985). The reader is referred to the original article for the selection criteria for fungicides. The economic criteria are given in a formula:

$$\frac{B_A+B_E}{C_A+C_E} > 1$$

Where:

B_A = Direct benefits from controlling a disease

B_E = Benefits of ancillary effects

C_A = Direct costs of product and application

C_E = Cost of ancillary effects

In brief, this formula means that there must be an economic benefit to applying the fungicide, and the ancillary costs and benefits also need to be taken into account.

3.1. Tree Pathology

3.1.1. Phytophthora root rot

The control of Phytophthora root rot (PRR) caused by *Phytophthora cinnamomi* is a high priority and many researchers have worked on it. The research findings are grouped chronologically according to projects. It is recommended that the entire section be considered because earlier results have often been superseded by more recent findings. Although *P. cinnamomi* is now classified as an oomycete rather than a fungus, much of the literature refers to *P. cinnamomi* as a fungus and this terminology may be used occasionally here.

A brief discussion of SAAGA's root rot control strategy in the mid-1980s was outlined by Moll (1984). The strategy was defined as: present, immediate future, and long term future. At the time, the present aim was to get phosetyl-Al (aluminium tris-o-ethyl phosphonate, Aliette®) registered in its injectable form. The immediate future involved the evaluation of PRR-tolerant rootstocks Duke 6, Duke 7 and G6 imported from California. The benefit of horizontal tolerance (as present in these cultivars) is that it is difficult for the pathogen to overcome this tolerance.

Graft incompatibility and PRR produce visually similar canopy symptoms, but PRR causes a decrease in the peroxidase activity in the leaves; the peroxidase activity in leaves from a tree with graft incompatibility did not change markedly. The peroxidase activity in the rootstock bark increased but not in the scion bark. The opposite is true for virus infection. The anthocyanin concentration increased in the leaves of trees infected with PRR, while the concentration decreased in trees with graft incompatibility, compared to healthy trees (CSFRI, 1977).

Grafted trees were shown to be more susceptible to *P. cinnamomi* than ungrafted trees, with trees with a Hass scion being especially susceptible to PRR (Botha & Kotzé, 1989b).

3.1.1.1. Chemical Control

The application of Aliette® (aluminium ethyl phosphate; 80% WP at 375g/100L water) and Ridomil® (metalaxyl; 5% granules at 200g/tree) improved tree condition, especially if the trees were cut-back heavily. Severely infected trees need to be cut back and treated with fungicide to recover (Moll *et al.*, 1978).

Metalaxyl (CGA 48988, Ridomil®), a systemic fungicide, gave very good control of PRR (Darvas *et al.*, 1978; Darvas *et al.*, 1979a; b) when applied at 0.4g or 1.6g every 8 weeks for newly planted trees. The same fungicide, at 50g a.i./tree every 10 weeks, "eradicated" *P. cinnamomi* from the soil and resulted in improved tree health (Darvas, 1978b). Metalaxyl (2.5g a.i./m^2) again gave good control in young trees in a replant situation. Ethazole (10g a.i./m^2) was equally as good. Dowco 444® and Chevron 20615® (milfuram) were inferior. Previcur N controlled disease symptoms but did not improve tree health. Foliar phosetyl-Al failed to control the PRR on younger trees – presumably due to the reduced leaf surface area for uptake (Darvas, 1982d; c), After four years of treatment on eight year old trees (starting in 1977), metalaxyl (2.5g a.i./m^2) only gave good control for the first two years after which tree condition regressed. Ethazole only gave good control at 10g a.i./m^2. Phosetyl-Al leaf spray (0.3% a.i.) was effective throughout the experiment, particularly in the fourth year but did not control the *P. cinnamomi* in the soil (Darvas, 1982d; 1983c).

Five fungicides: metalaxyl (5G and 25WP), phosetyl-Al (80% WP), Chevron 20615 (10G and 50WP; milfuram), M4408 (71% EC), and G1981 (25% WP), fungicide concentration, and the method of application (foliar spray, soil drench, or stem paint), were tested for the control of PRR in Edranol seedlings. When considering lateral root dry mass, the most effective treatments were: metalaxyl as a soil drench (2 g a.i./m^2 5G or 1g a.i. /m^2 WP) or stem paint (0.5g a.i.) and Chevron 20615 as a soil drench (2 or 4 g a.i./m^2 50WP). Treatments that were less effective were: Phosetyl-Al as stem paint (0.5g a.i.) or foliar spray (0.30 a.i./L), M4408 as a soil drench (2 g a.i./m^2) or stem paint (0.25 or 0.50g a.i., but phytotoxic at both concentrations), and Chevron 20615 as a stem paint (1g a.i.). Other treatment combinations were not effective (Snyman, 1982).

Trunk injections of phosetyl-Al (0.4g a.i./m^2 twice per season) provided excellent control of PRR in Fuerte, Hass, Edranol, and Ryan (Darvas *et al.*, 1983). It was suggested that the number of applications could be reduced to once per season after the second or third season. Trunk paints of phosetyl-Al (20g a.i./tree) and Dowco 444® gave slight control of PRR; metalaxyl gave no control (Darvas, 1983d). The relationship between tree recovery from PRR in the first year after injecting phosetyl-Al, the dose rate of the fungicide, and the initial disease severity were quantified by Darvas *et al.* (1985). Important results from that study were:

1. Dose rates of ≤0.3 g a.i./m^2 canopy were not effective in controlling PRR, but did slow its advance.
2. Rates above 0.8 g a.i./m^2 canopy were phytotoxic in the first year but the phytotoxicity did not persist into the second year.
3. Healthier trees required a higher dose of phosetyl-Al to achieve the same result, because the fungicide is diluted in the increased foliage and roots.

4. Injections need to be spaced evenly around the tree to avoid phytotoxicity and achieve control [*because of a low level of lateral distribution of phosphite in avocado trees – Ed.*].

Trunk paint, and sponge bands impregnated with phosetyl-Al were effective in controlling PRR, and resulted in faster tree growth for 3-4 months (Snyman & Kotzé, 1983a). Etridiazole (10g a.i./m^2) soil drench, metalaxyl (2.5g a.i.) soil drench, metalaxyl (125g a.i./L) stem paint and phosetyl-Al (100g or 400g a.i./L stem paint) controlled PRR in avocado seedlings. There was evidence that *P. cinnamomi* developed resistance to metalaxyl after exposure for more than two years (Snyman & Kotzé, 1983b). The following season, metalaxyl as a soil drench (5% a.i. granule, 2.5g a.i./m), and as a sponge band (0.5g a.i./tree) were the most effective treatments in the control of PRR (Snyman & Kotzé, 1984a). The application of metalaxyl and phosetyl-Al using stem paint and stem sponge band did not show any effect on stem circumference after two years, but it was an extremely dry period (Snyman & Kotzé, 1984b). It was concluded that further observations were required. It was suggested that the reduced efficacy of metalaxyl after repeated use was due to enhanced biodegradation in the soil. An integrated pest management system, incorporating metalaxyl if necessary, was recommended to control PRR while prolonging the efficacy of metalaxyl (McKenzie, 1984). Snyman & Kotzé (1984c), however, suggested that *P. cinnamomi* developed resistance, rather than enhanced biodegradation of the metalaxyl by soil micro-organisms [*this has subsequently been disproven – Ed.*].

Researchers from Ciba-Geigy concluded that metalaxyl (Ridomil 5G®) should only be used for two consecutive seasons, and then alternated with phosetyl-Al, as well as using cultural practices to reduce *P. cinnamomi* pressure (McKenzie & Margot, 1982). This was later confirmed when both *P. cinnamomi* and *Pythium splendens* developed resistance to metalaxyl after continuous application for five years. It was concluded that strains or isolates of *P. cinnamomi* were highly resistant to metalaxyl, and that there may have been increased breakdown of the metalaxyl by soil micro-organisms (Darvas & Becker, 1984).

The supplementation of phosetyl-Al trunk injections with $ZnSO_4$ (0.4g/m^2 canopy area) was recommended to improve tree condition did not result in the faster remission of PRR symptoms; the injection of N and B sources did not prove beneficial (Darvas, 1984b). Supplementation with calcium at 200ppm Ca^{2+} had a positive effect on PRR control (Snyman, 1984). In a preliminary report, trunk injections of H_2PO_3 or H_3PO_4 both increased the phosphorus concentration in leaves (Toerien & Slabbert, 1984).

It was later found that $ZnSO_4$ was incompatible with Aliette-Ca® (phosetyl-Ca) so alternative zinc formulations were tested. Zinc nitrate, Agrizinc®, and zinc chelate all raised the zinc concentration in avocado leaves; zinc acetate was not successful (Rowell, 1988a). [*Subsequently it has been found that the incorporation of Zn and/or B with phosphonate injections is not sufficient to raise leaf Zn levels – Ed.*].

The use of metalaxyl and phosetyl-Al in California was discussed by Coffey (1985a). The particular production factors in California, namely the high costs of labour and water, as well as the potential loss of efficacy after prolonged use were important factors. It was recommended that a pre-plant fungicide be applied, followed by a post-plant treatment 7-10 days later to assist the trees during establishment. [*Phosetyl-Al and later phosphonate products were never registered for avocados in California for PRR control. This was because no chemical company has been prepared to outlay the*

time, effort, and financial cost to register a common chemical for the relatively small avocado industry in the USA – Ed.].

A review on trunk injections for PRR control was given by Darvas & Bezuidenhout (1987). They discussed the use of phosetyl-Al, phosetyl-Ca, phosphorous acid, and potassium phosphite, as well as the inclusion of micro-nutrients in the injection formulation. Previously unpublished information on the use of *Bacillus* suspensions in the formulation was also discussed. The reader is referred to this article for more information.

In Australia, PRR control was/is done in an integrated manner (Pegg & Whiley, 1987), using:

1. Disease-free nursery trees.
2. Site selection for suitable soil water drainage.
3. Companion cropping (e.g. bananas [*not today because of high N requirement for bananas – Ed.*].) to increase organic matter and assist in reducing soil water loss by transpiration.
4. Cover cropping and mulching to increase organic matter content. This is important in increasing the biological control for *P. cinnamomi* (*i.e.* encourage a suppressive soil).
5. Nutrition – especially phosphorus, boron, zinc, and calcium. Soil calcium concentrations of 3000-5000 mg/kg were suppressive to *P. cinnamomi*.
6. Chemical control by injecting buffered monohydrogen dipotassium phosphite (phosphorous acid or potassium phosphonate).

The usefulness of phosetyl-Al and phosetyl-Ca (Aliette Ca®), with the addition of zinc, at a dose rate of 0.3g a.i./m^2 in controlling PRR and improving tree health was confirmed by experiments in South Africa by Wood *et al.* (1987) of Maybaker.

The treatment of non-symptomatic trees in a PRR-infected orchard was encouraged by Hanrahan & Paviot (1987) of Rhône-Poulenc because when treated, a 12% yield improvement was recorded for those trees.

Different inorganic compounds were tested as injections to control PRR, as an alternative or adjuvant to phosphorous acid. KOH, K_2SO_4, and boric acid could control PRR, but they were not as effective as phosphorous acid; hydrogen peroxide (H_2O_2) and hypophosphorous acid (H_3PO_2) were not effective; dibasic-ammonium phosphate (DAP) increased PRR. It was theorised that these compounds acted as nutrients, phyto-alexin inducers, or as fungistatic compounds (Bezuidenhout *et al.*, 1987b).

Three doses per year of phosphorous acid (0.1g/m^2), and the combination of phosphorous acid plus boric acid (each 0.1g/m^2), were both effective in improving tree condition by combating PRR; boric acid alone was not effective. Boron was acknowledged as being chronically deficient at Westfalia. A dose of 0.32g phosphorous acid/m^2 was more effective than phosetyl-Al at 0.4g/m^2 (Bezuidenhout & Toerien, 1988).

PRR-infected trees have depleted leaf nutrient levels, especially N, P, S, Zn, and B, and increased Cl levels compared to recovering trees. Yields were not immediately increased after phosphorous acid injection, because photosynthates were diverted to vegetative growth during the first 12 months of tree recovery. The use of KCl was discouraged as a source of K, and K_2SO_4 was recommended as an alternative, to avoid chloride toxicity (Whiley & Pegg, 1987).

It was shown that phosphorous acid does not induce the production of phyto-alexins but acts by a direct mode of action. Although concentrations never reach fungicidal levels, it was proposed that the phosphorous acid concentration was high enough to inhibit sporangium production and zoospore release and allow the plant enough time to activate host defence mechanisms such as the formation of suberin and tyloses (Botha *et al.*, 1988).

It was recommended that trees are injected 60 days after bud-break, after the active shoot growth and more during the summer root flush, to increase the phosphonate in the roots (Maas & Kotzé, 1990a).

Trees left untreated for two years after phosetyl injection remained in excellent health (CG rating of 1) with and without organic soil amendments. However further data were needed before a recommendation could be made (Köhne & Kirkman, 1991).

Phosphorous acid was only active endogenously and was not exuded in significant concentrations to inhibit *P. cinnamomi* cyst germination and appressorium formation on avocado roots (Van der Merwe, 1992a). In a follow up study, it was concluded that after 2 weeks the PO_3^{3-} concentration after trunk injection reached 9.8ppm and gave 87% control of root colonisation and gave control for 7-8 weeks. A foliar spray on small trees only resulted in a concentration of 2.45ppm and gave 47% control. Scanning electron microscopy did not show any difference between H_3PO_3-treated and control roots with regard to the ability of *P. cinnamomi* zoospores to recognise, encyst, germinate, and form appresoria. It was concluded that the defence mechanism is a combination of direct and indirect action (van der Merwe & Kotzé, 1994).

Isolates of *P. cinnamomi* from trees that were continuously treated with phosphonates were less sensitive to phosetyl-Al and H_3PO_3 *in vitro* than isolates obtained from trees not treated with phosphonates, suggesting that *P. cinnamomi* was developing resistance to phosphonates and monitoring needed to be continued (Duvenhage, 1994a). The *P. cinnamomi* from trees treated with phosphorous acid had developed some resistance to H_3PO_3 and phosetyl-Al, however the *P. cinnamomi* from trees treated with phosetyl-Al had not developed resistance (Duvenhage & Köhne, 1995a; 1996). The differences in growth inhibition of *P. cinnamomi* were non-significant in 1996 (Duvenhage & Köhne, 1997). Later it was found the *P. cinnamomi* from repeatedly treated trees was 10% less sensitive to H_3PO_3 and 21% less sensitive to Phosetyl-Al (Duvenhage, 1999). Atypical results were observed in 2000 due to heavy rains that were introducing new populations of *P. cinnamomi* from higher elevation orchards. Although *P. cinnamomi* from phosetyl-Al treated trees continued to show a reduction in inhibition, *P. cinnamomi* from H_3PO_3 treated trees showed an increase in inhibition, and *P. cinnamomi* from untreated trees showed a decrease in inhibition (Duvenhage, 2001).

Two mechanical injectors were compared, the Phillips gas gun and Rawlins injector. Each unit had positives and negatives, but were generally better than conventional injections with plastic syringes except that it was difficult to measure the actual volume injected and that remaining in the tree (Duvenhage & Köhne, 1995a).

Dimethomorph offered equal or better control of PRR as metalaxyl and phosetyl-Al at 10-100 mg/L doses, in nursery tree studies and further testing was recommended. Phytotoxicity was noted at 1000 and 10 000 mg/L (Duvenhage & Köhne, 1995b).

In an effort to improve the efficiency of PRR treatments, injecting after the spring and summer flushes was necessary to improve tree health, but this could be reduced to one injection after the spring flush to maintain tree health. Also, a 20% solution with half the number of injection points could be used. A trunk paint of 5% H_3PO_3 could also be used after the growth flushes to maintain tree health (Duvenhage & Köhne, 1996). Aliette of H_3PO_3 trunk sprays (0.8 g a.i./m^2 canopy area) applied four times resulted in phosphonic acid residues that were comparable to two trunk injections of H_3PO_3. Trunk sprays should be applied every 6-7 weeks from mid-September to mid- January to the thin bark of the tree to give comparable control to two trunk injections (Duvenhage, 1999).

The injection of avocado trees with H_3PO_3 resulted in damage to the wood. Un-neutralised 10 and 15% solutions of H_3PO_3 caused less damage than neutralised solutions but both 20% solutions caused similar damage. Sealing injection holes did not reduce the damage. The addition of both ZnSO4 and Solubor® together tended to increase wood damage in younger trees. Hence, the injection of avocado trees should be kept to a minimum to maintain tree health and keep damage to the wood to a minimum (Robbertse & Duvenhage, 1999). [*It is probable that the trunk damage is more apparent than real, as the stained wood is dead structural tissue, and the outer living conducting tissue is renewed by the cambium each season – Ed.*].

Leaf sprays (0.75% H_3PO_3, pH adjusted to 7.2, 943L/ha) resulted PO_3^{3-} concentrations comparable with trunk injections after 28 days. Care must be taken not to spray the soil as it will increase the risk of *P. cinnamomi* developing resistance (Duvenhage, 2001).

The use of a silicon dioxide drench (1L at 20mL/L before *P. cinnamomi* inoculation) in pot trials offered protection from PRR. The root mass of these treated trees was significantly higher than the negative control and comparable to a 1% phosphorous acid foliar spray. Diffusive resistance was lower in the trees from the above two treatments, indicating that these treatments reduced plant respiration, but did not affect chlorophyll fluorescence for more than a short period. Further field trials were recommended (Bekker *et al.*, 2005). Potassium silicate, when applied throughout the production season at 20L/tree at 20mL K_2SiO_3/L water, combatted PRR *in vivo*. The mode of action is both direct and indirect by increasing the concentration of phenolics in the tree (Bekker *et al.*, 2006a). The application of a potassium silicate drench resulted in increased feeder root density compared with PRR treatment using phosphonate trunk injection. With this disease control and greater root density, tree health was improved, boron uptake increased, and hence yields were also increased. Three applications of silicate were recommended: the first during flowering and fruit set (September), the second before fruit drop (November) and the third before the root flush (February-March). Silicate injections were not effective in controlling PRR. Silicon is take up by avocado roots but it is not readily translocated to the leaves. The increase in soil pH from the silicate drenches is an added benefit because the soil pH in many avocado orchards in South Africa is sub-optimal (Bekker *et al.*, 2007a). The re-application of silicon is important for disease control because silicon leaches from the soil, particularly if the CEC is low, as in a sandy soil. From pot trials, the effectiveness of silicon in PRR control would be incremental if *P. cinnamomi* was already present (Bekker *et al.*, 2007b). The effect on phenolics by silicon application is complex, but the application of silicon increased total phenolic content of avocado root tissue but decreased cell wall bound phenolics at certain times (Bekker *et al.*, 2007c).

Silicon dioxide (20.7%) had fungicidal activity but the effective concentration is variable depending on pathogen. Phytophthora was suppressed at concentrations of ≥5mL Si per L agar but *Fusarium* spp. and *Verticillium* spp. growth was enhanced at concentrations of 5-10mL/L. A minimum dose of 20mL/L was preliminarily recommended for PRR control. Soluble silicon also increases the medium pH which may slow fungal growth (Kaiser *et al.*, 2005). The next year it was found that the increased pH only had a partial effect in disease control and that soluble silicon has a fungicidal effect on *C. gloeosporiodes*, *Glomerella cingulata*, *Lasidiplodia theobromae*, *Dothiorella mangiferae*, *Pestalotiopsis maculans*, *Phomopsis perniciosa*, and *P. cinnamomi*. Complete disease control was consistently achieved at 80mL Si/L agar and in one of the two replications at 40mL Si/L agar (Bekker *et al.*, 2006b).

3.1.1.2. Integrated & Cultural Control

In a soil survey at Westfalia to determine soil characteristics related to PRR, the depth of topsoil was greater under healthy trees than sick trees. Better tree health was thought to be because of a higher organic matter content and nutrient concentration and a deeper soil would permit better drainage. Low soil calcium content, a high concentration of soluble salts, and a shallow topsoil can lead to increased PRR. Soil Mg, K, P, and Al were not correlated to PRR. Soil pH did not have an effect on PRR, because it was in the normal range of soil pH, which is not inhibitive of *P. cinnamomi* (Darvas, 1977d).

Prof. Zentmyer of the University of California, Riverside visited South Africa in February 1980. He was impressed by the research being done on combating PRR, particularly by Joe Darvas and Prof. Kotzé. He commended the efforts of the avocado nurseries to provide *P. cinnamomi*-free trees. He stressed the importance of combining treatments to combat PRR – such as resistant rootstocks, cultural practices, and fungicides. He advocated greater co-operation between the South African industry and the University of California Riverside (which is still continuing today to the benefit of both parties). He stressed the importance of planting avocados on free-draining soils to limit PRR (Zentmyer, 1979).

Wolstenholme (1979) gave an early review of integrated control of PRR, in relation to the discovery of the efficacy of Ridomil® and Aliette® in controlling PRR. Wolstenholme advocated an integrated approach to control and "live with" PRR, based on what he called the "Pegg wheel" principles of:

1. Tolerant rootstocks
    a. The use of clonal tolerant rootstocks has helped in managing the disease, permitted by Brokaw Nursery's (California) patented improved Frolich method of vegetative propagation.
2. Rapid soil drainage
    a. The classification of soils according to slight, moderate, and severe hazard, and PRR-suppressive soils, and planting accordingly.
    b. Planning for heavy rainfall by planting on ridges, and building drainage ditches to avoid turning a good quality soil to one riddled with PRR.
3. Organic amendments
    a. PRR-suppressive soils are characterised by the high level of microbial activity. The increased microbial activity is favoured by high soil organic matter content, and high calcium content.
    b. Mulching to increase the organic matter content can increase the suppressiveness of an orchard soil to PRR.

4. Inorganic nutrition
    a. South African avocado soils are generally very low in calcium and this can be ameliorated by liming, but the recommended application rate should be followed to prevent over-liming.
    b. PRR-suppressive soils have high total soil N (0.6-0.8%), with most of the N being tied up in humic residues rather than as plant-available ammonium or nitrate.
5. Judicious use of chemicals
    a. Wolstenholme cautioned on the judicious use of Ridomil® for PRR control, because injudicious use of Ridomil® would hasten resistance, and a holistic approach would still be needed in a high PRR risk area like South Africa.
6. Disease-free nursery trees
    a. This was already implemented at the time of writing (1979) in the major South Africa avocado nurseries.

[*An updated version of the "Pegg Wheel" was given by Wolstenholme & Sheard (2010)– Ed.*].

In a long term study, stag-horning was only temporarily effective in improving tree health. Velvet beans, lime, and chicken manure were ineffective, and even reduced the efficacy of metalaxyl. A phosetyl-Al foliar spray (six applications every four weeks) was ineffective in a re-plant situation, which was thought to be because the young trees had insufficient foliage to absorb sufficient fungicide. A soil drench of phosetyl-Al was variable and too expensive to be applied commercially [*except perhaps on small replant trees – Ed.*]. On mature trees, metalaxyl and phosetyl-Al were both effective. Metalaxyl was superior on a sandy soil while phosetyl-Al was more effective on a heavier soil. A combination treatment, without stag-horning, may be commercially viable because stag-horning results in losing at least one year's crop (Wood & Moll, 1981).

In a preliminary report, calcium (either calcium sulphate or calcium carbonate) improved young tree growth, but Ridomil® was also effective in improving tree growth (Snyman, 1981). In a replant situation, $CaSO_4$ (5 or 10kg/m^2) and $CaCO_3$ (3 or 6kg/m^2) did offer some protection from PRR but were not as effective as metalaxyl. Duke seedlings responded better to $CaSO_4$ and Guatemalan seedlings better to $CaCO_3$ in terms of stem thickness (Snyman & Darvas, 1982).

Prof. Kotzé outlined an integrated approach to PRR control, again stressing the importance of not relying on fungicides alone. The four aspects of PRR control are: disease free nursery plants, resistant or tolerant rootstocks, judicious use of fungicides, and sound orchard practices, including: liming, fertilization, irrigation, drainage (Kotzé, 1985a). These aspects still form the basis of PRR management in avocado orchards, as is shown by subsequent research and current recommendations. [*The implication is that chemical control alone is insufficient, especially in a high pressure disease situation. A holistic deal of remedial measures is necessary – Ed.*].

A good, brief review on PRR control in South Africa was given by Kotzé *et al.* (1987) [*recommended review – Ed.*] where they outlined the principle of the ANA (APIS), the fungicide research that led to phosetyl-Al/-Ca or phosphorous acid injections, fumigation, rootstock selection, and suppressive soils.

Citrus waste compost, made from mostly citrus peel, inhibited the growth of *P. cinnamomi* and *P. nicotianae in vitro* (van Heerden *et al.*, 1995). The application of 2-4kg of composted citrus waste was also effective in improving tree vigour in the field (Landman *et al.*, 1997).

3.1.1.3. Biocontrol & Suppressive Soils

Although already discussed under general PRR control, this section deals with specifics of biocontrol and suppressive soils.

The composition of the soil microflora could be linked to the presence of *P. cinnamomi*, whereby bacteria, fungi, and pseudomonads were lower in healthy soils and infected soils, while actinomycetes were higher in healthy soils. *Pencillium* spp. were more abundant in healthy soils than infected soils, while the opposite was true for *Gliocadium* spp.; *Trichoderma* spp. were isolated in significantly higher numbers from a stunted tree than healthy trees (Maas & Kotzé, 1989).

The *in vitro* detached root method was used to evaluate the potential of bacterial isolates as biological control agents for PRR. One isolate (A2.27) reduced root infection by 60% (Botha *et al.*, 1989; Maas & Kotzé, 1990b; Van der Merwe, 1990).

Six PRR-suppressive soils were identified in the Tzaneen area. The suppression was caused by endogenous soil microbes (Duvenhage & Maas, 1990; Duvenhage *et al.*, 1991).

The addition of nitrogen and calcium (both high in PRR-suppressive soils) reduced the pathogenicity of *P. cinnamomi* but did not increase the resistance of treated plants (Duvenhage, 1990). The following year it was concluded that calcium ($CaSO_4$) increased plant resistance rather than lowering *P. cinnamomi* pathogenicity (Duvenhage & Kotzé, 1991). It was later shown that the benefit of calcium supplementation was lost when trees were grafted to Hass (Duvenhage *et al.*, 1992).

Van der Merwe (1992b) found eight bacterial isolates that were antagonistic to *P. cinnamomi in vitro*, but *in vivo* results showed that none of the isolates succeeded in reducing the incidence of *P. cinnamomi* in the soil, and the method of application to the plant of soil is critical.

In an attempt to prevent phosetyl-Al resistance development in *P. cinnamomi*, and the reduction in trunk injections, trunk injections were stopped once trees that had recovered from PRR and suppressive soil techniques were applied. A legume cover crop (*Dolichos lablab*) or lucerne straw mulch (with or without 100kg/tree cattle manure) seemed to prevent yield reduction after four years, but cattle manure (100kg/tree) was not effective; further testing was warranted to improve the application and perhaps combine it with intermittent trunk injections (Duvenhage *et al.*, 1993).

Duvenhage & Kotzé (1993) found three fungal (*Aspergillus candidus*, *Paecilomyces lilacinus*, and *Trichoderma hamatum*) and two bacterial isolates (*Bacillus azotoformans* and *B. megaterium*) that significantly reduced PRR development and root colonization of Edranol seedlings. Three fungal antagonists *Paecilomyces lilacinus*, *Aspergillus candidus*, and *Trichoderma hamatum* were applied to young and mature orchards as biocontrol agents for PRR. At that time no significant differences were noted (Duvenhage & Köhne, 1995a). After 4 seasons, only the population of *T. hamatum* increased in the field (Duvenhage & Köhne, 1996). The populations of the antagonists plummeted in 1996, probably due to the very high rainfall that year (Duvenhage & Köhne, 1997). Tree condition tended to be better when trees were treated with the antagonists, but yield and *P. cinnamomi* populations were not significantly different, so the treated soil tended to be more suppressive (Duvenhage & Kremer-Köhne, 1998). In the final report it was concluded that *A. candidus* and *T. hamatum* populations both increased, tree and root health was improved and the soil tended to be more suppressive to *P. cinnamomi* but yield was not improved (Duvenhage, 1999).

Trichoderma harzanium (isolates C4 and BB5) and *T. hamatum* (isolate F56) significantly reduced root rot and stimulated root regeneration of seedlings. BB5 increased root growth in pine bark medium in the absence of *P. cinnamomi*. C4 and F56 significantly reduced the *P. cinnamomi* population, but BB5 did not. The presence of *Trichoderma spp*. decreased *P. cinnamomi* populations in suppressive soils. These isolates could be used to increase the suppressive nature of avocado orchards soil if they could be established in the field (McLeod *et al.*, 1995). [*And more importantly, maintain a high concentration for a sufficiently long period – Ed.*].

Three carrier substrates (millet seed, peat, composted citrus waste, and composted pine bark) were ineffective in cultivated *T. harzanium* for the control of PRR, and alternative methods were being investigated to establish the biocontrol agent in the rhizosphere (Landman *et al.*, 1996). *T. harzanium* was effective in increasing tree growth rate (and presumably in controlling PRR) both in the nursery and field. Results were improved in the field if the soil was solarised beforehand (3 weeks under clear polyethylene plastic of 30µm thickness. B*. megaterium* was ineffective in the nursery and in the field.

3.1.1.4. Antifungal Compounds

In an investigation into antifungal compounds present in the cultivars Edranol, Duke 6, and Duke 7, as well as an escape tree from Westfalia, leaves and/branches were assayed for fungitoxic compounds with the putative fungitoxic compound borbonol (Zaki *et al.*, 1980). It was suggested that other antifungal compounds are present in avocado trees, but it is unclear if these are effective against *P. cinnamomi*. Borbonol was effective against *Staphylococcus aureus*, and avocado seeds are used as a cure for dysentery and diarrhoea by native South Americans (Uphof, 1968). This could open another product line for waste avocado seeds. A number of fungitoxic compounds were identified in all the avocado tissues assayed (leaf, seed, skin, fruit flesh, and root). Post-harvest pathogens were inhibited to a considerably higher degree by leaf extracts than root pathogens. Root extracts had the greatest inhibition on the *P. cinnamomi* isolates tested (Wehner & Apostolides, 1981; Wehner *et al.*, 1982).

3.1.1.5. Pathogen Studies

A range of pathogenic soil fungi and oomycetes were isolated at Westfalia in 1978. Only *Phytophthora cinnamomi* was found in sufficient frequency to severely affect avocado trees there (Darvas, 1978a).

A survey of avocado soil-borne pathogens revealed that *P. cinnamomi* was the most common and most virulent pathogen, with *Pythium* spp. (also an oomycete) and *Fusarium oxysporum* also proving to be pathogenic. The application of Ridomil® (2.5g a.i./m^2) provided long-lasting control of *P. cinnamomi* and *Pythium* spp. but resulted in an increase in *Fusarium oxysporum* (Darvas, 1979b).

In a study on grapevine rootstocks in the Western Cape, *P. cinnamomi* was present in many nurseries. The amino acids aspartame, glutamate, and arginine attracted *P. cinnamomi* zoospores. The susceptible rootstock '99R' had higher concentrations of arginine and glutamate than the more tolerant rootstocks '143B Mgt' and 'Jacquez'. Foliar drenches of Aliette® and soil drenches of Ridomil® reduced *P. cinnamomi* infection. Hot water dips of dormant nursery vines at 50°C for 5-30 minutes eradicated the *P. cinnamomi* spores (Marais & De La Harpe, 1981).

Disease infection and severity of infection both showed an approximate normal distribution, with the highest frequency at disease ratings of 2-5 on the Ciba-Geigy scale. *P. cinnamomi* is not a particularly competitive saprophyte, so once it has killed the majority of the feeder roots and the tree health has

declined to a rating of greater than 6, the oomycete's food source is exhausted and the spore numbers decline (Darvas, 1982e).

The infection of avocado seedlings by *P. cinnamomi* was studied by Aveling & Rijkenberg (1986) and followed a pattern of:

1. Zoospores are attracted to the region of elongation above the root tip.
2. Zoospores encyst and germinate by germ tubes.
3. The germ tubes penetrate the root directly or form appressoria-like swellings before penetration. Penetration was mostly intercellular.
4. Invaded and neighbouring cells died rapidly.
5. The plant released phenolic compounds ahead of the infection but these were not effective in slowing the infection.

Besides *P. cinnamomi*, three other soil-borne pathogens were identified in Mexico: *Phymatotrichum omnivorum*, *Verticillium albo-atrum*, and *Armillaria mellea*. These pathogens were of minor economic impact in comparison to *P. cinnamomi* because of limited distribution in avocado orchards (Luna & Fucikovsky, 1987).

PRR-susceptible rootstocks (Edranol) exuded more amino acids than PRR-tolerant rootstocks (Duke 7, G6, and G755). *P. cinnamomi* zoospores are attracted by these amino acids, particularly arginine, aspartic acid, and glutamic acid (Botha & Kotzé, 1989a). This paragraph is repeated in §4.2 (Rootstock Selection).

3.1.1.6. Quantification

Darvas (1979a) developed a relatively simple semi-quantitative analysis for *P. cinnamomi* which could be used to determine the threshold between spot treatments or a blanket treatment for PRR. This method used five blue lupin seedlings (*Lupinus angustifolius*) which were grown in 300mL soil samples from the orchard in question. As the seedlings died they were surface sterilised with 0.1% $HgCl_2$ and plated on PDA for a few days to identify the pathogens.

Aerial photography using false colour near-infrared was tested on citrus orchards for the detection of root disease and/or water stress. The technique showed promise for the detection of PRR and/or water stress in avocado orchards. Healthy trees exhibited a red colour, whereas trees with mild stress showed up pink. The colour shifted to mauve and blue as stress increased. The plane was remote controlled with a 2.5m wingspan (Ehlers & Kotzé, 1982).

The elution and quantification of phosphite (PO_3^{3-}), phosphate (PO_4^{3-}), and ethylphosphonate, with a limit of detection of 0.01ppm was described by Bezuidenhout *et al.* (1985) using gas chromatography. It was shown that: (i) there is a correlation between the added amount of ethylphosphonate and phosphite and the measured amounts of these compounds, (ii) these compounds move more readily to roots than leaves but are detected in leaves and fruit at least 12 weeks after the application of phosetyl-Al. In a follow-up article, it was found the partitioning of phosphite favoured branches (50%) over roots (30%) over leaves (20%). Three genera of bacteria capable of oxidising phosphite to phosphate were isolated from avocado roots and leaves. This is important because phosphite is not utilised as a phosphorus source for plants, but phosphate is. The half-life of phosphorus in field-planted Fuerte trees was 6-10 weeks (Bezuidenhout *et al.*, 1987a). Phosphite moved rapidly into the

leaves of the avocado tree, but after 21 days there was a significant increase in the phosphite concentration in the roots; the concentration of phosphite in the roots was maximal after 7 weeks but still quite elevated after 9 weeks (Schutte *et al.*, 1988).

An *in vitro* method to screen rootstocks for PRR tolerance was developed by Botha *et al.* (1989). This method involved measuring PRR lesion development on excised/detached roots and leaves. This method was later used to evaluate escape trees for PRR tolerance (van der Merwe *et al.*, 1990). Nine of these trees were as tolerant to PRR as Martin Grande (G755) and six were significantly more tolerant than Duke 7. The method was subsequently improved, and it was shown that mycelium could be used as a source of inoculum instead of zoospores (Van der Merwe, 1990). Later results showed that there was a strong correlation between the above *in vitro* method and a pot trial with Duke 7 cuttings (Van der Merwe, 1993).

3.1.2. Trunk cankers

The causal agent of trunk- or crown canker in Duke 7 was identified as *Phytophthora cinnamomi* and was shown to be effectively controlled by phosetyl-Al and metalaxyl (Lonsdale *et al.*, 1988a). Duke 7, G6, and G755 rootstocks were highly susceptible to crown canker in greenhouse conditions, suggesting that stem and root tissue are differently susceptible to *P. cinnamomi* (Lonsdale *et al.*, 1988b). Duke 7 trees grafted to Hass were particularly susceptible to crown canker (Botha & Kotzé, 1989b). [*Mexican race rootstocks are more susceptible to P. cinnamomi trunk canker than Guatemalan race rootstocks. Hence the problem is much less severe in Australia, where Guatemalan rootstocks are mainly used – Ed.*].

Bacterial canker was reported in 1980. It was tentatively identified as *Pseudomonas* when further studies were underway (Myburgh & Kotzé, 1982; 1983). The pathogen was later identified as being *Pseudomonas syringae* (Korsten & Kotzé, 1984; 1985). The pathogen could be controlled using a warm water treatment of 42°C for 5 min, or slightly lower temperatures for longer. This treatment did not negatively affect avocado small branches. Monoclonal antibodies against the *P. syringae* were prepared from the cankerous lesions for further study and identification of the pathogen (Korsten *et al.*, 1987a). No relationship could be found between predisposing factors and bacterial canker – probably because of the low stress environment at the time. *P. syringae* can be transmitted through budwood so orchards showing symptoms of canker should not be used as a budwood source (Korsten & Towsen, 1997). [*Trunk canker can also be a symptom of severe boron deficiency, developing from splits in the trunk or branches, with copious white exudate. It is uncommon, and takes a long time to develop – Ed.*].

Phomopsis perseae was also identified as causing trunk canker in Martin Grande (G755) rootstock. It was controlled *in vitro* by benomyl (van der Merwe & Kotzé, 1991).

3.1.3. Avocado sunblotch viroid (ASBVd)

At the time (1978) the method of indexing trees for ASBVd was to either graft buds or cuttings to healthy seedlings, or grafting healthy buds or cuttings to seedlings of the suspect tree (Da Graca, 1978). The former method was preferable, but still took two years to confirm a diagnosis. Hass and Collinson were good indicator seedlings, and were grown at 30°C in a greenhouse. No biochemical test was available in 1978. The viroid was not mechanically transmissible. It is thermally inactivated at 56°C for 15 minutes. Transmission took two weeks after grafting (Da Graca, 1978). With improvements in this method, *i.e.* by growing the trees in a hot greenhouse (30/28°C day/night), and cutting back

growth after three months to induce new growth, ASBVd could be detected in nine months using five indicator plants (Da Graca, 1979).

A polyacrylamide gel electrophoresis (PAGE) method, that took only six hours to identify ASBVd, was outlined by Da Graca (1981). This was a great improvement from the initial time of 18 months. This method could identify $ASBVd_3$ and $ASBVd_5$. *Persea schiedeana* (Coyo), *Ocotea bullata* (black stinkwood), and *Cinnamomum camphora* (camphor) were artificially infected with ASBVd. *Persea indica* and *Cryptocarya liebertiana* were not infected at the time of the report (Da Graca & van Vuuren, 1981). Avocado flower buds contained high concentrations of ASBVd, and would be suitable for ASBVd indexing using PAGE – however this was not practical because flowering is over a limited period each year (Da Graca & Goodman, 1982). This method was tested the following year on field trees and concluded to be a success and the "quickest, simplest and most reliable index method" at the time (Da Graca & Mason, 1983). Unfortunately, difficulties were encountered, delaying the commercial roll-out of this method for ASBVd detection (Da Graca, 1984). Challenges were keeping samples viable for more than one month at -20°C, and the timing of the sampling for flowers. The following year, the sensitivity of the PAGE method was insufficient for reliable use and was discontinued (Da Graca & Trench, 1985a) in favour of the synthetic oligonucleotide probe method outlined by Bar-Joseph *et al.* (1985). This method was 128 to 256 times more sensitive than the PAGE method. This increased sensitivity is important because there is a hundred-fold variation in viroid concentration between leaves on an infected branch. The following year, samples were taken from the ANA-accredited nurseries for ASBVd analysis using Bar-Joseph's dot blot hybridisation method (Korsten *et al.*, 1986). Of the 915 trees tested that year, 3% were positive for ASBVd and 8% were possibly positive or subject to laboratory error. Continued monitoring and further refinement of the method was also suggested in a related publication (Bar-Joseph *et al.*, 1986). The following year 3125 trees were tested using the method. Each tree was tested twice in a 15-month period to reduce the chance of not detecting ASBVd due to seasonal and tissue variations (Korsten *et al.*, 1987b). Overall, 2% of the tested trees were symptomless carriers, with three nurseries being clean, and one nursery having a 9.2% infection.

Recommendations to prevent the spread of ASBVd were provided by Moll *et al.* (1984). These recommendations included:

1. Seed source
    a. Use seed from grafted trees that are 10 years or older
    b. Use ASBVd-free material for the rootstock. Zutano and Edranol were recommended in 1984
    c. Ensure trees remain ASBVd-free with annual inspections.
2. Rootstock source
    a. Use ASBVd-free material. Duke 6, Duke 7, G6, and G755 were recommended.
    b. This material should be grafted on trees that are 10 years or older and ASBVd-free
    c. Use nurse seed source that complies with above recommendations.
3. Scion source
    a. Only use material from grafted trees
    b. These trees must be 10 years or older and ASBVd-free
    c. Trees should be true to type, healthy, with consistently high yields
    d. Ensure trees remain ASBVd-free with annual inspections.

The effect of ASBVd on yield and fruit quality was severe in infected mature Fuerte trees. In the three year study, it was found that ASBVd-infected trees had a very low proportion of Class 1 and 2 fruit (Table 5). Even in "symptomless" Edranol trees, the yield was 82% that of the healthy trees (Da Graca *et al.*, 1983; Da Graca, 1985).

Table 5: Effect of ASBVd on the fruit quality on Fuerte fruit over a three year period (1982-1984) – from Da Graca (1985)

ASBVd/Year	Class 1	Class 2	Class 3
Healthy	**70%**	**27%**	**2%**
1982	77%	23%	0%
1983	59%	36%	6%
1984	68%	29%	4%
Infected	**21%**	**30%**	**50%**
1982	35%	12%	53%
1983	16%	58%	26%
1984	7%	21%	72%

Manicom & Luttig (1996) outlined an improved method for detecting ASBVd using digoxigenin (DIG) label for DNA hybridisation. This method was able to detect 1 infected leaf in a sample of 10 leaves at a level of 1ng ASBVd/g leaf. They were also testing the use of P.C.R methods to improve on the level of detection. Luttig & Manicom (1999) developed a technique using reverse transcription-polymerase chain reaction (RT-PCR) coupled with small-scale CF-11 cellulose column chromatography that would accurately detect ASBVd in avocado leaves, and were still to determine the maximum sample size.

3.1.4. Viruses

The use of PAGE to identify double stranded (ds) RNA as a marker for viroid infection was conducted by Da Graca & Trench (1985b). Most trees (rootstock and scion cultivars) that were tested contained at least one of AV1, AV2, or AV3.

Bar-Joseph *et al.* (1987) discussed viruses and viroids in avocado plants, focussing mostly on ASBVd because this is the only identified virus or viroid of economic importance in the industry. They did identify a Tobacco Mosaic Virus (TMV)-avocado isolate but it did not seem to be of economic importance.

The development of stem-pitting in Duke 6 was discussed by Moll *et al.* (1987). This disease precluded the use of Duke 6 as a rootstock in South Africa. The causal agent was not identified at that time, but thought to be a virus (paragraph repeated in §4.2 - Rootstock Selection).

A new project to identify double stranded RNA from avocados was initiated by Da Graca & Crookes (1989). Avocado virus 1 (AV1) was putatively cloned and used as a nucleic acid probe and work continued to identify two other suspected viruses (Cook & Nel, 1991). The following year it was concluded that AV1, AV2, and AV3 originated from the avocado genome, and were not viruses/viroids (Cook *et al.*, 1992).

3.1.5. Avocado black streak

Avocado Black Streak (ABS) is a disease isolated to California but the causal agent was not identified at the time. It did not appear to be caused by a virus so the authors were re-investigating potential fungal agents (Ohr & Murphy, 1987).

3.2. Flower Pathology

A number of microbes were isolated from avocado tissues on Westfalia Estate. *Alternia* spp., *Aspergillus* spp., *Botrytis cinerea* Pers ex Pers, *Cladosporium* spp., *Colletotrichum gloeosporioides*, *Gliocladium* spp., *Nigrospora* spp., *Periconia* spp., and *Pestalotia* sp. were isolated from avocado flowers. The presence of C. *gloeosporioides* may be a source of increased flower and fruitlet drop (Smith & Korsten, 1996).

3.3. Fruit Pathology

For the sake of convenience, fruit pathology is divided into pre- and post-harvest pathology, but it must be remembered that pre-harvest fungicides are required to control post-harvest diseases (viz. anthracnose and stem-end rot (SER)). Broad spectrum fungicides (especially copper formulations) are favoured for fungal control. As such there is overlap throughout this section and the entire section should be read before conclusions are drawn.

3.3.1. Pre-harvest pathology

3.3.1.1. Broad Spectrum Control

Cercospora purpurea (syn. *Pseudocercospora purpurea*) is the main cause of Cercospora spot (black spot) on avocados (Darvas, 1977a).

Cercospora spot was controlled with two applications of benomyl (0.025% a.i. with Nu-Film®) with the first spray in November (in Tzaneen) and the second 10 weeks later. Timing is critical, with the first application at fruitlet stage during the rainy season (Darvas, 1978c).

Fruit on the Western aspect of Fuerte trees are inclined to develop a higher incidence of Cercospora spot. Benomyl was more effective than Aliette® and Topsin® (thiophanate-methyl) for the control of Cercospora spot and anthracnose. Cercospora spore production increased during warm, wet conditions. Fruit exposed to infection early in the critical period (onset of warm, rainy summer period) developed significantly more Cercospora spots than those exposed later (Darvas & Kotzé, 1979a).

Difolatan® (85% captafol) was the most effective treatment in controlling Cercospora spot, anthracnose, and SER but resulted in an unpleasant odour up to four months after application (Darvas, 1981; Darvas & Kotzé, 1981b). Benlate® with three different stickers, Cupravit® and Kocide® (both copper oxychloride) gave good control. B77®, Baycor®, PP296®, and Aliette® were ineffective in controlling Cercospora spot (less than 58-68% exportable fruit).

Captafol (0.08% a.i.) in November, followed by benomyl in January, was recommended for the control of postharvest disease and Cercospora spot. Captafol should only be applied in November to prevent residues on the fruit (Darvas, 1982a; b). Captab® was ineffective in controlling Cercospora, while the treatments with copper included offered the best control (Darvas, 1983b).

Three applications of copper oxychloride was again an effective broad spectrum fungicide, Copper Flow® (2 applications; copper oxychloride) offered the best control of the fungicides tested in the early 1980s (Labuschagne & Rowell, 1983).

Copper oxychloride offered good control for three major fruit fungal diseases: anthracnose, Cercospora spot, and sooty blotch. CGA64250, CGA64251, and procymidone were not effective in disease control. Procymidone + benomyl, benomyl + Captab, and benomyl alone gave intermediate control (Kotzé *et al.*, 1982). The addition of the surfactant Nu-Film® was recommended over Agral® and Triton® because of its better water-fastness and it increased the fungicidal effect of benomyl *in vitro* – although Agral® did result in an improved distribution over the leaf surface compared to copper oxychloride (Denner & Kotzé, 1986).

A model for the number of Cercospora (*P. purpurea*) conidia (Z) was strongly correlated (R^2=0.875) to daily average air temperature (X, °C) and daily rainfall (Y, mm):

$$\boldsymbol{Z = 24.8 - 0.93X + 0.25Y}$$

Equation 1: Model for *Pseudocercospora purpurea* conidia number at Westfalia Estate, South Africa, to determine the timing for first spray - taken from Darvas & Kotzé (1987).
Z = conidia number,
X = mean weekly air temperature using daily (min+max)/2,
Y = total weekly rainfall.

The current formula, released in 2007 by SAAGA, is provided in Equation 2. According to this updated formula, spore release occurs when Z > 0. Cercospora infection takes place when Z value is ≥15 and fruit are larger than pigeon egg size. The first copper spray should be applied when fruit bigger than pigeon egg size and Z value >5.The potential for Cercospora spot infection is high when Z > 20.

$$\boldsymbol{Z = -58.99 - 3.22X + 0.18Y}$$

Equation 2: Updated general model for *Pseudocercospora purpurea* conidia number, used to determine the timing for first spray. The first spray should be applied when Z>5.
Z = conidia number,
X = mean weekly air temperature using daily (min+max)/2,
Y = total weekly rainfall.

Practically this means that infections escalate at the onset of the warm, rainy summer period and are maintained into March. [*No critical value was given in the original article – Ed.*]. Fruit picked with any moisture on the surface resulted in increased postharvest diseases. Prochloraz and wax (applied postharvest) decreased the SER losses. Pre-harvest sprays with benomyl, captafol, Cu-oxychloride, and Cu-hydroxide gave some control of postharvest disease (Darvas & Kotzé, 1987).

Captab® and benomyl were effective against Cercospora spot, but benomyl was not against SER or DC complex. Copper based fungicides were favoured for broad spectrum preharvest fungal control; Nu-Film® did not significantly improve the efficacy of copper oxychloride (Lonsdale & Kotzé, 1989)

Two applications of Flusilazol® (10% EC) were as effective as copper oxychloride (85% WP) in controlling Cercospora spot while cyproconazole (10% WG) and triadimenol (10% GR) were slightly less effective, and penconazole (10% EC) was largely ineffective (Lonsdale, 1991). None of these compounds left visible spray residues, like copper oxychloride, but they did not control sooty blotch. This was not deemed problematic because it can be removed with chlorine (Bezuidenhout, 1991b).

The optimal timing for the first pre-harvest spray for Cercospora spot control in Burgershall was between the third week of October and the second week of November – earlier than the (then) current recommendation (Lonsdale & Scott, 1991).

A practical system for the control of Cercospora spot was outlined by Botha (1992). The critical infection period was identified as the third week of November at Westfalia, but this would be different for each farm depending on temperature and rainfall, so the first round of fungicide sprays had to be before then to prevent infection. High risk orchards, those which remain damp and/or are on the northern slope, should be sprayed first. The second round of fungicide should be done 60-70 days after the first.

One round of copper oxychloride (of three) could be substituted for cyproconazole or flusilazol for the successful control of Cercospora spot at Westfalia, while soil-applied triadimenol was effective when applied in October but not January. Furthermore, copper ammonium carbonate effectively controlled Cercospora spot without leaving residue but was four times more expensive than copper oxychloride in 1992 (Lonsdale, 1992).

A first application of copper oxychloride (255g a.i./100L) in November followed by a second spray in January of either: 170g a.i./100L copper oxychloride, copper ammonium carbonate (198 and 330g a.i./100L), or cyproconazole (1.5g a.i./100L) were all effective in controlling black spot and sooty blotch at Westfalia. Triadimenol granules (0.04g a.i./m^2 drip area) were not effective when applied in January but were when applied in November; injections at the same rate were effective. All these treatments resulted in significantly less copper residue on the fruit at harvest. Two applications of copper were necessary for control of black and sooty blotch (Duvenhage, 1994b). However, triadimenol was not as effective the following season, and it was recommended injections should be applied 1-2 weeks before anticipated copper sprays, and granules 4-6 weeks before anticipated copper sprays (Duvenhage & Köhne, 1995a). Triflumizole provided good black spot control and left less visible residue (but did not control sooty blotch). Reduced copper oxychloride and copper ammonium carbonate in January were again effective in controlling both diseases and reducing visible spray residues. G49® wetter and Nu-Film® sticker did not significantly influence control of black spot, sooty blotch or visible spray residues (Duvenhage & Köhne, 1995a). Results were largely repeated the following season but triadimenol was not effective, even with earlier applications, and G49® and Nu-Film® did reduce visible spray residue without improving disease control (Duvenhage & Köhne, 1996).

In the KZN Midlands the critical infection period for Cercospora spot appears to be February to March – later than elsewhere in the country because of the lower temperatures. It was recommended that copper sprays start in November when the temperatures and humidity/rainfall increases. The copper sprays for the control of black spot were sufficient to also control postharvest diseases (Boshoff *et al.*, 1996).

Bion® (a salicylic acid compound), Flint® (a strobulorin), Ortiva® (a strobulorin), Avogreen® (*Bacillus subtilis* biocontrol agent), Solanacure® (*Bacillus* spp. biocontrol agent), and lime sulphur were tested for the control of fungal diseases at Westfalia. Bion® is expensive and while it controlled black spot but not anthracnose or SER, testing was stopped. Lime sulphur in conjunction with copper oxychloride was effective in controlling and testing would continue. Ortiva® was the better strobulorin and testing would continue. Avogreen® did provide control for black spot (Duvenhage, 2002). The following year, Ortiva®, and Bravo® (chlorothalonil), were tested against copper oxychloride with various additives:

lime sulphur (Thiovit Jet®), ferric chloride, Tecsaclor® (chlorine dioxide), and standard copper oxychloride. Copper oxychloride out-performed all the other fungicides. However, Ortiva® reduced postharvest anthracnose more than the other treatments, but not significantly (Willis & Duvenhage, 2003).

Following these findings a means to reduce the rate of copper application was sought at Westfalia. Using a mistblower (5 000L/ha four times per season) rather than hand gun application (14 000L/ha 3 times per season) with copper oxychloride (Demildex®, 3g/L) was mostly effective in controlling black spot in Fuerte (the fruit from the top inner section of the tree were not adequately protected at 10m x 10m spacing and 8m tree height) and was four times cheaper than hand gun applications. Copstar 120SC® (copper hydroxide, 3.5mL/L) and Copper Count-N® (copper ammonium acetate, 5mL/L) were also effective, while Polysun 320® (lime sulphur, 7.5mL/L) and Cueve® (copper octanoate, 10mL/L) were not effective at lower volumes. Visible spray residues were significantly higher when Wenfenix® (0.25%) was included (Willis & Mabunda, 2004). A number of alternative fungicide treatments were as effective as the standard treatment of Demildex® with hand guns or mistblower: Demildex® alternated with Bravo 500SC® (chlorothalonil) (50% reduction in copper), reduced Demildex® concentration (2g/L) with Agromos® (yeast cell extract) (33% reduction in copper), and Nordox 750WP® (cuprous oxide) (50% reduction in copper). Visible spray residues were noted in all Demildex® treatments but virtually no residues were noted for Nordox®. Copstar 120SC® (copper hydroxide) and Kocide 2000® (copper hydroxide) were not effective in controlling black spot, probably due to late rains prolonging the infection period (Willis, 2005). Although all fungicide treatments were effective in controlling fungal diseases, two applications of either Bravo 720SC® (chlorothalonil) or Ortiva® (azoxystrobin) with two applications of Demildex® (copper oxychloride) were the most effective treatment for disease control, although there were not significant differences between the fungicide treatments, including Copstar®, Nordox®, Agromos®, and Sporekill®. All treatments also resulted in visible spray residues at harvest without significant differences between treatments (Willis, 2006). A second season of good results from Ortiva® with Demildex® meant Syngenta registered the product for use on avocados. Strobilurin fungicides have to be managed to reduce disease resistance development. Bravo was not as effective in the second season (Willis, 2007). Either Copper Count-N (copper ammonium acetate SL 8% Cu) or Ortiva® could replace two applications of Demildex®. Both resulted in a reduction in applied copper. The application of Copper Count-N® for the last two applications significantly reduced visible spray residues compared to 4 applications of Demildex®. Microgreen® (copper oxychloride SC 33% Cu) was effective as the commercial control. Copper oxine (copper-8-quinolate WP 50% Cu) and HTCOP001 (copper complex SL 6% Cu) were not effective but significantly less copper was applied. CungFu® (copper hydroxide SC 35% Cu) was not effective but the tested rate was below the registered rate. Wetcit® was an effective adjuvant when reducing spray volumes (Willis & Mavuso, 2009).

Manicom & Schoeman (2008; 2009) reviewed the control of Cercospora spot in South Africa. Some general principles were that copper oxychloride is still the best available fungicide for Cercospora control; 15kg Cu/ha/year is the absolute minimum actual copper required for disease control but this may need to be increased to have good disease control; critical spray times are November-December and January; and several products are also able to control anthracnose and SER. Readers are referred to the original review for greater detail. The delay of spraying copper into November in the main growing areas was later concluded to be a mistake and sprays should commence in October, depending on rainfall and Z-values. The combination of copper with Ortiva® was confirmed as the

most successful treatment for fungal control. The use of adjuvants was promising but further testing was required to prove a statistical and economic benefit. A minimum dose rate of about 200g Cu/10 000L was recommended, when combined with Ortiva®. Further optimisation of the spray programme, in terms of copper use and spray residues, was possible (Manicom & Schoeman, 2010).

The application of paper sleeves on fruit decreased sunburn and Cercospora spot when applied before the rainy season. However, the trial was conducted during a drier season and needed to be repeated in a wetter season (Oosthuyse, 2008a).

The preharvest application of PolymerCoat® (a silicon-based product) reduced anthracnose and Cercospora spot development. However it increased grey pulp development in Fuerte. It was hypothesised that the product reduced conidia contact with the fruit but also interfered with gaseous exchange. Further testing was recommended (Oosthuyse, 2008b).

3.3.1.2. Sooty Blotch

The causal fungus of sooty blotch was described as *Stomiopeltis citri* Bitanc. At that stage there was no control of the fungus but investigations were underway (Kotzé & Theron, 1979). The identification was later changed to an *Akaropeltopsis* species (Theron *et al.*, 1981; Smith *et al.*, 1987). Captafol (160g a.i./100L) and copper oxycholoride (170g a.i./100L) significantly reduced sooty blotch on avocado trees; benomyl (25g a.i./100L) was not effective. Captafol also provided good control of anthracnose. Captafol was slightly phytotoxic to leaves and left a white residue that was difficult to remove (Kotzé *et al.*, 1981; Smith *et al.*, 1987). [*Today, sooty blotch is regarded as a disease complex caused by Stomiopeltis sp. and Akaropeltis sp. (Dann et al., 2013) – Ed.*].

The systemic fungicides Cyproconazole, Flusilazol, and Triadimenol, and copper ammonium carbonate were not as effective at controlling sooty blotch as copper oxychloride – especially in orchards with high disease pressure (Lonsdale, 1992).

Sooty blotch was effectively removed postharvest in a chlorine bath (Bezuidenhout, 1991b), and the use of chlorine with waxing did not negatively affect the fruit quality or ripening (Kremer-Köhne, 1996).

3.3.1.3. Pepper Spot

Speckle was caused by the teleomorph of *Colletotrichum gloeosporioides*, *Glomerella cingulata*. It was controlled by copper sprays, and if the disease is problematic, a minimum of two sprays per season is required. The critical infection period was January to February when fruit were wet, and the following year, mean minimum daily temperature and rainfall being the most important predictors. If temperature is above 18°C and rainfall for a 10-14 day period is above 20mm, severe pepper spot can be expected and corrective action should be taken (Schoeman & Manicom, 1998; 2000; 2001). Ortiva® and Flint® (both strobins), copper oxychloride with ferric chloride, Prasin® (a QAC), Benlate® (benomyl), and Tilt® (propriconazole) were tested against standard copper oxychloride. The standard double copper spray, or alternating copper/benomyl/copper were the most effective and cost-effective methods of disease control (Schoeman & Manicom, 2002).

3.3.1.4. Sclerocarpelosis (Stone Cells)

Sclerocarpelosis (stone cells) developing in avocado fruit flesh is thought to be caused by *Phytophthora citricola* – the cause of bark canker (Schroeder, 1985) but this was not confirmed using

Koch's postulates. The symptom is similar to orchard cold damage on fruit and may appear on trees with symptoms or without symptoms of bark canker.

3.3.2. Post-harvest pathology

3.3.2.1. Epidemiology

Stem-end rot (SER) in Tzaneen was caused by *Nectria* spp. and a *Phomopsis* sp., rather than *Diplodia natalensis*. A *Nectria* species was the predominant fungus in SER isolations, especially early season (April) (Darvas, 1977b). A *Phomopsis* sp. was also prevalent, especially mid-season (June). *Dothiorella* sp., *Colletotrichum gloeosporioides*, *Pestalotia* sp., and *Fusarium solani* were present in much lower frequencies. The infection moves more rapidly in the vascular bundles than the flesh, and vascular browning occurs before the invasion of the organism. In 1978, *Thyronectria pseudotrichia* was the predominant fungus causing SER in Fuerte, particularly in directly ripened fruit (Darvas, 1978d). The relative prevalence of *T. pseudotrichia* declined in cold stored fruit, while *C. gloeosporioides, Phomopsis perseae,* and *Rhizopus stolonifer* increased. In Edranol, *Dothiorella aromatica*, C. *gloeosporioides, T. pseudotrichia, Pestalotiopsis versicolor* were isolated from the SER infection. Fruit were more resistant to infection with the fruit stalk attached than with it removed – except for *D. aromatica* and *T. pseudotrichia* which could effectively penetrate the fruit stalk (Darvas, 1978d). Also in this study, the Dothiorella-Colletotrichum (DC) complex causing anthracnose was described as resembling cold damage but without the sharply sunken edges, normally present near the stem end. It was recommended that *Rhizopus stolonifer* be controlled in the packhouse because of its ability to penetrate the fruit stalk. *Botryodiplodia theobromae*, and *P. perseae* (as well as *D. aromatica*, and *T. pseudotrichia*) could also invade the fruit through the fruit stalk (0.5cm) (Darvas & Kotzé, 1979b).

Ryan was more resistant to anthracnose infection, compared to Edranol, Fuerte, and Hass; with Edranol and Fuerte being the most susceptible. Infection from *C. gloeosporioides* occurred in the orchard and remained latent until fruit softened. Four consecutive days of rainfall were necessary for infection to establish on the fruit. Detritus on the orchard floor, and dead twigs and branches in trees, are sources of inoculum. Anthracnose infection of local market fruit exhibited a J-shaped curve, declining from March to April, but increasing in May and then increasing substantially in June – for both Westfalia- and Levubu- sourced fruit (Kotzé, 1978). It was confirmed that Fuerte was more susceptible to fungal infections than Edranol and especially Hass, but disease incidence was related to rainfall and fruit maturity (Rowell & Durand, 1982).

An electron microscopic study on *Stilbella cinnabarina* (the asexual stage of *Thyronectria pseudotricha* – a major causal agent of SER) isolated from dry branches from orchards at Westfalia Estate, confirmed that the fungus was *Stilbella cinnabarina* (Denner, 1985).

As an initial step in a disease development model, *C. gloeosporioides* and *D. aromatica* had optimal linear growth at 20-30°C and 25-30°C *in vitro*, respectively, and linear growth was completely retarded below 5°C. It was concluded that temperatures below 15°C and 28°C *in vitro* prevented extensive infection (Denner *et al.*, 1986).

Dead leaves in the canopy were a major source of *C. gloeosporioides* primary inoculum. Conidia are spread by rain water to fruit which develop sporulating lesions and become the source of secondary inoculum. Copper sprays were a good control method for the primary inoculum. Anthracnose (body rot) was the major cause of fruit abscission. Larger lesions were associated with skin wounding and

smaller lesions associated with raised lenticels, but the mode of infection was unclear at that time (Fitzell, 1987).

Korsten *et al.* (1994b) isolated nine postharvest pathogens from avocado fruit from eight production areas in South Africa (Table 6). *C.* gloeosporioides and *D. aromatica* were the most prevalent, and *L. theobromae* (10.3%) and *P. versicolor* (4.6%) the next most prevalent. The other five pathogens were only present at some locations at very low frequencies (<1.2%). Eighty-six isolates of *C. gloeosporioides* from various avocado production areas in South Africa were compared and three groups, based on lesion size (virulence) were identified. Many of the isolates were highly virulent on avocados (Sanders *et al.*, 1996; Sanders & Korsten, 1997). It was found that 8.5% and 9.2% of *C. gloeosporioides* isolates were highly and moderately resistant to benomyl, respectively, and no isolates were resistant to TBZ or prochloraz (Sanders & Korsten, 1999).

Table 6: Mean isolation rate of nine postharvest pathogens from eight production regions in South Africa of fruit sampled from Pretoria market – taken from Korsten *et al.* (1994b)

Pathogen	**Mean isolation rate (%)**
Colletotrichum gloeosporioides	23.9
Dothiorella aromatica	20.4
Lasidioplodia theobromae	10.3
Pestaliopsis versicolor	4.6
Phomopsis perseae	1.2
Thyronectria pseudotrichia	1.1
Fusarium solani	0.1
Trichothecium roseum	0.1
Dreschslera setariae	0

Frequent sanitisation of all packhouse equipment (crates, trolleys, dump tank, packline, etc.) is required to reduce the pathogen load in the packhouse and reduce the risk of infection postharvest (van Dyk *et al.*, 1997a).

3.3.2.2. Benomyl and TBZ

Benlate® (benomyl) was effective in controlling *C. gloeosporioides*, but chilling injury was higher in Benlate®-treated fruit until the oil content reached 19% (fresh mass basis). Thiabendazole (TBZ; Tecto®) reduced the severity of SER. The addition of oil to the fungicide increased the effectiveness of TBZ but increased chilling injury. Acetic acid adjuvant reduced the control of *C. gloeosporioides* (Darvas, 1977c). The mixture of Benlate® 0.1% and Tecto® 0.4% gave good control of postharvest disease (Darvas, 1978e).

Adding fungicide (TBZ or Benlate®) to wax reduced the severity of SER, and dipping the stem end of fruit in wax, Benlate®, and TBZ was very effective in reducing the incidence of SER postharvest (Darvas & Kotzé, 1981a).

3.3.2.3. Prochloraz

Prochloraz (111g 45% EC/100L for 3 min) limited stem-end rot and anthracnose in late season Fuerte (Rowell, 1983).

A prochloraz (700 ppm a.i.) dip and an ultralow volume of the same at 5000ppm both reduced the severity of anthracnose, the DC complex rot, and SER (Darvas, 1984a). A 4min dip in prochloraz (45% EC, 60g a.i./100L water) and ultralow application of the same (500g a.i./100L water, approximately 1.6L/t) were effective in controlling anthracnose and SER. Prolong® wax (1.5%) delayed ripening but did not have an effect on disease control (Le Roux *et al.*, 1985). Prochloraz (45% EC, 5000ppm) with Prolong® wax (1.5%) was effective in controlling anthracnose, gave limited control of DC complex, with no control of SER. Lower concentrations of prochloraz, Imazalil (enilconazole), CGA 49104, and Fungaflor® (enilconazole) were not effective in controlling postharvest diseases (Darvas, 1985).

Prochloraz, captafol, benomyl, copper oxychloride, triadimefon, mancozeb, procymidone, and etaconazole were screened *in vitro* against *C. gloeosporioides* and *D. aromatica*. Prochloraz and captafol were the most effective but had different effects on the fungi. Prochloraz (20ppm) inhibited mycelial growth whereas captafol inhibited spore germination (Denner & Kotzé, 1985). [*Captafol is now classified as carcinogenic and no longer available – Ed.*].

A 500ppm treatment for 5 minutes of Omega® (prochloraz) was recommended for the control of postharvest fungal diseases. At the time registration had not been obtained and no MRL was required in the UK. The MRL in continental Europe was between 2 and 8 mg/kg (Anderson, 1986).

A reduced rate of prochloraz (200ppm), when acidified using 50mM HCl, was as effective as the standard treatment of 810ppm. A 15s dip was as effective as spraying (Mavuso & van Niekerk, 2010). The following year no difference was found between dipping and spraying fruit in the fungicide solution. No difference was noted between prochloraz EC and SC formulations, but only the SC formulation was registered for use on avocados. Acidified prochloraz was promising but not consistently better than the commercial standard and another season's data were

needed for a final recommendation (Mavuso & Van Niekerk, 2011). The prochloraz EC formulation resulted in slightly higher residues on the fruit but were not above the MRL of 2.0mg/kg. A treatment of 200ppm prochloraz with 50mM HCl or citric acid were as effective as the commercial standard of 810 ppm, and resulted in lower residues on the fruit (Mavuso & Van Niekerk, 2012).

3.3.2.4. Other Fungicides

A pre-harvest treatment of captafol in mid-November followed by copper oxychloride with Bitertanol in January was the most effective treatment in controlling post-harvest diseases, but this was affected by a very low disease incidence in 1981/2 (Darvas, 1983a).

Quaternary ammonium compounds (QACs) and the iodine-based compound Iodet® were tested for their efficacy in controlling postharvest diseases. QAC SU319® and Iodet® controlled anthracnose and SER, while Agrisan®, SU330®, Stericlen®, and 76% ethanol could control anthracnose (Boshoff *et al.*, 1995). The next year it was found that SU 319® or Terminator® could be used in a disinfectant bath (Boshoff & Korsten, 1996). [*QACs are no longer available for use – Ed.*].

Post-harvest treatment with phosphorous acid and potassium silicate were investigated for their anti-fungal activity. These two compounds do elicit a fruit response which may confer some disease protection (Bosse *et al.*, 2011). A pre-harvest spray of phosphorous acid (500ppm a.i. 14 days before harvest) decreased anthracnose development postharvest (Bosse *et al.*, 2012).

3.3.3. Biocontrol

A biocontrol agent (*Bacillus lichineformis*) isolated from the Fuerte phylloplane on Westfalia Estate inhibited postharvest fungi *in vitro* and postharvest, but could not compete with copper oxychloride in the field (Korsten *et al.*, 1988). The following year *B. lichineformis*, *B. subtilis*, and *B. cereus* were tested. The former two were more effective than copper oxychloride either in isolation, mixed together, or combined with copper oxychloride, when the bacterial concentration (10^8 cells/mL) was increased and four applications were used (Korsten *et al.*, 1989).

Postharvest applications of the successful preharvest treatments also controlled postharvest diseases. *B. subtilis* was again as effective as prochloraz against anthracnose, DC complex, and SER when mixed in TAG® wax and in a water bath (Korsten *et al.*, 1991). The following year it was concluded that *B. subtilis* would have to combined with a chemical control programme for the control of Cercospora spot, but was still considered effective for control of postharvest diseases (Korsten *et al.*, 1992). *B. subtilis* and its integration with prochloraz into TAG® were both effective in controlling the DC complex, SER, and anthracnose (Korsten *et al.*, 1993). Variable results were subsequently reported in the efficacy of pre-harvest application *B. subtilis* (and copper oxychloride) in the control of sooty blotch and black spot (Korsten *et al.*, 1994a).

A summary of the biocontrol programme was provided by Korsten (1995). *Bacillus subtilis* was repeatedly shown to be an effective component of disease management (both pre- and postharvest) but the commercialisation of the antagonist bacterium was a major obstacle and they had not managed to commercialise the product by 1995. The monitoring of the survival of the antagonist (*B. subtilis*) in the field is necessary because the bacterium is liable to die in the field. In this way the efficacy of the application and potential disease control can be determined. Monoclonal antibodies were developed for *B. subtilis* and were being tested using ELISA (Towsen *et al.*, 1995). The mode of action of *B. subtilis* control of pathogens was tentatively proposed by Korsten & De Jager (1995). They concluded that *B. subtilis* most likely has a multi-modal method of antagonism: (i) secreting antibiotic compounds/inhibitory substances, (ii) competing for nutrients, (iii) exclusion of the pathogen from the host, and possibly (iv) production of lytic enzymes. The proposed method is outlined in Figure 3.

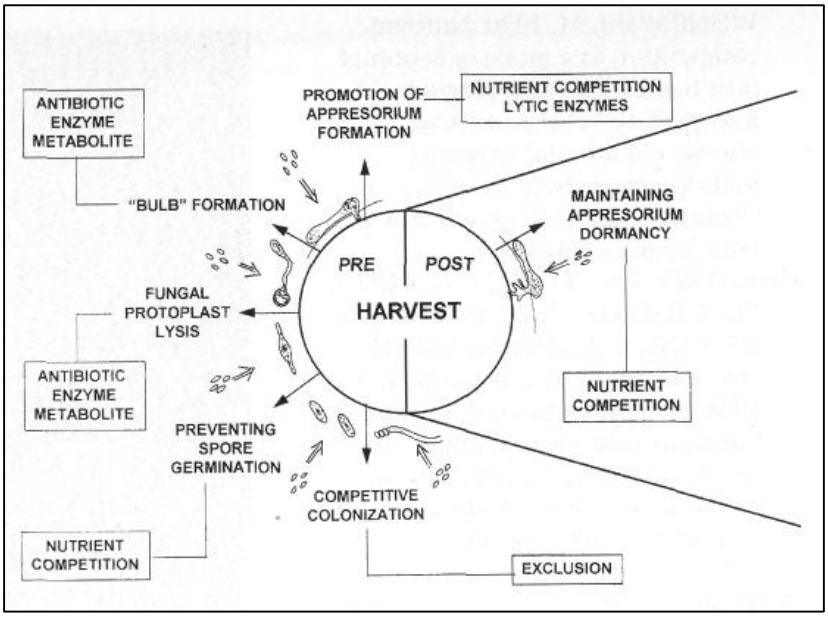

Figure 3: Hypothetical model showing possible modes of action of *Bacillus subtilis* for control of avocado post-harvest pathogen *Colletotrichum gloeosporioides* – taken from Korsten & De Jager (1995)

By 1996 the cultivation conditions for *B. subtilis* were optimized. Maintaining viable cells was difficult, and liquid culture with centrifugation or micro-filtration was unsuitable. The final product was cultivated on a bacterial carrier, with high cell counts and shelf-life at room temperature of several months, and soluble in water and TAG® wax. The product was protected by two patents (Korsten & Cook, 1996). *B. subtilis* was commercialised as Avogreen®. The formulation included spores with nutrients in a wettable powder form. The biocontrol agent was not effective in controlling postharvest diseases on a consistent basis, probably because of the use of spores when previously vegetative cells were used, and the spores were not given time to sporulate before the fruit was cooled. The formulation may also have had excessive nutrients which increased the growth of the pathogens. However, the chemical fungicides were also not consistently effective across the different packhouses. This formulation is therefore more suited to a pre-harvest application (Korsten *et al.*, 1998).

B. subtilis (isolate B246) controlled anthracnose and SER as effectively as TBZ (1.5g a.i./L). A combination of 10% ethanol with isolate B246 did show some promise but was not consistent. Anthracnose was better controlled than SER with the QAC Terminator® (didecyl-dimethyl-ammonium chloride), ethanol, and disinfectants. Potassium hypochlorite and tea and coffee extracts were not effective in controlling postharvest diseases. Variation in the control of anthracnose by TBZ was noted between Tzaneen and Hazyview, suggesting *C. gloeosporioides* had developed some resistance at Hazyview (Van Dyk *et al.*, 1997b).

Although the findings of Korsten & De Jager (1995) were confirmed, nutrient availability affected the ability of *B. subtilis* to antagonise *C. gloeosporioides* (Havenga *et al.*, 1999).

The preharvest efficacy of Avogreen® (*B. subtilis*) was enhanced with multiple applications by increasing the build-up of bacteria on the phylloplane. The inclusion of a nutrient source was speculated as being beneficial for colonisation. The method of application (spray cart vs. hand gun) was not significant but spray volume was. Spreaders and stickers should not be used as they reduce the survival of the bacteria (van Eeden & Korsten, 2003). The following season it was concluded that spreaders and stickers should not be used because there was no difference between the standard

treatment and the adjuvants. An additional winter spray was also not beneficial in controlling postharvest disease or Cercospora spot (Van Eeden & Korsten, 2004). D-(+)-trehalose and ammonium chloride were the most suitable carbon and nitrogen sources, respectively, to increase *B. subtilis* efficacy in anthracnose and Cercospora control without supporting pathogenic growth (Van Eeden & Korsten, 2006).

Bezuidenhout (1995) reviewed biocontrol in Europe and the USA in terms of (i) trends in biocontrol, (ii) product registration, (iii) product commercialisation, (iv) requirements for biocontrol of postharvest diseases, and (v) end user attitude, followed by conclusions and recommendations.

Trends in biocontrol: at the time, the vast majority of work (about 80% according to number of publications) was concentrated on soil-borne pathogens. Of 28 registered products, only two were registered for use on tree crops (*Agrobacterium agrobacter* and *Phlebia gigantea*), with the other 26 registered for ornamentals, vegetables, and cotton, with a high priority on seedling diseases. Original isolations techniques were needed to isolate biocontrol agents, e.g. using a bait technique to isolate *Sporodesmium sclerotivorum* which is effective against *Sclerotinia minor*. Isolation of an organism is just the first step. Formulation, quality control and application are just as important aspects that will determine if the product is commercially accepted. The production of a commercial product, from the biocontrol agent also required attention, to reduce the production and transport costs while maintaining product effectiveness. Leaf and postharvest diseases are relatively easily controlled by synthetic fungicides, so research into biocontrol of these diseases was lagging behind soil-borne pathogens. The use of biocontrol agents in Germany for apple blight, frost damage and fire blight in pears in the USA, and sour rot of citrus in the USA were mentioned.

Registration: The registration of biocontrol products was easier than synthetic fungicides, taking 1-2 years, compared to 8 years for synthetic products. Registration was easier if the organism occurred naturally in the country. Maximum residue levels for the agent may be required.

Commercialisation: The reliability and effectiveness of the product is critical in its commercial success. The major biocontrol success is *Bacillus thuringiensis* [*commonly referred to as Bt, which is now used in GMO cultivars – Ed.*] which is widely used on maize and soya beans in the USA. Smaller companies, or daughter companies of large companies, were more successful in producing commercial biocontrol products than large companies which traditionally concentrate on synthetic pesticides.

Requirements for biocontrol of postharvest diseases: There is resistance in Europe to the use of postharvest pesticides, so the use of postharvest biocontrol products would be strictly controlled. The following criteria would make the registration of a potential product easier:

- Preferably no antibiotic production, or the antibiotic must break down quickly.
- The organism should be naturally occurring and not genetically modified.
- It must not grow at temperatures above 37°C.
- It must not a pathogen for non-target organisms.
- It must not contaminate drinking water sources
- A good description and identification of the organism – the more information about the organism the better.
- Treatment of fruit where the skin is removed with biocontrol agents, is easier.

End User attitudes: Regulatory bodies like the Environmental Protection Agency (EPA) in the USA are highly regarded by the public. Lessons should be learnt from biocontrol products that are and were in the registration process, e.g. AQ10® from Ecogreen® (M-10 isolate from *Ampelomyces quisqualis* Ces.; syn *Cicinnobolus cesatii* de Bary).

For a biocontrol product to be successful, it must be safe, effective against the disease, cost effective, and reliable. Guidelines for the development of biocontrol agents were given:

- Targets, deadlines and reporting should be agreed upon by the researchers, industry and financiers.
- A clear outline of the target system must be done. The control of soil pathogens stands a relatively good chance of success. The use of postharvest fungicides is under pressure and the development of alternative products is critical.
- Research teams should concentrate on one or two problems. Financiers should make a long-term commitment for continuity, security and success of the project.
- Research programmes must be evaluated critically in terms of practically implementable results.
- Industry collaboration will be needed for a product to be registered locally and abroad (Bezuidenhout, 1995).

3.3.4. Application machinery

Hand guns and a mist blower (Eagle) were compared for their disease control effectiveness. The Eagle® did result in better disease control, at a lower cost, but this was negated in large trees where there was insufficient penetration into the canopy and at the top of the tree (Rowell, 1986).

Thermal fogging fungicides with a PulsFog® unit was effective for more resistant cultivars (Hass, Edranol, Ryan – not Fuerte) without leaving a residue as with hand gun application. Copper oxychloride could not be used because it clogged the machine and flowable formulations, e.g. copper ammonium carbonate, carbendazim, or flusilazole, were recommended. Spraying should only be done in windless conditions before or after the heat of the day (Duvenhage & Köhne, 1999).

A spray machine calibration form (included in the original article) was developed by Bruwer (2003a), taking into account a range of factors to accurately determine the volume per tree or per hectare.

The TracFog 100F, a tractor-mounted ultralow volume spray machine, had potential to achieve disease control at much-reduced spray volumes and copper usage. The smaller machine means it can be operated by a smaller tractor. The increased area sprayed per tank means that more orchards can be sprayed in the same amount of time than when using a mist blower. Further research was planned (Van Niekerk & Mavuso, 2011). The good results in disease control using ULV were confirmed the following season, and uniconazole was compatible with ULV application (124L/ha at 300g a.i./ha). However, the number of spray nozzles (two in the prototype TracFog 100F) would have to be increased to achieve good disease control in tall trees (Van Niekerk & Mavuso, 2012).

4. Genetic Resources

Prof. Wolstenholme, at the First World Avocado Congress, stressed the importance of having a local breeding programme, while continuing with chance selections/mutations (Wolstenholme, 1987a).

4.1. ARC Breeding Programme

Although the avocado breeding programme at the ARC-ITSC (formerly the CSFRI) in Nelspruit was terminated in 2000 (Wolstenholme, 2003), private companies continue with similar programmes to breed and evaluate superior selections of scion and rootstock cultivars. This section deals only with the ARC breeding programme.

The blueprint for the Avocado Improvement Programme (AIP) was outlined by Burger (1985). The AIP was for both scion and rootstock cultivars. The need for this programme was for the South African avocado (and other fruit) industries to remain competitive as suppliers of produce to Europe and elsewhere. The four phases in the AIP were:

1. Selection and importation of superior material
2. Production and maintenance of virus- and viroid-free plants
3. Multiplication and distribution of plant material
4. Recordkeeping, registration and certification.

The need for an effective local avocado breeding programme was discussed further by Terblanche (1988).

The strategy of the CSFRI's avocado breeding programme was outlined by du Plooy *et al.* (1992). It was hoped that the three stage strategy for scion and rootstock selections, combined with biotechnology techniques (RFLP and isozyme analysis), would yield superior local selections.

Bijzet & Cilliers (1995) outlined some breeding strategies that could be used in the avocado breeding programme. These include general combining ability, specific combining ability, cumulative effect of favourable genes, corrective mating, repeated back crossing, genotype x environment interaction, and male parent control. The effective adoption of these and other breeding strategies is important in a horticulturally young tree crop like avocado, where comparatively little is known of the breeding ability of existing cultivars.

4.1.1. Scion cultivars

The use of isozyme analysis, using phosphoglucose isomerase (PGI, EC 5.3.1.9), phosphoglucomutase (EC 2.7.5.1), leucine aminopeptidase (EC 3.4.11.1), malate dehydrogenase (EC 1.1.1.37), and alcohol dehydrogenase (EC1.11.1.7), was investigated on Fuerte, Ryan, Hass, Gwen, Esther, Pinkerton, Rinton, and Duke 7. Each cultivar had a unique PGI pattern - except Fuerte and Hass which were almost identical (Truscott & Lewis, 1992).

Feedback after two years' of evaluations was given by Bijzet *et al.* (1993). A few selections had been made at that time but findings were preliminary in the selection process. The following year, further progress had been made in producing seedlings for scion evaluation in Phase I, with six selections having potential (Bijzet *et al.*, 1994). In Phase II, 92 different scion combinations and 20 rootstock combinations had been planted in 1993 with evaluations starting in 1994 (Sippel *et al.*, 1994a).

Some selections showed promise in the fifth year and all three phases of the breeding programme had been implemented. Reed was indicated as having potential. The use of self-pollination of better cultivars was preferred because avocados are highly heterozygous. Self-pollination reduces vegetative vigour, and removes unwanted recessive genes from the breeding population. At a later stage, cross breeding will then have greater value according to Bergh (1987) (Bijzet *et al.*, 1996a).

Early results from the semi-commercial cultivar trials showed that Gwen was performing well, and the other selections BL135, BL149, and I373 had potential (Sippel *et al.*, 1996b). In addition to these cultivars/selections, 87-17-1, TX531, H222, #86 and OA184 were promising (Sippel *et al.*, 1997b). Pinkerton performed best at Levubu, and Gwen was a potential late season fruit. The 'Fuerte 3' selection yielded 20% more than standard Fuerte and was recommended for release. The imported selections H222, I373, #86, BL135, and TX531 were still promising. The best local selection was Eksteen. Further testing, including taste panels and cold storage trials, was required to eliminate non-performing cultivars (Sippel *et al.*, 1998b).

1996 was a challenging year for the local scion selection programme, with difficulties in obtaining material from the University of California and Israel, and the Phase I orchard at Westfalia being removed from the programme. The material sort from UC was: BL667, BL122, Gem, Harvest, Sirprize, Thille, HX73, and 34F2, and from Israel: Iriet, Ardith, Gill, Reed, and Green Gold. Velvick and Shepard (Australian origin) failed to establish in the gene source block and new trees had to propagated, but otherwise the trees in this orchard were "growing exceptionally well" (Bijzet *et al.*, 1997b).

The scion breeding programme was re-evaluated and the breeding cycle improved from a minimum of 24 years, to 18 and perhaps 13 years if farmers were willing to risk planting a new cultivar. The industry was cautioned on relying on Californian selections because of the troubles that industry was having with freezes and funding for the breeding programme (Bijzet, 1998b).

A cultivar block was established at Westfalia Estate, with 15 cultivars excluding Fuerte, Hass and Ryan, with two trees per cultivar grafted onto Duke 7. Promising selections would be transferred to another orchard at 20 trees per selection (Kremer-Köhne, 1998).

4.1.2. Rootstock cultivars

Twenty-seven PRR-tolerant rootstock selections were selected in primary screening trials at the ITSC. It was anticipated this number would be reduced after a second screening. It was recommended that at least 10 000 seedlings would need to be screened annually (Koekemoer *et al.*, 1994).

Between 1992 and 1994, 32 PRR-tolerant avocado rootstocks were selected by the ITSC in primary screening from almost 25 000 seedlings. Greenhouse screening of these selections was underway at the time of writing (Breedt *et al.*, 1995).

In the first yield results from Phase II evaluations (2 trees per scion-rootstock combination) at Levubu, Barr Duke had a dwarfing effect, especially on Hass, Ryan, and Gwen scions. Thomas and Duke 7 both produced a strong healthy tree (Sippel *et al.*, 1995a).

A poly-cross nursery (effectively an isolated orchard for rootstock breeding) was established in 1995 at the ITSC. Four seedlings were selected (total of 36 selections) in 1995 (Bijzet *et al.*, 1996b).

Results from the third year of the semi-commercial rootstock trial showed that there were differences between trial sites, but were too preliminary for recommendations (Sippel *et al.*, 1996a). Early results from the Levubu planting indicated that interactions between scion and rootstock exist. Unfortunately the trial site at Burgershall was lost due to heavy rain and was to be replanted at a new site (Sippel *et al.*, 1997a). After two year's yield, Duke 7, Thomas, G6, Duke 9, and G755 were very similar in terms of production efficiency (kg fruit/m^3 canopy), and on kg fruit/tree, Duke 7 and Thomas were the most promising , but at least three more years of results were needed for conclusive results (Sippel *et al.*, 1998a).

Another 3 323 seedlings were screened for PRR tolerant/resistance in the 1996 season and 5% were selected in the initial screening, with the 10 best seedlings being multiplied (Bijzet *et al.*, 1997a; Bijzet, 1998a). Another 20 seedlings were selected from 3 646 seedlings harvested in 1997. Two escape trees from Hazyview, TR and PvT (SA-RS\97-01; Bounty) were brought to the ITSC by Hough for further testing. PvT is moderately tolerant to waterlogging and PRR, and was being prepared for early semi-commercial release. Only 5 seedlings out of 41000 were selected after phase I screening between 1992 and 1998 (Bijzet, 1999).

4.2. Rootstock Selection

The industry was still using seedling rootstocks in the late 1970s, but a move to more PRR-tolerant clonal rootstocks such as Duke 6, Duke 7, G6, G22, G166, and G755 was recommended. Huntalas was rejected because it was infected with ASBVd (Toerien, 1977c). [*These California clonal selections were amongst the first to be tested at the time, and only Duke 7 ultimately stood the test of time – Ed.*].

Ernst and Holtzhausen began an experiment to determine the tolerance of seedlings of Duke, Edranol and Fuerte to PRR (Ernst & Holtzhausen, 1977b).

Early findings by Snyman & Darvas (1983) showed that *Cylindrocladium scoparium*, *Rhizoctonia solani*, *Fusarium oxysporum*, *Macrophomina phaseolina*, and to a lesser extent *C. destructans* were pathogenic to avocado (Edranol and Fuerte). There was evidence that there were rootstock differences in the susceptibility to these pathogens. Clonal Duke 7 was more tolerant to *P. cinnamomi* than Edranol seedlings, but susceptible to the combination of *P. cinnamomi* and *Cylindrocarpon destructans*; Edranol was susceptible to *Rhizoctonia solani*. Root morphology was suggested as a possible means of increased PRR tolerance (Snyman *et al.*, 1984).

The following clonal rootstock cultivars being tested in South Africa were mentioned by Wood (1984): Duke 6, Duke 7, G6, and G755.

The selection of avocado rootstocks was discussed by the visiting eminent Israeli scientist, Arie Ben-Ya'Acov, where he outlined the need for the global avocado industry of superior clonal rootstocks (Ben-Ya'Acov, 1985). It was suggested that, while imported cultivars from California (e.g. Duke 7) and Israel were necessary, local selections for PRR tolerance were preferable because South Africa has the "best ecological conditions" (from a plant pathology point of view) for *Phythophthora cinnamomi*. A comparison of the different clonal propagation methods for avocados was given in an appendix (Ben-Ya'Acov, 1985). [*Furthermore, Californian clonal rootstocks were predominantly of the Mexican race for cold tolerance and Israeli clonal rootstocks predominantly of the West Indian race for salinity tolerance – Ed.*].

The progress in the selection of PRR tolerant and resistant rootstocks in California was given by Coffey (1985b). The clonal selections Duke 6, Duke 7, G6, G6#1, Huntalas, G755A, G755B, G755C, etc. were included in a large scale Californian rootstock trial in 1984.

A long-term study on the variation of yield in particular orchards with seedling rootstocks was undertaken to identify low and high yielding trees in an orchard (Durand, 1986). After two years' data, yield curves were negatively skewed with a large number of trees not producing a crop. Consistently high-bearing trees could be identified as "super" trees for further evaluation as rootstock or scion selections.

The need for a dwarfing or semi-dwarfing rootstock was noted by Wolstenholme (1987a). The world industry is still searching for such a rootstock that lends itself to high density planting.

The selection G755 ('Martin Grande') was identified as being PRR resistant from Schieber and Zentmyer's (1987) botanical explorations in South and Central America,. The Guatemalan race was investigated because of its vigour and potential cold tolerance (Schieber & Zentmyer, 1987; Zentmyer & Schieber, 1987).

Rootstock breeding done by Cictamex in Mexico, focussed on tolerance to salinity, lime-induced chlorosis, and PRR, as well as dwarfing rootstocks. Colin V-33 and mutants of Fuerte and Rincon showed promise as dwarfing varieties (Sanchez-Colin & Barrientos-Priego, 1987). The use of Colin V-33 as an interstock was shown to reduce the height of Fuerte trees by 39% (interstock = 10-30cm) and 47% (interstock = 30-50cm) in 11 year old trees in Mexico. The interstock also reduced the canopy diameter, circumference of the scion trunk and main branches, and the distance to where branching started (Barrientos Priego *et al.*, 1987), effectively "shrinking" or dwarfing the tree. The mode of action was hypothesised to be increased IAA-oxidase, peroxidase, and phenolics in the bark of Colin V-33 which reduced the supply of auxins to the roots, and thereby a reduction in the production of cytokinins in the roots which reduced vegetative growth. It was shown that stomatal density was strongly negatively correlated to tree height and trunk circumference and could be used as a marker for vigour (Barrientos-Priego & Sanchez-Colin, 1987). [*This dwarfing behaviour was probably due to severe boron deficiency in Mexico – hence why it was not found at Westfalia when tested in South Africa – Ed.*].

Rootstock breeding and selection in Israel promoted the selection of a number of rootstocks that are adapted to specific limiting edaphic factors, e.g. salinity, alkalinity, PRR, temperature extremes, etc. (Ben-Ya'Acov, 1987). West Indian rootstocks were most tolerant to lime-induced chlorosis and high salinity, while Guatemalan rootstocks were the most sensitive to lime-induced chlorosis and Mexican rootstocks most sensitive to high salinity. West Indian rootstocks were most sensitive to poor soil aeration and low temperatures, but the scion was more important (in Israel) when considering cold tolerance. Their findings in productivity were important for future selection programmes. They found that:

- different sources of scion budwood had an effect on productivity,
- rootstock could drastically improve productivity,
- rootstock-scion interaction is important,
- large variation exists within each race
- the effect of rootstock, scion, and their interaction was consistent over seasons, and
- rootstock greatly affects tree size and therefore productivity per unit area (Ben-Ya'Acov, 1987).

Based on their findings, the number of rootstocks and scion budwood sources were reduced to only the best, and clonal rootstocks allowed the complete duplication of superior trees to increase the productivity of the Israeli industry as a whole. [*Clonal rootstocks are not widely used in Israel. West Indian seedlings, tolerant to saline soil, are mostly used but these seedlings are less variable than those of the other two races – Ed.*].

Hank Brokaw (Brokaw Nursery, California) gave a nurseryman's and grower's opinion on clonal rootstocks at the time (Brokaw, 1987). He found that:

- G755/Martin Grande was the most PRR tolerant rootstock at the time but suffered from lime-induced chlorosis in high pH soils.
- Thomas is tolerant to PRR but not salt tolerant; it is easy to establish.
- Barr Duke was not favoured.
- Toro Canyon is a good all-round rootstock and is particularly salt-tolerant and moderately PRR tolerant.
- P1 only had limited numbers but was "not bad".
- Borchard is PRR-sensitive but tolerant to lime.
- Duke 7 was considered to still be the best clonal rootstock for Californian conditions at the time.

The development of stem-pitting in Duke 6 was discussed by Moll *et al.* (1987). This disease precluded the use of Duke 6 as a rootstock in South Africa. The causal agent was not identified at that time, but thought to be a virus (paragraph repeated in §3.1.4 - Viruses).

PRR-susceptible rootstocks (Edranol) exuded more amino acids than PRR-tolerant rootstocks (Duke 7, G6, and G755). *P. cinnamomi* zoospores are attracted by these amino acids, particularly arginine, aspartic acid, and glutamic acid (Botha & Kotzé, 1989a). This paragraph is repeated in §3.1.1.5 (Pathogen Studies).

Partridge (1990) briefly discussed the three 'new' Californian clonal rootstocks Duke 7, G6, and Martin Grande (G755). He concluded that Duke 7 was the most promising of the three based on PRR tolerance and yield under Hass, but he did point out that Duke 7 is sensitive to waterlogging.

Growers were cautioned against planting Martin Grande (G755) because of its low yielding nature and extreme vegetative vigour (Whiley *et al.*, 1990). Duke 7 was favoured because its PRR tolerance, precocity, and good yields when grafted to Hass. Toro Canyon and Thomas were also mentioned as potential PRR tolerant rootstocks worth investigating in 1990.

Duke 7 significantly out-produced G6 and Martin Grande (G755C) at Westfalia in the first year of production (33, 15, and 6kg/tree), the latter rootstocks producing larger trees due to greater vigour (Köhne, 1991). Evaluations on horticultural characteristics of rootstocks were emphasised. Duke 7 outperformed G6 and G755C when grafted to Hass and Fuerte. Hass was noted as being more precocious than Fuerte – and therefore more productive in the first four years (Kremer-Köhne & Köhne, 1992). In comparing Fuerte grown on Duke 7 and G6 at Danroc (Kiepersol), after 6 years it was concluded that trees on G6 had a higher cumulative yield and were healthier and more vigorous. The increased vigour would mean that G6 trees would have to be thinned at an earlier stage (*with the practice of tree thinning used at the time – Ed.*). Fruit quality for both rootstocks improved over the 3 years of production (Kremer-Köhne & Köhne, 1994).

Early findings clearly showed that G755 (Martin Grande) was far more vigorous with poor yield compared to Duke 7 (Smith, 1993). Trials of Barr Duke, D9, and Thomas (compared to Duke 7) were planted (1ha each) at Westfalia and Thomas and Duke 7 were more vigorous than Barr Duke and D9 (Conradie *et al.*, 1994). G755 was removed from evaluations because of poor yield. High yielding trees identified at Westfalia Estate by Smith *et al.* (1993) were clonally reproduced for evaluations. No recommendations were possible the following year (Roe *et al.*, 1995). Thomas resulted in poor Hass yields, and while D9 and Barr-Duke reduced vigour. Yield results were however variable and hence Duke 7 remained as the recommended rootstock (Roe & Köhne, 1996a). While Duke 7 still remained the recommended rootstock, D9, Latas™ (Merensky 1), and Dusa™ (Merensky 2) showed promise, but Thomas and Barr Duke did not outperform Duke 7 (Roe *et al.*, 1998). Merensky 1 (Latas™) and Merensky 2 (Dusa™) were released on a semi-commercial basis by Westfalia Nursery in 1999 based on results from South Africa and California (Roe & Morudu, 1999a).

A dwarfing interstock & rootstock trial, including Wilg (Westfalia selection), Ryan, and Colin V-33 (compared to Duke 7) was planted. Wilg was the only rootstock that exhibited any dwarfing in the first year (Roe *et al.*, 1995). The results were confirmed the following season, but were still preliminary (Roe & Köhne, 1996a). Ryan and Colin V-33 rootstocks had little dwarfing effect on Hass and results were variable, with poor yields, while Colin V-33 interstock did not have a significant dwarfing effect. It was thought that it may increase productivity (t/m^3 canopy) and a semi-commercial planting on Hass/Colin V-33/Duke 7 was planted in 1995. Wilg exhibited the strongest dwarfing effect and monitoring was continued (Roe *et al.*, 1997). Results were confirmed the following year, in that Wilg was the most dwarfing rootstock but the growth restriction was not significant. Using Colin V-33 as an interstock was not effective in reducing growth significantly and cumulative yield was lower than Duke 7 (Roe & Morudu, 2000).

In rootstock field tests at Westfalia, tree health (planted 1996) from best to worst was: VC256, VC805, VC801, VC218, VC207, VC241, Duke 7, Edranol seedlings, and VC225. Crown rot (*P. citricola*) was noted in 10% of VC801. In another trial planted in 1998, the ranking was Velvick, Merensky II, Merensky III, Duke 7, Merensky IV, Gordon, Edranol seedling, and Jovo (Kremer-Köhne & Duvenhage, 2000). Similar results were noted the following year, but the heavy rains in early 2000 increased PRR in the trial. The 1996 planting tree health ratings were: VC805 (best), VC256, VC801, VC218, VC207, VC241, Duke 7, Edranol seedlings, and VC225 (worst). In the 1998 planting Merensky III was best, Merensky II, Velvick, Duke 7, Merensky IV, Edranol seedlings, Gordon, and Jovo. Similar trends were noted the following season but tree condition did not decline was rapidly as 2000. VC801 (despite crown rot) produced

the highest yield in the 1996-planted block and in the 1998-block Merensky II, Merensky III and Velvick-100 outperformed Duke 7 in yield and PRR-tolerance (Kremer-Köhne *et al.*, 2002)

In Argentina, preliminary results confirmed that G755C (Martin Grande) was very vigorous with poor yields and Duke 7 produced higher yields (11.5 t/ha on 150trees ha) than Lula (7.7t/ha on same spacing) (Foguuet *et al.*, 2001).

Dusa™® and Latas™® both performed well in rootstock evaluations, out-producing Duke 7, G6 and Gordon when grafted to Hass. In another trial, Thomas and Duke 9 were also identified as being potential PRR-tolerant rootstocks. Duke 9 was thought to be semi-dwarfing. Jovo and W14 were very PRR sensitive. Barr Duke, Edranol, Evstro, Duke 7, and G6 were inferior to Dusa™ and Latas™. G755A was highly PRR-tolerant, and had an acceptable first yield, but was the most vigorous – G755B was also highly PRR-tolerant, was not as vigorous, but was not productive (Botha, 1991).

A review of avocado rootstocks, the breeding programmes around the world but with a focus on South Africa was provided by Wolstenholme (2003). In his opinion 3-5 elite genetically diverse rootstocks are necessary with good PRR tolerance (even resistance) that are adaptable to a range of climatic and edaphic conditions and promote high yields, good fruit quality and reduced vegetative vigour. The reliance on Mexican race rootstock cultivars (Duke 7 and Dusa™) was criticised as there are beneficial characteristics in the other two races which could be exploited in production areas around South Africa. A local breeding programme, with a number of contributors was recommended, where local and imported selections are evaluated.

Clonal rootstock propagation was endorsed by Castro *et al.* (2005) because of the extreme variability in tree vigour and productivity on (Mexican race) seedling rootstocks in Chile.

4.3. Scion Selection

Brief descriptions of the following scion cultivars were made by Wood (1984): Alboyce, Bacon, Edranol, Ettinger, Fuerte, Hass, Horshim, Pinkerton, Ryan, Santana, Sharwil, Teague, Whitsell, Gwen, Ester, and, Reed. Readers are referred to the article for more information. [*Many of these cultivars are not commercially grown, and readers are referred to the recent list in Schaffer et al. (2013) – Ed.*].

Bob Bergh gave an insightful report on avocado breeding in California at the First World Avocado Congress (WAC) (Bergh, 1987). He discussed the benefit of self-pollinating promising scion cultivars rather than hybridising. Hass, Pinkerton, Irving, Stewart, Nabal, and Murrieta Green were promising parents for new selections. Avocado cultivars are very heterozygous so it is possible to get superior selections from self-pollinated progeny. He maintained that Hass was unsuited for Californian conditions, and would be replaced by second generation cultivars such as Gwen which is precocious and high-yielding - and Whitsell, Esther and Hx48 to a lesser extent. [*Hass is still the predominant cultivar grown in California, despite its limitations and Gwen is only grown on a small scale – Ed.*].

The interaction between rootstock and scion was reported by Ben-Ya'Acov (1987) and this was studied on a large scale in Israel.

Partridge (1990) gave an overview of the differences in cultural management for the five major cultivars grown in South Africa at the time: *viz.* Hass, Fuerte, Edranol, Pinkerton, and Ryan.

Shepard, Reed, and Gwen were discussed as potential scion cultivars in Australia. Shepard is an early green-skinned cultivar, notably produced in north Queensland. Reed is a late maturing green-skinned cultivar with round shape and good resistance to postharvest fruit diseases. Gwen was another cultivar that was touted at the time, because of its precocity, and semi-dwarfing and high yielding nature, but it had not been tested in South Africa in 1990 (Whiley *et al.*, 1990).

Gwen, T142, and TX531 were promising scion cultivars but needed further evaluations (Smith, 1993). Three green skin cultivars Shepard, Pinkerton, and Gwen, and two black skin cultivars BL122, T142 were promising and further testing was recommended (Conradie *et al.*, 1994). Lamb Hass, Iriet, Gil, and 1.14.2 were compared to Hass at Westfalia. Lamb Hass was the most promising late season black-skin, with Iriet also remaining in evaluations. The evaluation of Gil and 1.14.2 was terminated because of poor fruit quality and poor yield, respectively. Harvest, Gem, Sir Prize, BL 667, and Bonus were the next round of cultivars that were being screened at Westfalia (Kremer-Köhne, 1999b). Lamb Hass matures 2 months later than Hass and has larger fruit and yield, but is also alternate bearing. Internal quality after cold storage was also good. Some negatives of the cultivars were: early season Lamb Hass compared unfavourably to late season Hass, and Lamb Hass fruit develop colour while still firm and should be eaten at a higher firmness. Sir Prize, Harvest, Gem, Jewel, and BL 667 (Nobel) mature at the same time as Hass. Sir Prize and Jewel had too large fruit; Harvest had good yield, fruit size and quality. No yield information was available for 8-22-5 or Bonus (Kremer-Köhne, 2000). Similar results were found in 2000, with Sir Prize and Jewel having too large fruit, Nobel had poor skin colour development, and Jewel and 8-22-5 had high incidence of disorders. Harvest was the most promising cultivar (Kremer-Köhne, 2001). Gem and Harvest were retained for testing beyond 2001. Testing on Sir Prize, 8-22-5, Bonus, Nobel, and Jewel was stopped because these cultivars had poor yields, large fruit, poor fruit colouration, and/or physiological disorders (Kremer-Köhne, 2002).

In the final report on Lamb Hass at Westfalia, it was concluded that Lamb Hass had a greater cumulative yield than Hass over six seasons, trees were more precocious, fruit were larger, maturity was about two months later than Hass and the fruit can hang on the tree even longer. Lamb Hass fruit change colour while still firm and are eat-ripe at a higher firmness value than Hass. Importantly, Lamb Hass should be handled as a distinct cultivar and not treated as late season Hass. It should be shipped separately from Hass and at a higher temperature than Hass harvested at the same time to prevent cold damage (Kremer-Köhne & Köhne, 2001).

'Harvest' and 'Gem' were good late season black-skin cultivars, maturing about a month after Hass. Harvest produced 138t/ha in four years, however severe vascular browning was noted in the fourth year. Gem produced 2t/ha more than Hass (90 vs. 88t/ha) in the four years but fruit quality was good throughout (Kremer-Köhne & Mokgalabone, 2003). After five years the cumulative yields of Harvest and Gem were 75% and 10% higher than Hass. Fruit quality was good and the vascular browning noted the previous year in Harvest was not repeated. More trial sites were planned for these two cultivars (Kremer-Köhne & Mokgalabone, 2004). In the sixth season Gem (24.5t/ha) out-produced Harvest and Hass by 10 and 5 t/ha respectively, but Harvest still had the highest cumulative yield (195.2t/ha) compared to Hass (120.8t/ha) and Gem (137.8t/ha). Both Harvest and Hass were fairly alternate bearing (AI = 0.33 and 0.31 respectively) while Gem (AI = 0.14) was regular in its bearing. Harvest peaked at a count 12-14, Gem at 14-16, and Hass at count 18-22. Postharvest fruit quality was acceptable for all three cultivars but Harvest did not remain green upon ripening. Evaluation at Westfalia was discontinued in 2004 with further trials in Levubu, Kiepersol and KZN underway (Bruwer

& Mokgalabone, 2005). Early indications were that Grace has larger fruit (70% of fruit in count 10-14 range) than Hass (75% in count 16-20 range) and evaluations of Gem and Harvest in Kiepersol, Levubu and KZN (15 trees of each cultivar at each location) was underway (Bruwer & Mokgalabone, 2006). Although Grace produced larger fruit, and higher yields than Hass, its season coincides with Hass so its commercial benefit is limited. The results for Harvest and Gem in Kiepersol confirmed findings from Westfalia, where the two new cultivars had a higher yield than Hass, and larger fruit. Gem fruit quality was good but Harvest fruit developed vascular browning after cold storage, probably due to low orchard temperatures (Bruwer, 2007).

5. Anatomy & Physiology

Wolstenholme (1981) authored a popular article on root, shoot and fruit inter-relationships in fruit trees. The most important function of roots is growth because only young unsuberized roots are efficient in nutrient and water uptake. Suberization occurs faster under stress conditions such as drought or cold. Factors affecting root growth include: soil composition and chemistry, drainage, fertilization – especially boron which is often deficient in South African soils. Roots and shoots grow in rhythms around a hypothetical root:shoot ratio particular for the conditions, stage of development and plant type.

Fruiting strongly reduces root growth, more so in mature trees and in deciduous trees. Avocado fruits are very strong sinks for assimilates. The vegetative:reproductive balance fluctuates in accordance with crop load. Assimilate partitioning between roots, shoots, and fruit is ultimately controlled by root growth. Avocado fruit growth is particularly draining on tree reserves because of the high oil content.

PRR is the equivalent of root pruning, altering the root:shoot balance and the vegetative:reproductive balance, and reducing shoot growth and ultimately reducing overall tree size; this is compounded by the presence of fruit. He advocated management practices to restore the root:shoot balance by the use of fungicides, fruit removal, fertilization (mostly foliar N, Zn, and B), and shoot pruning. Equally important is the maintenance of an appropriate vegetative:reproductive balance which is very difficult in alternate bearing crops. A grower should remember the vegetative parts are a mirror image of the roots and healthy roots are the basis of a productive orchard.

Following on from that article, the concept of yield affected energy budgets and carbon partitioning was elaborated on in a later review (Wolstenholme, 1987b). Based on a yield target of 100t/ha for intensive apple production, and the adjusting for the energy content difference in avocado and apple fruit, he estimated the target yield for avocados is 32.5t/ha. Actual long term yields are much lower because:

1. Avocados are only partially domesticated
2. Ecophysiological adaptations to originating in montane Meso-American rain-forests
    a. Shallow, extensively suberized roots with a low frequency of roots hairs
    b. Leaves are shade adapted with a high stomatal density, with limited photosynthetic efficiency, low light saturation point (20-25% of full sunlight), and a low compensation point
    c. Flowering is profuse with limited fruit set, with a unique protogynous flowering pattern
    d. Cropping is biennial or irregular
3. PRR infection limiting root volume and restricting water uptake
4. High energy cost of fruiting because of oil content in flesh, and the large seed.

Practical implications were:

1. Select varieties based on improved harvest index – *i.e.* heavier more regular fruiting using semi-dwarfing trees with greater branching and compactness
2. PRR control

3. Manipulation of vegetative/reproductive balance using:
    a. Pruning
    b. Chemical/PGR manipulation
    c. Tree manipulation techniques, e.g. girdling
4. Canopy architecture re-design focussing on high(er) density plantings of smaller trees, with the intention of tree thinning once trees start to crowd each other
5. Careful consideration of late-hanging because of the severe drain on carbohydrates for the following year's crop.

5.1. Flowering

In preparation for a study on pollination, Coetzer & Robbertse (1986) reviewed avocado flower morphology and palynology. Major findings from the review were:

- Some flowers had defective ovules.
- There is no anatomical difference between abscised and retained flowers.
- Avocados have a moist stigma; there is a connection between the formation of callus plugs in the pollen tube and incompatibility.
- The germ sac apparently affects pollen tube growth.
- Temperature had a profound effect on flower opening and flowering cycles, pollen tube growth and fruit set where temperatures below 10°C and above 35°C inhibit pollen tube growth, fertilisation and fruit development.

From their own studies, avocado pollen is monad, spherical and polyporate with papillary projections on the outer surface. The size varies from 32.3 µm to 81.7µm with approximately 55% of the grains smaller than 50µm. Pollen sticks to the valves of the anthers. In most cases only the two larger, proximal anthers open, while the terminal anthers seldom open. Each proximal and terminal anther produces about 160 and 45 pollen grains, respectively. Only 12% of pollen was viable, and pollen grains smaller than 50µm were not viable (Coetzer & Robbertse, 1986). A boron deficiency in either parent (*i.e.* pistil or pollen) was shown to reduce pollen tube growth during fertilisation (Coetzer & Robbertse, 1987).

A summary of Australian research on flowering, pollination and fruit set was given by Sedgley (1987) at the First World Avocado Congress (WAC). Biennial (alternate) bearing was correlated to the carbohydrate status of the trunk and branches. In a controlled environment experiment, floral development in Hass and Fuerte plants was inhibited by tropical temperatures (33/23°C day/night temperature cycle) compared to a 25/15°C day/night cycle. Furthermore, high and low temperatures both disrupted the flower cycle. High temperatures resulted in increased fruitlet drop as vegetative development was favoured. Low temperatures drastically reduced the percentage of flowers opening in the female stage, but Type A cultivars (e.g. Hass) were more tolerant to lower temperatures during flowering, although the female stage was extended into the night. The optimal temperature for pollen tube growth is 25°C. Pollen tube growth is rapid and can reach the base of the style within 3 hours but can take 18-24 hours to penetrate the ovule. Fuerte had a higher proportion of defective embryo sacs than Hass resulting in fewer fertilised fruit – which explains why Fuerte can produce a higher proportion of seedless "cukes". There does not appear to be pollen-pistil incompatibility in avocado. Flower and fruitlet abscission is related to:

- The low percentage of fertilised flowers because of poor pollen transfer. This was noted in the first few weeks after anthesis.
- One month after anthesis, all dropped fruitlets were fertilised and had normal embryo and endosperm development. There was a problem 14 days after pollination. It was speculated that competition between fruitlets and between vegetative and reproductive tissues was responsible for this drop.

It was suggested that temperature sensitivity during flowering be used as a selection criterion.

Whiley & Winston (1987) conducted an interesting study in Australia on the effect of flowering on varietal productivity where they compared long term temperature data to flowering intensity of Fuerte, Sharwil, and Hass. This comparison allowed them to compare the time of optimal temperature range for flowering to actual flowering intensity, and thereby identify the most suitable cultivars for particular growing areas based on pollination and fruit set. If a cultivar flowered intensely during the time of the optimal temperature range, solid cultivar blocks could be grown, *i.e.* pollinizers would not be needed.

Flowering under greenhouse conditions was induced by at least four weeks of cold temperature stress [15-18°C day (8h)/10-13°C (16h) night]. The NH_3-NH_4^+ concentration in the leaves increased during the cold temperature stress but flowering could not be manipulated by exogenous low biuret urea. Leaf starch content decreased until peak bloom, indicating that carbohydrate reserves are utilised for flower development (Nevin & Lovatt, 1989).

Prof. Kotzé, in his preface to the 1991 Yearbook, mentioned the need to address fruit drop to increase yields by focussing on cross pollination, irrigation, pruning, fertilisation, and growth retardants (Kotzé, 1991).

Cuke formation in Fuerte is due to flowers that are female sterile and unable to produce viable seeds (Steyn *et al.*, 1993a). The anthers in 50% of flowers in both high- and low-yielding Fuerte trees had poor quality pollen but were macroscopically indistinct from those with viable pollen (Steyn, 1993). The defect resulted from disturbed meiotic division in the pollen mother cells. Ultimately, this means that many trees in an orchard are not suitable pollen donors – and may be a source of low yields. The next year only 20% of the ovules in a high-yielding Fuerte tree were functional and many flowers were sexually neutral, *i.e.* non-functional pollen and ovule). It was hypothesised that the high proportion of neuter flowers and protogynous dichogamy increases the chance of out-crossing in avocado (Steyn, 1994). [*Neuter flowers could also be part of the "sunflower" system to attract pollinators to the tree. A high proportion of cukes on a tree could also indicate ASBVd infection – Ed.*].

Avocado should be considered an outcrossing plant but self-pollination is possible (Robbertse *et al.*, 1994). *In vitro* pollination showed that Fuerte was a good pollinizer for Hass (31.6% of pollen tubes reaching the ovules) and Ettinger was to be the most suitable for Fuerte (14.7%). In contrast, for the same Hass and Fuerte, self-pollination resulted in only 11.5% and 1.6% of pollen tubes reaching the ovule, respectively. Open pollination studies showed that pollination in Fuerte is much higher than Hass at all stages of pollination (pollen on stigma, pollen tubes in style, and pollen tube in ovary), illustrating that pollination is Hass is a major limiting factor in production. In studying the effect of weather on pollination, effective pollination is only achieved on a few days of flowering. The following year's results confirmed that Fuerte (72.8%) and Ettinger (76.4%) were better pollen donors for Hass

than self-pollination (33.3%) but these numbers were much higher than the previous year (Robbertse *et al.*, 1995). Flowering dichogamy was affected by low maximum temperatures. Bee activity was also linked to the intensity of flowering, peaking in early September and terminating by the end of that month. Pollination is limited by ambient weather and bee activity to very few days during the flowering period. Their conclusion was that for good pollination the following conditions are required:

- A clear day, without too much wind and temperatures above 25°C [*and below about 30°C – Ed.*] to allow for the flowers to open correctly, and to have good bee activity
- An appropriate pollen parent to supply high quality pollen
- Pollinators in sufficient number and activity
- Healthy trees for sustaining pollen tube growth
- Pathogens under control so spores do not interfere with pollen tube growth (Robbertse *et al.*, 1995).

The use of Ettinger as a pollinator for Hass did not show any conclusive results in the first year at Westfalia (Kremer-Köhne & Köhne, 1995).

A detailed study of cross-pollination of Hass with Ettinger at Mooketsi showed that Ettinger pollen increased seed size, and may increase fruit size (Robbertse *et al.*, 1996). Pollination in Hass took place in the morning when the flowers are in the female stage, and there is sufficient viable pollen – preferably from a B-type cultivar. Ettinger can be considered a high quality pollinator for Hass and the ratio between the cultivars in the orchard still needed to be determined.

A small study in California found that cross-pollination of Hass with Zutano (and possibly Bacon) increased yield (Francis, 1996b).

Preliminary results indicated that the synthetic auxin naphthalene acetic acid (NAA; 100ppm at full flower) increased fruit drop but dichlorophenoxyacetic acid (2,4-D, 100ppm at full flower) increased fruit retention (Penter & Stassen, 1999).

The application of GA_3 delayed flower development and almost completely inhibited flowering at 250ppm applied multiple times. Because of variation in floral development in avocado trees, and because the phenological timing of the application is critical, multiple doses are recommended at a lower concentration to improve the treatment effect. When applied going into an “on year”, the treatment should reduce the crop and alternate bearing in the following season (Rossouw & Robbertse, 2001).

5.2. Phenology

Prof. Kotzé’s interesting article on the phases of avocado tree growth (Kotzé, 1979) stimulated research on phenological growth cycles in Australia by Whiley and co-workers. The SAAGA Avocado Management Chart can ultimately, therefore, be credited both to Kotzé’s insight and the Whiley Team for expanding the concept. The resulting more detailed phenological growth charts attracted worldwide interest as a basis for understanding tree management. Three stages of fruit development were identified: (i) floral bud differentiation (March to May), (ii) flowering and fruit set (June to December), and (iii) rapid fruit growth (January to March). (A fourth stage could be included, which is reduced fruit growth, and maturation.) The critical stage in producing a crop is the second, and in South Africa, this is challenging time to manage because spring is a time with hot, dry berg winds, low

water reserves, erratic rain, and widely fluctuating temperatures. The third phase is important in determining fruit size (important for the small fruit phenotype as discussed in §5.5 (Hass Small Fruit Phenotype)), and attention must be paid to irrigation and fertilization.

During a season with good fruit set (1980), ambient temperature, relative humidity, soil moisture (top 30cm), fruit fly, and nutritional status did not have an effect on flower and fruit drop, while ring-neck and fruit drop appeared to be correlated (Slabbert, 1981).

Wolstenholme & Whiley (1989) wrote a most useful review article on avocado phenology and carbohydrates. They discussed the phenological growth cycle of avocados which had recently been developed in Australia, and carbohydrate cycling in avocados and the effect carbohydrate concentrations have on tree vigour and yields. This discussion was continued the following year (Whiley & Wolstenholme, 1990), where the authors highlighted the importance of starch management, and its inclusion in the phenological cycle. Flowering depletes the starch reserves in a tree so the amount of starch in reserve is an important parameter for predicting yield. A deficit in starch (carbohydrates) in winter will limit flowering and fruit set. Also, late hanging will result in a depletion of the starch reserves through winter and therefore result in reduced flowering and fruit set the following season. The indeterminate spring flush only becomes a "source" once leaves are 80-100% expanded (25-60 days after bud break), and the greatest fruit drop occurred when the leaves were still a "sink" (or photosynthetically neutral). This is due to the growing leaves out-competing the fruitlets for assimilates and enhancing fruit drop, since 97% of the abscised fruit had formed normal embryos (Whiley, 1990).

The importance of understanding the pheno-physiological cycle of an avocado tree to improve crop management, and potentially increase yields was discussed by Wolstenholme & Whiley (1997). The carbohydrate status of a tree can be a limiting factor for fruit set, especially in drier climates. In other words, a higher carbohydrate concentration in a tree will reduce the risk of poor fruit set. They also maintained that avocado trees are 'source-limited', *i.e.* deficient in photosynthates, and orchard management should focus on improving photosynthetic efficiency (light, water, nutrient management) of the orchard. Avocado trees accumulate carbohydrates as a survival mechanism e.g. against drought.

5.3. Tree Physiology

Avocado (Edranol) is a photosynthetically typical C3 plant, in that solar radiation saturation for individual leaves occurs at a relatively low level, *i.e.* 200-250 $W.m^{-2}$ (about 20-25% of maximum solar radiation on a clear summer day) at 10-30°C, after which there is no increase in the rate of photosynthesis. Typical midday summer values in South Africa are about 1000 $W.m^{-2}$. Therefore avocados are adapted to shade conditions, although excessive shading reduces flowering. Radiation levels should not be a limiting factor (Bower *et al.*, 1977). [*However on the canopy scale, most leaves only received diffuse radiation ay any one time. In tall trees with close spacing, solar radiation is a limiting factor, especially on cloudy days and in south facing hill slope orchards – Ed.*].

Avocados are sensitive to water stress (excess and deficit), and stomatal resistance increased exponentially when soil water potential was less than (more negative) -30kPa, and leaf water potential less than -300kPa (pot trial). Net CO_2 exchange (*viz.* rate of photosynthesis) is negatively linear to stomatal resistance, so the net CO_2 exchange decreases exponentially during water stress. Due to the

accumulation of abscisic acid (ABA) during water stress, it takes 4-6 days after re-wetting for stomata apertures to be restored and the maximum rate of photosynthesis to be achieved. The water stress is exacerbated by solar radiation and high temperatures because transpiration is highly restricted during water stress (Bower *et al.*, 1977). Under adequate soil moisture conditions, the leaf surface temperature is about 0.6°C higher than the ambient air temperature, but under water stress conditions, the leaf temperature can be 6°C higher than ambient (Bower *et al.*, 1977). In the following year (1978), the authors concluded that soil water content needs to be carefully managed to prevent PRR (excessive water content), and depressed photosynthesis (insufficient water content) (Bower, 1978). Even an apparently healthy tree in a diseased orchard, with poor drainage became water-stressed at higher (less negative) water soil water potential. It was recommended that soil water potential be maintained between -25 kPa and -60 kPa in the feeder root zone. A diseased tree showed no stomatal reaction to soil water potential, with the stomata remaining partly closed throughout the day. Intervention, e.g. cutting back, fungicide applications and fruit removal, would be required if trees show water stress before the soil water potential reaches -50kPa (Bower, 1979).

Both leaf peroxidase activity and tree stem growth were affected by the scion, rootstock, and the interaction between the two. It was postulated that peroxidase activity is related to lignification which would increase resistance to *P. cinnamomi* infection. Peroxidase activity declined with tree age and it was thought that this could be linked to greater PRR as avocado trees age (Bower & Nel, 1981).

ATP, ADP, and AMP were quantified using a bioluminescence assay (Bezuidenhout *et al.*, 1985). This assay was suggested as a simple method to detect stress in the avocado tissues.

Vigorous trees had fruit with a lower calcium concentration; Fuerte fruit were likely to have a lower calcium content and concentration than Hass fruit. The calcium concentration in fruit peaked at 6 weeks after fruit set but the total calcium content in fruit continued to increase with fruit growth. It was suggested that preharvest calcium sprays, nitrogen fertiliser modification to reduce the vigour of the spring flush, the use of nitrate fertilizer rather than ammonium based nitrogen fertilizer, and the growth retardant paclobutrazol should be investigated further to improve fruit calcium content and thereby fruit quality (Witney *et al.*, 1986).

In a preliminary report, it was suggested that ammonia (NH_3-NH_4^+) accumulates in avocado leaves during water deficit and low temperature stress. This accumulation was thought to be because of increased photorespiratory nitrogen cycle, failure to re-fix NH_3 generated by glycine synthase, and the inhibition of protein synthesis, rather than the reduction of nitrate from fertilisation. Furthermore, a reduction in carbohydrates is not a pre-requisite for ammonia accumulation (Nevin & Lovatt, 1987).

Trends in total lipid concentration of Hass fruit flesh at two sites in KZN showed that at the cooler site the lipid accumulation continued to increase at a low rate, while at the warmer site there was a decline in lipid concentration with the following spring vegetative flush (Kaiser *et al.*, 1992). It was hypothesised that some of the lipids were remobilised to provide energy for the flush. The development of lipid bodies in the fruit flesh parenchyma and specialised idioblasts were confirmed in their study. Late hanging 'Hass' fruit in the KZN midlands resulted in fruit reaching a peak in oil content before declining in Spring. It was suggested that the lipids are a partially mobile energy source. Oleic acid (18:1, mono-unsaturated) is the predominant fatty acid and was 10% higher in fruit from the KZN midlands than fruit from Tzaneen. This is important because mono-unsaturated fatty acids are important in combatting heart disease. Phenologically, late hanging in the mesic KZN midlands did

not result in reduced yields after three years because of the non-stressful environment. Intensive management meant that critical energy levels (trunk starch levels) weren't breached – or the trees were able to photosynthesise adequate carbohydrates for subsequent flowering. Attempting to late hang fruit in a more stressful environment would probably result in pronounced alternate bearing and/or reduced cumulative yield (Kaiser & Wolstenholme, 1993a; b).

A heavy fruit set was shown to be deplete the starch in roots, phloem, and xylem around May and the starch concentration increased until November. In contrast trees with poor set showed a decline in starch by November as the trees set a large crop for the following season (van der Walt *et al.*, 1993). Further studies were conducted on this research and it was proven that the majority of carbohydrates are stored in the roots and wood and a heavy crop reduces the starch in the tree resulting in an "off year" the following year with alternate bearing ensuing (Davie & Van der Walt, 1994). During an "on year" much of the carbohydrates are found in the seed and fruit flesh of the fruit (Janse van Vuuren *et al.*, 1997).

Bertling & Cowan (1998) found that although the highest temperature and light intensity in an avocado orchard in the KZN midlands was on the East and North sides of the trees and the trees did show some signs of stress, photo-inhibition did not occur and fruit growth was not affected.

A preliminary study into the role of sugars in avocado fruit tissues found that sucrose predominated in the seed while mannoheptulose (a seven carbon sugar) and perseitol (sugar-alcohol related to mannoheptulose) predominated in the exocarp and fruit flesh in Hass, Fuerte, and Pinkerton. Further investigations into the role of these unusual sugars was suggested (Bertling & Bower, 2005). The concentration of C7 sugars in abscised fruit was lower than fruit than remained on the tree, suggesting a role for these sugars in fruit development (Bertling & Bower, 2006). Avocados have different anti-oxidant systems in different tissues, with the C7 sugar mannoheptulose being the major anti-oxidant in the fruit flesh. The concentration of mannoheptulose declined as fruit matured, indicating that the risk of oxidative browning increases as fruit mature. The major anti-oxidant in leaves was anthocyanins, and ascorbic acid predominated in the seed (Bertling *et al.*, 2007). The application of boron did not increase mannoheptulose concentration in fruit and leaves. The application of zinc decreased sugar concentrations in leaves and fruit. Girdling resulted in an initial decrease in C7 sugars in young fruit but the concentration recovered after two months. Sucrose either increased or remained constant indicating different physiological roles for these sugars. Since mannoheptulose declined as fruit matured and perseitol remained constant, different roles were also suggested for mannoheptulose and perseitol (Bertling *et al.*, 2008).

The cause of increased leaf abscission in Ryan during flowering and fruit set was investigated. It was thought that it was caused by drought stress and Ryan is more sensitive to drought stress than Hass and Fuerte. Chemical amelioration using dolomitic lime, Solubor®, NAA, 6-benzylamino purine, Kelpak®, sodium nitroprusside, and kaolin, was not successful (Roets *et al.*, 2006). The intensity of flowering was correlated to leaf drop in Ryan. No correlations were found between leaf abscission and nutrient or starch concentrations. Additional fertilization prior to flowering, or flower thinning may reduce leaf drop. Applications of the above chemicals made in May and June again were not successful and earlier applications in March or April would be investigated in future (Roets *et al.*, 2007). Fertiliser, PGR, and kaolin applications did not significantly reduce leaf abscission in the 2007 season, probably because it was a low stress season with lower natural leaf drop (Roets *et al.*, 2009a). [*Ryan is sensitive*

to both climatic and soil stress, and should be planted in cool, humid, mesic climates and on good (non-sandy) soils – Ed.].

5.4. Plant Hormones

Radio-immuno assays (RIAs) for the cytokinins isopentenyl adenosine and isopentenyl adenine, and abscisic acid were developed by Cutting *et al.* (1984). This was part of a larger project to develop RIAs for the five classical plant hormones, and their study in the clonal rootstock process, fruit development and avocado pheno-physiology. RIAs were conducted for IAA (auxin), abscisic acid (ABA), and the two cytokinins 2iP and IPA during Fuerte fruit development by Cutting *et al.* (1985). They highlighted the drop in auxin concentration from November, decrease in 2iP from January, and the steady increase in ABA during fruit development (Figure 4). (*These fluctuations may be linked to fruit drop in November and January – Ed*.). They also highlighted: (i) the importance of the seed, particularly the seed coat, in fruit growth, (ii) physiological stress during the first few months of fruit development will result in decreased fruit size (*and increased fruit drop – Ed*.), (iii) the use of the seed coat as a maturity marker, and (iv) smaller fruit where the seed coat has died prematurely will mature earlier and will ripen faster and possibly arrive soft if exported. (*This problem is still observed at the present time in European ripening units – Ed*.).

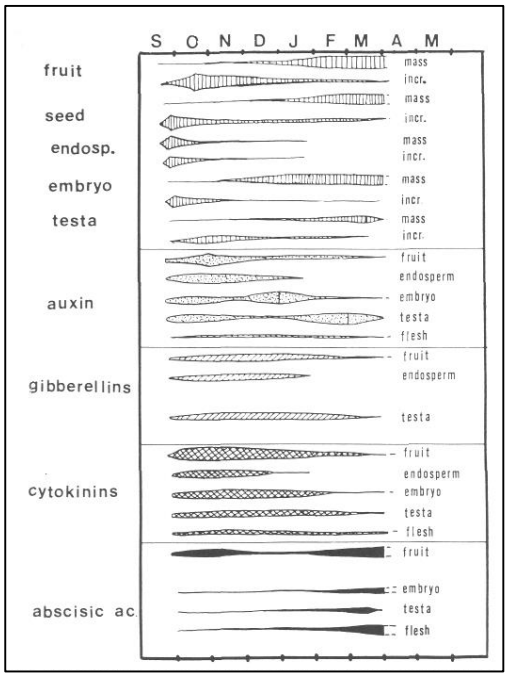

Figure 4: Tentative representation of 'Fuerte' avocado fruit and seed growth patterns and Plant Growth Substance trends in a warm environment from September to March - taken from Cutting *et al.* (1985).

When comparing Fuerte fruit harvested in April and August from Burgershall and Pietermaritzburg, Cutting *et al.* (1986) and Bower *et al.* (1986) found that:

1. The ABA concentration in the flesh increased as fruit ripened.
2. Fruit flesh from water-stressed tress and late-hung fruit had similar concentrations of ABA, which was higher in fruit from non-water-stressed trees and fruit harvested early. Water-stress includes excess and deficient water.
3. Fruit from water-stressed trees had a repressed ethylene climacteric.
4. ABA and PPO were positively related, and higher in trees with water deficit.

This research showed the physiological basis for potential poor quality and premature softening of fruit from water-stressed trees and late-hung fruit. The role of water loss as a potential trigger for ripening was suggested. This was confirmed in the summary reports by Cutting & Bower (1987) and Bower & Cutting (1987) for the first WAC. Following on from Cutting *et al.* (1986) and Bower *et al.* (1986), Bower & van Lelyveld (1986) showed that cold storage (30 days at 5.5°C) increased total and soluble PPO, and that soil water-logging/hypoxia (35kPa irrigation regime) increased PPO, but not as much as water deficit. The water stress was thought to have occurred in the first three months of fruit development. The infusion of ABA in harvested fruit was shown to result in increased PPO activity, decreased concentration of phenolics, and a higher incidence of grey pulp (Cutting *et al.*, 1989). They also showed that there is active ABA anabolism (*de novo* synthesis or release of bound ABA was not confirmed) and catabolism in avocado fruit which increases with maturity and during the climacteric peak. It was concluded that browning potential is a function of fruit maturity and the stress placed on the tree (and therefore fruit).

Gibberellins (GA_3) in fruit flesh decreased during the season and during ripening, and it was suggested that gibberellins are more related to fruit growth and quality. ABA concentration was low and there was no consistent trend in ABA concentration between harvest date, locality, and softness. Ripe fruit generally had a higher concentration of ABA and this was more variable. No correlation was found between PPO and browning (Hofman & Husband, 1987), but membrane permeability and phenolic concentration are also important. The application of GA_3 can be used to inhibit flowering but it must be applied at flower initiation and during early stages of flower development. Later sprays will enhance flowering. Stem injections would also be tested because of the cost of foliar applications (Rossouw *et al.*, 2000).

5.5. Hass Small Fruit Phenotype

The Hass small fruit problem surfaced in the early to mid-1990s. Hass trees bear a high percentage of small fruit, especially in warmer climates and as the trees become older. At that time it was one of the priority projects, but is no longer a problem because the market now prefers smaller sizes [*however this preference may change in the future – Ed.].*

Mulching increased average Hass fruit size by reducing soil and therefore tree stress – refer to §2.3 (Orchard Floor Management).

The vasculature in the avocado fruit enters the fruit as a cylindrical core and then branches into two concentric rings around the seed which coalesce at the distal end of the fruit and enter the seed coat as a solid core before branching again in the seed coat. In fruit with degenerating seed coat, there was limited water and assimilate movement, with almost inactive phloem cells and an accumulation of phenolics and PPO activity at the distal end of the fruit (Kaiser, 1993). The earlier senescence of the seed coat resulted in progressively smaller Hass fruit. Count 26 fruit or smaller resulted when the seed coat died 55-60 days after fruit set, when the first root flush ends and the summer vegetative flush begins. This is also the time of maximum environmental stress with high orchard temperatures, relative humidity and irradiance (Cowan *et al.*, 1997).

Tree condition of 3 or worse on the CG scale had more than 50% count 26 fruit or smaller (Kremer-Köhne & Köhne, 1995). The use of gibberellins (10 ppm a.i.) and paclobutrazol (250 ppm a.i.) in

September on 3-year-old Hass trees increased total yield from 0.7t/ha to about 2.5t/ha) without decreasing fruit size.

It was later hypothesised that increased ABA concentration in the seed was likely the cause of small fruit because the balance between cytokinins and ABA controls cell division and therefore fruit size. The involvement of glucose in the control mechanism was also proposed as a means to control HMGR activity and thereby isoprenoid synthesis (ABA:cytokinin ratio) (Cowan *et al.*, 1998). It was later proposed that an overproduction of cytokinins indirectly resulted in an increase in ABA turnover and this resulted in small fruit (Cripps *et al.*, 1999) [*simplified for clarity, for the biochemical interactions, refer to the original text – Ed.*]. Greater detail was given in the following year, with the Hass small fruit problem caused by reduced sucrose movement to the seed and fruit flesh, because of reduced sink strength of the fruit. This is caused by the degeneration of the seed coat, reduced symplastic continuity from reduced plasmodesmata conductivity, increased apoplastic sucrose metabolism (*i.e.* in the cell wall) which is similar to more mature normal fruit. These responses are linked to elevated ABA (Cripps & Cowan, 2000). An increased cytokinin+IAA: ABA ratio maintains cell growth and results in normal fruit growth, while a reduced ratio will reduce the cell growth rate and result in small fruit. This ratio is affected by the concentration of purine and molybdenum co-factor in the fruit (Taylor & Cowan, 2000).

It was proposed that the small fruit phenotype was caused by an interaction between cytokinins, ABA, HMGR, and soluble sugars. Small fruit occurred if the ABA:cytokinin ratio increased because intercellular movement of sucrose was inhibited. HMGR activity modulates both the production of ABA and cytokinins, and HMGR activity is also modulated by soluble sugars. This potential relationship indicated a complex control mechanism for cell division and fruit growth (Cowan, 1997). Seed tissue of small fruit had reduced HMGR activity, but there were no differences between the fruit flesh of small and normal fruit. Fruit growth was restored by the reversal of mevastatin-induced inhibition of HMGR activity by three intermediates of the isoprenoid: mevalonic acid lactone, farnesyl pyrophosphate, and geranyl-geranyl pyrophosphate. Glucose and re-/active oxygen species (AOS/ROS) were inhibitors of HMGR activity. Exogenous perseitol did not affect HMGR activity, but exogenous D-mannoheptulose increased HMGR activity and perseitol concentration (Richings & Cowan, 2000). [*From a grower point of view, this highly sophisticated physiological research gives a scientific explanation of the effects of environmental stress on fruit hormonal and sugar interactions. The "bottom line" is that early season stress causes premature abortion of the seed coat. For normal development, the avocado fruit is dependent on a functional seed coat until horticultural maturity – Ed.*].

5.6. Pinkerton Problem

Pinkerton is a high yielding cultivar but has had problems with internal and external fruit quality. There have been a number of research projects aimed at improving the fruit quality of this cultivar. These projects are summarised below.

The percentage of Pinkerton being planted in the early 1990s necessitated research on this cultivar. The cultivar has a long flowering period and the late set fruit grow at a faster rate than the first set fruit. This has importance for harvesting (larger fruit are least mature or perhaps immature) and sampling for fruit mineral analysis (Sippel *et al.*, 1992). Following on this study, Sippel *et al.* (1994b) concluded that the removal of flowers and fruitlets after a set date can hasten maturity by one month,

and increase fruit size in some locations. Their findings on the optimal postharvest storage temperature indicated that Pinkerton should be stored at about 7.5°C. The timing of fruit removal is critical, and is greatly affected by climate, but the retention of fruit from earlier flowering increased fruit number, fruit size, and hence yield, enhanced fruit maturity, and reduced the spread in maturity (Sippel *et al.*, 1995b). The grower would need to decide whether this manipulation is practically and economically feasible – especially in the current situation of rapidly increasing wages.

Pinkerton fruit (75% flesh moisture content (MC)) had acceptable internal and external quality when cold stored for 28 days at either 5.5°C throughout, or 5.5°C for 2 weeks, 4.5°C for one week, and 3.5°C for the last week (Schutte, 1994).

Kruger *et al.* (2000) gave a number of recommendations to improve the fruit quality of Pinkerton. In summary, these are:

1. Harvest earlier in warm, high risk areas with good soils and high rainfall. The maximum MC should increase from 75% to 79%, with minimum MC of 75%.
2. In cooler areas, fruit should be harvested earlier, bearing in mind crop load (a heavier crop has less grey pulp) and weather conditions, with a minimum MC of 72%.
3. Maturity testing in high risk areas should be done per orchard, with a larger sample and on individual fruit.
4. Remove the first set if it is small and the second set good.
5. Intensive rain 3 months before harvesting increases grey pulp.
6. A calcium content of 1000ppm in fruit weighing 50-100g is recommended provisionally. See Penter & Stassen (2000) for treatments.
7. Install calcium baths in packhouses for 10min application.
8. Fruit should be stored at 7°C under CA.

The following season these handling protocols were refined:

1. Maximum MC levels in high risk areas are 80-77% MC, and in low risk areas 80-75% MC.
2. Calcium concentration >1000ppm (in 50-100g size fruit)
3. Nitrogen content should be ≤1% in fruit flesh from March to harvest, with Ca content should be 500ppm for every 1% N in March, 400 in April, and 300 in May.
4. A storage temperature of 7°C (air delivery temperature) with controlled atmosphere (CA) and/or 1-MCP. The use of 1-MCP was first tested in South African avocados in 2000, and further research would follow (Kruger *et al.*, 2001).

Bower *et al.* (2000) concluded that grey pulp/fruit flesh discolouration was not a postharvest disorder (chilling injury), but originated pre-harvest from environmental, edaphic and cultural conditions. Grey pulp was actually reduced with a lower storage temperature. This was confirmed the following year, even though the severity of grey pulp was reduced in 2000 (van Rooyen & Bower, 2001). Reduced cold storage temperature (2°C air delivery) reduce grey pulp development by reducing the loss of membrane integrity during the cold storage period, but increased black cold damage. A balance between internal and external quality was sought between 2 and 5.5°C. Fruit origin, and cultural and pre-harvest factors were again a significant factor in grey pulp development (van Rooyen & Bower, 2002). Fruit nitrogen and micro-nutrient (Cu, Mn, B, Zn, K, and Ca) concentrations and the N:Ca ratio were related to the development of grey pulp in Pinkerton. Reduction of the cold storage temperature

to 2°C again decreased grey pulp, but a conditioning treatment was needed to reduce or prevent external chilling injury (van Rooyen & Bower, 2003)

Pre-harvest calcium applications delayed fruit ripening, but this increased the risk of postharvest fungal decay. Post-harvest applications of calcium did not have an effect on fruit ripening (Penter *et al.*, 2001).

Fruit from older Pinkerton trees were much less susceptible to grey pulp than fruit from younger trees, and the fruit set in older trees was more concentrated. Hence Pinkerton fruit should be not be exported from trees that are younger than five years of age. The maturity recommendations were further refined:

- Low Risk areas: MC of 80-73% MC during “on year”, and 80-75% during an “off year”.
- High Risk areas: MC of 80-75% during “on year”, and 80-77 during and “off year”.
- Fruit flesh Nitrogen content should be below 1% by March to reduce the risk of grey pulp, and below 1% by January to reduce the risk of black cold damage.
- Calcium: at least 1200ppm during November to reduce the risk of black cold damage with >880ppm in January and at least 600ppm in March.
- Ca:N ratio: at least 500ppm Ca for every 1% N until January and decrease by less than 100 per month (Snijder *et al.*, 2002).

Two types of rind disorder were identified (Kruger, 2012). Early season fruit developed classical external chilling injury but late season fruit developed fungal-associated senescence lesions. To prevent these disorders, recommendations were to:

- Monitor fruit maturity one month before harvest and continue fortnightly. Each sample should be of 10 fruit, with MC measured on individual fruit.
- Fruit mineral analysis should be done in November/December and February/March with 10 fruit per sample, which can be pooled.
- The use of the AVK[4] regime (9.5, 9.0, 8.5°C) early in the season, AVD (8.0°C) during the mid-season, and a modified AV9 regime late season (9.0, 8.5, 7.0, 6.0°C).
- The MMAU Reefer container was unsuitable.
- All consignments should be treated with prochloraz, waxed, and shipped under CA and/or treated with Smartfresh™.
- Holdback samples, kept at the approximately shipping temperature, were recommended.

[4] These AV codes are set by the PPECB and can be found on their website www.ppecb.com

6. Post-harvest

Jan Toerien (1981) provided an extensive explanation on the interpretation of postharvest results, outlining the roles of the producer, picker, packer, transporter, and agent.

1. Producer
    - Produce fruit that is not water-stressed or turgid at harvest.
2. Picker
    - Limit the time between picking and pre-cooling to reduce grey pulp.
    - Be conscious of fruit temperature during picking.
    - Selective picking according to fruit size.
    - Avoid wet fruit.
3. Packer
    - Limit time from picking to cooling.
    - Effective cooling.
    - Cellophane wrapping option to induce a modified atmosphere [*not used today – Ed.*].
    - Waxing, and/or the combination of cellophane and wax to deliver firm fruit and delay ripening.
    - Minimise and standardise packing times.
    - Use forced air cooling.
    - Temperature control in the packhouse.
4. Transporter
    - Cold chain maintenance.
    - The discussion of the problems faced at the time show a great improvement in the logistics chain for avocados from packhouse to the port and Europe.
5. Agent
    - Cold chain maintenance.
    - Move fruit as soon as possible in Europe.
    - Do not store avocados with other fruit [*especially those which release large amounts of ethylene, e.g. bananas and granadillas – Ed.*].

6.1. Fruit Maturity

6.1.1. Maturity methods

Oil content of fruit pulp was the standard maturity test before Swarts (1976a) demonstrated that oil content could be estimated using pulp moisture content (MC), in that each cultivar has a constant value for the sum of MC (%) and oil (%).

Holzapfel & Kuschke (1977) compared a number of oil extraction methods for avocado to determine the optimal method, in terms of repeatability, speed, safety, cost, and complexity. An oil extraction using Soxhlet equipment was the slowest and least repeatable compared to an infrared moisture analyser and oil extraction with chloroform and methanol. They also recalculated the constants to estimate oil content from moisture content for Fuerte, Edranol and Hass.

Table 7: Comparison between maturity constants determined by Holzapfel & Kuschke (1977) and Swarts (1976a).

Cultivar	n	Maturity Constant	Constant from Swarts (1976a)	Difference
Fuerte	19	87.7	89.8	2.1
Edranol	16	89.4	90.9	1.5
Hass	14	85.9	87.8	1.9

While the methods that Holzapfel & Kuschke (1977) employed may be slightly outdated 35 years later, the three methods investigated are still being debated in 2013, and the advantages and disadvantages listed in Table 8 remain the same.

Table 8: Comparison between three avocado fruit maturity methods

Method	Advantages	Disadvantages
Moisture Content	Rapid	Indirect method relying on the accuracy of the oil/moisture constant
	Reliable	Variability of moisture content within a fruit, tree and orchard
	Easy method	Open to sampling manipulation
	Easy maintenance of apparatus	
	Few sources of error	
Rapid Oil Extraction	Direct measure of oil concentration	Multiple weighings are sources of error
	Multiple samples depending on other equipment	Requires relatively expensive lab equipment
	More accurate than the Soxhlet method	Uses solvents so need fume cupboard
	Can be serviced relatively easily	
Soxhlet Extraction	Relatively accurate for dried samples	Least accurate method for undried samples
	Multiple samples possible with the right equipment	Slow
		Labour intensive

Fruit from the south (cooler) side of Edranol, Fuerte, and Hass trees had a lower oil content – which is important in the early season, where selective picking is required (Kotzé & Kuschke, 1978).

The variable maturity of fruit flesh tissue was illustrated by Schroeder (1985). The tissue between the seed and stem end was the least mature (lowest dry matter/highest MC) and the tissue below the seed, where the vascular bundles coalesce, had the highest dry matter. It appears that the fruit flesh tissue immediately surrounding the vascular bundles had the highest dry matter and therefore oil content, and was the most mature. Avocado fruit exhibit gradients in dry matter (moisture content) from the stem-end to the seed, and from the blossom-end to the seed, as well as radially from the seed to the exocarp (skin) (Schroeder, 1987). This was suggested to be related to uneven ripening and physiological disorder development. [*It also underlines the importance of sampling all the fruit flesh in a systematic manner in maturity testing – Ed.*].

Freeze drying (lyophilisation) correlated well with the oven-drying method for moisture content determination and allows for more samples to be processed (Sippel *et al.*, 1995b).

Fruit length, and fruit diameter were not reliable markers for maturity, but the mass:volume ratio showed promise, as it increased to a point and then declined at 12-13% oil content (fresh mass basis) (van Lelyveld, 1978). Pectin methylesterase (PME), polyphenol oxidase (PPO), and peroxidase (PO) could not be associated with fruit maturity. Pulp spot was not associated with fruit maturity, but was more likely linked to stress (temperature or water stress).

Kalala *et al.* (2005) suggested that seed water potential (Ψ_w) could be used as a maturity index because it is highly correlated to the days after full bloom (DAFB) and fruit flesh moisture content.

Two major fruit volatile compounds, α-humulene and β-caryophyllene, and two minor volatiles, 1-dodecanol and 1-pentanol, were identified. β-caryophyllene increased and α-humulene declined during the season (Tesfay *et al.*, 2011).

6.1.2. Maturity standards

The avocado producing areas in the warmer provinces (Limpopo and Mpumalanga) have different maturity standards to the cooler KwaZulu-Natal Midlands. These are addressed separately for clarity.

6.1.2.1. Northern Provinces

Preliminary results showed that Fuerte accumulated oil faster than Edranol but there were seasonal differences. More seasons' data were needed to draw firm conclusions (Smith & Huisman, 1982a). Later in the study, no differences were found between different fruit sets, and good correlations were found between oil content and MC (Table 9) (Smith, 1984c).

Table 9: Correlation between oil content and moisture content and the constant value to convert between the two values. The oil content (%) can be determined by subtracting the moisture content (%) value from the constant value for each cultivar - taken from (Smith, 1984c).

Cultivar	Correlation (r)	Constant
Fuerte	0.985	89.8
Edranol	0.833	90.9
Ryan	0.848	89.0
Hass	0.956	87.8

There was an excellent correlation between moisture content and oil content for each cultivar tested in Chile, but the regression equations were quite different to those developed in South Africa by Swarts (1976a) (Undurraga *et al.*, 1987).

Table 10: Regression equations to determine oil content in six avocado cultivars from Chile (Undurraga *et al.*, 1987)

Cultivar	Oil Content (%)	Correlation (R^2)
Negra de la Cruz	91.141 - 0.971*MC	-0.9925
Bacon	57.124 – 0.599*MC	-0.9974
Zutano	58.494 – 0.622*MC	-0.9869
Fuerte	84.507 – 0.905*MC	-0.9061
Edranol	53.246 – 0.561*MC	-0.9864
Hass	48.428 – 0.520*MC	-0.9750

The maturity constants obtained in the 1994 season from Kiepersol/Hazyview were 1-2 units lower than those obtained initially by Swarts (1976b) and the authors recommended having geographic and cultivar specific maturity constants to improve the conversions of moisture content to oil concentration and improved shipping temperature selection (Kruger *et al.*, 1995). They also recommended using oil concentration on a dry mass basis, rather than a wet mass basis. Kruger & Claassens (1996a) concluded that moisture content was less variable than oil concentration (dry mass basis), MC does not increase after heavy rains, and irrigation does not delay harvest by keeping MC elevated – but does result in a faster increase in oil and fruit mass. Differences were noted in the rate of maturation between 1994 and 1995, due to higher ambient temperatures in 1994 (Kruger & Claassens, 1996b). They categorised cultivars according to water content, oil content, and non-oil dry matter (Figure 5). Hass and Ryan have a high non-oil component; Fuerte and Edranol have a combination of high oil and moisture; while Pinkerton is intermediate. Furthermore they determined that the minimum sample size for determining fruit MC, for a 95% confidence, is 3-4 fruit.

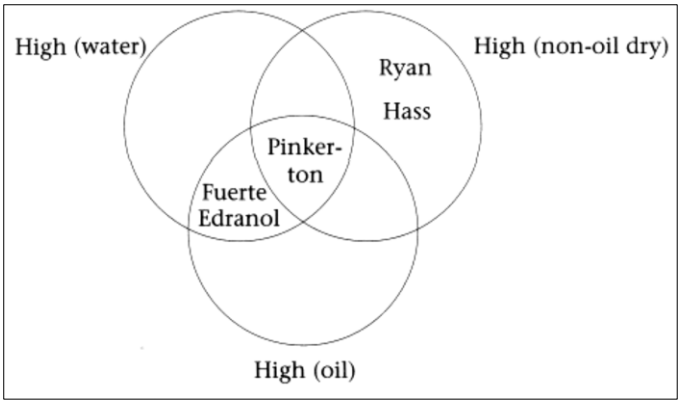

Figure 5: Relative status of each cultivar with regard to its oil, moisture, and non-oil dry component. Based on the 1995 season – taken from (Kruger & Claassens, 1996b)

Recommendations from Pinkerton were expanded to the other commercial cultivars in South Africa. Preliminary results were that good quality fruit should not lose more than 1% MC every 10 days. Optimum maturity for Fuerte was the same as Pinkerton (Table 11).

The emphasis was placed on nitrogen as a manipulator element, and the concentration of other elements, and soil pH be within leaf and soil norms. Fruit flesh (pulp) nitrogen concentration of Pinkerton, Fuerte, and Hass in Tzaneen, Barberton, Kiepersol and Nelspruit areas should not exceed 1.7% during November and be below 1% in January with no intermittent peaks. The practice of

increasing the storage temperature when using CA to reduce external chilling injury was acknowledged but should not exceed 1.5°C above the recommended temperature due to increased fungal decay (Snijder *et al.*, 2003).

Table 11: Optimum moisture content (MC) values for Fuerte, Pinkerton, and Hass in "on" and "off" years in low and high risk areas – taken from Snijder *et al.* (2003).

Cultivar	**Season**	**Low Risk Area**	**High Risk Area**
Fuerte & Pinkerton	On Year	80-73% MC	80-75% MC
	Off Year	80-75% MC	80-77% MC
Hass	On Year	78-71% MC	78-73% MC
	Off Year	78-73% MC	78-75% MC

Kruger *et al.* (2004) outlined risk factors for poor fruit quality in general:

- More mature fruit
- Faster maturation rate
- High potential soil
- Increased organic nitrogen fertiliser
- Warmer orchards
- Higher rainfall
- Younger trees
- Lower fruit load
- Larger fruit
- Lower storage temperature (external quality)
- RA cold storage
- Longer storage period

The revised maturity standards were:

Table 12: Maximum moisture content values for five cultivars according to area and season risk (Kruger *et al.*, 2004).

Cultivar	**Season Risk**	**Low Risk Area**	**High Risk Area**
Fuerte	Low	68	72-73
	High	70	75
Pinkerton	Low	70	74
	High	73	77
Hass	Low	65	69-71
	High	70	73
Edranol	Low	72	75
	High	72	75
Ryan	Low	65	70
	High	65	70

Specific fruit nitrogen concentrations for each area were not provided but fruit quality monitoring was recommended and a rough estimate was to follow the recommendations for Pinkerton (above).

6.1.2.2. KwaZulu-Natal Midlands

Avocados in KZN (Fuerte, Edranol, and Hass) did not conform to the moisture content maturity standards developed in (now) Limpopo. Although fruit were legally mature (*i.e.* moisture content (MC) < 80%), and all three cultivars reached legal maturity in late March, Fuerte only reached horticultural maturity in late June, Edranol in mid-August, and Hass in August-September (McOnie & Wolstenholme, 1982). The following year, the recommendation was that 77% MC be used as a minimum maturity standard for Fuerte, 72-73% MC for Edranol, 70% for Hass, and that Ryan be harvested in late October to mid-November. Selective picking of larger fruit, and on-tree storage of the remainder of the crop into December for higher prices was suggested (van den Dool & Wolstenholme, 1983). [*However, the trade-off is a reduced crop the next season, and aggravation of alternate bearing. Late hanging for higher prices is therefore an economic exercise, i.e. do higher prices compensate for reduced and alternate yields? – Ed.*].

The effect of late hanging fruit in KZN was investigated by Graham & Wolstenholme (1991). They concluded that late hanging should not extend long after the following season's flowering because of the high energy demands for two crops, which could result in excessive fruit drop and unsustainably low yields. If producers did late hang fruit, they encouraged fruit thinning and earlier selective picking of larger fruit. Flowering was also delayed and the spring vegetative flush reduced if fruit were late hung beyond September.

An increase in relative fruit maturity (decrease in moisture content) was related to changes in fruit mineral concentration, namely that calcium and magnesium were actively translocated out of the fruit as fruit matured (although calcium is considered immobile) - while potassium concentration fluctuated during the season (Cutting *et al.*, 1992). The total phenolic concentration increased slowly from June to September but increased rapidly in October (Fuerte from KZN). This combined with the decrease in membrane integrity from the reduction in calcium would predispose fruit to grey pulp – as was evident in the experiment. Hanging some fruit into the following season's flowering would therefore be discouraged based on fruit physiology and quality results [– *but is again an economic decision – Ed*].

Mans *et al.* (1995) concluded that minimum maturity for fruit from the KZN midlands was lower than fruit from the north: Fuerte: 75%, Hass: 75%, Edranol: 70%, and Ryan: 69%.

It was proposed was that 57% oil (DM basis) or 15% (wet mass basis) is the maximum maturity level for Fuerte from the KZN Midlands for good internal fruit quality. Pectin methylesterase and cellulase could not be used as a maturity marker (Kaiser *et al.*, 1995a; Kaiser *et al.*, 1996).

6.1.3. Near-infrared spectroscopy

The use of near-infrared spectroscopy (NIRS) to non-destructively measure and then sort fruit according to moisture content (MC) and internal fruit quality was reviewed by Blakey *et al.* (2008). A model was later developed using a benchtop NIR. Fruit flesh MC was more accurately measured in green skin cultivars than Hass, and more accurately on the day of harvest than a few days later (Blakey *et al.*, 2010). Later a handheld NIR was tested, and after the first year MC could be measured with a standard error of prediction (SEP) of 2.8% MC; if the skin of the fruit was removed the SEP was reduced to 2.2% MC. Testing continued to improve the robustness and accuracy of the model (Blakey & van Rooyen, 2011).

6.2. Picking & Handling

The removal of the pedicel [*more correctly fruit stalk and will be referred to as such in this review – Ed.*] from Fuerte fruit before storage resulted in increased chilling injury and anthracnose, but there was no significant increase in stem-end rot (SER) (Toerien, 1977a).

Rough handling of fruit did not consistently impair fruit quality – even if fruit were dropped 60 or 90cm [*presumably onto a hard surface but not specified – Ed.*] – but the removal of peel increased disease (Ramathoka, 1978). While this is not justification for rough handling of fruit, hard fruit are fairly resistant to handling.

Selective picking is necessary to pick early season Fuerte (February and March in hot growing areas) because of the variation in fruit maturity. Anthracnose and SER infections were high, because of the warm, wet conditions (Burelli, 1982).

The severity of bruising was related to the height from which the fruit was dropped and the firmness of the fruit; fruit were unlikely to bruise at firmness of more than 6.8kg of force (kgf) (Arpaia *et al.*, 1987). Early season fruit were more susceptible to bruising than mid- or late season fruit. Vibrational damage was noticeable on the fruit skin as lenticel damage (skin spotting) and internally when the fruit firmness was <2.7kgf for Hass and Pinkerton, and <11.3kgf for Fuerte.

Wet picking was particularly detrimental early in the season (late March – early April) for Fuerte when the practice significantly increased the incidence of black cold and lenticel damage, and for Hass when it increased lenticel damage and vascular browning incidence significantly (Duvenhage, 1993).

Picking fruit without fruit stalks was much faster than clipping and no pathological problems were noted in Hass over two seasons (Köhne & Kremer-Köhne, 1995).

6.3. Cold Storage

The time-temperature interaction was very important in determining fruit quality (including external chilling injury, physiological disorders, days to ripen, and disease development). Specifically, pre-storage at 16°C resulted in greater external chilling injury (cold damage), and a storage period of more than 21-28 days caused greater incidence of disorders. It was recommended that, in addition to temperature inspections, the time from picking to consignment also be regulated, in an attempt to reduce fruit quality losses because of prolonged holding at the packhouse (Vorster *et al.*, 1988).

An important review of pre- and post-harvest measures for long-term storage of avocados was written by Bower (1988). He outlined the importance of timing calcium applications to coincide with early fruit development (main cell division stage) to allow the maximum uptake of calcium into the fruit; the importance of controlling the spring flush, and managing water stress to control growth without negatively affecting calcium uptake. Fruit maturity, cold storage temperature and duration, and atmosphere management (CO_2, O_2, and humidity concentrations) are all important factors in determining the storage potential of avocados.

Vorster *et al.* (1990) discussed an integrated approach to postharvest management to maintain fruit quality during shipment from South Africa to Europe. Important points were:

1. Fruit maturity, and selective picking early in the season to reduce variation in maturity.
2. Step-down temperatures to reduce external chilling injury and soft landings.
3. Time-temperature interaction.
4. Effective cooling using correct carton and pallet design; controlled/directed airflow; humidified air with limited temperature gradient between air and fruit.
5. Potential use of controlled and modified atmosphere.

Postharvest mass (water) loss was related to storage period, fruit maturity, and days to ripen. It was surmised that these three factors are inter-related and also affect fruit quality. Methods to limit postharvest water loss (wax, higher RH, shorter duration between picking and cooling) were recommended to better maintain fruit quality (Cutting & Wolstenholme, 1991).

6.3.1. Temperature management

Postharvest fruit age, and prevailing temperature were identified as the main factors that affected fruit quality overseas. Postharvest fruit age could be shortened with better packhouse management, and shorter transit time between the packhouse and port. Extended cold chain breaks during loading and inspection were identified as being detrimental to fruit quality (Smith, 1982).

A good practical review of postharvest handling of South African avocados was given by Eksteen & Bester (1987). The emphasis of the review was on cooling and cold chain maintenance. The major conclusions were:

1. The cold storage temperatures must decrease as the season progressed, and could decrease during the cold storage period to maintain internal and external fruit quality
2. The cold chain must be started as soon after harvest as possible and it must be maintained throughout.
3. Limit the postharvest life of the fruit as much as possible, focussing on efficient logistics and marketing.
4. The use of effective cooling systems is imperative.

The SAAGA Temperature Committee recommended greater use of refrigerated road transport. CA containers were being tested by the PPECB in conjunction with exporters, and the committee was working with the South African Bureau of Standards (SABS) to develop minimum requirements for cartons. The growth in the export of avocados meant two ships were hired to export avocados, with the possibility of a third if volumes justified (Eksteen, 1990).

Eksteen & Henning (1992) identified four critical factors to improve fruit quality in Europe:

1. Very accurate air delivery temperature control (within ±0.5°C of set point).
2. Variable optimum carrying temperature which varies with maturity.
3. Step down temperature regime, stepping down with increasing maturity and fruit age.
4. The postharvest age of the fruit should not exceed 28 days (without CA and 1-MCP).

They further confirmed that there were improvements from 1988 to 1991 in the refrigerated motorised transport of South African avocados. Temperature regimes were being followed (although there were mechanical problems in some containers); and improved pre-cooling resulted in better loading temperatures and therefore the pulp temperature was closer to the carrying temperature. Cold chain maintenance and carton and pallet design were again stressed (Eksteen & Henning, 1992).

The age of fruit on arrival at the port, affects the firmness on arrival in Europe and hence determines the temperature tolerance for intake at the harbour holding store. These tolerances are outlined in Table 13. Fruit older than 28 days postharvest are much more likely to develop chilling injury and arrive soft. Air and pulp temperature need to be controlled, close to the set temperature, to prevent softening (supra-optimal) and chilling injury (sub-optimal) (Bezuidenhout *et al.*, 1995).

Table 13: Temperature tolerance levels depending on postharvest fruit age – taken from Bezuidenhout *et al.* (1995)

Fruit age*	**Max Pulp Temp above Initial set temp (°C)**
<3	+4
4-6	+3
>7	+2

* Days between picking and arrival at port

Older and softer fruit developed more quality defects (internal and external) during transport, storage, distribution and marketing. Internal and external defects were correlated – suggesting general poor handling through the cold chain. Holding store conditions, particularly temperature and relative humidity, needed attention: low temperatures caused black cold, high temperatures caused softening, and low RH caused brown cold. Actual shipping regimes had little effect on fruit firmness on arrival – it was the handling and temperature management prior to the port and after discharge that had the greatest effect on softening. Ryan temperature recorders were inadequate. The importance of following established protocols, particularly fruit age and temperatures, to maintain fruit quality was stressed (Eksteen *et al.*, 1997). Similar results were found the following season: inadequate pre-shipment temperature control nullified the benefit of shipping fresher fruit. Early season temperatures should start at 7.0°C rather than 7.5°C. CA shipment was recommended for the first 6 weeks of the Fuerte season, but was not needed for Hass (Eksteen *et al.*, 1998). Feedback from the 1997 season from the PPECB was used to formulate practical procedures, technical evaluation procedures, set guidelines for the large 1998 crop to ensure that the consignments were efficiently exported, and propose further research. CA was recommended for the first 4-6 weeks of the Fuerte season (Eksteen, 1998; 1999).

6.3.1.1. Pre-Cooling

The temperature of fruit in the orchard, especially sun-exposed fruit, can exceed 30°C in the afternoon. Picked fruit should be kept in the shade and taken to the packhouse, graded and packed as soon as possible after harvest. Fruit should be palletised in a cold room and then forced air cooling used to remove field heat as quickly as possible (Slabbert & Toerien, 1979).

It was concluded by Lunt & Smith (1981) that forced air cooling was necessary to cool avocado to 5-6°C pulp temperature within 12 hours of palletisation. Passive cooling took 20-28h depending on air flow and carton design.

The importance of pre-cooling fruit before containerization was stressed by Bester (1982) because there was only a small difference between energy entering the container and its cooling capacity.

Forced air cooling for 2-8 h increased external chilling injury and days to ripen. While the authors acknowledged the importance of air temperature, air speed, and duration, they did not address the issue of relative humidity. A low relative humidity would desiccate the fruit and result in worse

external chilling injury. Forced cooling is now a global standard in packhouses, and the technical issues encountered here were resolved. The lack of wax may also have contributed to the worse external chilling injury. Also, cellophane wrapping significantly increased pulp spot, vascular browning, and grey pulp, resulting in a recommendation that its use be discontinued. Significant differences between experiments were found, and concluded that preharvest factors had a significant effect on postharvest fruit quality. Furthermore, they found significant differences between count sizes: smaller fruit had higher ECI, stem-end rot, and days to ripen, while larger fruit had worse vascular browning and grey pulp; count 12 and 14 fruit had the worst pulp spot. These results suggest significant differences in maturity between small (less mature) and larger fruit (more mature) (Slabbert & Toerien, 1984) [*presuming the seed coat is healthy – see the "Hass Small Fruit Phenotype" section for more information. Also, larger fruit is associated with more vegetative (more vigorous) trees with smaller crop loads. Excessive vegetative vigour increases the risk of poor internal fruit quality because the increased N and reduced Ca concentration in the fruit pulp – Ed.*].

6.3.1.2. Cold-Chain Maintenance

After a detailed study of South African fruit in Europe in 1981-2, it was concluded that there were severe breaks in the cold chain and mishandling of fruit that resulted in poor fruit quality, especially later in the season (Kuschke, 1983).

In the 1990 season pre-cooling at the packhouse and carton design, stacking configuration, and pallet density all needed to be improved to ensure that all the cartons in a pallet and container were within temperature specifications. The temperature of inner cartons of a pallet was 2-5°C higher than the carrying temperature, and it was impossible to reduce the pulp temperature to the carrying temperature if precooling was inadequate (Eksteen & Henning, 1991).

The postharvest age of fruit should be less than 26 days. A too high loading temperature results in increased fruit softening. The provisional maximum differential between pulp loading temperature and the instruction temperature, according to fruit age is given in Table 14. Further data were needed to confirm these guidelines. Lenticel damage was correlated to too low temperatures in the container, but not cold damage. Too high temperature at packhouse loading was not related to softening. The firmness on delivery at the packhouse correlated to firmness at arrival in Europe, and it was recommended that fruit firmness be measured with MC on delivery (Bezuidenhout & Eksteen, 1994).

Table 14: Provisional maximum differential of pulp temperature at loading, and the instruction temperature, according to postharvest fruit age – taken from Bezuidenhout & Eksteen (1994).

Fruit age (days)	Loading Pulp Temperature (°C)	Differential from Instruction (°C)
22	9.0	3.5
24	7.5	2.5
27	6.3	0.8

Eksteen (1995) outlined details of every step in the postharvest chain, from picking to discharge in Europe, to maintain fruit quality. It is critical that the cold chain is started as soon as possible and maintained until fruit are ripened or sold. The reader is referred to the main article for more details.

Breaks anywhere in the cold chain were detrimental to fruit quality (mostly shrivel, but anthracnose and poor skin colour development to a lesser extent), but the fruit recovered physiologically in terms

of respiration and ethylene production. Storage at 1°C mitigated some of this quality loss (Blakey & Bower, 2009).

The rate of softening during cold storage is an interaction between fruit maturity and storage temperature (Lemmer *et al.*, 2009). Fruit softening was preceded by an increase in respiration rate and return air delivery temperature. CA and Smartfresh™ slow the rate of softening and the respiration rate during cold storage. The respiration rate in RA, CA, and Smartfresh™-treated fruit remained stable for the about 20 days of cold storage and then increased significantly. The respiration of Pinkerton fruit increased about four days earlier than Hass and Fuerte, but the respiration rate was lower for Pinkerton during this period. The respiration rates of Maluma and Ryan are fairly similar to Hass at the same temperature. However Maluma has a higher respiration rate at harvest and this declines more slowly than Hass when placed in cold storage. At the end of cold storage the respiration rate of Maluma fruit increased at a slower rate than Hass. Cold chain breaks drastically increased pathological decay and shorten days to ripen, and increase grey pulp particularly in Fuerte. The treatment of fruit with Smartfresh™ reduced the impact of cold chain breaks (Lemmer & Kruger, 2010; 2011; Kruger & Lemmer, 2012).

6.3.1.3. Step Down Temperatures

Cold storage temperature for Fuerte could be dropped later in the season without causing external cold damage once the total number of hours the orchard air temperatures was 17°C was greater than about 10h during the two days before harvest. Cold damage and days to ripen were negatively correlated to storage temperature (Swarts, 1982).

The storage temperature later in the cold storage period should be lowered to reduce the risk of grey pulp. Cold damage, pulp spot, and grey pulp were highly significantly correlated to each other. Maturity and fruit size were also positively related to pulp spot and grey pulp development (Bezuidenhout, 1983a).

Step down temperature regimes during the season were advantageous in prolonging shelf life. The authors recommended using both oil content and the number of hours below 17°C (ambient air temperature) as factors to determine the optimal storage temperature. After the first season, they concluded that the Fuerte season could be divided into four stages. The storage temperature (air delivery) could drop from 6.5 at the beginning of the season to 5.5°C by about mid-April, and to 4.5°C in late May in the northern provinces (Smith & Lunt, 1984).

Table 15: Recommended storage temperature for Fuerte during the season, based on oil content and number of hours below 17°C two days before harvest.

Stage	Oil Content (% FM)	Hours below 17°C	Recommended Storage Temperature (°C)	Approximate Date for Change*
1	<16	<5	6.5	5 April – 18 April
2	16-20	>10	5.5	18 April – 22 May
3	20-26	>15	4.5	22 May – 4 August
4	>26	-	Do not export by sea	4 August – end

***Date will depend greatly on the prevailing weather. The dates are only a guide, and are for warm rowing areas.**

A step down temperature regime during the season, from 6.5 to 5.5 to 4.5°C was effective in reducing cold damage and maintaining fruit firmness during cold storage. It is critical that the difference between the set and actual temperatures is minimal (Smith, 1985).

The use of step down storage temperatures gathered momentum after Toerien (1986) showed that temperatures could be safely lowered from 5.5 to 3.5°C after two weeks of cold storage. His recommendation was to have a temperature regime as outlined in Table 16 – but taking fruit maturity into account when deciding on a storage temperature regime. Furthermore, he suggested changing from the telescopic carton design to the ILB carton. *[Attention must be drawn to Bezuidenhout (1983) stating that the climacteric stage occurred within the first 13 days of cold storage – Ed.*].

Table 16: Variable air temperature regime for the cold storage of avocados for 4 weeks - taken from Toerien (1986).

Week	Air Temperature Formula	Example
1	X + 1.5	7.0°C
2	X + 0.0	5.5°C
3	X – 1.5	4.0°C
4	X – 2.5	3.0°C

(X = 5.5°C)

The concept of step down temperatures was further investigated and discussed by Vorster *et al.* (1987). Hass and Ryan fruit could be stored as low as 3.5°C without the development of ECI (discrete patches). In later experiments, it was shown that fruit from later flower sets were more cold-sensitive than earlier sets which were more mature. Selective picking early in the season was emphasised to meet minimum maturity and reduce fruit quality losses. Minimising the time between the first and last harvest dates for fruit for a particular vessel was also emphasised, as first fruit picked had the highest chilling injury (Vorster *et al.*, 1989). Fruit quality (cold damage and soft landings) was vastly improved in the 1989 and 1990 seasons with the step down temperature regimes, compared to the 1988 season when a standard temperature of 5.5°C was used for Fuerte (Vorster *et al.*, 1991). Feedback of fruit quality from the export market also suggested adjustments to the planned step down temperature regimes.

Various step down treatments were investigated for fruit from Everdon (KZN midlands) but crop load was the major factor in determining the risk of physiological disorders (Donkin *et al.*, 1994). They concluded that fruit from a high-yielding tree with a reduced spring vegetative flush was less likely to develop physiological disorders because the fruit had a relatively higher concentration of calcium. Hence poor quality fruit would occur in "off" seasons. Reducing the vigour of the spring vegetative flush, and using cultural practices (such as mulching and soluble calcium) to increase calcium uptake [*early in fruit development – Ed.*] were recommended. The next season, step down temperature regimes for KZN midlands fruit did not significantly improve fruit quality compared to fruit stored at 5.5°C (Donkin *et al.*, 1995). Also, the total phenolic concentration did not change significantly during the season and did not correlate with pulp spot and grey pulp development (*these disorders are affected by phenolics, PPO, and membrane stability – Ed.*). The ethylene production during cold storage was not affected by storage temperature (5.5 vs. 7.5°C) but fruit stored at the higher temperature did have a higher climacteric peak. They also noted that the climacteric peak only occurred after removal from cold storage – contrary to the perception at the time that the climacteric occurred during cold storage.

The export of Gwen and Pinkerton by sea freight was feasible, using constant 5.5°C, or step-down treatments of 6.5-4.5°C, or 5.5-3.5°C for Gwen, and 5.5-3.5°C and 6.5-5.0°C for Pinkerton in simulated static cold storage trials (Roe, 1995).

Optimal temperature regimes for Fuerte fruit from the KZN midlands were higher than fruit from the northern provinces (Mans *et al.*, 1995; Mans, 1996b). The summary is given in Table 17.

Table 17: Recommended temperature regimes for KwaZulu-Natal - taken from (Mans, 1996b)

		Storage Week			
MC (%)*	Regime	1	2	3	4
75-78	1	8.5	8.5	7.5	6.5
72-75	2	8.5	7.5	6.5	5.5
67-71	3	8.5	7.5	5.5	4.5
≤66	4	7.5	7.5	6.5	4.5

*MC = pulp moisture content

6.3.1.4. Ultra-Low Temperature Storage

Cold sterilisation (technically cold disinfestation) is a potential method to sanitise fruit in respect of unwanted insect pests, and therefore make such fruit acceptable to import countries, *i.e.* overcome phytosanitary trade barriers. Fruit flies and false codling moth in particular are of concern. Very low pulp temperatures of about 1°C for a specified period are required to kill the insects and disinfest the fruit.

Cold disinfestation did not render Hass fruit unacceptable when tested semi-commercially. If the insect mortality was of a Probit 9 level, this treatment should be suitable for implementation. Interactions between fruit origin and position in the container (and therefore temperature) resulted in differences in external chilling injury, lenticel damage and ripening. Further testing was required to determine variation within the container and whether container modifications can improve the temperature uniformity (van Rooyen, 2009). The fruit quality of Hass stored at 1°C (ADT) was again acceptable in terms of cold damage, lenticel damage, grey pulp, days to ripen, and colour development. In some cases fruit quality was superior after storage at 1°C rather than 5.5°C (viz. brown cold damage, colour development, and grey pulp). Modifications to the shipping container to attain better temperature uniformity in the container would need to be approved by USDA-APHIS and/or shipping companies. The logistics of applying pre-conditioning still needed further research (van Rooyen & Bezuidenhout, 2010).

A storage temperature of 1°C for Hass was equally effective as 1-MCP treatment in maintaining fruit firmness, and reducing vascular browning and grey pulp; external chilling injury was slightly higher at 1°C. Cold chain breaks, but especially a 24 hour delay in cooling, significantly increased mass loss, vascular browning and softening (if not treated with 1-MCP). It was concluded that fruit could be shipped at 1°C without 1-MCP only if the cold chain could be maintained. If not then standard treatment of higher temperature with 1-MCP should be used. Results from anti-oxidant activity and concentration generally confirmed these findings (Kok *et al.*, 2010; 2011; Kok *et al.*, 2012).

A storage temperature of 2°C for Fuerte rather than 5.5°C with 1-MCP was promising in terms of internal quality and fruit firmness maintenance. Waxing fruit did reduce external chilling injury however this needs to be addressed before it could be implemented safely. Cold chain breaks, but especially a 24 hour delay in cooling, were again detrimental, in terms of external chilling injury and fruit softening (Lütge *et al.*, 2010; Lütge & Bower, 2011). A reduction in storage temperature, the use of 1-MCP, waxing, and cold chain maintenance better maintained the concentrations of anti-oxidants and total anti-oxidant activity during cold storage. However differences between treatments were not

always significantly different [*probably because of a low sample number – Ed.*]. Fruit quality in the trial was good and hence no correlation between anti-oxidant activity and fruit quality was found (Lütge *et al.*, 2012).

Storage for 8 weeks was possible if fruit were stored at 1°C (Hass) or 2°C (Fuerte) and treated with 1-MCP (Kok *et al.*, 2011; Lütge & Bower, 2011). Fruit maturity was a major factor in the success of long term storage. Early season fruit could not be stored this long because of external chilling injury [*perhaps a pre-conditioning step-down treatment would improve this – Ed.*], and late season fruit had a high incidence of fungal decay [*which could be improved with a fungicide treatment before ripening as Lemmer et al. (2007) concluded – Ed.*].

6.3.2. Waxing, packaging, atmosphere modification & 1-MCP

Toerien (1977b) tested two waxes and cellophane wrapping for harvested fruit. Both TAG® and DM2HB® resulted in improved internal and external fruit quality (anthracnose, SER, VB, and fruit flesh discolouration) compared to the untreated control. DM2HB® had a more positive effect on fruit quality, but resulted in unattractive fruit. Cellophane in combination with either of the waxes further improved fruit quality. Toerien *et al.* (1978) found that the removal of the fruit stalk "button" did not negatively affect Edranol and Fuerte fruit quality after cold storage, if benomyl 50% WP, 0.4% a.i. and TBZ 45.1% EC, 0.2% a.i. were included in the wax (TAG 70® at 1L/1 000kg fruit).

Wax, cellophane, and the combination, incrementally reduced mass loss of Fuerte fruit (68% MC) (Kotzé & Kuschke, 1978). However in a subsequent study, cellophane wrapping was inferior to waxing, and the combination treatment, in terms of external appearance, and firmness (Lunt *et al.*, 1981). The added cost of the cellophane wrapping was not justifiable and their use was phased out.

After testing five different waxes, it was concluded that waxing has a variable effect, depending on cultivar and maturity. A "denser" wax slowed softening, allowing shipment at higher temperatures (Smith & Huisman, 1982c).

Controlled atmosphere storage (10% CO_2, 2% O_2 at 5.5°C) extended the shelf life of Fuerte, Edranol, and Hass by up to 5 days compared to fruit stored in RA. Pulp spot was completely eliminated in Fuerte, and grey pulp drastically reduced in all three cultivars. The incidence of anthracnose increased with CA storage. The incidence of vascular browning was variable between the control and CA storage. Ethylene absorption and 6% carbon monoxide (CO) with CA had no beneficial effect on fruit quality. Packing of avocados in polyethylene bags and treatment with Prolong® wax gave good results (Truter & Eksteen, 1982). Similar results were found the following season. In additional trials, polyethylene (PE) bags wrapped around individual fruit improved fruit quality, but temperature control was critical. Sealed PE bags adversely affected internal fruit quality. CO_2 shock treatment (18% CO_2 for 6 days at 5.5°C) was promising but needed further testing (Truter & Eksteen, 1983).

The PPECB began to test modified- and controlled atmosphere storage in 1984. At that stage modified atmosphere (MA) and controlled atmosphere (CA) were promising, but still had technical issues that needed to be resolved before the technology could be used commercially. Most importantly these related to the development of anaerobic conditions ("suffocation") (Ginsberg, 1984).

Yair Aharoni from the Volcani Centre in Israel visited South Africa in 1983 for four months under the auspices of a scientific exchange programme between the two countries. He outlined the progress in

using controlled- and modified atmosphere storage, step down treatments (termed gradually decreasing temperatures), and sub-atmospheric pressure storage. All these treatments improved the storage life of avocados (Aharoni, 1984). Research continues into all but the last method, because of cost.

Short-term CO_2 shock (10, 15, or 20%) for 2-4 days did not seem have a beneficial effect on internal or external fruit quality, but did slow ripening. It was concluded that preharvest factors had a major effect on postharvest quality (Slabbert & Veldman, 1984).

Fuerte fruit were stored in anaerobic conditions at 5 and 25°C to investigate the effect on fruit physiology. Avocado fruit are highly sensitive to anaerobic conditions, turning brown and glassy. Interestingly, mass loss during ripening appears to be related to the respiration rate – *i.e.* the mass loss is not only water loss (Nel *et al.*, 1984).

Three types of modified atmosphere packaging (MAP) made from high density polyethylene delayed ripening with consequent increased SER and anthracnose (Durand, 1984). Fruit that were waxed took longer to ripen and mixed ripening was worse. Modifications to the plastic may improve results.

Atmosphere modification has received attention over the years as a means to prolong storage life of avocados. Controlled atmosphere, modified atmosphere packaging, and CO_2 shock all showed potential to maintain fruit quality (reduced external chilling injury, grey pulp, and pulp spot) of avocados, and increased the days to ripen (DTR) after removal from cold storage, but with increased fungal rots in the more severe treatments (Eksteen & Truter, 1985; Truter & Eksteen, 1987). Under CA, a CO_2 concentration of 10% resulted in significantly higher incidence of anthracnose. Variable results (probably due to excessive CO_2 concentrations causing "suffocation") were observed in the MAP treatments. The authors highlighted the practical challenge of having to remove MAP prior to ripening.

Pallet and carton design was investigated by Boelema (1987). It was concluded that for optimal cooling of avocados the following were needed:

1. A carton with optimal air circulation
2. A stacking pattern which lined vents up vertically and horizontally
3. Full vehicle containers
4. An un-interrupted cold chain
5. A free flow area (total area of openings as a % of carton area) of at least 8%
6. 5mm clearance between fruit and the lid (or carton above) – this was not necessary if forced cooling was used.

This research resulted in a re-design of the avocado pallet (1,110 x 1,120mm) and carton to optimise cooling (Boelema, 1987). [*The carton that was designed from this research has since been superseded and does not have a lid – Ed.*].

Shrink-wrapping fruit with a multi-layered film (MY; oxygen permeability of 1750 cc/m^2/24h at 1 atm and 22°C) showed promise in increasing shelf-life but there were concerns about fungal decay and physiological disorders (Rowell, 1988b).

CA storage decreased postharvest physiological changes (ripening and senescence) compared to CO_2-shock and regular atmosphere (RA)-storage. Although the PPO activity and total phenolic concentration were relatively high, browning did not result because membrane integrity was maintained (Bower *et al.*, 1989). At the time, practicalities and cost meant that large-scale CA-storage was not feasible. CO_2-shock treatment resulted in better fruit quality than RA-stored fruit but the treatment did not "hold" fruit in a less advanced state as did CA-storage.

Storing fruit in CA using a "Freshtainer" 40ft container (7.5°C for 8 days, 5.5°C for 7 days) resulted in better avocado fruit quality than fruit stored in regular atmosphere at 5.5°C for the same period. One problem with this system was that the concentration of CO_2 (set to naturally increase to a maximum of 10%) only reached 5.5%, and the concentration of oxygen was set to 2% but remained at 2.5% (Eksteen & Truter, 1989).

CA (2% O_2, 10% CO_2) and CO_2 shock (25% CO_2 for 3 days) both significantly reduced grey pulp incidence compared to fruit stored in regular atmosphere. Interestingly, the CA storage resulted in the highest PPO activity at ripeness (Truter *et al.*, 1991).

Two days of high CO_2 (5 – 25%) or low O_2 (0.21 – 4.2%) shock treatment at ambient temperature did not show any significant difference in diseases, or physiological disorders; the effect of the gas concentrations on days to ripen was generally variable (Allwood & Cutting, 1994). Brown cold damage was noted in this trial, when fruit were treated at 0.21% and 3.0% O_2. This was probably low intensity suffocation because symptoms developed before cold storage. Results were not repeated in the second season. The treatment could not be recommended, but further testing was needed to determine the effect on fruit quality (Allwood & Wolstenholme, 1995).

Stafresh®, a natural wax emulsion containing shellac and carnauba, was a good alternative to TAG wax (polyethylene wax). Avocado oil, sunflower oil, 1% and 2% chitosan (Nutri-Save®), cellulose-based polysaccharide (NatureSeal 2020®), carnauba emulsion (Tropical Fruit Coating 213), and shellac were unsuitable (Kremer-Köhne & Duvenhage, 1997).

The presence of ethylene (10ppm) in the storage atmosphere resulted in greater fruit softening, while the removal of ethylene using ethylene absorbing filters reduced softening during cold storage (Holcroft & Kruger, 2001).

Very high CO_2 shock treatments (20-50% CO_2 for 24-96h) were detrimental to fruit quality, while fruit stored in RA had superior quality to CA (CO_2:O_2 not provided). 1-MCP treatment also showed promise in maintaining fruit quality during cold storage (Maré *et al.*, 2002).

Smartfresh™ (1-methylcyclopropene; 1-MCP) at a dose of 500ppb, at the initial storage temperature, was as effective as CA in maintaining fruit firmness during cold storage. The refinement of the dosage and exposure period were needed, and semi-commercial trials were planned for the following seasons (Lemmer *et al.*, 2002). In semi-commercial trials, 1-MCP was as effective as CA in maintaining fruit firmness. Fruit softening was more inhibited in smaller fruit (count 18) than larger fruit (count 10/12). The inhibition of softening was also greater in Fuerte fruit than Hass fruit. A clear relationship between 1-MCP treatment and fungal decay was not noted, but poor fruit quality and high 1-MCP did increase fungal decay in fruit from some orchards. A dose of 500ppb was more effective in consistently reducing grey pulp than a 300ppb dose. It was recommended that a dose of 300ppb for 16 hours be

used as a standard treatment across cultivars and count sizes and applied within 3 days of harvest (Lemmer *et al.*, 2003).

Preliminary results showed that potassium permanganate as an ethylene scrubber was not necessary during CA storage (Huysamer & Maré, 2003).

A threshold value of 6% mass loss was identified for the development of external chilling injury when Hass fruit were stored at 2°C (ADT). Most water loss occurred during pre-cooling at the packhouse. MA bags were suggested as a means to reduce water loss and allow for the shipment of avocados at a lower temperature – both for phytosanitary requirements and improved internal fruit quality (Bower & Magwaza, 2004; Bower, 2005).

1-MCP increased the safe harvest period (maximum maturity) considerably, from 75% MC in high risk orchards and 68% MC in low risk orchards to 64-66% MC (dose dependent) (Lemmer *et al.*, 2005b).

Waxing can be deleterious to fruit quality, as it may restrict gaseous exchange. The use of GA postharvest was ineffective in improving fruit colour development and reducing external chilling injury. Micro-perforated polypropylene bags reduced colour development during cold storage. Increased exocarp colour development was hypothesised to be related to stress during cold storage and not a symptom of chilling injury. Fruit storage at 1°C ADT did not negatively affect fruit quality after ripening (Bower & Papli, 2006).

Combining CA (6% CO_2 and 4% O_2) and Smartfresh™ (dose not given) allowed Fuerte fruit to be stored for up to two months and Hass for up to three months. Beyond these durations the incidence of fungal disease and physiological disorders was too high to be economically feasible (Lemmer *et al.*, 2006). By applying a second fungicide treatment (prochloraz or TBZ) immediately prior to ripening, the pathological decay in Hass fruit stored for three months was significantly reduced. A CA of 10% CO_2 and 3% O_2 was also effective in reducing decay, but did result in skin discolouration during storage – which would be deleterious for green skin cultivars. The combination of CA and Smartfresh™ treatment inhibited grey pulp development for three months (Lemmer *et al.*, 2007).

Commercial ripening trials conducted in the UK, using South African fruit showed that large Smartfresh™-treated fruit ripened faster than CA-treated fruit, but smaller Smartfresh™-treated fruit took longer to ripen than those of the same size stored in CA. A cut-off of 70% MC for Smartfresh™, for fruit for ripening programmes was recommended. Although Smartfresh™-treated fruit took about half a day longer to ripen than CA-stored fruit, the ripening pattern between the two treatments was similar (Kruger & Lemmer, 2007).

Both micro-perforated (9µm) polypropylene bags, or a polyethylene bag with an ethylene scrubber were more effective than wax for the maintenance of fruit quality during cold storage, in terms of mass loss and firmness, and external chilling injury at 2°C. A commercial means of implementing the treatment was sought (Bower & Jackson, 2003). The commercial implementation of MA packaging was addressed the following season where various types of packaging were examined (Bower & Magwaza, 2004). Water loss during pre-cooling greatly affected the development of external chilling injury. The best treatment, in terms of water loss and chilling injury were the sealed bags (1 or 10 fruit each), but an unsealed carton liner was superior to untreated and waxed fruit. The recommended plastic for the bag was micro-perforated polypropylene with an anti-mist coating. Bags are not

commercially viable if the fruit are to be commercially ripened because they would have to be opened before ripening to prevent suffocation. Further work on carton liners or pallets wraps was suggested. The use of MA bags delayed cooling of fruit, with the duration dependent on the pulp temperature. On a cool day (12-14°C) the delay was 13h and on a warm day (30°C) it was 26h to reach a stable temperature of 5-7°C. Also, the pulp temperature of the fruit in the MA bags stabilised at a slightly higher temperature. It was recommended that pre-cooling be done before fruit are placed in MA – probably a pallet wrap type system (Bower & Blakey, 2008).

CA and 1-MCP treatment delayed and increased variable ripening; wax only slightly delayed ripening. A treatment of 25°C for 10 hours before ripening 1-MCP-treated fruit was recommended to reduce variable ripening (Lemmer *et al.*, 2005a). Manipulation of the CO_2:O_2 ratio at 5°C synchronised ripening after Smartfresh™ treatment and storage for 28 days. The most promising treatment was 20% CO_2, 2% O_2 but further trials were required (Roets *et al.*, 2009b).

The application of potassium silicate via a water bath increased the silicon concentration in the fruit flesh. Concentrations of 0.5-1.3% were promising in improving postharvest fruit quality by reducing electrolyte leakage and increasing fruit mass; a concentration of 2.5% was too high and resulted in fruit quality loss (Bertling *et al.*, 2009). Silicon suppressed respiration and ethylene production, and this is correlated to the silicon application rate. Only fruit from orchards with low disease pressure should be used because the reduced respiration and ripening may increase fungal decay. Potassium silicate at 2940ppm Si was the most effective in suppressing respiration and ethylene production (Kaluwa *et al.*, 2010).

6.3.3. Heat treatments

Heat treatments were investigated as a means of conferring cold temperature tolerance. Dry heat (4-8h at 40°C) was ineffective; warm water baths (4-36h at 32-40°C) resulted in skin damage; but vapour heat (1.5-3h at 40°C) reduced skin damage and pulp spot compared to the untreated control without reducing ripening time; 10min at 48°C improved fruit quality but shortened ripening time (Donkin & Wolstenholme, 1995).

Results from New Zealand showed that hot air and hot water treatments were effective in reducing chilling injury of Hass fruit at 0-0.5°C cold storage. For hot air, treatments of 38°C for 3, 6, or 10h, and 40°C for 30min were the most effective. For hot water, the most effective treatment was 38°C for 60-120min. These treatments induced the synthesis of heat shock proteins which confer protection against cold damage (Woolf *et al.*, 1996).

Vapour heat treatments (5 or 10min at 48°C or 90min at 40°C) did show some promise in maintaining firmness during cold storage, but made fruit more susceptible to quality losses after a cold chain break; further testing was required because 48°C was too high and variation was noted between growers and harvest dates (Bard & Kaiser, 1996).

A hot water bath treatment of 20-30 min at 40-42°C was effective in reducing chilling injury in Fuerte, but further testing was required. Pre-treatment with wax, and pre-conditioning further reduced chilling injury. The treatment was more effective on early season fruit, but less effective on Hass (Kritzinger & Kruger, 1997). It was later recommended that packhouses do not use heat treatments because of the variation within consignment and the lack of repeatability (Kritzinger *et al.*, 1998).

Hot vapour treatment extended shelf life (slower ripening) but damaged the skin and reduced colour development in Hass. The best treatments for Fuerte were 38-40°C for 4-8h or 42°C for 2-4h; for Hass it was 38°C for 4-8h (Weller *et al.*, 1997). The following year slightly different optimal treatments were identified, however, a good option is 38°C for 4-8h to slow ripening without damaging the skin (Weller *et al.*, 1998).

The treatment of both Hass and Fuerte with a 5 minute hot water bath at 46°C before storage at 1.5°C for 28 days did not yield consistent results. The reduction in black and brown cold damage was inconsistent, and there was no effect on internal quality or ripening. Ancillary results indicated that Hass could often be stored at 1.5°C with little cold damage/chilling injury and reduced softening during cold storage (Kremer-Köhne, 1999a).

Heat treatment prior to cold disinfestation (2°C for 28 days) was investigated by Grové *et al.* (1999c). Hass was the most responsive cultivar to the treatments, and more mature fruit were more tolerant to the cold disinfestation, *i.e.* less chilling injury. Although a heat treatment of 46°C for 5 minutes did reduce external chilling injury in Hass fruit, results were inconsistent and the treatment could not be recommended for commercial use (Grové *et al.*, 2000b).

A hot water bath treatment with a temperature of 38°C for 15-30 minutes improved colour development in early season Hass, shortened the number of days to ripen, and reduced external cold damage and disease development. However results were variable and the treatment could not be recommended for commercial use without further testing (Blakey & Bower, 2007).

Maluma is susceptible to a disorder termed 'vascular staining' which is red staining of the vascular bundles. It was recommended that Maluma fruit be harvested between 77 and 74% MC and treated with Smartfresh™ at 300ppb; CA also reduced the incidence and severity of the disorder (Mhlophe & Kruger, 2012). Vascular staining in Maluma was an ethylene-related disorder, and the use of ethylene inhibitors 2,4-D and 1-MCP decreased the development of this disorder, while exogenous ethylene enhanced its development (Ernst, 2012).

6.4. Ripening

Due to some fruit arriving soft in the UK, a model for fruit ripeness for the warm growing areas was developed to predict the maximum fruit maturity for exporting fruit. Using moisture content, days after flowering, and days to ripen, a model was developed that could predict the week when exports should cease in a particular season, but not the following season. This was thought to be because of different climatic conditions between the seasons, which affected fruit development (Durand, 1981).

Local market "ripe-and-ready" avocados became available in 1980, with some semi-commercial testing of ripened fruit. Fruit were treated with 5% ethylene for 24h at 16-18°C with good results, even without subsequent forced cooling. Problems with variable/checkerboard ripening were noticed. Fruit could be stored at 1°C for a month after ripening but lost firmness very quickly once removed from cold storage (Rousseau, 1981).

Fruit water potential (estimated from the fruit stalk) was negatively correlated with ripening rate, but not respiration and ethylene production (Bower *et al.*, 1982). This research highlights the importance of irrigation management, PRR control, and timing of harvest to reduce water stress in fruit with consequent premature softening.

Anthracnose development was correlated to storage temperature. Anthracnose doubled if the temperature increased from 10°C to 18°C (Bezuidenhout, 1983b). The fruit water potential had an effect on the rate of ripening. Fruit with a highly negative water potential ripened faster in a curvilinear manner. Furthermore, fruit water potential was affected by long term soil water potential. Fruit water potential was optimal at a soil water tension of 35-55kPa. A high soil water tension would also have a negative effect on fruit quality by reducing the accumulation of calcium and other mineral nutrients in the fruit. Following on from this research, with sub- and supra-optimal irrigation (80kPa and 35kPa thresholds, respectively, compared to a control treatment threshold of 55kPa) both negatively impacted calcium accumulation in the first 16 weeks after fruit set. Calcium is required for cell wall and cell membrane stability, among many other physiological roles. This research highlights the importance of correct irrigation practices, particularly at the time of flowering and the four subsequent months, on fruit size, quality, and ripening (Bower, 1984; Bower, 1985) (paragraph repeated in §2.4 (Irrigation)).

The effect of exogenous ethylene treatment was examined using "Quik-Ripe" fruit ripening chambers (0.2m^3 fibreglass containers). Cold storage, even for periods of 2-4 days at 5.5°C, resulted in faster subsequent ripening, and ethylene treatment had an additive effect. Avocado fruit were insensitive to exogenous ethylene immediately after harvest. Ripening was reduced from four days to one day after leaving fruit at ambient temperature for four days before ethylene treatment (Köhne, 1985a).

The "La Barge" ripening chamber was effective in ripening small quantities of fruit. Attention must be paid to ripening temperature to prevent heat damage, and fruit should not be ripened on the day of harvest. A delay of two days shortened the ripening in the chamber by 2 days. Ethylene leaked out of the chamber and could cause surrounding fruit to ripen or senesce (Swarts, 1985).

Cellulase activity increased during the season, with cold storage, and during fruit ripening. Early season fruit have a low cellulase activity at harvest, which increases as fruit mature to about 30% of the maximal activity at harvest. Storage potential, ripening time, and shelf life decrease as fruit mature. It was suggested that an increase in cellulase activity preceded an increase in ethylene activity. Pectin methylesterase (PME) declined during the season and during ripening, while the related polygalacturonase (PG) increased during ripening but not during cold storage. These enzyme studies showed that softening is only reduced or delayed by cold storage, and fruit are "primed" to ripen once restored to ambient conditions – indicated by the climacteric being hastened by cold storage (Fuchs & Zauberman, 1987).

The respiration rate of Hass fruit was relatively high, Fuerte, Pinkerton, and Edranol intermediate, and Ryan low. Interestingly, two climacteric peaks were noted in this trial – which the authors suggested was due to different fruit tissues having different climacteric peaks. Furthermore, a CO_2 shock treatment, directly after harvest or during cold storage, synchronised the climacteric and produced a single peak (Kruger, 1996).

The CO_2 climacteric peak occurred a few days before, or the same day as the ethylene climacteric, followed by a protein climacteric about 4 days later (directly ripened fruit). Pectin methylesterase (PME) activity decreased during ripening; cellulase peaked 7 days after harvest and polygalacturonase (PG) activity about a week alter. However, differences were noted between individual fruit, which is likely to be a cause of variable ripening (Blakey *et al.*, 2009).

The storage of fruit at 1°C and/or in MA bags reduced fruit metabolism during cold storage without affecting fruit quality during ripening. These treatments, alone and particularly in combination reduced respiration, ethylene production, sugar depletion, protein synthesis, mass loss, and water loss. The MA bags were useful in reducing external chilling injury (Blakey *et al.*, 2010).

Soil moisture content at the time of harvest had an effect on ripening and variable ripening which may be linked to inefficient irrigation, especially during dry seasons (Kruger & Magwaza, 2012).

6.5. Quality Control and Assurance

The role of the PPECB was outlined by Schreuder (1994), where he explained how the Board was constituted and the services the PPECB offered.

A very real problem, that of a lack of a standard identification system in postharvest quality assessment, was addressed by Swarts (1984). [*A similar system was furthered by White et al. (2004) who produced an Internal Avocado Quality Manual and these documents are recommended for people involved in avocado research and quality management – Ed.*].

An excellent review on quality assurance was written by Milne (1998). The reader is referred to the original text which discusses fruit quality, respiration, ethylene production, transpiration, temperature, controlled atmospheres, storage duration, pre-harvest factors, critical points in the supply chain, and the role of research in improving fruit quality.

6.5.1. Overseas technical officer

The SAAGA Overseas Technical Officer (OTO) normally gives an annual report on fruit quality of South African exports in Europe. Temperature compliance and fruit quality, both internal and external, are the major issues that are reported on. Also refer to §6.3.1 (Temperature management).

Routine inspections in the UK began in 1976, but it took a few years to establish satisfactory protocols and reporting. Fuerte had problems with anthracnose, fruit flesh discolouration, and pulp spot. Edranol, Ryan and Hass had excellent quality. With regard to temperature compliance, there were many instances (67%) where the temperature during transit to Cape Town was above 5.5°C, often due to warm loadings. Temperature control was satisfactory during the rest of the transit period (Rowell, 1978).

In the OTO report from the 1981 season the major defects were: anthracnose (36% incidence), SER (16%), vascular browning (40%), grey pulp (21%), pulp spot (16%), and cold damage (5%). It was concluded that the grower was mainly responsible for quality defects but packing dates and cold chain breaks also affected fruit quality. Models to predict fruit quality still required further data for practical application (Bezuidenhout & Kuschke, 1982). Compared to the 1981 season, the incidence of pulp spot (16% vs. 6%), vascular browning (40% vs. 30%), and cold damage (5% vs. 2%) in 1982 was lower, but the incidence of skin blackening increased (0% vs. 10%). The quality of airfreighted fruit was not superior to fruit sent via sea freight (Bezuidenhout & Kuschke, 1983).

In the 1988 season report from the Overseas Technical Officer (OTO), it was noted that:

1. External chilling injury (ECI) on Fuerte was largely under control because of step-down temperature regimes, but Pinkerton and Edranol had unacceptably high levels of ECI.

2. Skin discolouration (*presumably brown cold damage – Ed.*) declined during the Fuerte season but was high throughout the season.
3. Grey pulp (GP) was a major concern. Pinkerton and Edranol fruit had high levels of GP throughout the season, Hass and Ryan had peaks of GP incidence in the middle of their seasons, and Fuerte had relatively little GP in the 1988 season. The control of grey pulp needed serious attention because of serious financial losses.
4. The incidence of pathological decay was very low, so disease control measures at the time were satisfactory.
5. Average fruit age was not problematic but fruit from some packhouses was older than 28 days from harvest which resulted in an exponential increase in disorders.
6. Pinkerton, Edranol, and Ryan were discouraged from export, because of poor fruit quality, in favour of Fuerte and Hass.

The feedback for the (then) record "on" crop from 1989 was very positive from the OTO because of step down temperature regimes, and a greater effort in reducing the time form picking to shipping. This reduced the proportion of soft landings, while also reducing external chilling injury (cold damage). Pulp spot (early) and grey pulp (later season) were a problem in Fuerte, and the internal quality of Pinkerton was a serious problem (LeClercq, 1990).

The 1999 season ("off year" with high rainfall) was one with poor fruit quality: black cold damage, soft arrivals, and grey pulp. Problems that were indicated were: fruit arriving at port too warm, and late picking (fruit too mature). The use of CA was defended, in that it kept fruit harder for longer periods compared to RA. A maximum maturity standard was recommended. Pinkerton quality was very poor, even under CA shipment and urgent attention was called for (Nelson *et al.*, 2000).

Despite good fruit quality, prices were poor in the 2000 season because of over-supply/poor market co-ordination. The European market was increasingly seeking Hass avocados, with declining demand for green-skin cultivars. This was likely due to greater QA stringency at the retailer level, and preference for smaller fruit. Green-skin cultivars generally have worse quality and larger fruit than Hass, hence the shift to Hass. Problems were encountered with Lamb Hass [*this cultivar cannot be handled like conventional Hass and handling procedures should have been developed for this cultivars to succeed – Ed.*]. The use of CA was recommended for all cultivars, and container-CA rather than break bulk CA. Pinkerton again had problems with grey pulp and black cold damage. In-land containerisation was beneficial in maintaining the cold chain, and the use of rail was recommended [*provided Transnet's service was reliable and convenient – Ed.*]. Shipping of deadline fruit was discouraged because these fruit typically have not been cooled sufficiently (Nelson *et al.*, 2001).

The 2001 season also had quality problems, because this season was a marked "off year". Black cold injury in Fuerte was higher than 2000 ("on year") but lower than 1999 (previous "off year") and was common throughout the season with some growers' fruit being more susceptible which was thought to be related to nutrition. Later season fruit did develop grey pulp as expected, and the implementation of maximum maturity levels was encouraged. For Hass the major quality defects were soft arrivals and grey pulp. This was due to fruit age, as the average fruit from picking to arrival age was 28 days. Pinkerton continued to be problematic with grey pulp and black cold damage (Nelson *et al.*, 2002).

In 2002, a high volume season, fruit quality was generally good but black cold injury (especially in green skin cultivars), grey pulp in late season fruit, and fungal decay of Pinkerton were noted by the OTO. Better cold chain maintenance and the use of CA, with better supply co-ordination all contributed to better fruit quality (Nelson *et al.*, 2003).

The 2004 season generally had good quality fruit, with cold injury (notably late season Hass) and grey pulp (later season fruit) still being problematic. 1-MCP was used extensively in 2004 with generally good results. Poor results were found when the 1-MCP was applied more than three days after picking. The use of break-bulk co-shipment with Valencia oranges was acceptable, but 1-MCP doses would have to be increased and pre-cooled citrus co-loaded to avoid delayed cooling. Furthermore cold chain breaks at loading and unloading would have to be addressed to maintain fruit quality (Nelson, 2005).

Although fruit quality had improved in 2005, notable fruit quality problems were: soft arrivals, lenticel damage in Hass, and grey pulp in late season Fuerte. The use of 1-MCP as an alternative to CA reduced the incidence of soft arrivals. Greater attention to temperature and cold chain maintenance to reduce black cold damage and soft arrivals, was needed (Nelson, 2006).

Fruit quality in the 2009 season was poor, relative to fruit from competing countries. Although soft arrivals and external chilling injury have largely been solved, major problems were mixed/variable ripening and slow ripening, lenticel damage, cosmetic damage, poor colour development in early season Hass, and grey pulp in late season fruit. Maturity testing, and adherence to minimum and maximum maturity standards was recommended, as well as extra care during harvesting to limit lenticel damage (Nelson, 2010).

Fruit quality in the 2011 season was mediocre, due to inclement weather (hail and increased rain), on the European market. Although 1-MCP had drastically reduced the incidence of soft arrivals and grey pulp, lenticel damage in Hass and black cold injury on Fuerte and Pinkerton remained the major quality defects (Nelson, 2012).

Recurring themes from the OTO reports were firstly that fruit quality was generally better in "on" crop seasons, and poorer in "off" crop seasons. This can be explained by the over-riding importance of tree "crop load", which in turn (in the absence of climatic upsets and other "black swan events") impacts on tree vigour. A heavy ("on") crop is associated with reduced tree vigour, weaker shoot and root growth flushes, and lower fruit pulp N content combined with higher fruit Ca content – all favouring better fruit quality as long as diseases and pests are well managed, and hail incidence low. In contrast, a poor cropping "off" season is accompanied by vigorous growth flushes. Thus fruit pulp N content is higher, and Ca content lower. This is taking and industry-wide perspective – the situation on some individual farms and even different orchard blocks may be "out-of-sync" with the industry bearing cycle. Alternate and irregular bearing remain industry problems – Ed.

6.5.2. Letaba Co-Operative

In an effort to improve the percentage of exportable fruit, Letaba Co-op monitored fruit quality daily throughout the 1980 through 1985 seasons, and gave feedback to growers on fruit quality (Smith *et al.*, 1981). They estimated that the percentage of exportable fruit could be increased by 6-10%. Interestingly, handling damage was high at the start of the 1980 harvest (12%), declining within a month to 4%, but also increased in July. The following season they noted a higher incidence of fruit fly damage (14.3% in 1981 vs. 6.0% in 1980), sunburn (12.6% vs. 5.5%, wind (6.2% vs. 4.0%), Cercospora

spot (5.1% vs. 4.0%), but a decline in handling damage (1.6% vs. 4.0%) (Smith & Huisman, 1982b). The incidences of fruit fly damage and Cercospora spot were again high in the 1982 season, along with sooty mould. These three cull factors could be much reduced with an effective spray programme. Edranol was noted as being susceptible to handling damage – exacerbated by the dry season in 1982 (Smith, 1983). In the 1983 season, small fruit was a major problem, particularly in Hass, because of drought and the dry-land orchards. Sunburn, the other major cull factor in that season, accounted for 10-20% of culled fruit. Fruit fly damage decreased to 4.5% in 1983, because of the dry weather, while sunburn increased to 14.9% (Smith, 1984a). Small fruit was the other problem in 1983, but did decline compared to the previous season (41.6% to 26.2% across all cultivars). The internal quality of Fuerte, Hass, Ryan and Edranol was markedly better in 1983 compared to 1982 (Smith, 1984b). This may be because 1983 was an "on year" when internal fruit quality is typically better. Grey pulp and pulp spot were high both in Fuerte (about 10%) in April, lower in May, and increased in June and July to maxima of 25% and 15%, respectively. Pulp spot was problematic early in the season for Fuerte. For all the cultivars, the severity and incidence of grey pulp, SER, and vascular browning increased during the season. The importance of pre-harvest fungicide sprays was stressed because Cercospora spot and sooty mould reduced the percentage of exportable fruit (Smith, 1984d).

Spray residues accounted for 31% of rejections in the 1985 season (1.1% of total air freight volume of 1.8 million cartons), followed by incorrect labelling (24%), and lesions (11%) and softening (8%) (Pieterse, 1986).

6.5.3. Westfalia

Fruit softening and cold damage were correlated to the deviations of the actual storage temperature from the recommended temperature in the 1988 season. Too high temperatures resulted in fruit softening, and too low temperatures resulted in cold damage (Bezuidenhout *et al.*, 1989). The following season fruit quality was much improved because temperature control on the vessels was better, with less deviation from the set temperature (Bezuidenhout, 1990). Unfortunately during the 1990 season fruit quality was poor due to increased postharvest fruit age, poor temperature management and poor fruit handling in the packhouse (Bezuidenhout, 1991a).

Tree yield has an effect on fruit quality. Fruit from very high yielding and very low yielding trees had inferior internal quality, but superior cold tolerance (reduced cold damage), and fruit from high yielding trees ripened faster than those from low yielding trees (Cutting & Vorster, 1991).

Practical guidelines to improve fruit quality were given by Bezuidenhout & Vorster (1991). Dry land orchards should be picked as early as possible. Spray programmes should be tailored for each orchard because cool, damp orchards have a higher risk of fungal infections, and tree condition should be managed to improve fruit quality (a sick tree has "sick" fruit). Micronutrient deficiencies were identified as being a possible cause for pulp spot development. The 1991 season had poor quality fruit in terms of soft landings, because fruit were two days older on arrival in Europe than in previous seasons. Fruit were picked according to Cercospora spot severity rather than maturity, and the step-down temperature regimes were not always followed – sometimes being 5°C higher than recommended. These three factors needed to be resolved to improve fruit quality on arrival in Europe (Bezuidenhout, 1992). The drought in the 1992 season resulted in an increased incidence of soft arrivals in Europe. The time between packing and arrival in Europe was significantly correlated with softening and the incidence of cold damage. A faster response time and training was needed on the

ships to follow temperature recommendations promptly and maintain fruit quality (Bezuidenhout, 1993).

6.6. Defects & Disorders

The major fruit quality defects in the late 1970s were anthracnose, SER, cold damage, grey pulp, and pulp spot. Observations at the time indicated that anthracnose and SER infections were related to temperature and humidity in the orchard. SER infection was also increased when fruit were harvested too early (high MC). The cause of grey pulp was not identified, but fruit maturity was known to have an effect and it was recommended that fruit not be exported if the MC was 60% or below. The incidence of pulp spot was high early in the season but disappeared after 4-6 weeks. The cause of pulp spot was unknown at the time. It was noted that for every two weeks that fruit were hung on the tree, the days to ripen declined 1 day, and for every week of cold storage the DTR also declined 1 day (Swarts, 1978).

A brief, but insightful, review of postharvest physiological problems of avocados was provided by Ginsberg (1985). Similar discussions are still occurring at the present time, so while major advances have definitely been made in exporting avocados from South Africa, there is still room for improvement, particularly in temperature and ethylene management.

6.6.1. External defects

The effect of external defects on internal disorders was examined by Durand (1978). It was recommended at the time that grading standards could be relaxed for carapace skin (wind damage or early insect damage), russetting (thrips damage), and mechanical and hail damage, but not for sunburn and insect damage.

6.6.2. Ring-neck

Fuerte was more susceptible to ring-neck than Edranol and Hass. High levels of N and K, and a low level of Mg were associated with higher incidence of ring-neck (Toerien, 1979a). (Later i*dentified as a symptom of water stress – Ed.*)

Ring-neck produces corky lesions in the fruit stalk and fruit of avocados. Tyloses (outgrowths of parenchyma cells) were detected in the protoxylem vessels of affected fruit. It was suggested that ring-neck is caused by water stress (Engelbrecht, 1981).

6.6.3. Pulp spot

In a progress report on the ultrastructural changes associated with pulp spot, it was reported that the coagulation of the groundplasm occurred in the fruit flesh parenchyma cells, and the presence of an electron dense deposit in the tracheary elements of affected areas was noted. This deposit may affect transport to, and water relations in, the fruit flesh parenchyma (Engelbrecht, 1979). PPO was confirmed to be present in the thylakoids and prolamellar bodies of the etioplasts of normal fruit, but were absent in the etioplasts of pulp spot-affected fruit (Engelbrecht, 1982).

Pulp spot was related to an imbalance in the soil Ca with other nutritional elements (Mg and K particularly) and the well-balanced base status in acid soil is necessary to prevent pulp spot development (Fouché, 1983). [*SAAGA recommends a soil Ca content of at least 750 – 1000 mg/kg, and this together with a correction of a zinc deficiency should be sufficient to eliminate pulp spot – Ed.*].

Fruit with a high incidence of pulp spot had significantly lower Ca level than fruit without the disorder. Calcium nitrate did not reduce the incidence of pulp spot and was ineffective in increasing Ca content in fruit (Veldman, 1983).

A comparison between Fuerte fruit with and without pulp spot, from the same orchard and picking date, showed that fruit without pulp spot had a higher Zn concentration than those exhibiting pulp spot. It was hypothesized that the higher Zn concentration resulted in more bound Ca being released from chelating and complexing agents (e.g. lignin, organic acids, and proteins) for transport to the fruit, thereby increasing the fruit Ca concentration and resulting in more stable cell membranes (Vorster & Bezuidenhout, 1988).

6.6.4. Grey pulp

The physiological disorder termed grey pulp, fruit flesh discolouration, internal browning or diffuse discolouration is discussed here. Also refer to §5.6 (Pinkerton Problem).

The browning of avocado fruit flesh was acknowledged as being complex, with the physiological condition of the fruit playing a large role in the development of different types of browning. Three types of browning were identified by Engelbrecht (1978):

Normal Browning: Normal fruit flesh cells have many vacuoles and are characterised by the presence of lipid bodies of differing size. Rough endoplasmic reticulum (RER) is present and in some cells there are a high number of free ribosomes present. Mitochondria are well developed, and chloroplasts are characterised by poorly developed grana and thylakoids. This structure of the chloroplasts gives a good correlation with the green-yellow colour of the fruit flesh of the ripe avocado. The cell walls are relatively thick.

Cells with browning show a number of structural changes. The most important is the disappearance of the tonoplast (vacuole membrane). This causes a mixing of the vacuole contents with the cytoplasm. The endoplasm is grainy at the onset of browning, but this disappears as browning progresses. The mitochondria, lipid bodies and cell walls do not show any structural changes, while the middle lamella shows a slight thickening. These ultrastructural changes concur strongly with other findings regarding senescence of other plant tissues.

Browning of the distal vascular bundles: In some fruit the basal portion of the vascular bundles were normal but the distal portion of the same bundles had browning. The browning can spread to the surrounding flesh tissue. The most important characteristic is presence of tyloses in the cell lumen of some tracheid elements in the affected portion of the vascular bundles. In some vases affected bundles did not have these tyloses. The tyloses are outgrowths from the xylem parenchyma. At the start of browning the tonoplast is absent and after further browning the mitochondria, ER and ribosomes are indistinguishable, only the lipid bodies being still clearly identifiable. The role of tyloses was still not clear, however.

Browning after exposure to the atmosphere: After cutting fruit, some fruit rapidly develop a grey-brown colouration on the cut surface. A fine fibrous deposit was found in the vacuole of some vascular parenchyma cells and the lumen of some tracheids. In some tracheids a thick amorphous deposit was found.

PPO is only present in the chloroplasts and etioplasts of the fruit flesh tissue and that brown fruit flesh tissue did not have PPO in these plastids. This indicates that PPO moves out of the grana during browning and that there were no structural changes in the thylakoid membranes (Engelbrecht, 1987).

Peroxidase and PPO activities were lower in the proximal (upper) half of Fuerte fruit. The activity of phenylalanine ammonia-lyase (PAL) was higher in pulp spot-affected fruit than healthy fruit (Van Lelyveld *et al.*, 1983).

The storage temperature later in the cold storage period should be lowered to reduce the risk of grey pulp. Cold damage, pulp spot, and grey pulp were highly significantly correlated to each other. Maturity and fruit size were also positively related to pulp spot and grey pulp development (Bezuidenhout, 1983a).

Fruit flesh discolouration and pulp spot arise from different pathways (Van Lelyveld, 1984). Fruit affected by fruit flesh discolouration and grey pulp contained higher concentrations of total phenolics than unaffected fruit, and this increase was thought to occur preharvest. The important phenolic compounds in disorder development were: catechin, epicatechin, chlorogenic acid, and cinnamic acid derivatives. PO activity was higher in fruit with flesh discolouration, possibly linked to ethylene.

Treatment with various calcium salts (chloride, phosphate, arsenate and nitrate calcium salts) had limited effects on the browning mechanism, but calcium chloride and calcium arsenate did reduce the respiration climacteric, while calcium nitrate hastened the climacteric (van Rensburg & Engelbrecht, 1985). The limited effect was probably due to minimal uptake of the calcium during treatment (Eaks, 1985).

Storage longer than four weeks was shown to increase grey pulp considerably. Fuerte fruit from Schagen appeared to be relatively more cold-sensitive, so a reduced storage temperature (3.5°C) in the final week of storage is only successful if fruit are sufficiently mature. This level of maturity (oil or moisture content) is different for the various production areas (Rowell, 1988c).

Distal-end browning or dusky cold damage (Afrikaans: bolverkleuring) was an external and internal fruit disorder causing major fruit quality loss in the mid-1990s for fruit from the KZN midlands. Investigations could not determine the causal agent (Kaiser *et al.*, 1995b).

Problems in the 1996 season were thought to be due to much higher rainfall than the 1994 and 1995 which resulted in the faster and greater accumulation of oil and faster decline in fruit flesh moisture content. The increased rainfall negatively affected internal quality (pulp spot and grey pulp) with a lag of about 50-60 days in Hass and about 70 days in Fuerte. This may be due to the reduced transpiration reducing nutrient accumulation (especially calcium and boron) in the fruit (Kruger & Claassens, 1997).

Grey speckle [*a form of grey pulp – Ed.*] thought to be a symptom of preharvest cold damage was positively related to fruit maturity, fruit size and negatively correlated to fruit calcium. Preharvest freeze injury (frost damage) was more prevalent on the “short” longitudinal side of fruit because this side is exposed to the cold air. The short side was also more mature than the long side because it is exposed to more sunlight. Freeze damaged fruit had lower nitrogen and magnesium than healthy fruit. This may be due to less healthy trees, with lower nitrogen and less foliage, offering less protection to the fruit. Magnesium is also lower in outside fruit (Kruger *et al.*, 2008). Grey speckle and preharvest

freeze injury were not noted the following season, probably because of higher orchard temperatures in the second season (Magwaza *et al.*, 2009a).

6.6.5. Black cold injury

External chilling injury (cold damage) was caused by moisture loss from the fruit before and/or during cold storage, and not just low temperature. It is important that during postharvest handling, pre-cooling and cold storage relative humidity is high (or vapour pressure deficit low) to reduce water loss (Donkin & Cutting, 1994).

A review of black cold injury (chilling injury, cold damage) was given by Kruger *et al.* (2002). The role of nutrition, storage temperature, atmosphere modification, and packhouse procedures was being examined in an attempt to reduce the disorder. A negative correlation between fruit iron concentration and early season black cold injury exists, and a positive correlation between fruit nitrogen and iron concentrations. The authors hypothesised that early season black cold injury is a result of low iron concentration in the fruit, while late season black cold injury is related to a low calcium concentration, and may be a form of rind senescence because the symptoms are quite different. Furthermore heavy rain 2-3 months before harvest was suggested to be an indicator/cause of poor internal and external fruit quality (Lemmer *et al.*, 2005b).

6.6.6. Pre-harvest cold damage

The detection of internal pre-harvest cold (frost) damage was possible with a packline-mounted near-infrared spectrometer (NIR). Due to limitations in the fruit volume that is scanned, there was some misclassification of fruit with frost damage if the damage was only slight. Rotation of the fruit while under the NIR unit would increase the accuracy of frost damage detection (Blakey, 2012).

6.7. Firmness Meters

The second prototype of the firmometer (Figure 6), a non-destructive fruit firmness meter was described by Swarts (1979). Firm fruit had a reading of 15-20 units, and ripe fruit a value of 100 units. Fruit firmness did not decline until after fruit were harvested. The rate of softening was accelerated as fruit matured and after cold storage. Some softening was observed during cold storage. A third prototype was later developed to overcome some design faults and reduce the build-cost. Using this prototype, fruit softening was accelerated if there was a delay in cooling or a cold chain break, even if the cold storage temperature was subsequently restored (Swarts, 1981).

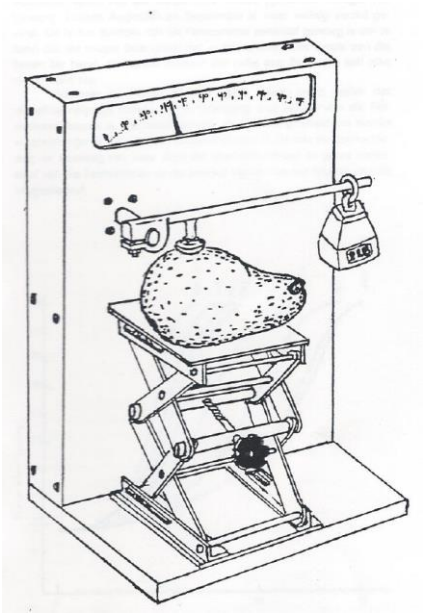

Figure 6: Sketch of a firmometer in operation – taken from (Swarts, 1979).

The densimeter (manufactured by Bareiss in Germany) was a viable alternative to the firmometer as a firmness meter – and it is non-destructive. The densimeter does have some limitations on Hass because of the cultivar's pebbly skin affecting repeatability, but is still a useful instrument (Köhne *et al.*, 1998).

The Halls Avoscan® and densimeter correlated well, but not linearly, and it was less accurate in Hass than Fuerte. The Avoscan® could be used to identify fruit which are too soft to be exported (Kruger & Rowell, 1998).

7. Nursery & Propagation

Jan Toerien noted that there was a great need for improved nursery management in 1977. The industry was still using seedling rootstocks at this stage but a move to more PRR-tolerant clonal rootstocks (Duke 6, Duke 7, G6, G22, G166, and G755 were available at the time) was needed. The standard nursery practices to prevent the entry of *P. cinnamomi* into the nursery were outlined in this paper. The reader is referred to the article for further details (Toerien, 1977c).

7.1. Fumigation & Pasteurisation

Soil sterilisation: steam is better than chemical, and of the chemicals tested, Basamid® (dazomet), methyl bromide, and then Vapam® (metam sodium) (CSFRI, 1977).

Disinfection of nursery medium by sterilization at 93°C, pasteurization at 63°C, methyl bromide, and an untreated control was tested (Allan *et al.*, 1981). The three methods of disinfection were superior to the untreated control but the experimental error, due to using seedling rootstocks, was too high to determine differences between the treatments.

Methyl bromide (MeBr) as a fumigant for nursery medium was reviewed by McLean & Kotzé (1992a). Even distribution of the gaseous methyl bromide is facilitated by using clear plastic during fumigation, having the medium at about 66% of field capacity, creating a void between the medium and plastic, and only treating when the medium temperature is more than 8°C at 100mm depth. Control of *Fusarium solani* and *P. cinnamomi* was complete at 300 and 150 g MeBr/m^3 of medium, respectively, when treated for 48 h at 66% field capacity; mila and composted pine bark were used as medium (McLean & Kotzé, 1992b). [*The use of methyl bromide is being phased out in accordance with the Montreal Protocol, because of its toxicity– Ed.*].

Bungay (1994) provided a short review on the process of steam pasteurisation of growing medium in the nursery, highlighting the use of a miniature mobile, low pressure electrode steam generator for small scale use. This steam generator was tested *in vitro* and was comparable to methyl bromide treatment. It was recommended that a treatment of at least 60 min at 75°C was sufficient to sterilize nursery medium. The re-colonisation of the medium was affected by the composition of the medium (and the specific environment) and a light medium was recommended for subsequent PRR control by antagonistic fungi. An investigation into the utilisation of thermotolerant *P. cinnamomi*-antagonistic fungi such as *Paecilomyces variotii*, *Verticillium fungicola*, and *Aspergillus fumigatus* was suggested (De Jager & Kotzé, 1994).

7.2. Propagation

Ernst began his study on the morphological and physiological factors affecting rooting of avocado cuttings. The effects of root zone heating (20, 25 and 30°C), potting medium (1:1:1 peat:vermiculite:perlite, 1:3 peat:sand, 1:1 vermiculite:sand, and 100% vermiculite), auxin treatment, root grafting, and etiolation were investigated, as well as the anatomical and physiological differences between different material (Ernst & Holtzhausen, 1977a).

A water treatment method for canal water for H.L. Hall & Sons was outlined. This involved flocculating the water with aluminium sulphate and passing it through a conical settler, then filtering the water through a sand filter, and then treating the water with calcium hypochlorite (5 ppm). The tank where the water is treated with calcium hypochlorite should be opaque to prevent UV light degrading the

chlorine. Micropore™ filters were very effective in removing flocculant and zoospores but these filters were too expensive to be economically viable (Mitchell, 1977a).

Ernst & Holtzhausen (1978) published a summary of Ernst's MScAgric thesis on rooting avocado cuttings, concluding that:

i. Fuerte cuttings took 90-240 days to root when treated with 1% IBA plus 1% benomyl plus 98% talc if bottom heat was maintained at 30°C and defoliation reduced.
ii. No relationship exists between callus formation and root development.
iii. Rooting medium is not critical.
iv. No anatomical difference was found between physiologically juvenile and mature cuttings, and mature cuttings of different cultivars.
v. The method of etiolation, *viz.* burying a lateral shoot to induce etiolated shoots is an innovative method of etiolation while keeping the cutting alive (Ernst & Holtzhausen, 1978).

Points for successful clonal propagation of avocados were outlined by Moll *et al.* (1978):

i. Duke 6 is easier to work with than Duke 7 as it is more vigorous.
ii. Plants should be placed in the etiolation chamber as soon as the buds on the grafted "rootstock scion" have burst and the first leaves are about 1cm long.
iii. The temperature in the etiolation room must be maintained at 22-25°C.
iv. A systemic fungicide is needed in the etiolation room because it is warm and humid.
v. The etiolated plants can be ridged up once they are 20-25cm long, and then returned to daylight.

In looking to improve the Frolich method at the Westfalia Nursery, Toerien investigated wounding the etiolated rootstock, and/or applying IBA, to induce root formation. A 50% ring barking with 1% IBA induced 50% more rooting after 32 weeks (Toerien, 1979c) [*far too long to be commercially viable – Ed*]. The treatment of the budwood with Benlate® (5g/L) and the anti-transpirant VaporGuard® (20mL/L) for 5 minutes increased graft success to 97.5% from 72.0% without VaporGuard® (Toerien & Slabbert, 1979). Terminal cuttings, with the terminal meristem gave the highest percentage of plants ready for transplanting after 10 weeks (92.5%), compared to terminal cuttings with the terminal meristem intact (82.3%) and graft-wood with two lateral buds (47.1%) (Toerien, 1979b).

The treatment of cuttings [*cultivar not specified – Ed.*] with 1% IBA significantly increased rooting success by about 20% after 240 days. When combined with aeration of the medium, a success rate of 75% was achieved. The fungicides Daconil® (chlorothalonil), Captan, and benomyl increased defoliation and did not significantly reduce cutting dieback and death (Ernst, 1981). Etiolated cuttings 50mm in length were produced by placing mother material (200mm long cuttings with 10±2mm diameter, from two growth cycles) horizontally in vermiculite or sawdust. A success rate of 80% was achieved after 60 days. Terminal die-back of the mother material was a problem. (Ernst, 1983).

SAAGA implemented the Avocado Plant Improvement Scheme (APIS) in 1984. The aim of the APIS was, and still is, to "endeavour to produce avocado plants which are disease-free and of the highest possible quality for the long-term benefit of the industry". This involved the elimination of ASBVd and *P. cinnamomi* in nursery trees, and improved horticultural characteristics (Partridge, 1984).

In this regard, the Avocado Nurserymen's Association (ANA) developed minimum standards for avocado nurseries in South Africa, as well as participation in the APIS to achieve the aims stated above.

The objectives of the APIS were/are:

1. Identification of superior cultivars with improved yield, and fruit quality.
2. Identification of survival trees with improved *P. cinnamomi* tolerance.
3. Import and evaluation of new cultivars (rootstock and scion).
4. Research into propagation.
5. Education of growers on the benefits of participation in and the value of APIS.

As of 1985, 11 nurseries were members of ANA, to continue with the APIS (Partridge, 1986). Aims going forward from 1985/6 were to:

1. Provide certified ASBVd-free nursery trees,
2. Initiate a rootstock screening programme,
3. Scion selection and breeding programme, and
4. Identification of superior trees and monitoring of their yield.

Ernst & Holtzhausen (1987) suggested that the auxin hormone IAA be applied to semi-hardwood avocado cuttings after callus formation to induce root formation. Rooting was improved if cuttings had produced sufficient callus within 60 days. The balance between cytokinins and auxins in callus development, which is affected by medium pH and medium aeration, is important in rooting avocado cuttings. Rooting of semi-hardwood cuttings was very slow in these experiments (8-13 months), [*confirming that the rooting of avocado cuttings without etiolation is difficult and not commercially viable – Ed.*].

McKenzie *et al.* (1988) discussed the production of avocado trees in the context of a chain, with each production stage a link in the chain. They outlined the importance of rootstock and scion-wood health and quality, moderate temperatures, fertilisation, and adequate medium air-filled porosity. They hypothesised that the carbohydrate status of the scion mother tree is an important factor in graft success.

Points for the control or PRR in the nursery were given by Maas & Kotzé (1990a). The reader is referred to this article for more detail. While most modern avocado nurseries implement the points, as they are also required by the ANA/APIS, one interesting point was to have the mother blocks grown under hail/shadenet.

7.3. Tissue Culture

An interesting review on tissue culture was done by Prof. Allan Allan (1981). Readers are referred to the article for more information on tissue culture.

Nel & Kotzé (1982) were able to produce rooted plantlets of *Persea indica* from a single bud cutting. Sixty explants were obtained from one axillary bud in eight weeks by treating the bud with cytokinin (6-benzylaminopurine) to decrease apical dominance. At the time, the authors were still working on propagating avocado cultivars. Efforts to culture Duke 7 and Edranol were not successful (Nel *et al.*, 1983a). Hendry & Van Staden (1982) were also working on propagating ASBVd-free plants. Practical problems with shoot-tip grafting occurred, where the stem and shoot-tip browned and desiccated.

They also conducted some trials propagating stem cuttings, and meristem culture on agar. Nel *et al.* (1983b) produced rooted cuttings which were ready for transplant 7-11 weeks after initial bud culturing; the success rate however was only 50%. A review on avocado tissue (*in vitro*) culture by Nel & Kotzé (1984) highlighted the difficulty in the *in vitro* culture of avocado. *In vitro* culture can be used to eliminate viruses from plant material, by using meristem tip culture, since viruses are absent, or in very low concentration, in the rapidly dividing tip. These researchers endeavoured to adapt this method for avocados because chemo-and thermotherapy were not entirely effective in eliminating viruses. Tissue culture was also being investigated as a method for the rapid multiplication of material for nurseries. At this stage, the researchers were still trying to perfect the technique. The following year, preliminary results showed that the shoot tip micro-grafting could be successful on avocados if the material was cut under water and the tips submerged in water for 24h before placing into nutrient medium. The shoot tip must be placed to the side of the rootstock to allow for union between the cambial tissue and the tip. High transplant mortality was observed if plants were transferred to soil. This was overcome by grafting the tips onto established seedlings in a greenhouse (Nel & De Lange, 1985).

Harty (1985) had success in propagating Duke 7 explants using a modified culture medium that included kinetin, L-glutamine, L-arginine, and iron sulphate. The composition of this medium is provided. While Duke 7 explants could be established and multiplied in one step, the rooting of the explants was still to be achieved.

Differences in the tissue culture of two promising rootstocks, IV-8 and GA-13 were given by Pliego-Alfaro *et al.* (1987). The optimal nutrient and hormonal concentrations were cultivar-specific and rooting was poor. [*Chapter 10 in Schaffer et al. (2013) provides the latest international research on avocado biotechnology – Ed.*].

Duke 7 plants were successfully cultured *in vitro*, with results comparable to commercial tissue culture systems, but the initiation of rooting was inconsistent. The best rooting was obtained using etiolation in combination with 5mg/L IBA; the cytokinin BAP inhibited rooting (Wessels, 1996).

Hannweg (1997) outlined some principles of tissue culture and gave an update on the ITSC's efforts in tissue culture of avocados.

8. Fruit Products

8.1. Avocado Oil

The seasonal change in oil content of Fuerte, Edranol, Ryan, and Hass increased linearly with decreasing moisture content from 5 April to 22 August (R^2 =0.95). The moisture content plus oil constant was 90% in the early season, and this increased to 92% by late July. This agrees with (Swarts, 1976a), and is higher than the 88% found by Holzapfel & Kuschke (1977). The fatty acid profile changed during the season, as oleic acid (18:1) increased, palmitic (16:0) and palmitoleic (16:1) declined, and the other minor fatty acids remained largely unchanged. Free fatty acids, which give an indication of oil quality, were low (about 0.1%) and declined during the season. Phospholipids were also low (<0.1%) and declined slightly. The recovery percentage using a laboratory scale centrifuge increased from 54% in April to 63% by late August, compared to a Soxhlet extraction (Du Plessis, 1979).

The importance of avocado oil as a means to remove low grade fruit from the local market was already established by 1981 at Letaba Co-op. The Co-op used a mechanical extraction method, similar to the method still used by Westfalia Fruit Products (Smith & Lunt, 1981).

Human (1987) gave an insightful review of the chemistry, nutritional and cosmetic properties, and the methods of extraction and refinement of avocado oil. The methods of extraction and refinement have not changed much since then. The steps involved in extracting crude avocado oil are heating in water, centrifugation, and further settling and decanting. Crude oil is refined by bleaching, deodorising, winterising, and alkali refining (free fatty acid removal). The use of the unsaponifiable fraction was of great interest to the pharmaceutical industry because of the unnamed “H-factor”. Avocado oil has a phytosterol which aids its penetration into the skin, which is very useful for cosmetics and soaps.

Financial modelling by de Waal (1992) showed that avocado processing would be necessary for the South African avocado industry to survive. Processing would remove low grade fruit from the local municipal markets and hence keep prices at the markets elevated, while still obtaining some economic value from the low grade fruit. Hence a processing plant was commissioned by Westfalia at Politsi in 1991.

The extraction of avocado oil from ripe fruit using super-critical CO_2 was possible within 1 h at 540 atm (95% oil) and within two hours at 350 atm (94% oil). A reduction in the pressure would require less capital expenditure (Botha & McCrindle, 2003). The extraction of avocado oil using super-critical CO_2 was comparable to extracting using hexane in terms of free fatty acids (FFA). However the CO_2 entrains during extraction artificially elevating the FFA values and it would need to be removed prior to FFA analysis. Hexane co-extracted chlorophyll which needs to be removed during industrial purification, but super-critical fluid extraction (SFE) did not. This would improve the economic viability of industrial FE extraction. The concentration of unsaponifiable matter decreases as the SFE proceeds, but the fractions can be mixed to increase the concentration. The faster extraction time and the absence of organic solvents makes this method attractive (Botha, 2004).

8.2. Minimal Processing

Freezing is a good processing method to preserve avocado pulp, and a minimum oil content was 15%. Maturity did not affect the flesh colour of frozen avocado slices and pulp. Edranol was the superior

cultivar for freezing while Fuerte and Hass were intermediate and Zutano was inferior (Olaeta & Rojas, 1987).

The storage of frozen and refrigerated avocado halves, slices and pieces was acceptable but the texture and flavour of the product after storage needed improvement. Anti-oxidants, such as citric and/or ascorbic acid, with vacuum packaging were necessary to maintain the colour of the product during storage (Bower & Dennison, 2003). The following season the problems were successfully addressed: pasteurisation eliminated tissue collapse, off-flavours, and browning. The frozen product was successfully stored for six months. Modified atmosphere packaging was not successful if oxygen was present in the atmosphere (Bower & Dennison, 2004). Refinement of this product continued, and the final method involved selecting firm ripe fruit, surface sanitising the fruit before cutting, heating the pieces to a pulp temperature of 80°C in a boiling water bath to denature PPO and leach phenolics out of the flesh, and freezing the pieces in a blast chiller rather than liquid nitrogen. Polypropylene or polyethylene packaging was acceptable, and MA and vacuum packaging were not necessary. This process resulted in a product with acceptable taste and colour after six months of storage at -18°C. Refinement of the process would improve the texture of the product (Bower & Dennison, 2005).

9. Entomology & Market Access

9.1. Insect Pests

A colour photographic guide to the various insect pests, and their symptoms, on avocados in South Africa was provided by Du Toit & De Villiers (1990). They also warned against using broad spectrum insecticides because they would affect the natural control of pests.

9.1.1. Fruit flies

Fruit damage from fruit fly and false codling moth (FCM; *Cryptophlebia leucotreta*) for a producer in Tzaneen was 7.3% in 1977 and 5.0% in 1978, Fruit fly damage was 6.8% and FCM damage 1.2% (total 8%) for a producer in Nelspruit in 1978, indicating that fruit fly especially was a causing significant economic losses, and effective control methods were needed. The pheromone products Trimedlure® for fruit fly and an unnamed synthetic pheromone (a mixture of cis- and trans-8-dodecenyl acetate) for FCM, and different types of traps, were being tested for efficacy. At that stage they recommended a standard trap with the synthetic pheromone for FCM. The parasitoid *Trichogrammatoidea lutea* Gir. was being reared at the ARC-ITSC for testing against FCM (Schwartz, 1978) (paragraph repeated in §9.1.4 (False codling moth & other moths)).

To determine the symptoms of fruit fly, FCM, and mechanical damage, fruit were artificially exposed to Natal fruit fly (*Ceratitis rosa*), Mediterranean fruit fly (*C. capitata*), and FCM, and also mechanical damage, at four stages of fruit growth. Mediterranean fruit fly did not lay eggs on avocado fruit, but Natal fruit fly did. Fruit fly damage in small fruit is characterised by a star-shaped lesion while FCM produces a raised crater with raised edges. Carapace skin is caused by mechanical damage at golf ball fruit size (Du Toit *et al.*, 1979). Natal fruit fly did not play a major role in reducing fruit quality (Edranol) in the Letaba district (Du Toit & Tuffin, 1981).

De Villiers & van den Berg (1987) maintained that avocado insect pests in South Africa were of minor importance because of sufficient biological control. They listed the identified insect pests as: Natal fruit fly, soft scales, armoured scales, coconut bug, thrips, mealy bugs, looper, leaf rollers, and false codling moth (FCM), providing good colour photos of the pests and symptoms, and also lists of their natural enemies. The importance of restricted chemical control was stressed.

By 1990, avocado insect damage on fruit had reached fairly serious economic importance (R10-13 million annually). The major pests were coconut bugs, thrips, fruit flies, false codling moth, and stink bugs, and resulted in 10-13% of the fruit having insect damage. Losses were anticipated to increase rapidly with new avocado plantings unless control measures were implemented (Dennill & Erasmus, 1991). Results were similar, but more severe the following year, when it was estimated that insect damage caused R13 million worth of damage (Erichsen, 1992). Stinkbug damage was not as severe in 1993 as previously (1.2% of Fuerte, 3.1% for Hass), but the situation could change rapidly; the development of a biocontrol strategy of stinkbugs was recommended (Joubert & Claassens, 1994).

Hard avocados are not a suitable host for Mediterranean fruit fly and Natal fruit fly and they were unlikely to survive cold storage shipment (Brink *et al.*, 1997). The population of Mediterranean fruit fly was too low to regard this species as an avocado pest, but the population of Natal fruit fly and Marula fruit fly (*C. cosyra*) during February may be problematic in the Nelspruit area (Grové *et al.*, 1998).

9.1.2. Thrips

In California, Malathion and Pyrenone® only provided "fair" control of greenhouse thrips (*Heliothrips haemorrhoidalis* Bouché) and were negatively affecting beneficial insects. Acephate was a promising insecticide, but the use of IPM was stressed (Goodall *et al.*, 1987b).

Orius thripoborus (Hesse) (Hemiptera: Anthocoridae) was identified as a potential biocontrol agent for red-banded (*Selenothrips rubrocinctus* Giard) and greenhouse thrips (Dennill, 1992). Dennill & Erasmus (1992) found that thrips showed a preference for fruit which were in contact, and hence described a method for monitoring thrips in avocado orchards.

Greenhouse and red-banded thrips were still of little economic importance to the avocado industry between 1990 and 1992 (Dupont, 1993a).

Both Citrimet® (methamidophos) and azodrin (monocrotophos) were effective broad spectrum insecticides for avocados against thrips, scale, mites, and neither exhibited phytotoxicity. Citrimet® was more effective against mites, mealy bug, and scale than azodrin, but further testing was required (Erichsen & Schoeman, 1993a).

A parasitic wasp, (*Tripobius semiluteus* Boucek; Eulopidae) was discovered parasitizing pine tree thrips at the ARC-ITSC in Nelspruit (Mbombela) with potential for control of red-banded and greenhouse thrips (Steyn *et al.*, 1993b).

9.1.3. Scale

Heart-shaped scale (*Protopulvinaria pyriformis* Cockerell; Coccidae) developed from a sporadic pest to a serious one in the late 1980s. The secreted honeydew resulted in sooty mould growth which blemished the fruit skin and reduces photosynthesis. Parastioids and predatory coccineliids were unable to control the scale. Further studies on control of the pest were underway (du Toit & De Villiers, 1988). The young nymphal stage of scale are more sensitive to pesticides. The life cycle study of heart-shape scale revealed that there were two generations per year. The optimal times to spray (in Nelspruit) were November/December and April (De Villiers, 1989).

CGA 211446 (a chitin synthesis inhibitor) from Ciba-Geigy was more effective in controlling heart-shaped scale than another chitin synthesis inhibitor buprofezin (FBC), but its effect on predators and parasitoids was not determined at that time (Steyn *et al.*, 1993c; 1994).

The parasitoid species *Metaphycus galbus* (Annecke), *M. helvolus* (Compere), and *M. stanleyi* (Compere), and to a lesser extent *Coccophagus* and *Tetrastichus* spp., parasitized up to 25% of all stages of the total population of heart-shaped scale. The *Metaphycus* spp. were dominant during late summer and early autumn, and were then replaced by the *Coccophagus* and *Tetrastichus* spp. in winter. The parasitism was not effective in controlling the population of heart-shaped scale (Du Toit *et al.*, 1991).

The brown house ant (*Pheidoli megacephala* F.) did not have a significant effect on the number of scale insects on 'Ryan' avocado trees. The mulch layer under the trees provides an adequate habitat for the ants so they do not enter the canopy to obtain honeydew from the scale (Du Toit & De Villiers, 1992).

9.1.4. False codling moth & other moths

Fruit damage from fruit fly and FCM for a producer in Tzaneen was 7.3% in 1977 and 5.0% in 1978, Fruit fly damage was 6.8% and FCM damage 1.2% (total 8%) for a producer in Nelspruit in 1978, indicating that fruit fly especially was causing significant economic losses, and effective control methods were needed. The pheromone products Trimedlure® for fruit fly and an unnamed synthetic pheromone (a mixture of cis- and trans-8-dodecenyl acetate) for FCM, and different types of traps, were being tested for their efficacy. At that stage they recommended a standard trap with the synthetic pheromone for FCM. The parasitoid *Trichogrammatoidea lutea* Gir. was being reared at the ARC-ITSC for testing against FCM (Schwartz, 1978) (paragraph repeated in §9.1.1 (Fruit flies)).

Pheromones for the luring of *Amorbia cuneana* (Lepidoptera) were developed in California and an important finding from this research was that different populations (sub-species) of *A. cuneana* responded to very specific and different ratios of two isomers of a the pheromone. They were still developing a pheromone for looper (*Sabulodes aegrotata*, Lepidoptera) (Bailey & Goodall, 1987).

Insect pest recruitment into avocados in South Africa was increasing in the early 1990s. Erichsen & Schoeman (1994a) highlighted the growing importance of the damage caused by moths. This includes FCM, citrus leafroller (*Cacoecia occidentalis* Wlsm; Tortricidae), apple leafroller (*Tortrix capensana* Walker; Tortricidae), and looper (*Ascotis reciprocaria reciprocaria* Walker; Geometridae). It was estimated that moth pests caused R414 700 worth of fruit damage in 1991 season in the Nelspruit-Hazyview area. The use of insecticides should be kept the minimum to prevent greater pest recruitment in the future, and information on predator/parasitoids should be collected. Looper damage was less than 0.5%. Hence the use insecticide was not recommended because it could upset the ecological balance between pest, predators, and parasitoids. They warned that looper damage in avocados may become problematic if neighbouring citrus orchards are sprayed for looper, and hence upset the ecological balance (Erichsen & Schoeman, 1994b).

The start of research on FCM disinfestation began with a literature review by Grové *et al.* (1999a). FCM causes cosmetic damage on avocado fruit, but the host status of avocado for FCM needed to be established because it would require phytosanitary disinfestation for export to certain countries. FCM larvae developed in bagged, rotten avocados but penetration was only superficial. The ability of FCM larvae to develop in hard avocados was still to be determined (Grové *et al.*, 1999b). FCM larvae were only able to develop to the first instar, and only reached a depth of 4mm as the flesh is an unsuitable medium for development (Grové *et al.*, 2000a).

Preliminary results from Tate & Hattingh (2000) indicated that FCM disinfestation could be achieved with a 38°C vapour heat treatment with CA (<1% O_2, 5% CO_2) for 8-12h, or 25°C treatment with CA for 24-48h, or 1.5°C RA for 22 days. Probit 9 level was the next step in the evaluation of these treatments. A 46°C hot water dip was ineffective.

Isomate®, an FCM sex pheromone which disrupts mating, was tested in Nelspruit but results were not available at the time of publication (Schoeman & De Beer, 2008; 2009).

9.1.5. Bugs

Coconut bug was identified as a potential insect threat to the avocado industry in 1985/6 after it was first recorded in South Africa on mangoes in 1977 (Viljoen, 1986).

A study on the ecological and biological aspects of the coconut bug was started but no results were available at the time of publication (van der Meulen & Du Toit, 1992).

Fruit insect damage became particularly severe in the Hazyview area in the early 1990s. An ecological study was conducted to gather more information about the insect damage. Coconut bug (*Pseudotheraptus wayi* Brown; Coreidae) and another, then unidentified, insect were causing damage early in fruit development. They recommended sampling fruit in the band of 1 - 2m above ground level, and not at head height (Dennill & Dupont, 1992). The following season they concluded that "protrusions" are caused by stinkbugs, including *Nezara viridula* L. (Pentatomidae) and indentations are caused by coconut bug. They also concluded that protrusions were more prevalent in Hass than Fuerte. Damage is caused early in fruit development and damaged fruit do not abort. The protrusions are caused by a highly mobile insect as no edge effect was observed. Indentations from coconut bug were density dependent, enhanced fruit drop and reduced fruit mass – and were therefore less energy expensive than protrusions. Lastly, there was no correlation between the two symptoms, suggesting that the protrusions are not caused by coconut bug (Dupont, 1993b).

The causative agent of protrusions in Hass fruit, particularly in Kiepersol, was believed to be an insect and damage was done in early September, but the species was not identified at that time (Du Toit *et al.*, 1993).

Citrus leafhopper (*Penthimiola bella*; Cicadellidae) was identified as the causal agent for pimple-like lesions (Afrikaans: vosknoppe) and not stinkbugs. This was because of the total absence of stinkbugs during the period of lesion development and the correlation between the depth of the corky lesion and the length of piercing-sucking mouth-parts of citrus leafhopper (Bruwer & Claassens, 1995). Necrotic fruit lesions were later identified as being caused by the coconut bug and were suggested as the causal agent for fruit malformation (Bruwer, 1996).

Twenty Hemiptera species were identified in avocado trees in the Nelspruit/Hazyview area, with woolly stinkbug (*Atelocera raptorial* Germar; Pentatomidae), *Decipha viridis* Synave (Flatidae), and *Parapioxys sp.* (Eurybrachidae), the coconut stinkbug, and *Dysdercus nigrofasciatus* Stal (Pyrrhocoridae) being the five most abundant. Large numbers of Hemiptera over-winter in avocado trees so chemical control before flowering was recommended (Van den Berg, 1998).

The avocado bug (*Taylorilygus* sp.) was also suggested as being responsible for pimple-like lesions. The pest balance shifted in the Kiepersol area between 1994/5 and 1996/7. Fruit cull due to leafhopper damage decreased from 18% to 7%, but the percentage of culled fruit due to stinkbug damage increased from 3.7 to 32%. Consequently, the total fruit damage increased from 22% to 39.4%. Hass was the most susceptible to insect damage compared to Ryan, Fuerte, Edranol and Pinkerton. Two applications of endosulfan, metomil, mevinphos, and deltamethrin were all effective in reducing insect damage below the economic threshold of 5% blossom infestation (Bruwer, 1997). [*The use of endosulfan is being phased out globally since 2012 because of its threat to human health and the environment, and was banned in South Africa in April 2012 – Ed.*]. A single insecticide spray (Klartan®, Chess®, or Bulldock® were all effective) was recommended when the blossom development on the

cooler side of the tree is 80% completed. The remaining blossom will ensure that the bugs do not move to feeding on fruitlets, and at this stage there will not be a second generation of bugs as there will not be nectar available for adult colonisers (Bruwer, 1999b).

Avocado bugs feed preferentially on flowers, causing flower drop. The less mobile immature stages would feed on fruitlets while the highly mobile adult stages move to flowering trees and cultivars. The immature stages reach maturity in 5-6 weeks after fruit set and then migrate to other cultivars or alternative host plants (e.g. weeds). Feeding on fruit smaller than 5mm resulted in fruit drop and feeding on larger fruit resulted in fruit malformation. No further damage was caused by sucking bugs once the fruit were 30mm in diameter. Later-flowering cultivars, like Hass, Ryan and Edranol, are more susceptible to damage because pest numbers are highest at this time. Damaged Hass fruit was less likely to drop. The Levubu, Letaba, and Kiepersol regions had high levels of fruit damage (42-58%) while northern KZN and the midlands had much less damage (15-17%), with avocado bug being the predominant pest. Eggs hatch after an average of 5 days. The immature life cycle duration of five nymphal stages lasts an average of 29 days and the adult avocado bug lives for about 45 days (Bruwer, 1998; 1999a; 2000b).

An integrated pest management strategy and pest monitoring method were outlined by Bruwer (2000a). Thresholds for blossom infestation of 20% in an “on year” and 10% in an “off year” will give a 5% and 3% cull factor at harvest – at or below the economic threshold of 5%. A minimum of 30 inflorescences need to be inspected during scouting in an “on year” and 60 in an “off year” for correct decision-making. An easy-to-use scouting form was developed with explicit explanations whether to spray, sample more inflorescences, or not spray. As part of the IPM strategy, it was recommended that weeds are not controlled during flowering and fruit set to reduce the pest pressure on the avocado trees. Single sprays of Bulldock® (beta-cyfluthrin) and Ace® (acephate) were effective in controlling avocado bug below the economic threshold. Thioflo® (endosulfan), Malathion® (mercaptothion), and Dipterex® (trichlorfon) required multiple sprays to control avocado bug. Phosdrin® (mevinphos), Dedevap® (dichlorvos), Lannate® (metomil), and the organic products neem oil (azadirachtin), Expellar® (rotenone), pyrethrum, and Exterminator® (pyrethrum and essential oils) did not provide control under the economic threshold even after multiple sprays. Bulldock® and Ace® were also the most cost-effective insecticides. Bulldock® increased the pest status of all three investigated non-target pests (long-tailed mealy bug, heart-shaped scale, and tea red mite). Ace® did not increase the pest status of these three pests and would be suitable for inclusion in an IPM programme because it provides effective control after one spray, is cost effective, and does not disrupt biological control of non-target pests. At the time Bulldock® was the only insecticide registered for the control of sucking bugs on avocado. Multiple applications of Bulldock® caused an unnecessary increase in non-target pests. “Soft” insecticides were later investigated, to prevent the increase of the pest status of non-target pests. Besides Ace® (acephate), a double spray of Organo Z® (neem oil with pyrethrum) during late blossoming was effective without increasing non-target pests. Both were in the process of being registered for use on avocado (Bruwer, 2001; 2002; 2003b; 2004). Similar results were found for the control of coconut bug (*Pseudotheraptus wayi*), where fruit damage occurs between November and March in the Nelspruit/Kiepersol area. Cumulative damage exceeded the 5% threshold in early December (Bruwer, 2005; 2006).

The coconut bug (*Pseudotheraptus wayi*) was confirmed as the most economically important insect pest for avocados in South Africa. Fruit on perimeter trees are more severely damaged by the bugs,

but hot spots do occur in orchards, usually restricted to a single tree. Symptoms were dependent on the stage of development when the fruit were damaged. Colour photos are provided in the original text. Acephate was the only registered product available but residues from use late in the season would restrict its use. Yellow obstruction traps were not successful and trap crops were still being investigated (Schoeman *et al.*, 2010). Fruit maturity was directly related to the severity of coconut bug damage. Out-of-season fruit are highly susceptible to coconut bug damage because of a lack of alternate fruit during the summer. *Beauveria bassiana* was suggested as a possible biocontrol agent. Pinkerton was the most susceptible to coconut bug, followed by Fuerte, Hass, and then Edranol (Schoeman *et al.*, 2011).

An investigation into "pimple-like" protuberances on fruitlets in the Soutpansberg area, which negatively affected fruit quality, identified a number of Hemiptera and Auchenorrhyncha species as possible pests, but further work was needed to identify the pest and control strategies for it (Alberts, 2004). The causal pest was identified as a heteropteran (*Taylorilygus* or *Lygus* spp.; Miridae) feeding on fruitlets. In 2005 only beta-cyfluthrin was registered for use and spraying at the cauliflower stage was recommended to prevent interference with pollinating insects (Alberts, 2005). A number of other minute sucking bugs caused pimple-like protuberances. These were identified as belonging to the Heteropteran suborders Sternorrhyncha and Auchenorryncha. Further studies, including climatic modelling continued (Alberts, 2009). Improvements in trapping (rather than sticky traps and sweep nets) for monitoring of avocado bugs was needed, and the use of semio-chemicals was suggested. Attempts were being made to develop an open GIS system to monitor avocado bug populations to provide and early warning system, and would be available in coming seasons (Alberts, 2010; 2011). Mirids (avocado bugs) were attracted to red and green sticky cards but a trained scout can also monitor for the bugs between 07.30 and 10.00 am. The bugs are able to gain enough heat every morning to be active during the day. The GIS system for early warning was effective if information was supplied in a timely manner (Alberts, 2012).

Bats were investigated as biocontrol agents in Levubu and it was found that Hemiptera bugs composed a higher percentage of the bats' diet in macadamia orchards than natural habitats, suggesting that bats do contribute to biocontrol of stinkbugs in orchards. More research was necessary for confirmation (Taylor *et al.*, 2011).

9.1.6. Beetles

Carapace skin could either be caused by mechanical damage from twigs, or beetle damage during feeding, but these could be distinguished from each other (Rowell *et al.*, 1979).

An invasion of avocado beetle (*Monolepta apicalis* Sahlberg) was first noted in South Africa in Kiepersol in early January 1993. The damage was rapid and severe to fruit and leaves. Careful monitoring of this pest was recommended to determine if it was becoming a major pest (Erichsen *et al.*, 1993; Erichsen & Schoeman, 1993b). A comparison between beetle and looper damage was given by Erichsen (1993) to clearly distinguish the two types of insect damage – the reader is referred to the original manuscript for further details.

9.2. Bees & Pollinators

Flowering should also be considered when discussing bees and pollinators. Please refer to §5.1 (Flowering).

Preliminary findings indicated that bees collected small amounts of both pollen and nectar throughout the flowering period (du Toit & Swart, 1993). Their conclusions after two years were that honey bees visit flowers to collect both nectar and pollen throughout the flowering period, where colonies are introduced. High ambient temperatures resulted in more foraging bees collecting water to cool the hive. The introduction of hives into the orchard to increase pollination was recommended (Du Toit & Swart, 1994).

Honey bees (*Apis mellifera* L.) were the major pollinator of avocado trees at Westfalia Estate, but small carpenter bees (*Allodape microsticta* Cockerell) and various species of blow flies (Calliphoridae) were minor pollinators (Eardley & Mansell, 1993; 1994; 1996). In their final report, it was recommended that the population densities of, especially, small carpenter bees and blow flies be increased to reduce the reliance on honey bees which are not particularly attracted to avocado flowers (Eardley & Mansell, 1996).

Robbertse *et al.* (1996) concluded that avocado orchards alone can maintain bee colony size during flowering, but the brood production declines. Honey bees tend to forage along rows of fruit trees and moved up to 300m down rows, but only 200m across rows and windbreaks. Self-pollinated Hass trees had poorer fruit set and increased fruit drop compared to Hass cross-pollinated with Ettinger (Johannsmeier *et al.*, 1997). Their findings were different to Robbertse *et al.* (1996), in that size and brood production of the colonies were maintained because of the low natural honeybee population. The following year's results highlighted that pollinizers can be effective in reducing risk of poor fruit set due to environmental fluctuations (e.g. poor vs. good rain affecting the flowering of indigenous flora) (Robbertse *et al.*, 1997). Also, as the trees grew and the rows closed, the bees did not move between rows as much. The hedgerows forced the bees to visit the Ettinger trees resulting in greater fruit retention in Hass trees 5m from the Ettinger pollinizers, than those 50m away. The fruit set rating in caged trees that were cross-pollinated with bees was double that of self-pollinated Hass. Effective pollination was much reduced in aged stigmas and pollen, indicating that self-pollination is not an optimal management strategy. Only 50% of the Hass pollen in 1996 was viable, but 99% of the Ettinger pollen was viable. In the third year of the study, it was found that the visitation of bees to flowers was more important than pollinizers, in cages and open trees. Temperature is very important in determining effective pollination, and needs to be between 25 and 28°C for optimal pollen tube growth, and 20-25°C for flowers to open. Pollination can be greatly increased by wild honeybees, but their presence in the orchards can fluctuate greatly from year to year. To reduce the risk of crop failure, it was recommended that 6-10 hives be placed at 400m intervals to achieve at least 5 bees/m^2 canopy flower surface (Robbertse *et al.*, 1998).

The following year, the three year study concluded (Johannsmeier & Morudu, 1999). They concluded that a pollinizer was not necessary in South Africa, but may reduce the risk of failed fruit set occasionally if the wild honey bee population is limited and hived honey bees are diverted to other pollen sources. Cross pollination reduced fruit drop. Fresh pollen is needed for effective pollination. Hives should be placed into orchards in groups of 6-10 hives not more than 400m apart, to ensure 5 bees per 20 inflorescences. Honey bee colonies in flowering avocado orchards maintained colony size, brood production declined and little surplus honey was collected as avocado flowers are a medium source of nectar and a minor source of pollen for honey bees. Hence, beekeepers should be paid for avocado pollination.

9.3. Phytosanitary Market Access

Focus was placed on the phytosanitary requirements for new markets, especially the USA, with work done on irradiation and fumigation. Difficulties were noted in the government-to-government communication because political issues and structures which had to be understood to make progress (Reay, 2002).

9.3.1. Irradiation

Gamma irradiation of Fuerte fruit with Cobalt 60 at 4 and 7krad was detrimental to internal and external fruit quality and fruit did not soften completely. A reduced dose of 3krad did not have an effect on fruit quality or ripening rate (Smith & Jansen, 1983).

Gamma irradiation was unsuitable as a phytosanitary treatment for avocados because of internal browning and fungal decay at even low doses of 100Gy (Durand *et al.*, 2010).

9.3.2. Cold disinfestation

Cold disinfestation was chosen as the preferred phytosanitary mitigating treatment for South African avocados, rather than irradiation or heat treatment. Please refer to §6.3.1.4 (Ultra-Low Temperature Storage) for more information.

10. Economics

In 1983, a yield of 5t/ha was required to remain profitable, and 15t/ha was achievable (Milne, 1983).

Intensive production was recommended as being the most profitable production method (as compared to extensive and intermediate production) because of higher, earlier maximum production, and a longer orchard lifespan [*the planting densities were not provided in the original article – Ed.*] (Toerien *et al.*, 1984).

The optimal timing for orchard replacement was discussed by Groenewald & Du Toit (1985). The procedure was to use (i) discounted future values, and (ii) amortisation of the future values of the replacement orchard, and (iii) comparison of the expected cash margin of the current to the replacement orchard. When the expected cash margin of the current orchard is lower than the amortised value, it would be appropriate to replace the orchard. Technology to improve the productive life of an orchard would obviously delay replacement. Price changes did not seem to affect the replacement age. High rates of inflation, and lower liquidity, and higher income tax rates, would both delay the replacement age. Orchard replacement should be staggered to ensure suitable cash flow. The authors emphasised the importance of accurate keeping of useful records to make informed management decisions, because timely orchard replacement will affect the long term profitability of a business.

An analysis of the South African export market and our competitors was done by van Zyl & Groenewald (1986). This analysis showed that there would be increasing competition in the European market from Israel early in the South African season, and from California throughout the season - and Kenya and Martinique to a lesser degree. Spain and South American countries were considered to be a risk because they would compete directly with South Africa. A price reduction of 10% was anticipated. The benefit of a weak Rand is only temporary because of the subsequent increase in input costs and inflation. To increase profitability increasing sales and decreasing costs were recommended. Specifically, France and Britain were considered the markets with the biggest potential growth, with the Benelux countries third in priority for marketing focus. The consideration of consumer preferences (cultivar, fruit quality, packaging, and supply of ripe avocados) was considered an important means to increase demand and sales. To decrease costs, new developments should be restricted to high yielding areas, and capital costs should be curtailed. A reduction of input costs when profitability is decreasing will obtain the highest net farm value over the long term. Regarding research funding, it was also recommended that research projects be prioritised for the best cost:benefit ratio.

Calatrava (1987) modelled avocado consumption in Europe from the 1970s to 2000 and concluded that marketing would be critical to grow European demand, because of the increase in supply to Europe, and to prevent over-supply and a price reduction. The education of supermarkets and consumers in the handling and gastronomic potential was stressed. This is still important to this day with very large volumes coming from South America. A related study looked at the methodology for the estimation of avocado consumption in the Spanish market, because limited consumption in the local Spanish market was inhibiting growth of that industry (Calatrava *et al.*, 1987). At that stage avocado sales were highly price sensitive, and a reduction of 35% would increase consumption by a factor of 2.5, but a reduction of 20% would only increase consumption by 25%. The Granada market was at a turning point in changing avocados from a luxury product to a commodity. The interaction

between advertising and district rent level (*i.e.* household income) was significant meaning advertising could be targeted for greater efficiency.

The 1986 and 1988 seasons were profitable for South African avocado growers, but the 1987 season was disastrous because of a very large crop from Israel (Toerien, 1989). At the time average production was 5.02t/ha and the export percentage was 55%. Toerien discussed the need to improve both production per ha (aim for 15 t/ha) and fruit quality (85% class 1) to increase profitability. The management factors affecting production are:

1. Farming method (intensive or extensive)
2. Soil preparation
3. Plant density and vegetative growth control
4. Tree quality
5. Scion cultivar choice and quality of material
6. Irrigation
7. Fertilisation
8. PRR control.

He also briefly discussed the identification of "super trees" and the need to improve the local market. The implementation of knowledge from research (*i.e.* extension and improved management) is necessary to increase yield and quality.

Exchange rates were concluded to be crucial in the viability of avocado production – even though there have been major changes in the local and global economy, this discussion is still pertinent. An anticipated weaker rand going forward from 1990 was expected to increase profit margins at that time (Van Zyl, 1990).

The major problem of a decreasing gross selling price in Europe, despite improved fruit quality, and coupled with increasing production costs was discussed by Toerien (1992). He once again stressed the importance of (i) increasing production per hectare from research and implementation of proven technology, (ii) increasing production efficiencies (cost control), and (iii) co-ordinating market supply to avoid over-supply. Because of a growing number of countries supplying fruit into Europe, information exchange between all the countries would be essential to prevent over-supply.

Sartorius von Bach & Grote (1994) gave a detailed analysis of the avocado trade in the European Community. Their conclusions were:

1. The consumption of avocados is mostly influenced by economic growth, cultural factors, and nutritional knowledge. The European population has shown (*and continues to show – Ed.*) increasing consciousness of health and nutrition.
2. The supply of avocados into Europe was mainly from Israel, South Africa, Spain, Mexico, and Kenya and most of the fruit were exported to France, with lesser volumes going to the UK, Germany, and the Netherlands. The relationship (and therefore trade intensity) between France and these exporting countries was an important factor.
3. The growth of Spain as a grower and exporter was projected as a complicating factor for other exporting countries, because it is a member of the EC and is close to the main market of France.

4. Growth in the European avocado market was dependent on (i) self-sufficiency of the domestic (EC) production (mostly Spain), (ii) the interest in tropical fruit, and (iii) the ability to deliver the required volume at the required quality standard timeously. Trade policy was found to affect the growth of the European avocado market.
5. The prospects of the Western European avocado market were still favourable at that time.

A review of the local and international avocado industry was done for the Development Bank of South Africa by van Zyl & Ferreira (1995). Their concluding remarks, which are still relevant today, were:

- The avocado producing countries should promote avocado consumption in importing countries with an effective advertising and education programme.
- The nutritional qualities of the avocado should be emphasized.
- The co-ordination of volumes between exporters and importers was stressed.
- Producers need to increase productivity and implement research findings to remain competitive.
- Technical research programmes should continue, including research on irrigation and water saving.
- The correct choice of cultivar to meet market demand was important.
- The collation of market information in a confidential manner would be beneficial to guide marketing strategies.

11. Marketing

Key Points by the Chairman of the European Committee (Shelton, 1981) were:

- SAAGA's European Committee formed in 1972.
- Principal responsibility is to administer the advertising and promotion appropriation for the UK and advise the Management Committee in South Africa on any matter adversely affecting the sales and marketing of avocados in SA. Also to deal and report on any matters that affect the industry once fruit have left SA. It developed policies and procedures to be adopted if the discharge or distribution of fruit is hampered or delayed, and to reduce the damaging effect on the market of poor quality fruit.
- Improved relationship with container shipping companies.
- Problems were soft landings and mixed ripening/soft landings, and poor air circulation in containers.
- Did not find any problem with immature fruit in Europe, but more concerned with greater volume later caused by delayed shipments.
- Anthracnose, pulp spot, grey pulp, discrete patches/ECI, fruit size and uniformity could be problematic.
- Felt that fruit should be waxed and wrapped in cellophane – as was standard practice at the time.
- Recommended focussing on ventilation for rapid and uniform cooling.
- Recommended marketing co-ordination to reduce market over-supply.

Prof Kotzé stressed the importance of marketing in 1988, because of the rapid increase in production from 1987 to 1990 (Kotzé, 1988). At that stage the supply of avocados to Europe was greater than demand, there was a limited local market, and the volume of processed avocado products was negligible. He also stressed the importance of fruit quality in marketing, including immature, blemished, and excessively small fruit together as poor quality produce. Thankfully, this call was heeded and the local market and avocado processing were subsequently developed.

As part of the greater emphasis on market research, Van Zyl & Conradie (1988a) reported on the factors that influence demand for avocados in the urban black demographic segment. This study still has relevance today. The price elasticity of domestic demand is relatively elastic (1.13 - 1.93), meaning that an increase in income would be relatively greater if price was reduced, and that the income elasticity of avocados was highly significant and relatively elastic (1.21 – 2.39) meaning that avocados were a luxury item. No near substitute was found for avocados. The faster increase in the expendable income and population growth of the non-white population, was identified as having the highest potential for an increase in domestic avocado consumption. Price, quality, and availability are major factors in avocado sales (Van Zyl & Conradie, 1988b). Preference was shown for ripe fruit, and green-skinned cultivars were favoured, and sales were generally high frequency and small quantity. Their detailed survey results are available in the 1988 Yearbook (Van Zyl & Conradie, 1988b). Furthermore, Van Zyl (1988) discussed the institutional aspects of a marketing strategy for avocados, where he advocated a voluntary membership to an association that would centralise some aspects of avocado marketing – rather than a government-regulated approach as was common in the 1980s.

The South African avocado industry's exports to Europe grew rapidly from 1970 to 1980, declined slightly from 1981 to 1984 but production surged in 1985 and 1986. The average annual increase was

20%, and accounted for 20% of the European supply, second only to Israel. His points regarding the global avocado industry are still apt today:

1. World trade continues to grow and improve, and logistical problems have been and are being overcome.
2. Developing countries, in many cases, have well-developed agricultural industries.
3. Exchange rates are very fluid and have a major influence on competitiveness.

As the single channel market system was dismantled, Lourens (1988) recommended greater co-ordination and co-operation in the South Africa avocado industry to ensure it was sustainable. More specifically:

1. Plantings should be planned to prolong the season and meet demand.
2. The local market needs to be developed.
3. Processing needs to be made a priority to remove low grade fruit from the local fresh fruit market.
4. Fruit quality needed to be improved so that sub-standard fruit would not be accepted at the municipal markets.
5. The export market needed to be planned, co-ordinated and expanded.

Finally, he encouraged the South African avocado growers to band together to manage the industry amongst themselves because no-one else has the industry's best interest at heart (Lourens, 1988).

The key-note address at the 1992 Symposium was given by Lötter of the South African Citrus Co-operative Exchange (SACCE), in which he discussed the advantages and disadvantages of the single channel marketing of citrus from Southern Africa (Lötter, 1992). Although single channel marketing is no longer in effect in South Africa, the advantages of the system were:

1. Improved production and harvesting efficiency because of centralised research. The central body means research is more cost effective, and the collection of levies to fund research and extension is possible.
2. Cost effective pre-cooling.
3. Transport efficiency in rail, road, and shipping because of economies of scale.
4. Co-ordinated supply of consistent quality fruit onto the export market.
5. Promotion of industry affairs, notably with the State, export countries, service providers, and research.

The disadvantages are:

1. Lack of comparable alternative options can lead to dissatisfaction.
2. Legal enforcement breeds resentment from individualists.
3. Distribution of profits to growers can make employees unmotivated and not cost conscious
4. Single channel is inclined to be inflexible, which was addressed by SACCE.
5. Conformity with minimum standards, or inclination to mediocrity because of loss of individual identity.
6. Subsidisation of inefficient/bad growers who need extra attention from staff.

A diet enriched with mono-unsaturated fatty acids reduced coronary heart disease without compromising weight loss. Avocados are rich in mono-unsaturated fatty acids and nutrient dense, suggesting that avocados are beneficial for preventing coronary heart disease without affecting weight loss (Pieterse *et al.*, 2003).

12. Research

Research stands on three legs: research workers, money, and facilities. In 1974 SAAGA provided R5 000 for research. Research was conducted by Westfalia, Hall & Sons, Letaba Co-op, and by the Universities of Pretoria and Natal. Research was voluntary and SAAGA does/did not instruct institutes to conduct research. Prof. Kotzé rejected the suggestion that SAAGA hire its own research workers as it is/was too expensive. The priority of each industry-wide concern was determined by the *ad hoc* committee and growers. Projects had to be industry/area-wide and not only a problem for individual growers. Finding researchers that were not already committed to other projects soon proved to be a challenge. The major problems at that time were postharvest disorders and diseases (32%) and PRR (22%), and these received 46% of the budget. He supported the purchase of instruments to be used at institutions with a proven track record of quality research. As discussed in the relevant section, international visitors came to South Africa to offer advice to the growers. This continues to the present. Significant breakthroughs at this stage included PRR and postharvest disease control. Moderate success was achieved in producing clonal disease-free nursery trees (Kotzé, 1981).

Prof. Kotzé provided an overview of the research projects running in 1984 and 1985. Research projects continued on PRR control, fruit quality and maturity, ASBVd; and the number of projects on postharvest physiology began to increase. Prof. Kotzé gave a very informative summary of 10 years of SAAGA research, highlighting the successes of PRR control, and efforts in postharvest quality, ASBVd, and looking forward to entomological studies and breeding and selection of rootstocks and scions (Kotzé, 1984; 1985b). The projects for the 1985/86 financial year are outlined in Kotzé (1986a); (Kotzé, 1986b).

Prof. Wolstenholme (1987a) gave a key-note address on global avocado research at the First World Avocado Congress in Pretoria. It is interesting to note that, while the avocado industry has definitely advanced, the industry still faces the same problems 26 years later.

In 1989 Prof. Kotzé mentioned that, although South Africa's avocado production was about 1% of global production, the research co-ordinated by SAAGA was of the highest quality although the amount of money spent on research was relatively small. This is because SAAGA does not have its own research facilities and researchers, but contributes funding to research centres for specific projects (Kotzé, 1989).

The decline in the State's contribution to agricultural research, and the need for SAAGA to contribute more to research funding, was mentioned through the years. The importance of research was illustrated by Kotzé (1990), who showed that the total South African annual production increased in the 1980s. The percentage of exportable fruit also increased, both in large part because of the implementation of research results – specifically PRR control. In a comparison with other agricultural industries, where the research budget was 1-2% of income, the funding for avocado research in South Africa was about 0.3%. He suggested an increase in research funding to ensure the industry remained competitive and sustainable in the long term (Kotzé, 1990).

Prof. Kotzé noted that the research budget in 1991 was severely cut because of drought, hail and wind damage, but SAAGA was focussing on increasing production per hectare by concentrating on improving fruit set (Kotzé, 1992).

As a means of comparison, the research programme of the California Avocado Society was shared and discussed at the 1991 SAAGA symposium. Their programme focussed on increased productivity and maintaining tree life and health, with a few miscellaneous projects (Francis, 1992).

A brief overview of Merensky Technological Services (now Westfalia Technological Services) was given by Köhne *et al.* (1994). Most of the projects are discussed in detail in separate reports. At the time MTS's (now WTS) research budget was at least R2.5 million, with eight researchers in employment.

The three research priorities for KwaZulu-Natal producers in 1994 were:

1. Improving fruit quality after cold storage, and improving the implementation and timing of cold storage regimes for KZN fruit.
2. Improving count distribution of small size Hass – as it had become a problem in KZN a few years after Limpopo and Mpumalanga (previously part of the Transvaal province).
3. Improving production because KZN yields are typically lower than in the north, and orchards have high alternate bearing (Slabbert, 1994).

Jan Toerien showed that the industry received a benefit of at least R36 million (1997) annually at the subsidised cost of R4.5 million over 11 years (1987-1997) and the real cost of the research was R26 million. This worked out to be a cost of 8c/carton for the benefit of R4.80/carton. He warned that research funding for SAAGA would have to increase, because of reduced subsidisation by the state institutions (Toerien, 1997a; b).

Keevy (1999) commended the success that research had delivered in the past, but urged greater efforts in solving alternate bearing, increasing productivity, and gaining access to new markets.

Research projects in 2001 were aimed at addressing alternate bearing, market access, reduced pesticide use (IPM), fruit quality, and increased productivity (Vorster, 2001).

13. Visitors

Prof. Zentmyer visited South Africa in February 1980 (Zentmyer, 1979). This is discussed in more detail in the pathology section.

Don Gustafson visited South Africa in 1980. He was impressed by sterile nurseries at Westfalia, Halls and of Bertie le Roux, and warned nurseries not practicing sterile practices of the dangers of PRR infection in the nursery. He commended the general avocado research being done in South Africa, particularly the work done on PRR (Gustafson, 1981).

His recommendations were:

1. Tile drainage to remove excess water from an orchard to reduce the risk of PRR infection.
2. Continue with fruiting cultivar testing.
3. Set up a laboratory for soil, water, leaf and root rot analyses.
4. Use irrigation during the dry winter months.
5. Concentrate on zinc deficiencies and do not assume sickly trees are infected with PRR.
6. Conduct research on postharvest technology to deliver high quality fruit to Europe.
7. Control weeds.
8. Conduct research on old avocado orchards that are to be re-planted to determine the best treatments to ensure good growth of re-plant trees.

Don Gustafson visited South Africa again in 1983. He suggested using tensiometers to monitor soil water content, and to use leaf analysis, with particular focus on zinc deficiency which many farmers assumed was PRR (Gustafson, 1984).

A brief outline of the early history of the cultivation of the avocado was given from the first known written record of avocados from 1519 to 1605 AD (Zentmyer *et al.*, 1987).

Jan Toerien gave a brief summary of his trip to Europe, California, Guatemala, and Chile with the objective of gathering genetic material for Westfalia's gene pool for future breeding (Toerien, 1988).

Stefan Köhne visited Mexico with the view of exchanging ideas and collecting budwood of dwarf trees. He provided a brief overview the Mexican industry in his report (Köhne, 1990).

14. Looking Forward

Some SAAGA projects have fundamentally changed avocado production in South Africa, and indeed the world. Other projects – as is the nature of research - have fallen by the wayside. Looking into the future, what will be the threats to the industry that will need to be met by researchers and growers? Broadly speaking, the continued cost-price squeeze requires attention throughout the value chain for long-term sustainability of farming operations. Broadly speaking, efforts to (i) improve production efficiency, (ii) increase production per ha, (iii) improve fruit quality, (iv) continue growth in traditional markets, and (v) expansion into new markets are suggested and discussed. The previous headings are used as a framework for the discussion. This is personal opinion, and the reader is welcome to disagree.

14.1. Orchard Management

14.1.1. Tree density & growth control

A continued cost-price squeeze will necessitate greater efficiencies throughout the supply chain, but especially in production. The ever-increasing minimum wage in South Africa requires greater labour efficiency, greater use of mechanisation, and smaller trees to increase picking efficiency and reduce the risk of workers being injured while picking fruit. High density orchards (500 – 1000 trees/ha) with smaller trees designed for mechanisation would seem to be the obvious answer. However a large proportion of the avocado orchard soils in South Africa have high vegetative growth potential, because of a mesic growing season climate with relatively high rainfall. This is completely different to California and Chile where high- and ultra-high density orchards are planted in areas with steep slopes, low potential soils, and low rainfall during the growing season. The maintenance of intensively managed high density orchards on an extensive scale is challenging if there is high vegetative growth potential (high tree vigour) in mesic, relatively low stress climatic and soil environments.

The 1980s standard of about 200 trees/ha (7m x 7m spacing) has been replaced by today's 300 – 400 trees/ha to realise an earlier return on the capital investment. This has been made possible with the use of growth retardants and better pruning practices. The question to be answered now is, "can tree density be increased further on a large scale?"

Closer spacing has been shown to be technologically feasible – at least in the medium term before tree thinning may be required, but the early high-density (500 – 1000 trees/ha) trials at Westfalia and at Burgershall Research Farm did not result in such spacings being widely adopted. Perhaps the ideas of Köhne and Kremer-Köhne and of Stassen and Snijder (§2.6 - Growth Control) were ahead of their time. A high density planting, in a suitable location, using a combination of growth retardants, suitable pruning regime, tree manipulation techniques, and a more suitable scion and rootstock cultivar combination, may yet be feasible. It is acknowledged that the availability of nursery trees and land security are further complicating factors in the implementation of large scale high density planting in South Africa. It is also pertinent to point out that countries or growing areas that have (at least in part) adopted orchard treed densities in the 500 – 1000+ tree/ha, in addition to having comparatively much more stressful climatic and soil environments (semi-arid to arid), also have access to better qualified and trained (and much more expensive) labour. To use contemporary jargon, a paradigm shift in management intensity and labour efficiency would be needed in South Africa.

Linked to high density plantings, the dearth of SAAGA-funded research on the use of growth retardants and pruning options for the average grower since the work of Stassen & Snijder (§2.6.1 Pruning) is surprising. Pruning, even for standard tree density plantings, has become standard practice but genuinely scientifically determined guidelines are conspicuous by their absence. Different estates and growers adopt different approaches – anecdotal evidence and opinion reign supreme. Trial-and-error orchard management is expensive. Hard scientific evidence over the long-term is needed. Experience may well be the best teacher, but it comes at a price.

14.1.2. Water & fertilisation

South Africa is a water-limited country, and irrigated agriculture uses a high percentage (50 – 60%) of the available surface water. As the population grows there will be a greater demand for water for domestic use. This will result in the cost of water increasing, and its quality and availability for agriculture use declining, steadily over time. Improved water-use efficiency, from a cost and accreditation perspective, will require better irrigation management. At the time of writing, SAAGA is funding research on irrigation optimisation and these findings are anticipated with interest.

Further complicating the water picture is the spectre of climate change and extreme weather events (high temperature, drought, flood, violent storms, etc.). This will impact strongly on agriculture and orchard management. Research in stress physiology will be vital, and breeding will become key to the growers' chances of adapting and living with the consequences of climate change and extreme weather.

The fertilisation/nutrition research has been limited, with the exception of nutrient deficiency symptoms and boron research (§2.5 - Nutrition & Fertilisation). The "Pinkerton Problem" did however yield ancillary information on nutrition (§5.6 - Pinkerton Problem). The manipulator element nitrogen, the chronically deficient micronutrient zinc, and soil organic matter dynamics are "fertile fields" for research. Fertiliser research is long term in nature, and affected by other orchard management practices (e.g. pruning and irrigation) so perhaps these could be refined in a holistic manner in a large scale "orchard of the future" as is done in deciduous fruit crops. Leaf and soil norms for new clonal rootstocks and scion cultivars should also be established.

14.1.3. Expansion of plantings

In recent years there have been new plantings in non-traditional areas, e.g. the Eastern Cape and Western Cape to augment the supply of South African avocados in the summer months. It is anticipated that these plantings, and plantings in marginal or sub-optimal areas in the traditional avocado production areas, will continue. These areas have their own challenges in terms of edaphic and climatic conditions, and pests and diseases. Perhaps moderately high density orchards (500 – 800 trees/ha), as discussed above, would be viable in these locations where the environmental stress is greater on the trees.

14.1.4. Shadenet

The risk of crop failure due to extreme weather conditions (e.g. very hot days, high winds, hail, and frost), especially after the crop damage seen in 2011 from hail and frost, has prompted research into farming avocados under shadenet. The increased area of citrus grown under shadenet, with the accompanying technical experience needed for this specialised type of farming, has also contributed to the greater interest in growing avocados under shadenet. Shadenet structures are a potential solution to reduce the risk of crop loss and damage, but also increase the external quality of fruit by

reducing wind damage and sunburn. Protected culture (i.e. shadenet) may also be a mitigating technology for anticipated climate change. A trial was started in 2013 and the early results are encouraging but the long term effects on fruit quality and tree physiology are still to be determined. Economics will be a major factor in determining the viability of such structures, especially for mid-season cultivars.

14.2. Pathology

There is continued pressure on pesticide use, especially postharvest fungicides, in Europe. More efficient spray machines, with reduced water and fungicide application rates, and copper alternatives have received funding in the recent past and continue to receive funding from SAAGA. These should be a high priority so solutions can be found before such legislation is passed. Alternatives to synthetic postharvest fungicides should be identified. Options are to apply the synthetic fungicide/s pre-harvest only, or find "generally recognised as safe" (GRAS) compounds for use postharvest that are cost-effective. The use of more disease resistant scion cultivars, especially as an alternative to Fuerte which is highly susceptible, would decrease the amount fungicide that is required. This is part of a long term scion breeding strategy that would encompass a number of traits.

Also linked to market access, an alternative to prochloraz (a pre- and/or postharvest fungicide) is needed because the use of prochloraz is prohibited in the United States as it is considered a carcinogen.

14.3. Genetic Resources

The next generation of rootstocks, with greater PRR tolerance, salinity tolerance, and water use efficiency, that match or increase current rootstocks in terms of yield efficiency is a priority in reducing operating costs. New scion cultivars, with focus on extending the traditional season, increasing productivity, increasing fruit quality and fruit disease resistance, are also needed. New selections must be thoroughly tested before commercial release. Most of the local research is now done by private companies due to the competitive advantage that new genetic material offers.

14.4. Anatomy & Physiology

Research on anatomy and physiology is expensive, but can provide important explanatory information on observed responses. These could be included in future trials to explain responses, and move beyond "spray-and-pray" trials. This research has typically been done by universities, and there is a lack of experienced avocado researchers at South African universities at the present time.

14.5. Post-harvest

South African avocados on the European market are generally of good quality, in part due to the strict standards set by the PPECB and the excellent work done by Gawie Eksteen and Robbie Robinson in the past. Research is needed into improved post-harvest handling to identify new technology that can reduce costs and improve the consistency of fruit quality.

Although many years' worth of results have shown that South African fruit can be stored at 1°C air delivery temperature, postharvest research and QA focussing on new markets will probably be required when these markets open for South African avocados.

A project to develop ripening protocols has been discussed, but the protocols provide a competitive advantage that ripeners do not want to divulge.

14.6. Nursery & Propagation

The propagation of clonal avocado rootstocks is complicated by the need for etiolation to increase rooting to a commercially sustainable level. There is a commercial benefit for the nursery in improving the method devised by Frolich in the 1950s (e.g. the “Brokaw”, ”Allesbeste” and ”Hofshi” methods as discussed by Ernst *et al.* (2013)) so this research will be done by private nurseries for their own benefit.

14.7. Fruit Products

With increasing plantings of avocado worldwide, especially in Peru which has the same window as South Africa in the European market, preference for black skin cultivars in Europe, and an increasing supply of green-skin cultivars on the local market suggests an increasingly important role of alternative avocado products (oil, guacamole, etc.) in the medium term.

14.8. Entomology & Market Access

14.8.1. Pests

The number of insect pests of avocados, and their economic impact, has steadily increased as the industry has grown in South Africa. And with increased global trade there is always a risk of new insect pests being introduced. Also, the expansion of avocado orchards into new areas may result in the establishment of existing species as economically important pests, as was observed in the early 1990s.

14.8.2. Market access

The access to new markets is a high priority for SAAGA, with considerable funding allocated to this goal annually. The United States and Japan are the most likely to open first. SAAGA-funded research has proven that cold disinfestation is an effective treatment for insect pests, and can be done without compromising fruit quality. Government approval is now needed to be able to export our fruit to markets requiring phytosanitary treatment of fruit. The delivery of fruit that is compliant with importing regulations, on a consistent basis, is the next challenge.

14.9. Economics, Marketing & Research

The South African avocado industry is a more competitive industry when compared to the early days of SAAGA. Companies are competing on a global scale and are no longer willing to divulge technical and technological innovation that provide them with a competitive (financial) advantage. As the South African avocado industry has matured, producers have realised this and have increased spending on private research and extension. The large industry role-players have their own technical and/or research departments to conduct internal research. Along with the decline in government financial support, and technical information being published in the (former) “Avo Info” newsletter and Subtrop Quarterly Journal, this explains why the number of articles in the SAAGA Yearbook has declined over the years.

Conclusion

From humble beginnings in the 1970s, the organised (under SAAGA) South African avocado industry has grown and provided invaluable technological advances for the global industry over the years. The industry, like any other, has its challenges, but it continues to grow and remains an important player in the international avocado industry. From the authors' perspective, looking back on the last 35 years of SAAGA research and the local industry has been fascinating. The next 35 years should be just as interesting in the South African avocado industry.

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List of Abbreviations

Abbreviation	Explanation
1-MCP	1-methylcyclopropene; an ethylene inhibitor
a.i.	Active ingredient
ABA	Abscisic acid; a PGR
ABS	Avocado black streak
ADP	Adenosine diphosphate
ADT	Air delivery temperature
AI	Alternate bearing index
AIP	Avocado improvement programme
AMP	Adenosine monophosphate
ANA	Avocado Nurserymen's Association
AOS	Active oxygen species
APIS	Avocado plant improvement scheme
ARC	Agricultural Research Council; South African public research institute
ARC-ITSC	Agricultural Research Council – Institute for Tropical and Subtropical Crops based in Mbombela (Nelspruit)
ATP	Adenosine triphosphate
CA	Controlled atmosphere; in contrast to Regular Atmosphere
CAC	California Avocado Commission
CEC	Cation exchange capacity
CG	Ciba-Geigy
CPPU	N-(2-chloro-4-pyridyl)-N'-phenylurea; a cytokinin PGR
CSFRI	Citrus and Subtropical Fruit Research Institute; later the ARC-ITSC
DAFB	Days after full bloom
DAP	dibasic-ammonium phosphate
DC complex	Dothiorella-Colletotrichum complex; a postharvest fungal rot
DIG	digoxigenin
DM	Dry matter
DNA	Deoxyribonucleic acid
DTR	Days to ripen
EC	Emulsifiable concentrate
EC	European Community
ECI	External chilling injury; aka black cold, cold damage
ELISA	Enzyme-linked immunosorbent assay
EPA	Environmental Protection Agency; USA government department
ER	Endoplasmic reticulum
FCM	False codling moth
FFA	Free fatty acids
GA	Gibberellic acid; a PGR
GIS	Geographic information system
GR	Granule formulation
GRAS	Generally regarded as safe compound
HDP	High density planting; in contrast to standard density planting

HMGR	3-hydroxy-3-methyl-glutaryl-CoA reductase; rate controlling enzyme in mevalonic acid pathway
IAA	Indole acetic acid; and auxin PGR
IBA	Indole butyric acid; and auxin PGR
IPA	Isopentenyladenine; a cytokinin PGR
IPM	Integrated pest management
ITSC	Institute for Tropical and Subtropical Crops; see ARC-ITSC
KZN	KwaZulu-Natal; a province in South Africa
MA	Modified atmosphere
MC	Moisture content
MRL	Maximum residue limit
NAA	Naphthalene acetic acid; and auxin PGR
NIR	Near-infrared
NIRS	Near-infrared spectroscopy
OTO	Overseas technical officer; a SAAGA officer based in Europe
PAGE	Polyacrylamide gel electrophoresis
PAL	Phenylalanine ammonia lyase; an enzyme involved in the biosynthesis of polyphenols
PDA	Potato dextrose agar
PE	Polyethylene
PG	Polygalacturonase; a cell wall degrading enzyme
PGR	Plant growth regulator
PME	Pectin methylesterase; a cell wall degrading enzyme
PO	Peroxidase
PPECB	Perishable Products Export Control Board; a South African public entity to perform cold chain services for exported perishable products
PPO	Polyphenol oxidase; an enzyme that causes tissue browning
PRR	*Phytophthora cinnamomi* root rot
QA	Quality assessment/assurance
QAC	Quaternary ammonium compound
RA	Regular atmosphere; in contrast to controlled- and modified atmosphere
RER	Rough endoplasmic reticulum
RFLP	Restriction fragment length polymorphism
RH	Relative humidity
RNA	Ribonucleic acid
ROS	Reactive oxygen species
RT-PCR	Reverse transcription polymerase chain reaction
SAAGA	South African Avocado Growers' Association
SABS	South African Bureau of Standards
SACCE	South African Citrus Co-operative Exchange
SC	Suspension concentration formulation
SDP	Standard density planting; in contrast to high density planting
SEP	Standard error of prediction
SER	Stem end rot
SFE	Super-critical fluid extraction

SL	Soluble liquid formulation
TBZ	Thiabendazole; a postharvest fungicide
TMV	Tobacco Mosaic Virus
UC	University of California
ULV	Ultra-low volume
USDA-APHIS	United States Department of Agriculture - Animal and Plant Health Inspection Service
VB	Vascular browning
WAC	World Avocado Congress
WG	Wettable granule formulation
WP	Wettable powder formulation
WRR	White root rot caused by *Rosellinia nectrix*

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