

**EFFECTS OF POTASSIUM AND MULCHING ON  
*PERSEA AMERICANA* MILL. CV. HASS PHENO/PHYSIOLOGY,  
YIELD AND FRUIT SIZE**

**By**

**Warren van Niekerk**

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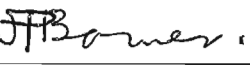
## DECLARATION

I hereby declare that the work reported in this dissertation is the result of my own investigation, except where acknowledged.

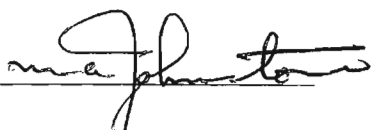
Signed: 

Warren van Niekerk

I certify that the above statement is correct.

Signed: 

Prof. J.P. Bower  
Supervisor

Signed: 

Dr. M.A. Johnston  
Co-supervisor

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## INTRODUCTION

The 'Hass' avocado is preferred by overseas consumers due to its excellent internal keeping quality and superior taste. It is furthermore important to the South African avocado industry as it is late maturing and so fills a niche market locally and abroad. However, 'Hass' trees bear a large number of unacceptably small fruit (Kremer-Köhne and Köhne, 1995). The poor consumer acceptance of these small fruit (Moore-Gordon *et al.*, 1997) in a predominantly export orientated market (Cutting, 1993) causes considerable financial losses, estimated to be over R30 million in 1994 (Moore-Gordon and Wolstenholme, 1996) and possibly more than R50 million by 2001 (Wolstenholme, A.-pers. comm., 2001).

The 'Hass' small fruit phenomenon is not restricted to diseased and/or unhealthy trees (Moore-Gordon and Wolstenholme, 1996), with even healthy trees producing a significant proportion (5-25 %) of small fruit (Kremer-Köhne and Köhne, 1995). Furthermore, small fruit are often randomly interspersed with large fruit on the same flowering stem of a seemingly healthy tree, indicating that the problem is a physiological one and occurs without pathogen involvement (Blanke and Bower, 1991). The problem appears to increase under stressful growing conditions (Moore-Gordon and Wolstenholme, 1996) and with increasing tree age (Cutting, 1993) and is particularly noticeable in orchards situated in warmer and/or drier climates (Hilton-Barber, 1992; Whiley and Schaffer, 1994). The long-term solution to this problem lies in one of two strategies, i.e. to find the physiological mechanism for the random development of small fruit and thereby manipulate the tree through the application of growth regulators or hormones, or to breed new large-fruited black-skinned cultivars. Both "processes" are time-consuming and so an interim amelioration of the problem through mulching with pinebark has been suggested (Moore-Gordon *et al.*, 1997). The benefits derived from mulching include increased water and nutrient availability (Gregoriou and Raj kumar, 1984), improved soil structure and porosity (Gallardo-Laro and Nogales, 1987) and a narrowing of the diurnal soil temperature range (Gregoriou & Raj Kumar, 1984). In addition, mulching creates a suppressive environment to the *Phytophthora cinnamomi* (*Pc*) root rot fungus therefore reducing the impact of this phytopathogen (Turney and Menge, 1994). Mulching promotes healthier, more consistent root growth that not only ameliorates stressful conditions for the roots, but ultimately reduces



“whole-plant” stress. The highly beneficial effect of mulching with composted pinebark, in both ‘Hass’ fruit size and especially yield, has been summarized by Moore-Gordon *et al.* (1997).

Moore-Gordon (1997) revealed that several interrelated factors are involved in the control of ‘Hass’ avocado fruit size. The results he obtained suggested that the ‘Hass’ small fruit phenotype was induced by a low cytokinin (CK) : abscisic acid (ABA) ratio, which through a cascade of events was thought to reduce hydroxymethylglutaryl-coenzyme-A (HMGGR) activity and thereby retard fruit development. According to Chapin (1991) a CK : ABA ratio reduction of this kind comes about through an increase in the level of root and leaf ABA in response to abiotic/biotic plant stress. An increase in the level of ABA triggers a decline in leaf elongation and growth, ultimately limiting carbohydrate production due to the lower vegetative growth demand, which in turn causes a corresponding reduction in the photosynthetic rate. The net result being reduced vegetative growth in response to a limiting or stress factor, resulting in a reduction in the amount of photoassimilate available for fruit growth. Furthermore, Moore-Gordon (1997) found a correlation between the ‘Hass’ small fruit phenotype and early seed coat senescence. Early seed coat senescence is apparently a stress-induced physiological response (Whiley *et al.*, 1986) that substantially reduces the supply of nutrients, assimilates and plant hormones to the developing fruitlet, considerably retarding fruit growth (Cutting *et al.*, 1986).

## **AIMS AND OBJECTIVES**

Fruiting responses to different systems of soil management have been variable, and particularly so in early experiments in this field (Tisdall, 1989). These responses seem to vary with region, site history, crop, cultivar and from year to year. Nevertheless, Tisdall (1989) states that a straw mulch usually increases the growth and yield of fruit trees, and Moore-Gordon and co-workers (1995, 1996, 1997) found mulching with composted pinebark to significantly improve ‘Hass’ avocado yield through an increased fruit size and number. This study proposes the use of a filtercake mulch as an alternative to pinebark used by Moore-Gordon (1995, 1997) as a strategy to improve ‘Hass’ avocado fruit size, while rejuvenating tree vigour and maintaining a consistent bearing habit and high yield from year to year. The strategy is based on simulating

root zone conditions from the avocado's natural habitat, where it has evolved in a rainforest environment and is able to "litter feed" in the natural leaf litter mulch present on the forest floor. Orchard floor mulch application is thought to create familiar edaphic conditions similar to those encountered on the forest floor, and in so doing alleviate stress. Composted filtercake was chosen as an alternative to composted pinebark primarily because it is a waste product of nearby sugarmills in the Kwazulu-Natal midlands, making it much cheaper than pinebark. Furthermore, filtercake often contains many nutrients that remain from the sugar-milling process. These nutrients are mostly tied up by the organic molecules of the mulch and it was hoped that this nutrient release would take place in the preferred slow release manner during organic matter decomposition. It is also likely that this nutrient release would then largely substitute inorganic fertilizers, further justifying the cost of applying the mulch.

In addition, potassium (K) has been found to play a number of indispensable roles in higher plant cells (Maathuis and Sanders, 1996). A study on the reduction of abiotic/biotic plant stress in an attempt to increase fruit size without considering this vital element in some way would therefore be incomplete. Thus K was applied at various rates in conjunction with the control, pinebark and filtercake treatments in order to determine what effect this element has on the pheno/physiology and yield of 'Hass' avocado.

## **CHAPTER 1**

# **LITERATURE REVIEW: AVOCADO TREE GROWTH DYNAMICS**

## **1.1 PLANT GROWTH DETERMINANTS**

The avocado has genetically evolved to its present form or growth habit as a result of millions of years of natural selection. In manipulating this form to suit our needs we therefore have two main determining factors to consider:

1. The plant's genetic make-up;
2. The environment in which it has evolved.

Since the genetic make-up is in the short-term unalterable to us as horticulturists, we are left with the option of altering the plant's growing environment in order to achieve a desired phenotypic expression. If this is to be done effectively, a thorough understanding of the physiology and growth habits of the tree are vital.

## **1.2 HORTICULTURE OF THE AVOCADO**

### **1.2.1 ORIGIN**

Due to historic human selection for improved plant growth and yield, the avocado as we know it today is so far transformed from its ancestors that it is very difficult to trace both the ancestors and their origins (Storey *et al.*, 1986; Scora and Bergh, 1990). Nevertheless, a general consensus based on plant distribution and taxonomic evidence indicates that the avocado originated in or around South-Central Mexico (Chandler, 1957). The primitive avocado, *Persea americana*, seemingly gave rise to three different races: Mexican, Guatemalan, and West Indian (Chandler, 1957; Embleton and Jones, 1966; Bergh, 1975; Storey *et al.*, 1986). Besides developing in geographically different areas, these races were also found in climatically varied habitats and display varied traits.

The Mexican race with its anise-scented leaves and smaller fruit with smooth, thin skins was originally found in the Mexican highlands, and has the greatest resistance to cold and a medium heat tolerance (Embleton and Jones, 1966; Bergh, 1975). The Guatemalan race with its non anise-scented leaves, larger fruit, with rougher, thicker skins than the Mexican race, seemingly developed in the Guatemalan highlands. It is less resistant to cold than the Mexican race and more sensitive to high temperatures (Chandler, 1957; Storey *et al.*, 1986). The West Indian race with its non anise-scented leaves has fruit of variable size with skins a little smoother and thinner than those of the Guatemalan race, and probably originated in the hot, humid lowlands of Central and South America. It displays the least cold and most heat tolerance of the three races (Embleton and Jones, 1966; Bergh, 1975). These variable traits have been useful in the different climates of the world's avocado enterprises, either as entities or hybrids thereof.

Today, these "horticultural races" are better regarded as "botanical varieties" or subspecies, giving rise to the varieties *americana* (West-Indian or Lowland ecotype or subspecies), *guatemalensis* (Guatemalan ecotype or subspecies) and *drymifolia* (Mexican ecotype or subspecies) (Scora and Bergh, 1990). Of these, the Guatemalan ecotype (subsp.) has the most valuable horticultural genes, and today's most widely grown cultivars are Guatemalan or are hybrids between Guatemalan and either Mexican or West-Indian types.

### 1.2.2 CULTIVARS

Chandler (1957) stated that more than 700 cultivars or hybrids had been tested in the United States alone in the 50 years of preceding research. This was largely due to the early stage of development of the avocado industry at the time, and very few of these cultivars showed any commercial promise.

Of the useful cultivars, 'Duke 7' is of pure Mexican origin and used mainly as a rootstock. 'Fuerte', 'Hass', 'Puebla', 'Zutano', 'Bacon' and 'Pinkerton' are considered hybrids between the Mexican and Guatemalan races (Storey *et al.*, 1986), whilst 'Nabal' and 'Rinton' are pure Guatemalan cultivars (Chandler, 1957). Some of the most commercially successful cultivars in Florida are Guatemalan-West Indian hybrids such as 'Booth 7', 'Booth 8' and 'Lula' (Storey *et al.*, 1986). Mexican-West Indian hybrids have been produced, but none have become

commercially important. In general, cultivars of Californian origin (“subtropical” as opposed to “tropical” cultivars) have dominated the avocado industry. ‘Fuerte’ was the first important cultivar developed and used as a benchmark of excellence amongst the “first generation” cultivars. Although still popular in South Africa, ‘Fuerte’ lost favour in California in the 1960’s/1970’s due to poor yield in their colder climate as a result of being sensitive to cold during fruit-set (Wolstenholme, A.-pers. comm.). Subsequently, ‘Hass’ was developed as the best of the “second generation” cultivars and is still overwhelmingly dominant in the cool subtropics due to being more tolerant of cold during fruit set.

The performance of any one cultivar will therefore depend on both the genetic and climatic origin of that variety, and hence the climate in which it is grown.

### **1.2.3 CLIMATIC FACTORS**

#### **1.2.3.1 Temperature**

Temperature is one of the major climatic factors affecting the growth dynamics of the avocado. Apart from actual frost damage, air temperatures of less than 12°C at night can influence flowering patterns and fertilization by reducing the number of flowers with a female stage (Sedgley, 1977). Nirody (1922) observed that cooler air temperatures facilitated “self-pollination” due to a partial overlapping of the male and female phases of each flower. Air temperatures less than 18 C° also result in reduced insect activity and hence less pollination (Bergh,1967; Peterson, 1955) and have been shown to promote root growth and dry matter accumulation, with the opposite being true at air temperatures greater than 18 C°(Lahav and Trochoulis, 1982). Root-zone temperatures above 30°C are thought to be damaging to roots, which has led to practices such as mulching and cover cropping to help reduce soil temperature-related stress (Whitmore, 1986). The effect of reduced root growth and low dry matter accumulation at high air temperatures would in turn affect the rate at which water and nutrients are taken up by the tree. This has a cascading effect on various physiological processes within the tree giving rise to occurrences such as abnormal flowering and pollination, as well as pronounced fruit drop.

The type and magnitude of response to an air temperature regime will depend largely on the tree's age, physiological state, crop size, nutrition and stress status.

#### **1.2.3.2 Rainfall and humidity**

Relatively little is known about the avocado's climatic requirements as far as rainfall and humidity are concerned. It has, however, been observed that excess water may reduce yield and fruit quality (Bower and Cutting, 1987) due to reduced root zone oxygen content (Stolzy *et al.*, 1971) and promotion of the *Pc* root rot fungus (Zentmyer, 1984). Water stress on the other hand can also occur quite easily and is particularly disadvantageous during and after fruit set (Cutting, 1984), causing fruit shedding and wilted leaves. High humidity during and after fruit set is known to be beneficial if excess fruit drop is to be minimized (Bower and Cutting, 1988).

From this brief overview it is apparent that not only have environmental factors had a great deal to do with the evolution of the avocado tree to its present form, but they have such a dramatic bearing on the tree's growth habits from day-to-day that processes as integral as pollination and fruit set are affected.

### **1.3 PLANT GROWTH FACTORS**

#### **1.3.1 WATER UPTAKE**

Water is generally considered the most important limiting factor to plant growth (Syvertsen, 1985; Smith and Griffiths, 1993). It plays a vital role in so many processes both outside and within any plant, that it is necessary to discuss its use as a manipulative tool.

Water must be transported to the leaves every day to ensure that transpirational and nutrient losses are replenished. In order for this transport to take place, the leaf water potential must always be lower than the soil water potential. In addition, plant enlargement occurs almost entirely as a function of increased cellular water content. The process of enlargement seems to depend on the simultaneous uptake of water, cell wall extension, and solute accumulation

(Boyer, 1985). As water moves through the soil it dissolves mineral elements and many other substances, and upon entering the roots carries many of these solutes across the cell membranes, so allowing for a mechanism of nutrient transport to and into the roots (Aung, 1974). Once inside the roots, water with its dissolved solutes and plant growth substances moves via the xylem vessels to the aerial parts of the plant, where they are used in a number of assimilatory processes.

Maintaining the optimal plant water status in the avocado is vital if the negative effects of water stress on productivity and fruit size are to be minimized (Whiley *et al.*, 1988). Water stress during critical stages of fruit development results in an increase of the occurrence of pedicel ring-neck (Whiley *et al.*, 1986). Pedicel ring-neck has in turn been associated with premature seed coat senescence (Whiley *et al.*, 1986) which is a common trait among undersized fruit. According to Schroeder and Wieland (1956) avocado fruit can also act as water reservoirs under conditions of water deficit, and so leaves requiring water for growth may draw on fruit for their requirements. Avocado leaves therefore exert a priority over fruit for water, which will impact on fruit growth and final size (Wolstenholme, 1986).

Passioura (1988) cited Brouwer (1954) as showing that the most rapid water entry point into a root is the area just behind the zone of elongation. This is thought to be due to the presence of newly matured xylem vessels and not yet cuticularized root surface tissues (Hansen, 1974). Therefore, if sufficient water and nutrient uptake is to occur at peak demand periods, the larger the proportion of healthy white avocado feeder roots present in the root mass, the better. According to Passioura (1988), low air temperatures, anoxia, nutrient deficiency and dehydration all markedly decrease the permeability of roots to water.

### **1.3.2 ASSIMILATE PARTITIONING**

The improvement of yield potential in crops has in the past been achieved largely from an increase in assimilate partitioning into the harvested organs rather than from a higher carbon assimilation efficiency (Gifford and Evans, 1981). There is also general consensus that yield improvements will primarily come from the selection for improved resource allocation to the fruit, rather than from improved photosynthetic efficiency (Patrick and Wareing, 1981;

Stephenson , 1981; Geiger and Giaquinta, 1982; Loomis, 1983; Gifford *et al.*, 1984; Cannell, 1985; Daie, 1985; Wolstenholme, 1986; 1990). Although this has mostly been achieved through selection by plant breeders for larger fruit (Cook and Evans, 1983) or more harvestable fruit under progressively improved systems of agricultural input (Daie, 1985), further increases in this manner may become more difficult. It is for this reason that an understanding of the factors which control assimilate partitioning can be useful in defining new approaches to improving fruit size.

#### **1.3.2.1 Source : Sink Relationships**

Assimilate partitioning is the result of a co-ordinated set of transport and metabolic processes which govern the flow of assimilate from sites of production (sources), overwhelmingly the leaves, to sites of utilization (sinks) such as fruit and all growing tissues (Raven *et al.*, 1986; Salisbury and Ross, 1978; Patrick, 1988). Avocado fruit growth and development is dependent on several interrelated processes (Bower and Cutting, 1988; Moore-Gordon, 1995) such as:

- 1) The number of cell divisions during the early stages of fruit development, which contribute to sink strength;
- 2) The development and maintenance of vascular tissues for the translocation of source derived assimilates;
- 3) An adequate supply of the 'building blocks' of the fruit, such as water, nutrients and photo-assimilate;
- 4) Plant growth regulators.

According to Whiley and Schaffer (1994) avocado leaves are known to pass through a period as metabolite 'sinks' while developing, and go through a transition to primary photo-assimilate sources when they reach one third to half their final size. Although the leaves are the primary sources of photo-assimilate, other parts of the plant such as green stems, floral organs (Evans and Rawson, 1970; Ong *et al.*, 1978) and even young, green fruit can sometimes make substantial contributions (Blanke and Whiley, 1995) to carbon fixation. 'Sinks' on the other hand, are the regions of meristematic growth or storage, and utilize translocated carbon (Blanke and Whiley, 1995). Patrick (1988) noted that these assimilates are mainly



carbohydrates such as sucrose, sorbitol, stachyose or raffinose and according to Wolstenholme (1990), also includes perseitol in the case of the avocado.

### 1.3.2.2 Carbohydrates

Turner (1986) proposed that the carbon balance of a tree is made up of two components:

- 1) The net production of carbohydrates by photosynthesis;
- 2) The partitioning of the produced carbohydrates to the parts of the tree where they are needed.

Cull (1989) proposed that carbohydrates may be the key to the understanding and management of tree crops. According to Finazzo and Davenport (1987) the carbohydrate content of the plant has often been correlated with early fruit development and so also overall eventual yield. Carbohydrates are therefore important for a number of reasons. They:

- a) are important structural compounds (Raven *et al.*, 1986; Wolstenholme and Whiley, 1989, 1997);
- b) act as the chief energy source and therefore the major substrates for respiration (Raven *et al.*, 1976; Oliveira and Priestley, 1989; Janse van Vuuren *et al.*, 1997; Wolstenholme and Whiley, 1989, 1997);
- c) are the primary photosynthetic products and so are the basic pre-cursors for proteins, lipids and other compounds such as plant growth regulators (Oliviera and Priestley, 1989; Janse van Vuuren *et al.*, 1997).

Carbohydrates, proteins and lipids collectively make up over 90% of the dry mass of plants, with carbohydrates constituting over 65% of the dry mass of tree crops (Wolstenholme and Whiley, 1989; Wolstenholme 1990). In addition, stored carbohydrates are comprised of a soluble and an insoluble fraction (Gifford *et al.*, 1984; Daie, 1985; Patrick, 1988; Oliveira and Priestley, 1989). Soluble carbohydrates such as sugars (eg. glucose and sucrose) are mobile in solution and are able to be transported to sinks and used immediately upon demand (Cull, 1989). Insoluble carbohydrates, such as starch and cellulose, first have to be broken down to a soluble state before they can be transported and used in any assimilatory functions. Plants are thus able to store carbohydrates in an insoluble form if there is an excess supply over and above the tree's immediate needs (Wolstenholme and Whiley, 1989; Whiley, 1994). Scholefield

*et al.* (1985) noted that in avocado trees in temperate southern Australia, sugars were seen to vary less than starch throughout the year, indicating that sugars were not the major storage carbohydrate, but rather formed a 'pool' of carbohydrates available for immediate use within the tree. This 'pool' of carbohydrates is maintained at a fairly consistent level through starch storage and assimilation, resulting in the greater observed variations in starch content compared to soluble sugars.

Whiley *et al.* (1988) report that the total carbohydrate content of tree crops reflects definite seasonal rhythms, indicating that changes in seasonal growth events have the effect of either drawing on, or supplementing the carbohydrate levels within the tree. The accumulation of storage carbohydrates begins roughly at the end of the vegetative growth phase in autumn and continues through winter to reach a peak at the beginning of spring (Scholefield *et al.*, 1985; Whiley and Wolstenholme, 1990; Whiley *et al.*, 1996a). The accumulated carbohydrate levels decrease from spring to autumn as aerial and root vegetative flushes draw on the reserves, with the largest decrease occurring during flowering, shoot growth and fruit development (Scholefield *et al.*, 1985; Wolstenholme and Whiley, 1989; Janse van Vuuren *et al.*, 1997). According to Scholefield *et al.* (1985) alternate bearing of the avocado in temperate southern Australia appears to be closely related to the storage carbohydrate levels in the tree, since it has been observed that high yields follow a high starch accumulation during the previous winter and result in low levels of starch and so also low yields, the following year.

Whiley *et al.* (1996b) state that this is however a stress response, with avocado trees growing in less stressful environments not exhibiting as much carbohydrate storage as those growing in stressful environments.

It is therefore evident that carbohydrates are in one way or another linked to every process within the avocado tree, and that the management of the carbohydrate levels from season to season will undoubtedly pay dividends in consistent tree vigour and yields.

### 1.3.3 ROOT : SHOOT RATIO

In the whole plant economy, specialized organs such as roots and shoots are in constant competition for available energy, minerals and nutrients to further their growth and development (Aung, 1974). The avocado is no exception to this, and performing a measurement of the differential growth of the two organs allows for a comparison of the observed growth pattern in terms of a root : shoot ratio. This then conveniently provides an index for evaluating the performance of each organ in a certain growth environment (Aung, 1974; Reynolds and Thornley, 1982).

Several models for root : shoot assimilate partitioning have been proposed:

- a) the “whole plant” model (Davidson, 1969);
- b) the transport-resistance based model (Thornley, 1972a; b);
- c) the resistance-utilization model (Thornley, 1977);
- d) the substrate level partitioning or storage pool model (Reynolds and Thornley, 1982);
- e) the stress control model (Hunt and Nicholls, 1986).

According to Thornley (1977), any organ has the potential to function either as a source or a sink. The source-sink status of that organ at a given time will depend upon its physiological stage of development, internal composition and environmental stress status. In accordance with this, the underlying principle of all these models is one of the tree attempting to overcome the most growth limiting factor by partitioning assimilates and resources to the limited region.

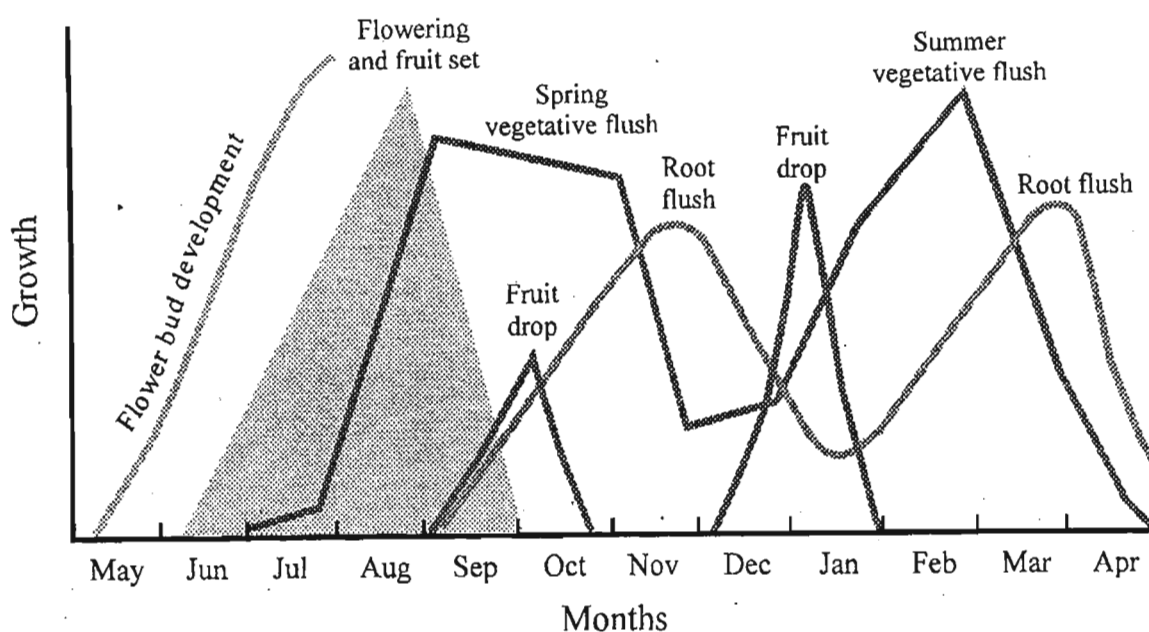
If the root : shoot ratio assimilate partitioning is coupled to the fact that reproductive structures such as fruit are also strong sinks for carbohydrates (Cannell, 1971; 1985; Kozlowski *et al.*, 1991), it becomes evident that maintaining vigour through a balanced growth of both the roots and shoots as well as obtaining consistent yields year after year becomes a delicate matter of well timed management decisions. In order to make these well timed management decisions, a clear understanding of the pheno/physiological cycling patterns within an orchard in a specific area are vital.

## 1.4 PHENO/PHYSIOLOGICAL CYCLING

Phenology has been defined as the relationship between climate (the environment) and periodic biological phenomena (Wolstenholme and Whiley, 1989). As stated already, environmental factors have a dramatic impact on plant growth and dictate seasonal changes or developmental growth phases (phenophases) within genetically determined limits (Whiley, 1994). These phenophases include events such as root and shoot growth flushes, flower initiation and maturation, fruit-set, fruit growth and maturation and fruit and leaf-drop. If these phenophases are recorded on a time scale such as a calendar year and in relation to meteorological data (Whiley *et al.*, 1988) a tangible visual conceptualization of growth events throughout the year is possible (Whiley *et al.*, 1988; Wolstenholme and Whiley, 1992), and called a phenological growth model. The incorporation of physiological data such as leaf/bark starch concentrations, leaf nutrient analyses, gaseous exchange patterns and chlorophyll concentrations/activity to this model further refines it into a pheno/physiological growth model (Whiley, 1994).

The value of such a model is that it becomes easy to conceptualise the cyclical seasonal patterns of the avocado, which are repeated every year, though not necessarily on the same time scale or with the same intensity of growth for each stage. Upon recognising a phenological event orchard manager and scientist alike are therefore equipped with a means of knowing what pheno/physiological events have already taken place, and what is still to come. Orchard managers can come to recognize and understand critical growth changes and are then better equipped to make well timed management decisions to maximize tree productivity (Wolstenholme and Whiley, 1989).

The basic phenological growth model (Fig. 1.1) is two dimensional, integrating a time scale ( $x$ -axis) in months, with the magnitude of response ( $y$ -axis) as growth. It illustrates the sequence of growth events over a full fruiting cycle. Growth events may take place earlier or later from year to year due to changes in growing conditions, but they will usually (not under extreme environments) follow the same sequence, thereby allowing the model to be a useful management strategy tool for growers in diverse regions. Phenological events therefore simply shift left or right along the  $x$ -axis in response to warmer or cooler climates (Whiley *et al.*, 1988; Whiley, 1994).



**Fig. 1.1 Phenological growth model of 'Fuerte' avocado growing in a warm, sub-tropical climate at Nambour, S.E. Queensland (after Whiley, 1994).**

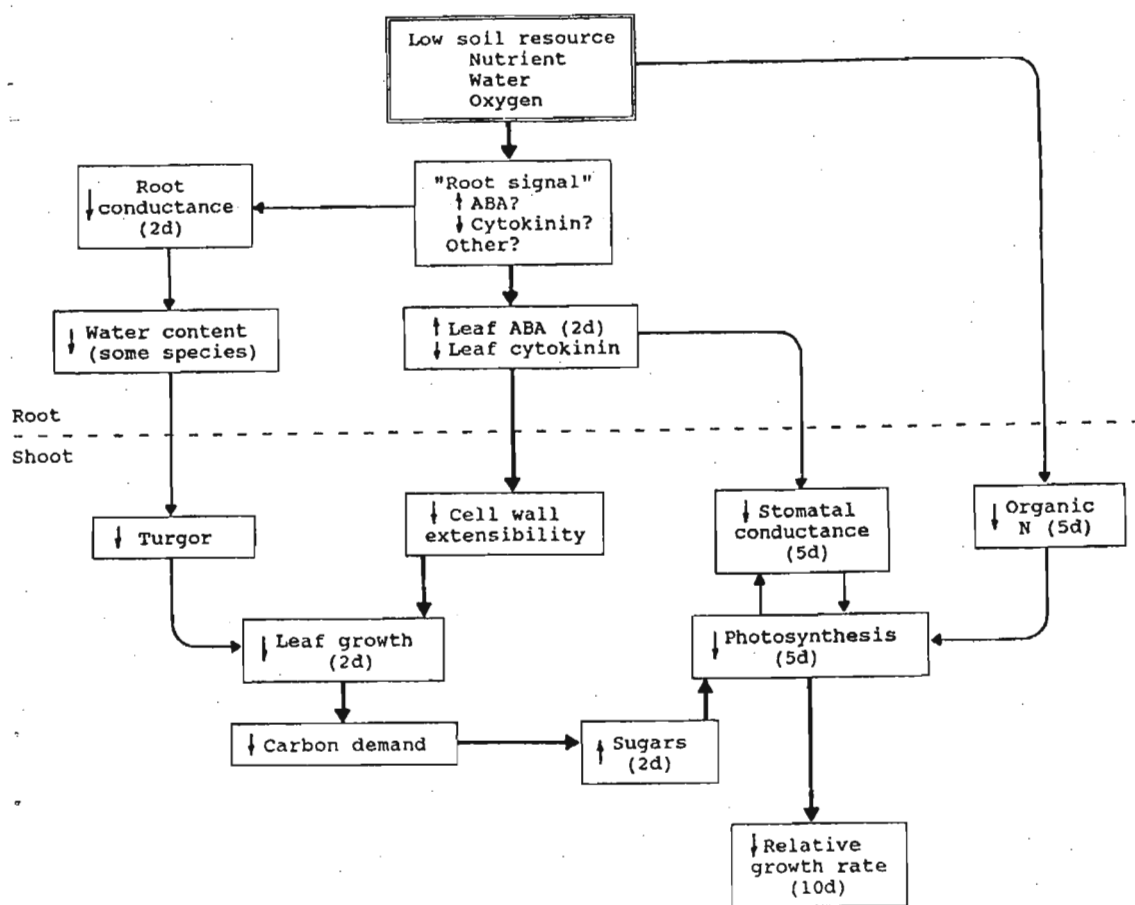
## 1.5 PLANT STRESS FACTORS

Plants such as the avocado are seldom situated in an optimal environment for peak physiological functioning and growth, due to continual fluctuations in environmental factors such as solar irradiance, soil water content, air temperature, relative humidity and soil nutrients. In addition, there are a multitude of other factors such as different soil types with differing properties of nutrient and soil water availability, and a great many pests and pathogens which all impact on plant growth. The plant is therefore continuously encountering new combinations of environmental, physical and biological stress. Seasonal environmental changes and other biotic and abiotic factors will either induce or release stress, which will impact on the physiology of the tree (Whiley *et al.*, 1996b) and so ultimately on its phenological state and performance.

According to Chapin (1991) there are two lines of research which suggest that plants have a centralized system of stress response which enables them to react to any physiological stress,

regardless of nature. First, ecologists have noted common traits among all plants situated in resource impoverished environments (e.g. deserts, tundra, shaded understorey, and infertile soils). These plants commonly have a low photosynthetic rate, a low capacity for nutrient uptake and exhibit a slow growth rate (Chapin, 1980; Grime, 1977; Parsons, 1968). Secondly, physiologists have observed that plants respond to environmental stress by changing their plant growth regulator balance, often by producing more ABA and less CK (Chapin *et al.*, 1988). It is thought that these changes are the trigger that directly elicits reduced growth in response to environmental stress (Chapin, 1991). It has therefore been proposed that there is a complex physiological framework that regulates plant growth in response to environmental stress, and that this framework involves changes in plant growth regulator balance, water relations, carbon balance, and nutrient utilisation (Chapin, 1991).

Chapin (1991) has proposed a mechanism (Fig. 1.2) by which a given stress (in this case lack of nitrogen (N)) results in reduced growth. This mechanism operates as follows: a low soil resource such as water, nutrient or oxygen, triggers a change in the plant growth regulator balance by increasing root ABA and so also ultimately leaf ABA levels and/or decreasing cytokinin transport from the roots to the leaves (Blackman and Davies, 1985). The increase in leaf ABA results in reduced cell wall extensibility, eventually causing a decline in leaf elongation and growth. Alternatively in some plants, the higher ABA concentration in the roots may cause a lower root hydraulic conductance, reduced turgor and in so doing reduce leaf growth. Regardless of which mechanism is used, the reduced leaf growth then impacts on the carbohydrate accumulation within the plant by causing a lower demand by the plant for carbon, so allowing for carbohydrates to accumulate. Photosynthesis then declines to match the lower carbohydrate requirement of the plant. This probably occurs through an ABA induced decline in stomatal conductance (Schulze, 1986) and a decline in the concentrations of photosynthetic enzymes (Evans, 1989). The important point is that the decline in leaf elongation and carbon requirement probably leads to the decline in photosynthesis, and not the other way around.



**Fig. 1.2 A simplistic view of the proposed cause-and-effect network linking a limited resource (in this case N) with slow growth (Chapin, 1991).**

The rapid effects of stress on leaf enlargement through this hormonal trigger mechanism may therefore serve as an early warning system that allows the plant to reduce growth and change patterns of carbohydrate allocation before a severe imbalance between carbon and the limited metabolite occurs. By maintaining this balance between carbon and the limited metabolite, plants are able to minimize the cost of growth (Bloom *et al.*, 1985). It is possible that this may be the mechanism by which plants reduce their rate of acquisition of other non-limiting resources to maintain an internal balance of metabolites i.e. to minimize the cost of growth by keeping all resources equally limiting. If this is the case, it is likely that a large proportion of inputs in the form of fertilizers, water and pest control are being unnecessarily applied or going to waste due to a limiting factor (e.g. N) resulting in the plant limiting its uptake of other nutrients in its endeavours to keep all resources equally limiting.

A combination of changed endogenous factors, rather than a single factor are therefore likely to bring about the reduced growth of plants in response to stress, with the trigger being hormonal in the form of ABA. Any stress factor (e.g. low water availability, low nutrient availability, a phytopathogen) will therefore simply activate this stress response system ultimately causing a reduction in leaf growth and photosynthesis and a lower nutrient uptake rate, resulting in an overall slowing in plant growth. It is possible that this is then often interpreted in the field as a lack of vigour (reduced leaf and shoot growth) and ultimately results in a dramatically reduced yield and/or many small fruit being borne by the tree due to the now limited resources being allocated toward reproductive growth.

### **1.5.1 THE ROLE OF POTASSIUM IN PLANTS**

As a plant macronutrient, K is accumulated in plant cells from relatively dilute soil solutions and is indispensable for many vital processes (Maathuis and Sanders, 1996). Its uptake in plants is highly selective and closely coupled to metabolic activity, whilst K availability in soils is variable, depending on soil pH, moisture and chemical composition (Mengel and Kirkby, 1982).

It forms the principle inorganic constituent of the cytosol and acts as the dominant counterion for the large excess of negative charge on proteins and nucleic acids (Maathuis and Sanders, 1996). In doing so, K is involved in cell extension and other turgor-driven osmoregulatory processes, which are related to vacuolar  $K^+$  concentration (Marschner, 1986). This is primarily achieved through  $K^+$  inward and outward fluxes at a cellular level, which create an osmotic potential that causes cell extension or reduction, resulting in the movement of plant cells and organs such as the opening and closing stomata through guard cell turgor changes (Raschke, 1975; MacRobbie, 1987) and the movement of leaves in nyctinastic plants (Satter and Galston, 1981). The extent to which sugars and other low-molecular-weight organic solutes contribute to the osmotic potential and turgor-driven cell expansion therefore depends, in one way or another on the K nutritional status of the plant.

In addition, a large number of enzymes are either completely dependant on or stimulated by  $K^+$ , and are therefore activated by  $K^+$  induced conformational changes in the enzyme protein (Leigh and Wyn Jones, 1984). This is made possible through the relatively low charge : mass



ratio of  $K^+$ , resulting in a small hydration shell and therefore a low tendency to order water, making the ion very compatible with the conformational integrity of proteins when present at high concentrations (Franks and Eagland, 1975). Such enzyme activation systems can result in some gross chemical changes occurring under K-deficient circumstances, including the accumulation of soluble carbohydrates, a decrease in starch content, and an accumulation of soluble nitrogen compounds (Marschner, 1986).

Another function of  $K^+$  is the activation of membrane-bound proton-pumping ATPases, which facilitate the transport of  $K^+$  from the external solution across the plasma membrane into root cells, thereby making K the most important mineral element in cell extension and osmoregulation (Marschner, 1986). In addition, K affects plant photosynthesis at various levels through acting as the dominant counterion to the light-induced  $H^+$  flux across the thylakoid membranes and for the establishment of transmembrane pH gradient necessary for the synthesis of ATP (Tester, 1990). This counterflow is impaired under drought stress conditions, during which time dehydration isolated chloroplasts lose large amounts of their  $K^+$ , causing a decrease in photosynthesis. This decrease can however be overcome by high concentrations of extrachloroplastic  $K^+$  (Marschner, 1986). Furthermore, K fulfills important functions in both sucrose loading, and in the rate of mass-flow-driven solute transport in the sieve tubes, and thus the transport rates of photosynthates from source to sink (Marschner, 1986).

Second to N, K is the mineral nutrient required in the largest amounts by plants, and a deficiency thereof results in retarded plant growth, loss of turgor and wilting under conditions of limited soil water supply. Furthermore, plants receiving an inadequate supply of K are often more susceptible to frost damage and fungal attack (Marschner, 1986), whilst an increase in the rate of K fertilization has been shown to result in a slight decrease in fruit drop in 'Hass' avocado following frosts (Lahav and Kadman, 1980).

## 1.6 ROOT ROT

Avocado root rot was reported as early as 1929 by Tucker in Puerto Rico (Labanauskas *et al.*, 1976) and has since then proven to be the primary constraint to avocado production in most areas in which this fruit tree is grown (Zentmyer, 1980; Ploetz and Schaffer, 1989). The disease is caused by the fungus *Pc* which attacks the fine white feeder roots and causes their decay (Whiley *et al.*, 1987), resulting in the tree rapidly becoming water and nutrient stressed (Sterne *et al.*, 1978; Whiley *et al.*, 1986). Ultimately trees may wilt, defoliate and eventually die if conditions favouring infection are not ameliorated.

Although the prevalence and severity of root rot has resulted in widespread losses of avocado trees throughout the world, the disease is conspicuous to many areas (e.g. Florida) only during periods of flooding, hurricanes and tropical storms, which are responsible for periodic heavy rains (Ploetz and Schaffer, 1989). The primary reason for this is that soils with poor internal drainage provide the fungus with a favourable environment for its development, and reduce oxygen diffusion from the atmosphere to the roots by up to 10 000 times (Labanauskas *et al.*, 1976). It has been found that *Pc* requires free water to form sporangia and zoospores, and to allow for spore mobility and infection to take place (Zentmyer, 1955). Nevertheless, Pegg (1976) found it difficult to isolate *Pc* from undisturbed rainforests on red basaltic soils in Australia. This was found to be the case even if the rainforests were situated adjacent to *Pc* devastated avocado plantations, thereby suggesting that either the fungus cannot invade this very stable ecosystem, or that it establishes itself and soon disappears due to the suppressive nature of the soils or the ecosystem as a whole.

Pegg (1976) also found minimal losses through root rot to occur in some orchards where *Pc* was easily recoverable from beneath very healthy trees. He listed the characteristics of these soils as follows:

- 1) high soil organic levels (>2%) and therefore a high cation exchange capacity and high base saturation;
- 2) high calcium levels;
- 3) high nitrogen levels, with most nitrogen tied up in old organic residues;
- 4) pH (H<sub>2</sub>O) 6-7;
- 5) low bulk densities and a wide range of available moisture, so that the trees were rarely under transpirational stress;
- 6) soil extracts cause massive breakdown of the fungus.

Broadbent and Baker (1974) reported that in a *Pc* suppressive orchard at Tamborine Mt., Queensland, higher populations of bacteria and actinomycetes were present in the soil than was the case for root rot conducive soils. Furthermore, the exchangeable calcium, magnesium, nitrogen and organic matter content was also higher than in root rot conducive soils.

It is important to note that in both the suppressive rainforest ecosystem and the infected soils with healthy trees, organic matter and the resultant ecosystem it forms would seem to be the key common component resulting in either the total absence of, or the suppression of *Pc*. Cultural practices that enhance the soil organic matter content would therefore seem to be beneficial in the reduction of root losses through *Pc* root rot.

## **1.7 CULTURAL PRACTICES IN AVOCADO GROWING**

A multitude of different orchard soil management systems have been proposed and used in different parts of the world for a great many crops. These include cultivation, zero tillage with the use of herbicides, mulching and cover cropping. In choosing a soil management system, it has to be borne in mind that it affects tree growth by changing the dynamics of the various components of the orchard environment, such as soil physical properties, moisture and nutrient availability, pest and disease prevalence, and the abundance of soil flora and fauna (Haynes,

1980). Ultimately, however, an orchard manager adopts a particular soil management practice for two principal reasons:

- 1) to facilitate day to day orchard operations ;
- 2) to enhance the growth and productivity of the tree crop.

Mulching is one such system that has been well documented to increase the growth, vigour and yield of fruit trees (Jacks *et al.*, 1955; Cockroft, 1966; Childers, 1973), and has come to be widely accepted as a standard practice in most situations where avocado is grown commercially.

### **1.7.1 MULCHING AND NUTRITION**

A mulch may be defined as any layer of plant or other suitable material that is applied to the soil, without incorporation into the soil (Turney and Menge, 1994; Wolstenholme *et al.*, 1996). A diverse number of materials can therefore be used, including: manure, sludge, saw-dust, wood chips, straw, shredded prunings, plant foliage, filterpress/filtercake, paper, plastic, sand, and gravel. Mulching benefits the soil and orchard floor in various ways, but mostly by improving soil physical properties through an increased organic matter content where organic mulches are used (Turney and Menge, 1994).

#### **1.7.1.1 *Benefits of Mulching***

##### **1) Increased Organic Matter Content**

In undisturbed soils the organic matter content (organic N and C) is highest near the soil surface and declines steadily down the soil profile (Haynes, 1980). Soils that are cultivated freely over a number of years invariably contain a considerably smaller percentage of organic matter than soils subjected to minimum tillage or left with a cover crop or mulch covering the soil surface (Allison, 1973). Soils covered with organic mulches therefore retain and increase their organic matter content much better than do cultivated soils. These high levels of soil organic matter content are particularly important in relation to soil structure, porosity and mineral nutrition (Haynes, 1980; Turney and Menge, 1994).

## **2) Improved Soil Structure**

In their natural condition, soils are made up of individual primary particles that are aggregated into secondary particles (clods, crumbs or peds) in a specific structural pattern (Haynes, 1980). The size distribution of peds plus the size distribution of the pore spaces both within and between the peds determines soil structure and so also its porosity (Baver *et al.*, 1972). Turney and Menge (1994) note that organic matter additions to the soil improve soil structure and porosity by causing fine clay particles to aggregate into these larger granules or peds. Soils composed of these more stable aggregates allow for far greater gaseous exchange of O<sub>2</sub> and CO<sub>2</sub> to take place between the soil and the atmosphere through improved porosity. In addition, soil structure impacts on many other processes such as soil infiltration and evaporation rates, soil water holding capacity and so also plant water availability.

## **3) Water Conservation**

Mulching affects various soil hydrological properties and processes. These include:

- a) reduced evaporation from the soil;
- b) reduced run-off and erosion;
- c) increased permeability of the soil surface to air and water;
- d) increased soil water holding capacity.

Organic mulches influence the soil physical properties in two major ways. The first is the effect on air and water transmission properties, including the infiltration rate and the second is the capacity of the soil to hold moisture in the profile (water holding capacity) for plant water uptake. Organic matter from mulching increases the number of macropores (0.5 to 50  $\mu\text{m}$ ) and so also infiltration rate in heavy clay soils which are composed predominantly of micropores, whilst improving the water holding capacity of sandy soils (Gallardo-Laro and Nogales, 1987; Turney and Menge, 1994). In addition, bare soils may easily become unstable through aggregate breakdown resulting in “crusts” forming on the unprotected surface. This decreases the infiltration rate of the soil, causing high runoff and a greater risk of erosion on sloping land (Tisdall, 1989). Mulching helps prevent or reduces the occurrence of this phenomenon.

Gregoriou and Raj Kumar (1984) found mulching avocado (‘Pollock’) and mango (‘Julie’) with weathered coffee hulls significantly ( $P < 0.001$ ) increased the soil water content throughout the

dry season in Trinidad. Robinson (1993) similarly reported that a thick banana trash mulch in banana orchards at Levubu (South Africa) maintained a water content equal to field capacity after 24 mm of cumulative evaporation from the last irrigation, and sustained only a 7 mm loss after 44 mm of cumulative evaporation. This was in comparison to the 16% and 54% respective depletion in available water in the bare soil rows, indicating that mulching significantly reduced evaporative water losses in bananas ('Williams'). This is particularly pertinent to water stress in 'Hass' avocado, as studies by Lahav and Kalmer (1977) on irrigation regimes in Israel showed a 50% reduction in yields of trees irrigated at 21-day and 28-day intervals as opposed to trees irrigated at 7-day and 14-day intervals. In addition, Tisdall (1978) found the infiltration rate of a mulched soil to be 80 times higher than the unmulched control. Earthworm activity has also been noted to be as much as 14 times greater in mulched soil, creating a macroporosity 14% higher than the unmulched control (Tisdall, 1978).

#### **4) Reduced Aggregate Breakdown**

Mulching prevents raindrop dispersion of surface aggregates, reducing crusting and compaction of the soil surface. A thick layer of mulch also reduces soil compaction due to mechanical and/or human activities such as spraying, harvesting and orchard traffic (Turney and Menge, 1994).

#### **5) Enhanced Weed Control**

Mulching can control weed growth effectively, thereby reducing herbicide usage. The germination of many annual weed species can be prevented by the application of a composted mulch to bare soil surfaces (Turney and Menge, 1994). In a crop free mulching trial in North Carolina Skroch *et al.* (1992) found organic mulches significantly ( $p < 0.01$ ) reduced total weed counts by 50% compared to control plots. Similarly, Gregoriou and Raj Kumar (1984) found mulching to significantly ( $p < 0.001$ ) reduce weed scores at all recorded dates in their avocado and mango trial in Trinidad. Assuming a weed free mulch is used, weed control can therefore be aided through mulching resulting in reduced herbicide use and, depending on mulch cost, lower production costs.

## 6) Improved Mineral Nutrition

Organic matter acts as a nutrient store, allowing for the slow release of nitrogen and other elements that are often very mobile and easily leached from the soil. This can in turn eliminate or reduce ground water nitrate contamination and reduce the amount of nitrogen and other chemical fertilizers that need to be applied (Turney and Menge, 1994).

High levels of organic matter in soils also help in maintaining a higher soil fertility status through the actual mineralization of the organic matter being used as a mulch. Organic matter decomposition is often measured by the mineralization of nitrogenous compounds to the simpler mobile inorganic N forms such as  $\text{NH}_4^+$  and  $\text{NO}_3^-$  (Haynes, 1980). These more mobile forms of N are easily lost from soils low in organic matter through leaching, gaseous volatilization and chemo- and biological denitrification. Mineralization tends to occur rapidly under favourable biological environmental conditions (Campbell, 1978; Haynes and Goh, 1978) such as those found in hot, moist, well aerated soils. Orchard soil management practices such as cultivation, herbicide application or mulching which alter the soil environment also affect the rate at which mineralization takes place and, consequently, the levels of mineral N held in the soil (Stevenson and Chase, 1953; Mori and Sadamori, 1955; Ljones and Edland, 1960). According to Haynes (1980) mulching may increase or decrease available N in the soil depending on the carbon to nitrogen (C/N) ratio of the mulching material. If the mulch has a C/N ratio greater than 30 (e.g. wheat straw), immobilization of N by microflora is likely to exceed mineralization, resulting in mineral N levels in the soil decreasing. This occurs due to the mulch having insufficient N to supply the increased populations of soil micro-organisms needed to decompose its carbon structure (Wolstenholme *et al.*, 1996). This period where immobilization exceeds mineralization has been referred to by Handreck and Black (1994) as the N “draw-down” or “negative” period during composting and can be overcome by extra N fertilization. This “draw-down” period is usually absent if the C/N ratio of the mulch is less than 30 (e.g. succulent vegetation), whilst ideal mulch materials such as humus usually have a C/N ratio of approximately 10:1 (Wolstenholme *et al.*, 1996).

Stevenson and Chase (1953) compared the effect of mulch, grass sod and clean cultivation on the microbial activity of soil in a peach orchard and found a higher level of microbial activity and greater mineralization under mulch than under sod or clean cultivation. According to

Wolstenholme *et al.* (1996) the elements phosphorus (P), calcium (Ca) and boron (B) are especially important for healthy and prolific plant root growth. Stephenson and Schuster (1945) reported marked increases in the soluble states of these three elements in addition to N, K and magnesium (Mg) under a mulch. Similarly, Weeks *et al.* (1950) found mulched plots to maintain a reserve of N for a period of nine years after mulch discontinuation and found P levels to be eight times higher in mulched than unmulched plots. Whiley *et al.* (1996b) proposed better B uptake in mulched B deficient soils as a potential reason for the increased 'Hass' fruit size found by Moore-Gordon *et al.* (1995) and Moore-Gordon and Wolstenholme (1996). Wolstenholme *et al.* (1996) further reported that composted mulches, such as pinebark, are good sources of *inter alia* K and B, and cite Gupta (1979) as finding that most of the B in acid leached soils is tied up in organic matter, from where it is gradually released for plant uptake through the action of microorganisms.

The leaching of exchangeable bases, such as Ca and Mg, from upper soil layers may cause a reduction in surface soil pH (Haynes, 1980) and result in a lower nutrient availability to plant roots. Mulch-derived organic matter adsorbs many of these elements thereby dramatically reducing leaching, whilst increasing the cation exchange capacity of soil (Turney and Menge, 1994) and so also the availability of many nutrients to plant roots (Lanini *et al.*, 1988). Furthermore, a higher organic matter content both in terms of the mulch and incorporated organic matter has a positive effect on earthworm establishment and activity (Tisdall, 1978) as well as on microbial activity. This is important as earthworms "till" the soil and incorporate organic matter from the soil surface into the soil profile, whilst improving soil structure and porosity. In addition, laboratory incubation studies of undisturbed soil profiles by Leger and Millette (1977) showed that earthworm presence had an effect of raising the soil pH by as much as one pH unit in 100 days. The magnitude of the increase depended on the species of earthworm present and probably occurred due to the earthworm feeding habits and calcium compound secretions from their calciferous glands (Wallwork, 1970). An enhanced earthworm population may therefore be a contributing factor to maintaining a less acidic soil pH and so improve nutrient availability for plant root uptake.

Depending on the type of mulch used and its C/N ratio, mulching can therefore effectively save on fertilizer additions and cost by acting both as a nutrient store and source, resulting in greater nutrient availability over an extended period of time.



## 7) Suppressed *Phytophthora cinnamomi*

Work concerning the use of mulches and gypsum to help create a more suppressive environment to *Pc* in avocado orchards was pioneered in Australia (Broadbent and Baker, 1974; Pegg *et al.*, 1982). According to Wolstenholme *et al.* (1996) the so called “Pegg Wheel” concept of an integrated management control strategy was widely promoted in South Africa in the 1970's, before chemical control of *Pc* was available (Wolstenholme, 1977). A vital spoke on this management wheel was the use of organic mulch to increase the suppressiveness of orchard soils to *Pc*. It was, however, shown that organic amendments with gypsum additions were insufficient to prevent tree decline on shallow and/or poorly drained patches of otherwise well-drained kraznozems in very high rainfall areas of Eastern Australia (Trochoulis *et al.*, 1986). The same was found to be true for South Africa, resulting in Wolstenholme and le Roux (1974) recommending plantings of avocado only on soils with at least 1.5 - 2.0 m unimpeded drainage.

Nevertheless, avocado orchards have been found in Australia in which trees were healthy and productive, even though *Pc* was present and the climate favoured disease development (Broadbent *et al.*, 1971). The soils in which these trees were growing were termed “suppressive soils”. Pegg (1977) demonstrated that fowl manure-enriched organic mulches could be used to restore lost suppressiveness, and that some non-suppressive soils can be rendered suppressive by intensive cover cropping and the use of dolomite and fowl manure. Similarly, Duvenhage *et al.* (1993) found a yield decline within four years of stopping phosphonate injections in ‘Fuerte’ avocado trees, but that this decline was inhibited by organic matter additions in the form of mulch and cover crops. The mechanisms of root disease and nematode control by mulching have been fully discussed by Turney and Menge (1994). These include increased populations of soil microorganisms which compete with or inhibit fungal pathogens; the production of *Pc* inhibitory volatiles such as ammonia and nitrite, and toxins such as saponins and organic acids; encystment of *Pc* zoospores by organic matter; increased host resistance by induced phytoalexin production; and an improved root growth environment in terms of aeration, drainage and soil temperature not suitable for *Pc* survival.

## **8) Amelioration of Soil Temperature and Atmosphere**

Mulching reduces wide soil temperature fluctuations by reducing soil heat absorption, mainly through an improved moisture status (Turney and Menge, 1994). This results in improved root growth, especially in areas where summer temperatures are above the 18 - 28 °C optimum for growth of avocado rootstocks ('Duke 7' and 'Velvick') (Whiley *et al.*, 1990). Wooldridge (1990) found mulching with hay in ridged pear orchards in the Western Cape reduced seasonal soil temperature variation and eliminated diurnal variation relative to a vegetation free surface, whilst increasing O<sub>2</sub> and lowering CO<sub>2</sub> levels under the mulch. Similarly, Skroch *et al.* (1992) found organic mulches stabilized daily temperature fluctuations by reducing maximum temperatures by 2.2 - 3.3 °C and elevating minimum temperatures by 1.1 - 2.2 °C. Tisdall (1989) cites an extreme example of soil temperature being 24 °C under a straw mulch in comparison to 52 °C under a bare surface in a trial by Cockcroft and Hughan (1964).

## **9) Improved Shoot and Root Growth**

According to Wolstenholme *et al.* (1996) good mulches allow deeper and more extensive root growth, both in the litter layer and in the more fertile topsoil. This is evidently made possible by the improved soil structure, porosity, aeration and temperature and is beneficial to avocado roots since they have a high oxygen requirement (Stolzy *et al.*, 1971). Moore-Gordon and co-workers (1995, 1996) quantified this by finding substantially more root growth under a composted pinebark mulch. Similarly Gregoriou and Raj Kumar (1984) found a coffee hull mulch to consistently increase root and shoot growth in 'Pollock' avocado trees in both wet and dry seasons in Trinidad.

Whilst no attempt has been made to encompass all aspects of the benefits of mulching, this brief overview has shown that there are a great many advantages in the use of mulch. Nevertheless, there are of course also a few potential problems that exist.

### **1.7.1.2 Disadvantages of Mulching**

#### **1) Cost**

Depending on the type of mulch used, both the application of the mulch and the mulch itself might be costly (Turney and Menge, 1994). The eventual cost of applying a of mulch will consist of three factors *viz.* the distance it has to be transported to the orchard from the site of production; its bulk density and so the mass of mulch that has to be transported to and within the orchard; and the cost of the mulch product itself. These costs have to be balanced against the benefits of applying the mulch.

#### **2) Increased Frost Damage**

Mulches can increase the danger of potential frost damage occurring by insulating the soil from incident radiation, thereby reducing soil warming during the day (Leyden and Rohrbaugh, 1963). This effect can, however, be minimized by applying mulch only under the tree canopy and leaving the spaces between rows bare. According to Wolstenholme *et al.* (1996) this is unlikely to be a problem in South Africa since the frost hazard is low and most mulches are indeed placed only under the drip zone of the tree.

#### **3) Increased Weed Seed Presence**

Uncomposted organic mulches may contain significant amounts of weed seed which will be introduced into the orchard if the mulch has not been thoroughly composted (Turney and Menge, 1994). This can be avoided through proper composting of mulches prior to application.

#### **4) Heavy Metal Contamination**

Certain sludges and effluent products that can be used as mulches may contain contaminants, such as heavy metals, which could accumulate in fruit at concentrations that are dangerous to consumers (Galardo-Laro and Nogales, 1987). This is an avoidable situation if timely analyses are performed on mulch materials prior to application.

### **5) Nitrogen “Draw-down” Effect**

Mulches with a high C/N ratio ( $>30$ ) may have insufficient nitrogen to support the increased microorganism populations that are produced during decomposition (Turney and Menge, 1994). This can cause a short-term nitrogen deficiency or “draw-down” period during which the tree would have to be supplied additional N through extra N fertilization to meet its needs (Handreck and Black, 1994; Turney and Menge, 1994).

### **6) Upset Nutrient Balance**

According to Wolstenholme *et al.* (1996) certain mulches (especially those with a low C/N ratio) can decompose rapidly, thereby supplying significant amounts of nutrients. The danger then exists of upsetting the nutrient balance in the tree, one consequence of which could be an upset vegetative-reproductive balance (Wolstenholme and Whiley, 1990) resulting in lower yields. A careful study of leaf, soil and mulch analyses should lead to a management strategy where this situation does not arise. Nevertheless, this highlights the fact that mulches are a powerful management tool if used correctly, but can cause many problems if the wrong mulch is chosen for the wrong reason or a mulch is incorrectly applied e.g. at the wrong time. Wolstenholme *et al.* (1996) provide an extensive review concerning the correct use of mulches.

### **7) Increased Fire Hazard**

Upon drying out during dry winters, mulches create an increased risk of runaway fires in orchards (Wolstenholme *et al.*, 1996). Such fires can cause devastating damage to trees, but are easily avoidable if necessary precautions are taken in advance to thwart any such occurrence.

## **1.7.2 FILTERCAKE AS A MULCH**

Filtercake is the fine organic material that is removed during clarification of extracted sugarcane juice, and is readily available in sugarcane producing areas. It is usually used in a composted state with a C/N ratio of below 20:1 and contains 60 to 80 % moisture (Blackburn, 1984) and high amounts of nutrients (Table 3.1) such as P, Ca and Mg (Alexander, 1971). These properties make it a useful organic fertilizer, especially when applied to phosphate-deficient soils and to fields in which the topsoil has been removed or exists in a thin layer. In addition,

it may contain between 6 and 20 % vegetable wax, which has in the past been extracted for commercial use in several countries (Blackburn, 1984). Filtercake dressings have been shown to improve sugarcane yields by partially eliminating nematodes and aluminium toxicity, whilst increasing the number of beneficial microbes (Alexander, 1971).

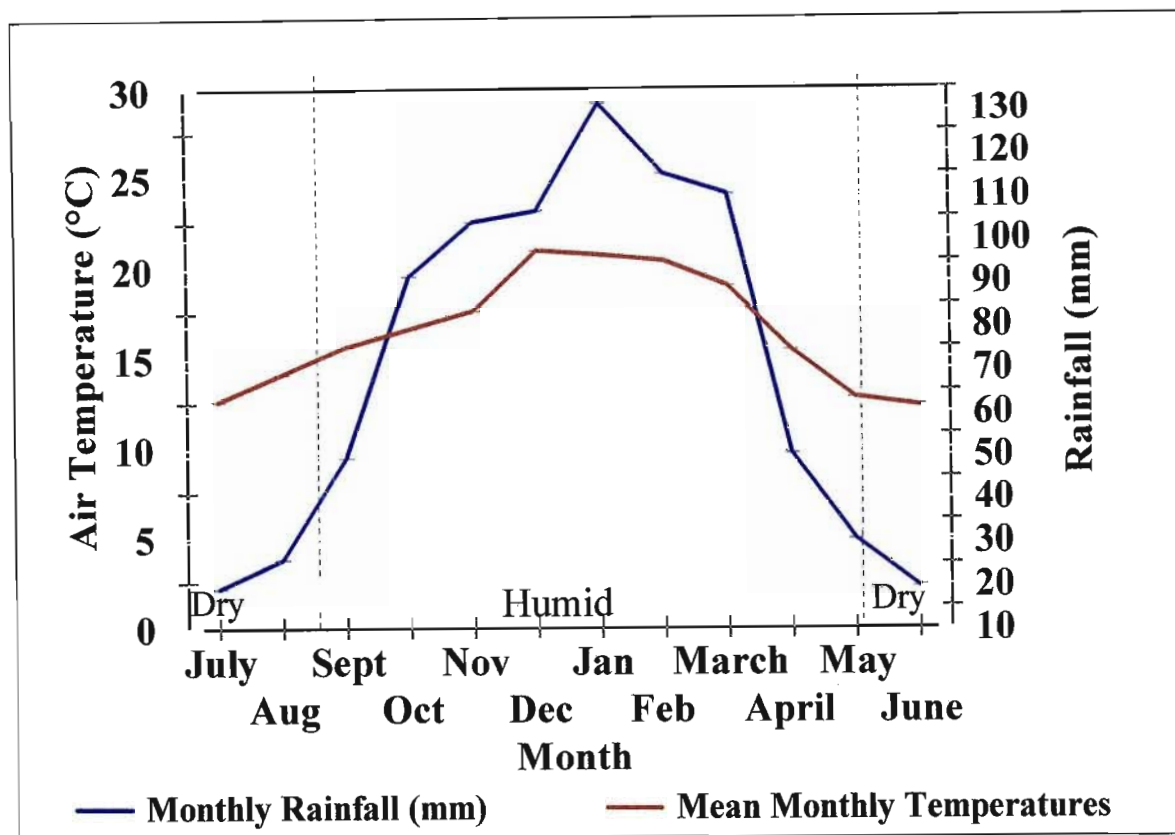
## CHAPTER 2

### MATERIALS AND METHODS

#### 2.1 STUDY SITE

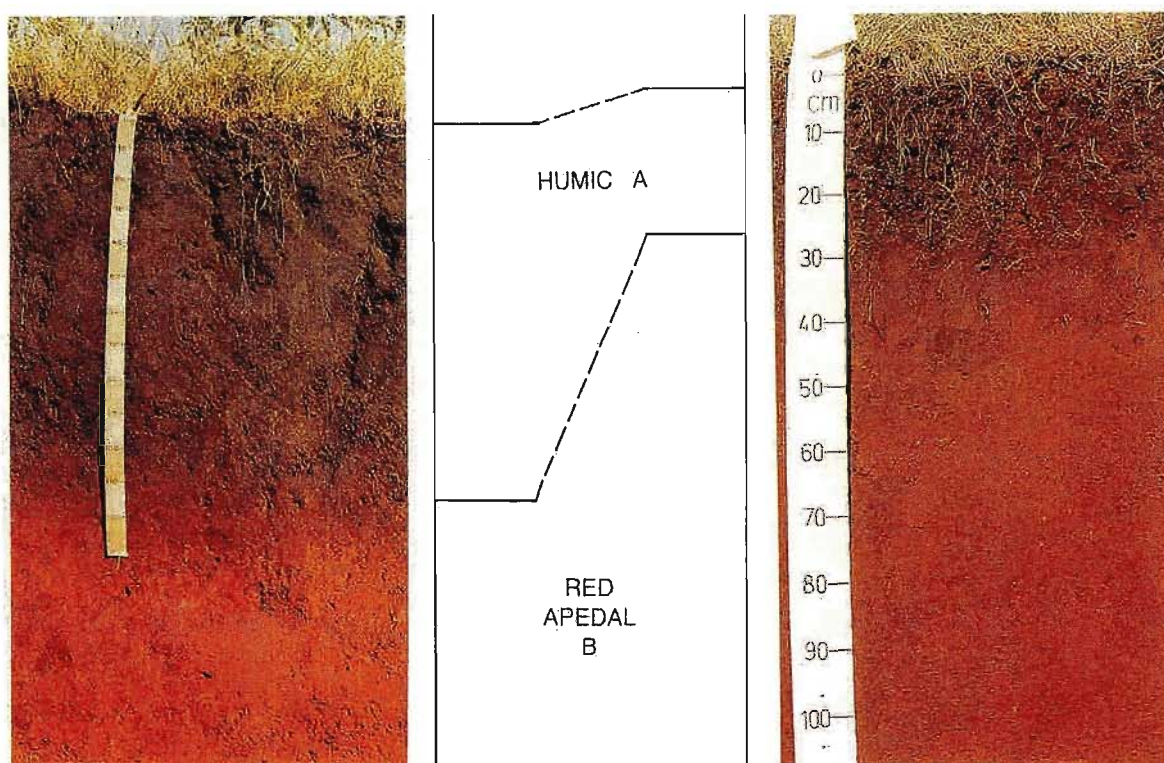
The study was conducted at Cooling Estate (29°27'S, 30°40'E) situated at Bruyns Hill near Wartburg in the Kwazulu-Natal midlands. According to the classification system of Phillips (1973), the orchard was situated in Bioclimatic region 3a, which is characterised as being a mistbelt region with evergreen forest, short forest and wooded savanna, including upland forest and wooded savanna of the Ngome faciation. This bioclimatic region occurs at an altitude of between 915 and 1372 metres, and is humid to subhumid with a mean annual temperature of 16 - 18 °C and rainfall of 800 - 1600mm.

Over the one year period (July 1996 - June 1997) that meteorological equipment was available for use, the mean annual air temperature was 17.5 °C, with an average daily temperature range of 11.1 °C . Absolute maximum and minimum air temperatures for December were 36.6 °C and 11 °C, and for June 25.3 °C and 2.8 °C respectively. Mean elevation is 950 m above sea level, with a 35 year average rainfall of 856 mm per annum. In this region, the period from May to August is considered ecologically dry, with the remaining months being ecologically humid (Fig. 2.1).



**Fig. 2.1** Climatogram of Cooling Estate. Rainfall data are long term averages from 1964 - 1998 (35 years) (Appendix 1), and temperature data is over one year (1996 - 1997) of meteorological measurements.

Trees were cultivated in an Inanda (Ia) soil form (Fig. 2.2), which is characterised by a Humic A horizon overlying a Red Apedal B horizon. Topsoils are characteristically freely drained with a low base status, whilst accumulating relatively large amounts of humified organic matter (organic carbon >1.8%) in moist climates that are cool or cold (MacVicar *et al.*, 1984). Typically the subsoil is of a medium to heavy texture (clay content 35 - 55%), lacking well formed peds other than porous micro-aggregates. These materials with weak macroscopic structure form in a well-drained, oxidizing environment to produce coatings of iron oxides on individual soil particles giving rise to the diagnostic red colours of these soils (MacVicar *et al.*, 1984). Actual soil analyses for the trial site prior to implementation are presented in Appendix 2a.



**Fig. 2.2** Soil profile of an Inanda (Ia) soil form (MacVicar *et al.*, 1984).

## 2.2 STANDARD MANAGEMENT

Normal cultural methods were implemented with the general management level being of the highest standard. No cover crop was planted in the orchard. Roundup® was applied as a herbicide throughout the orchard, outside the canopy drip zone. Weeds were then slashed by hand and allowed to mulch the inter-row area.

Trees were fertilized in split applications bimonthly (beginning in January), based on preliminary leaf and soil analysis (Appendices 2 and 3) and phenological stage. Total annual amounts of actual active fertilizer applied are shown in Table 2.1. Copper (Cu) and zinc (Zn) were applied in very small quantities to the soil, since foliar sprays of these compounds were used as fungicides. Irrigation was based on tensiometer readings and applied through a micro-jet system (two micro-jets/tree) with the capacity to apply 25 mm on a 12 hour cycle. Tensiometers were placed at depths of 300 mm and 600 mm, with irrigation scheduling aiming



at keeping the matric potential of the soil water in the -10 kPa to -40 kPa range. Standard injections of phosphorous acid in the form of a 20 ml, 10% Tree Doc® solution were carried out in November of each year. Dual purpose antifungal and foliar feed sprays of  $\text{CuOCl}_2$  and  $\text{ZnO}_2$  were applied once in November each year.

**Table 2.1 Total annual amounts of fertilizer applied in grams/tree over a ten year period at Cooling estate.**

Year	'88	'89	'90	'91	'92	'93	'94	'95	'96	'97	'98
LAN (28)	160	160	180	155	400	600	800	800	1400	1350	1350
KCl (50)	75	110	160	270	600	730	1200	1500	1600	2500	2480
Super-P (10.5)	350	160	210	250	350	400	600	800	800	3800	2450
Lime	500	0	1000	0	0	0	0	0	0	0	0
Cu	1	2	3	3	3	1	1	1	0	0	0
Zn	1	2	2	1	2	1	1	1	0	0	0
B	1	2	2	1	2	1	52	52	100	100	0

### 2.3 EXPERIMENTAL DESIGN

A block of 72 eight-year-old 'Hass' trees on clonal 'Duke 7' rootstocks at a planting density of 100 trees  $\text{ha}^{-1}$  were selected for the trial (block 32/33). The trees were situated on a South-East facing gentle slope, with row orientation in a north-west to south-east direction. Nine treatments were applied, and replicated four times, with two trees per plot/replication (2 trees/treatment/replication = 18 trees/replication) (Table 2.2).

Treatments are represented as follows:

C = Control

0 = 0 kg Potassium/Tree

FC = Filtercake

1 = 2.5 kg Potassium/Tree

PB = Pinebark

2 = 5.0 kg Potassium/Tree

The experimental design was a  $3 \times 3$  factorial giving the nine treatments applied to eight trees/treatment.

**Table 2.2 Field experimental layout showing actual positions of treated trees in rows within four replications.**

Replication 1	Tree 1 FC0	Tree 2 & 3 C1	Tree 4 & 5 FC1	Tree 6 & 7 C0	Tree 8 & 9 PB1
	Tree 10 FC0	Tree 11 & 12 PB2	Tree 13 & 14 PB0	Tree 15 & 16 FC2	Tree 17 & 18 C2
Replication 2	Tree 19 PB0	Tree 20 & 21 FC0	Tree 22 & 23 C1	Tree 24 & 25 PB1	Tree 26 & 27 C0
	Tree 28 PB0	Tree 29 & 30 PB2	Tree 31 & 32 FC2	Tree 33 & 34 C2	Tree 35 & 36 FC1
Replication 3	Tree 37 PB1	Tree 38 & 39 C0	Tree 40 & 41 FC2	Tree 42 & 43 FC0	Tree 44 & 45 C2
	Tree 46 PB1	Tree 47 & 48 PB2	Tree 49 & 50 C1	Tree 51 & 52 PB0	Tree 53 & 54 FC1
Replication 4	Tree 55 FC2	Tree 56 & 57 FC0	Tree 58 & 59 PB1	Tree 60 & 61 FC1	Tree 62 & 63 C2
	Tree 64 FC2	Tree 65 & 66 PB0	Tree 67 & 68 C1	Tree 69 & 70 C0	Tree 71 & 72 PB2

## 2.4 APPLICATION OF MULCH AND POTASSIUM

Filtercake was composted for six months prior to application (in October 1996) of a 100 mm thick mulch layer from tree trunk to canopy drip zone (Fig. 2.3). Composted pinebark (Gromed® coarse potting mix) was applied in a similar fashion, resulting in approximately 2.5 m<sup>3</sup> of each mulch being applied per tree. Control trees were left “as is” in the orchard, with the natural leaf litter mulch undisturbed. K was applied at rates of 0 kg, 2.5 kg and 5.0 kg active total potassium/tree/year. Applications were done in two split soil dressings annually in November 1996 and 1997, and February 1997 and 1998. These applications were done over and above the general management fertilizer applications (Table 2.2). To prevent “chloride leaf burn” KCl was alternated with K<sub>2</sub>SO<sub>4</sub> between seasons.



**Fig. 2.3** Photograph taken in December 1996 showing how the filtercake mulch was applied up to the canopy dripzone.

## **2.5 PHENO/PHYSIOLOGICAL DATA COLLECTION**

Tree canopy diameter and stem circumferences (above and below the graft union) were measured once a year in June using a surveyors measuring pole and measuring tape respectively. Ten shoots were randomly tagged around each tree and marked prior to the spring flush in 1996. Shoot flush extension was measured on these at monthly intervals from the beginning to the end of the spring flush for a particular season. This was done using a ruler, and measuring from the last hardened intercalation to the shoot tip. No pronounced summer flush was noted throughout the duration of the trial.

Root growth was monitored by visually estimating (on a scale of 1 to 10) the area covered by white healthy feeder roots under a newspaper mulch layer (Whiley *et al.*, 1988). The newspaper mulch was placed 1 m from the micro-jet nozzle on the south-west side of each tree to avoid direct sunlight (Moore-Gordon and Wolstenholme, 1996). One rating per tree was done per month from spring to autumn. Groupings of “poor” (0 to 2), “medium” (3 to 4) and “good” ( $\geq 5$ ), as described by Kaiser and Wolstenholme (1994) were chosen.

Leaf samples for mineral analysis were taken from each tree on a monthly basis to determine the levels of K over the year. Approximately fifteen leaves from hardened shoots were randomly selected from around the tree for this purpose, and were never taken specifically in relation to fruit position. Leaves were therefore excluded from analytical sampling if they were not hardened yet or of an advanced age.

## **2.5.1 CATION ELEMENT ANALYSIS**

The cation K was analysed from leaf samples using inductively coupled plasma atomic emission spectroscopy (ICP-AES). No fruit mineral analyses were performed.

### **2.5.1.1 Procedure**

Leaf samples were brought in from the field in individually marked paper packets and dried in a Labotec® forced draught oven at 28°C for 72 hours. This was done to allow for sufficient sample dessication for milling purposes without volatilising any elements. Upon removal from the oven, samples were immediately milled in a Krups® coffee grinder to a  $\leq 1$  mm particle size and stored in plastic vials at -18°C.

Approximately 0.5 g (to nearest mg) of milled leaf material was placed in a 20 mL wide-form, porcelain crucible. All samples were handled in monthly batches of 72 to avoid confusion between sample sets and keep conditions within a sampling set as homogenous as possible. Crucibles were placed in a cold Labcon® muffle furnace set to 500°C before the furnace was switched on and samples allowed to ash for two hours upon the furnace reaching 500°C. After complete ashing, samples were allowed to cool, moistened with de-ionized water and digested in 10 mL of a 1:1, 4 M HCl/HNO<sub>3</sub> acid solution. Samples were then placed on a heated

homemade sand-bath in a fume cupboard until most of the acid solution had evaporated (approximately 20 minutes).

Upon removal from the sand bath, samples were remoistened with approximately 10 ml of de-ionized water, whereupon liquid sample was transferred onto Whatman® No. 541 filter paper in a plastic funnel and allowed to drain into a 250 ml volumetric flask. Crucibles were thoroughly stirred with a glass rod and repeatedly washed with de-ionized water to prevent any sample losses. Similarly, filter paper precipitate was washed repeatedly until the volumetric flasks were made up to volume and immediately capped with plastic stoppers. Prior to use, all equipment was acid washed in a 1:1, 30 % (v/v) HCl/HNO<sub>3</sub> acid bath and rinsed in de-ionized water five times to remove any acid residue.

The Varian® Radial ICP-AES in the department of chemistry, University of Natal, Pietermaritzburg was used to determine leaf nutrient concentrations of K. For each sample set the ICP was allowed to perform automatic self-calibration and stabilization before the blank and standards were introduced. The ICP computer programme used linear regression to calculate the accuracy of the standard curve and produced a correlation coefficient ( *r* value). The *r* value had to be ≥0.99 for the calibration to be accepted as accurate enough and measurement to continue. Analysis was done individually on each of the 72 samples. No sample dilutions were performed. Instead, standards were made up to within the required range on the standard curve (Table 2.3). A 0.1 M HCl blank was used.

**Table 2.3 Element composition of standards used (mg L<sup>-1</sup>) to calibrate the Varian® Radial ICP-AES.**

Element	Standard Composition (mg L <sup>-1</sup> )				
	1	2	3	4	5
(K)	1.25	2.5	5	10	20

Values (**X**) indicating concentrations of K were produced in mg L<sup>-1</sup>, therefore requiring the following formula to provide a percentage value (**Y**):

$$Y \% = X \text{ mg L}^{-1} \times 250 \text{ ml} \times 1/0.5 \text{ g} \times 1/10^4$$

## 2.6 FRUIT SIZE AND YIELD MEASUREMENTS

At the end of each season (July) all the fruit were harvested from individual trees and fruit count size distributions determined gravimetrically according to the number of fruit per 4 kg export carton.

Fruit was graded as follows:

- |                          |                          |
|--------------------------|--------------------------|
| ● Count 10: 366 to 450 g | ● Count 18: 211 to 235 g |
| ● Count 12: 306 to 365 g | ● Count 20: 191 to 210 g |
| ● Count 14: 266 to 305 g | ● Count 22: 171 to 190 g |
| ● Count 16: 236 to 265 g | ● Count 24: 156 to 170 g |

Fruit of count size greater than 24 were regarded as reject or oil grade since they were not of a saleable size.

Total tree yields were calculated by adding the product of the number of fruit per count size and the class centre mass of that count size category, for all the count sizes fruit were graded into. Reject fruit were weighed separately and added to this. In addition, all the fruit for each tree were weighed in lug boxes and counted, allowing for average fruit mass for each tree and ultimately each treatment to be determined. This also allowed for a check on the accuracy of using class centres to determine total yield.

One carton of count size 18 fruit was taken per tree during the 1997 harvest and stored at simulated shipping temperatures of 5.5 °C for 30 days. Fruit were then cut in half and visually inspected to determine whether any internal quality differences between treatments were evident. No significant differences in internal quality were found between fruit from different treatments, and no reference to this is made in the results chapters.

## **2.7 AGROMETEOROLOGICAL MEASUREMENTS**

Agrometeorological measurements including air temperature, root zone temperature and root zone water content for each treatment were monitored over a period of 198 days.

Thermocouple sensors were used for temperature measurements and were placed into the soil/mulch at a depth of 70 to 100 mm. Thermocouple sensors were replicated three times within treatments in order to produce more accurate results. ThetaProbes (Model ML1 from Delta-T Devices LTD, United Kingdom) were used to measure soil water content. Due to limited channels and ThetaProbes being available, no replication of water content measurements were performed within treatments. All sensors were connected to a CR21X datalogger (Campbell Scientific, Logan, Utah).

### **2.7.1 THETAPROBE SOIL WATER CONTENT DETERMINATION**

#### **2.7.1.1 Introduction**

The ability to precisely and accurately measure soil water content is of utmost importance if soil and water resource use are to be optimized in agricultural systems (Lukangu *et al.*, 1999). The ideal technique for doing so needs to be fast, precise, non-destructive, inexpensive, allow *in situ* measurements and be representative of a large area. In addition, soil properties such as texture, air filled porosity (AFP), water holding capacity (WHC), solute concentration and chemical composition vary greatly from soil to soil, making it difficult to find a single technique or sensor that can accurately measure soil water content for every soil type without needing lengthy recalibration. However, the ThetaProbe approximates one such instrument (Fig. 2.4). Each ThetaProbe is adjusted during manufacture to provide a consistent output when measuring media of a known dielectric constant, making it readily media interchangeable without system recalibration (Delta-T Devices, 1995). The most important use of the ThetaProbe is probably that it allows the user to very efficiently schedule irrigation from area to area, thereby saving water and nutrients from deep percolation whilst optimizing crop production through timely irrigation (Lukangu *et al.*, 1999).



### 2.7.1.2 Operating principles

The ThetaProbe is essentially a frequency-domain reflectometry (FDR) sensor that consists of a waterproof housing containing electronics, which has four sharpened stainless steel rods attached to it at one end, and an input cable attached at the other end (Fig. 2.4). The cable provides connection to a suitable power supply and an analogue output signal, whilst the steel rods are inserted into the soil.

The sensor measures soil parameters by applying a 100 MHz signal from a crystal oscillator via a specially designed transmission line to the stainless steel rods. The transmission line is specially designed in that it has a varying impedance as the impedance of the soil changes. This impedance has two components, viz. the apparent dielectric constant and the ionic conductivity. The signal frequency has, however, been chosen to minimize the effect of ionic conductivity, resulting in changes in the transmission line impedance being almost solely dependant on the soil's apparent dielectric constant.



**Fig.2.4 A ThetaProbe.**

The 100 MHz signal is therefore applied to the rods, which transmit that signal between them and return it along the transmission line as a given voltage or voltage standing wave. However, the magnitude of transmission between the rods will depend on the medium surrounding them which in turn affects the return voltage. If that medium is wet, the transmission signal will be greater than if the medium is dry, resulting in differing return voltages. The ThetaProbe therefore simply measures the ratio between the input oscillator voltage and the voltage returned from the rods, producing a voltage standing wave ratio (VSWR) as a measure of the apparent dielectric constant ( $\epsilon$ ) of the soil. It is a well documented fact for many soil types that there is a linear correlation between the square root of the dielectric constant ( $\sqrt{\epsilon}$ ) and volumetric water content ( $\theta$ ) (Topp *et al.*, 1980; Knight, 1990; Whalley, 1993; White *et al.*, 1994), resulting in the ThetaProbe indirectly measuring water content.



### 2.7.1.3 Data conversion method

According to Delta-T Devices (1995), the following fifth order polynomial of the sensor analog output voltage (V) can be used to estimate the square root of the dielectric constant ( $\epsilon$ ) of the soil:

$$\sqrt{\epsilon} = 1 + 6.19 V - 9.72 V^2 + 24.35 V^3 - 30.84 V^4 + 14.73 V^5 \quad (2.1)$$

Since soils have differing mineral and organic properties, the soil water content  $\theta_v$  ( $\text{m}^3 \text{m}^{-3}$ ) is calculated from this square root of the apparent dielectric constant by using the calibration constants  $a_0$  and  $a_1$  in the following manner:

$$\theta_v = (\sqrt{\epsilon} - a_0)/a_1 \quad (2.2)$$

where  $a_0 = \sqrt{\epsilon_0}$  which is the square root of the apparent dielectric constant obtained using the ThetaProbe in air dry soil, and  $a_1 = \sqrt{\epsilon_w}$  which is the difference between the square root of the dielectric constant of saturated soil ( $\sqrt{\epsilon_w}$ ) and dry soil ( $\sqrt{\epsilon_0}$ ) divided by the soil water content ( $\theta_{vs}$ ) at saturation:

$$a_1 = (\sqrt{\epsilon_w} - \sqrt{\epsilon_0})/\theta_{vs} \quad (2.3)$$

Factory values for  $a_0$  and  $a_1$  of 1.6 and 8.4 for mineral soils, and 1.3 and 7.8 for organic soils are used respectively for these data conversion giving the formula used as:

$$\theta_v = (1 + 6.19(V/\theta_{vs}) - 9.72(V/\theta_{vs})^2 + 24.35(V/\theta_{vs})^3 - 30.84(V/\theta_{vs})^4 + 14.73(V/\theta_{vs})^5 - 1.3)/7.8 \quad (2.4)$$

For the purposes of this study a value of  $1 \text{ m}^3 \text{m}^{-3}$  was used for  $\theta_{vs}$ .

Note, volumetric soil water content is the ratio between the volume of water present in a sample and the total volume of the sample. This is a dimensionless parameter that can be

expressed either as a percentage volume (% vol) or a ratio ( $\text{m}^3 \text{ m}^{-3}$ ). Therefore  $0 \text{ m}^3 \text{ m}^{-3}$  corresponds to a completely dry soil, and  $1.0 \text{ m}^3 \text{ m}^{-3}$  to pure water (Delta-T Devices, 1995).

#### **2.7.1.4 Materials and methods**

Soil water content was measured continuously and averaged for each minute interval and again every hour. One probe for each of the treatments C0, FC0 and PB0 (three probes) was buried at approximately the same depth as thermocouple sensors (70 to 100 mm) by digging a rectangular hole, and inserting the 60-mm-long sensing rods into the side profile of the hole. Sensing was done by the datalogger using a differential voltage instruction assigned for higher resolution measurement. Measured voltages were transformed to volumetric soil water content values using the fifth-order polynomial equation (Eq. 2.4) described previously.

## **2.8 STATISTICAL ANALYSIS**

A split-plot analysis of variance was conducted testing for significant differences at the 1 % ( $p \leq 0.01$ ) and 5 % ( $p \leq 0.05$ ) levels. In addition, standard errors were calculated allowing for comparisons between treatments (SE (diff)).

## **CHAPTER 3**

### **PHENO/PHYSIOLOGY AND YIELD OF AVOCADO**

#### **3.1 PHENO/PHYSIOLOGICAL RESULTS**

It is important to mention at this point that large variations in pheno/physiological growth between trees is very typical of the avocado (Wolstenholme, A.-pers comm., 1996). In attempting to overcome this through experimental design four replications, with two tree plots per replication have been used, resulting in eight trees being tested per treatment. Nevertheless, within treatment variations were sometimes large, resulting in high standard errors often making statistical analysis fairly meaningless in describing clear overall treatment trends.

##### **3.1.1 ANALYSIS OF FILTERCAKE**

Mineral analyses were performed on the filtercake material to establish the extent to which it could be considered an organic fertilizer in addition to being a mulch. The options considered for analysing the filtercake were either to do a digestion of the materials, or extract the nutrients according to normal soil analysis. It was decided to adopt the former option, as this was a measure of the total amounts of minerals present, and not simply the immediately available nutrients. This option was preferred, since eventually the material would break down completely and a large proportion of the contained minerals would become available to the plant. Furthermore, interim results would still reflect quantities of mineral lost by the mulch, which was the reason for performing a repeat analysis. Complete digestion analysis results for filtercake are given in Table 3.1.

Results reflected in Table 3.1 for 6 and 12 month old filtercake refer to the time from production by the sugarmill. Six month old filtercake was therefore the composted material applied in

treatments used. A random filtercake sample was taken for analytical purposes at the 12 month old stage, and was unfortunately, inadvertently taken from a FC2 tree (Table 3.1). This explains the apparent increase in observed K present at the 12 month composted stage. Nevertheless it is clear from Table 3.1 that six-month-old composted filtercake has a very high mineral nutritional status for a mulch. This undoubtedly impacted positively on tree growth and yield, as soil analysis prior to trial implementation (Appendix 2a) indicated that nutritional levels in the orchard were low in comparison to industry norms for avocado (Appendix 2b). Furthermore, significant decreases in most of these minerals with increasing mulch age (6 month to 12 month) suggests that they exist in available forms for plant uptake. This view is supported by the fact that mineral element availability to plants is largely reduced by a soil pH of below 6 (Haynes, 1980), which is why farmers spend large sums of money applying lime to orchard soils. Since the filtercake mulch pH was 8.02 (in KCl), it is therefore not unreasonable to expect the mulch to have an ameliorating effect on the existing low soil pH (Appendix 2) of the orchard, thereby allowing for the greater availability of nutrients to avocado trees from both the soil and mulch upon filtercake mulch application.

**Table 3.1 Total mineral analysis of filtercake. The time scale in months refers to the total age of the filtercake from production by the sugarmill, ie. number of months composted.**

Sample	N (%)	P (%)	K (%)	Ca (%)	Mg (%)	C/N Ratio
6 Month Filtercake	1.16	0.73	0.19	1.24	0.27	16.7
12 Month Filtercake	0.78	0.35	0.28	0.49	0.17	10.5
Sample	Na (%)	Zn (mg kg <sup>-1</sup> )	Cu (mg kg <sup>-1</sup> )	Mn (mg kg <sup>-1</sup> )	B (mg kg <sup>-1</sup> )	pH (KCl)
6 Month Filtercake	0.03	103	51	963	Not Determined	8.02
12 Month Filtercake	0.05	55	34	405	Not Determined	Not Determined

In addition, the C/N ratio of the filtercake is well below the 30:1 limit stated by Haynes (1980) as being the point where N immobilization begins to exceed mineralization, and at 10.5:1 after 12 months of composting is extremely close to the optimum of 10:1 stated by Wolstenholme *et al.* (1996) to be found in humus. This, coupled to the high filtercake N content, virtually eliminates the possibility of a N “drawdown” or deficient period during further mulch composting.

In attempting to determine the total quantities of the abovementioned nutrients added in the filtercake mulch per tree it was calculated that for the approximately 28 m<sup>2</sup> of mulch cover per tree, approximately 1000 kg of actual filtercake material was applied. Approximate amounts of these elements applied per tree are presented in Table 3.2.

**Table 3.2 Approximate amounts of nutrients applied in the filtercake mulch (6 month composted) per tree.**

Sample	N (kg)	P (kg)	K (kg)	Ca (kg)	Mg (kg)
6 Month Filtercake	11.6	7.3	1.9	12.4	2.7
Sample	Na (kg)	Zn (kg)	Cu (kg)	Mn (kg)	B (kg)
6 Month Filtercake	0.3	0.103	0.051	0.963	Not Determined

Although these approximations (Table 3.2) again show that large amounts of nutrients were applied per tree through the filtercake, it should be remembered that these nutrients are not available to the tree instantaneously and become available over time in the preferred slow release manner. Nevertheless, this means that for K treatments involving filtercake a total quantity of 4.4 kg K was present in 2.5 kg K treatments, and 6.9 kg K in 5kg K treatments.

### 3.1.2 CANOPY DIAMETER

Canopy diameter extension was measured in order to compare general treatment differences of aerial vegetative vigour in terms of old and new growth extension. Results presented in Figure 3.1 show the observed trend in canopy extension for the 1996/97 and 1997/98 seasons.

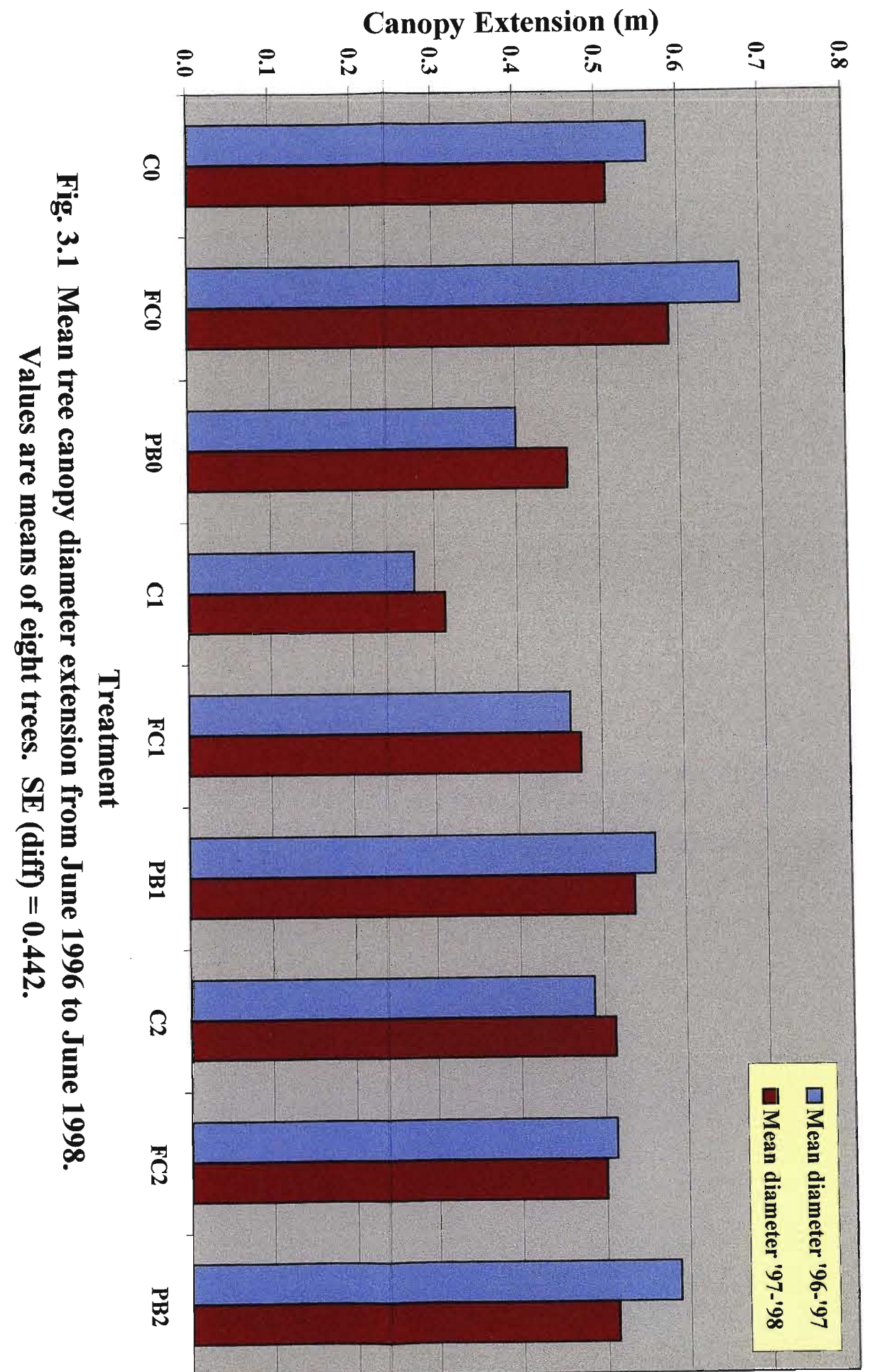
Control trees exhibited more canopy extension at the C0 (1.08 m) and C2 (1.00 m) treatment levels than at the C1 (0.59 m) level. Filtercake trees displayed most canopy extension at the FC0 (1.26 m) treatment level, with higher rates of K application seemingly suppressing aerial vegetative growth. Similar to control trees, the intermediate K treatment (FC1) produced less canopy diameter extension compared to the other filtercake treatments. This trend did however not hold true for pinebark treated trees, with most vigour being exhibited by PB1 and PB2 trees (1.10 m), and least by PB0 trees (0.86 m). From an overall perspective, FC0 trees produced more canopy growth (1.26 m) than any other treatment, with the opposite being true for C1 treated trees.

These results indicate that higher rates of K application are advantageous to aerial vegetative growth if pinebark is to be used as a mulch, whilst intermediate application rates appear to be deleterious to canopy extension in the case of control and filtercake treated trees.

### 3.1.3 SHOOT GROWTH

Shoot growth measurements were performed in order to obtain a more specific verification of aerial vegetative growth than that measured through canopy diameter extension. Results presented in Figure 3.2 show the observed trend in shoot flush for each season from August 1996 to January 1998.

No differences in flushing periods were observed between treatments (Fig. 3.2), with trees typically starting the spring flush in late August / early September and ceasing shoot extension by late December / early January. A very weak second period of shoot extension hardly qualifying as a summer flush took place almost immediately after the spring flush had ended in January 1997, and lasted for approximately one month. This did not re-occur in 1998.





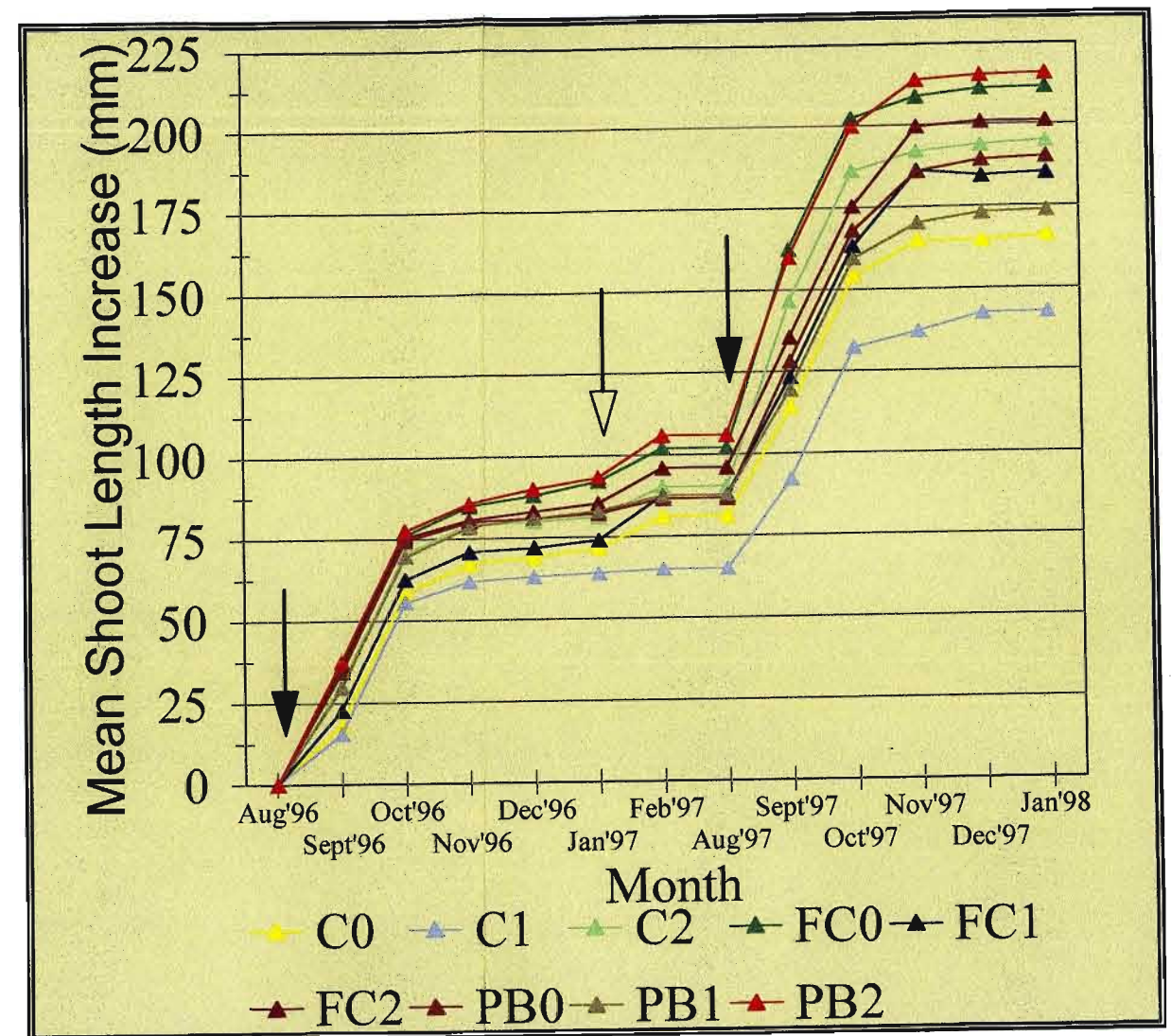
In each season C2 trees produced more shoot extension than C0 and C1 trees, with a mean difference in growth of 29 mm between C2 and C0, and 52 mm between C2 and C1 by the end of the 1998 spring flush. C1 trees exhibited significantly lower ( $p \leq 0.05$ ) shoot growth than all mulch treated trees. Shoot extension for filtercake trees was consistently greatest for FC0, followed by FC2 and FC1 trees, with FCO tree shoot extension being significantly greater ( $p \leq 0.05$ ) than all control treatments. In pinebark treatments, PB2 trees produced shoots of a greater length than PB0 and PB1 trees. From an overall perspective, PB2, FC0 and FC2 trees all produced an aggregate mean shoot growth of over 200 mm, whilst C0 and C1 consistently produced little shoot growth. This may be indicative of the N deficient condition existing within the orchard (Appendix 3a and 3b), where mulches appear to help retain applied inorganic N, and in the case of filtercake supply additional N.

With the exception of the differences measured between PB2 and PB1 treated trees (Fig. 3.2), these results are consistent with those obtained in the more general canopy diameter extension measurements (Fig. 3.1). This difference highlights a clear trend throughout of the intermediate K treatments producing less shoot growth than the zero or 5.0 kg K treated trees.

#### 3.1.4 STEM CIRCUMFERENCE

Measurements of stem circumference increase were performed as a measure of tree growth and/or carbohydrate storage through secondary trunk thickening. Results presented in Figure 3.3 are composite means of above and below graft union stem circumference increase.

Of the control treatments, greatest trunk thickening was observed at the C2 treatment level (90 mm) and least at the C1 level (44 mm). A similar trend can be seen in pinebark treated trees, with the PB2 trees showing more trunk thickening (86 mm) than PB0 trees (74 mm), whilst PB1 trees only thickened 67 mm. This trend did however not hold true for filtercake treated trees, where most trunk thickening occurred at the FC1 (116 mm) and FC2 (96 mm) K treatment levels, whilst FC0 trees exhibited less trunk thickening (66 mm). Of all applied treatments, FC1 trees produced the greatest stem circumference increase, and C1 trees the least.



**Fig. 3.2 Vegetative shoot flush comparison from August 1996 to January 1998. Solid arrows indicate start of spring flush and hollow arrows start of summer flush. Values are means of 10 shoots per tree and 8 trees per treatment. SE (diff) = 40.02.**



These results follow a similar trend to those observed in aerial vegetative growth (Figs. 3.1 and 3.2), where once again the intermediate K treatment appears to have had a negative effect on stem circumference increase for control trees, and in this case pinebark treated trees, whilst K additions have impacted positively on trunk thickening in filtercake treated trees. Interestingly, at the zero K rate pinebark mulch treatments produced the greatest degree of stem thickening of the mulch materials. This indicates that either the minerals released from the filtercake were being prioritised elsewhere, or existed in ratios or quantities detrimental to trunk thickening in FC0 trees.

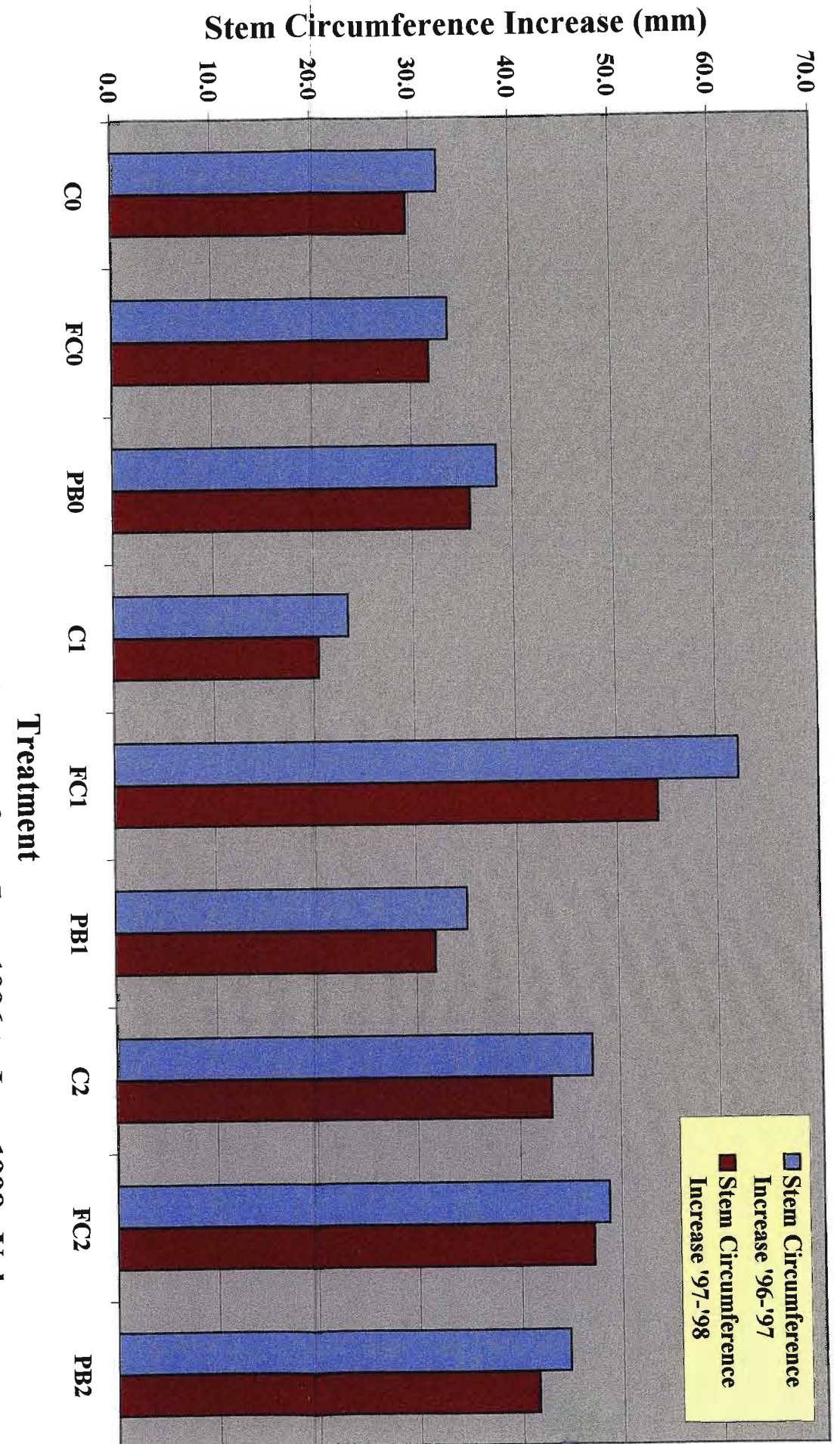
### 3.1.5 ROOT GROWTH

Root growth measurements were performed to try and establish to what extent assimilates were being employed in root growth as opposed to shoot or reproductive growth. Results presented in Figure 3.4 show the observed trend in root growth for the 1996/97 and 1997/98 seasons, whilst Table 3.3 shows the mean root growth over this time-period.

Root flush periods occurred at approximately the same time for all treatments (Fig. 3.4), with most trees reaching peak root growth for the first season in January 1997. The second season root flush was far weaker and peaked a month earlier (December) than in the first season (Fig. 3.4). This was possibly due to a particularly mild winter preceding the second spring flush, during which time a “medium” root flush that peaked in July occurred. Exceptions to peak root growth timing for the first spring flush were C0, C2 and PB1 trees which reached a root flush peak in April 1997, and PB0 in February 1997 (Fig. 3.4). The only exception to peak root growth timing for the second spring flush were FC0 trees, which again peaked in January (Fig. 3.4).

Throughout all root flush periods, control trees exhibited more root growth in the C1 and C0 treated trees compared with C2 trees (Fig. 3.4; Table 3.3). This indicates that the intermediate (2.5 kg) K treatment level promoted root growth (C1), whilst the 5.0 kg K treatment (C2) had an inhibiting effect on fresh root development. In filtercake treatments the most root growth was observed in FC0 treated trees, with a decreasing trend in fresh root development evident with an increase in the level of K applied (Fig. 3.4; Table 3.3). This did not hold true for

Fig. 3.3 Mean stem circumference increase from June 1996 to June 1998. Values are means of eight trees. SE (diff) = 4.98.





pinebark treatments, whereby no significant differences ( $p \leq 0.05$ ) in mean root growth were evident between treatments (Table 3.3). Nevertheless, PB1 trees exhibited an extended period of root growth that peaked lower compared to PB0 trees in January 1997 (Fig. 3.4).

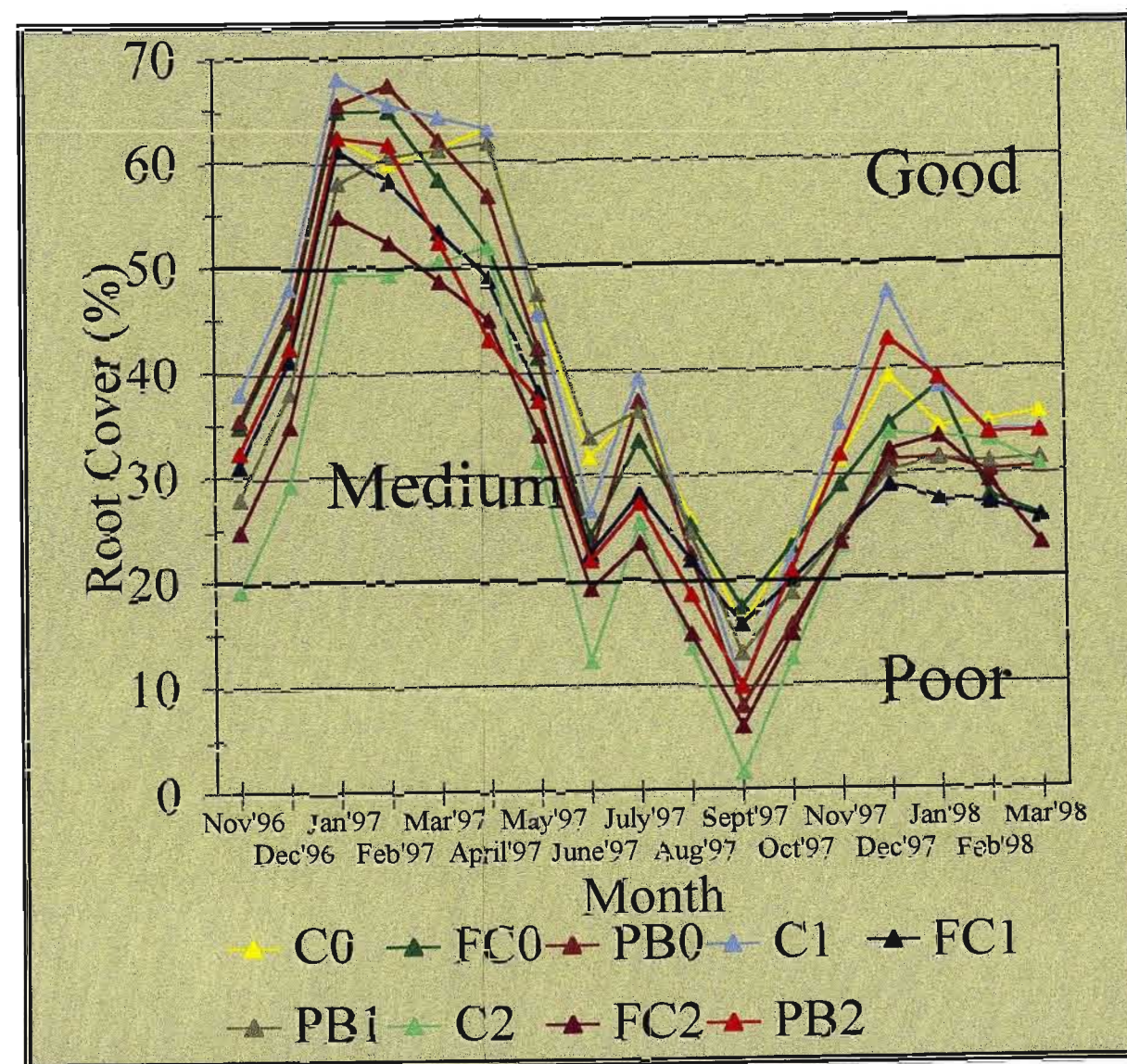
**Table 3.3 Mean root growth from November 1996 to March 1998. Values are means of 8 trees over 17 months. SE (diff) = 15.17.**

Treatment	Mean Root Cover (%)
C0	39.94
C1	41.51
C2	29.58
FC0	37.78
FC1	33.84
FC2	30.42
PB0	37.04
PB1	37.14
PB2	36.08

For a substantial portion of the first summer root flush (January 1997) most trees were allocated a “good” rating ( $\geq 50\%$ ), with the majority reaching a peak root growth of above 60%. The only exceptions to this were C2 and FC2 trees (Fig. 3.4). This indicates that high rates of K application played a role in reducing surface root flush for control and filtercake trees, whilst PB2 trees were still able to increase root production. In PB0, PB2, and all filtercake mulch treated trees, peak root flushing occurred over a two month period (January to February 1997) in the first season, compared to four months (January to April 1997) in PB1 and all control trees (Fig. 3.4). This indicates that PB1 and control trees allocated more time to root growth than did mulched trees.

### 3.1.6 ROOT : SHOOT RATIO

A root : shoot ratio comparison was done for the months that the parameters coincided (Fig. 3.5). This was done to try and establish what the optimal ratio during these periods of vegetative competition would be, if an ensuing maximum fruit yield was to be achieved.



**Fig. 3.4 Treatment comparison of root growth periods from November 1996 to March 1998. Values are means of eight trees. (“Poor” is  $< 20\%$  root cover, “Medium” is  $20\%$  to  $50\%$  root cover, and “Good” is  $\geq 50\%$  root cover.) SE (diff) = 15.17.**



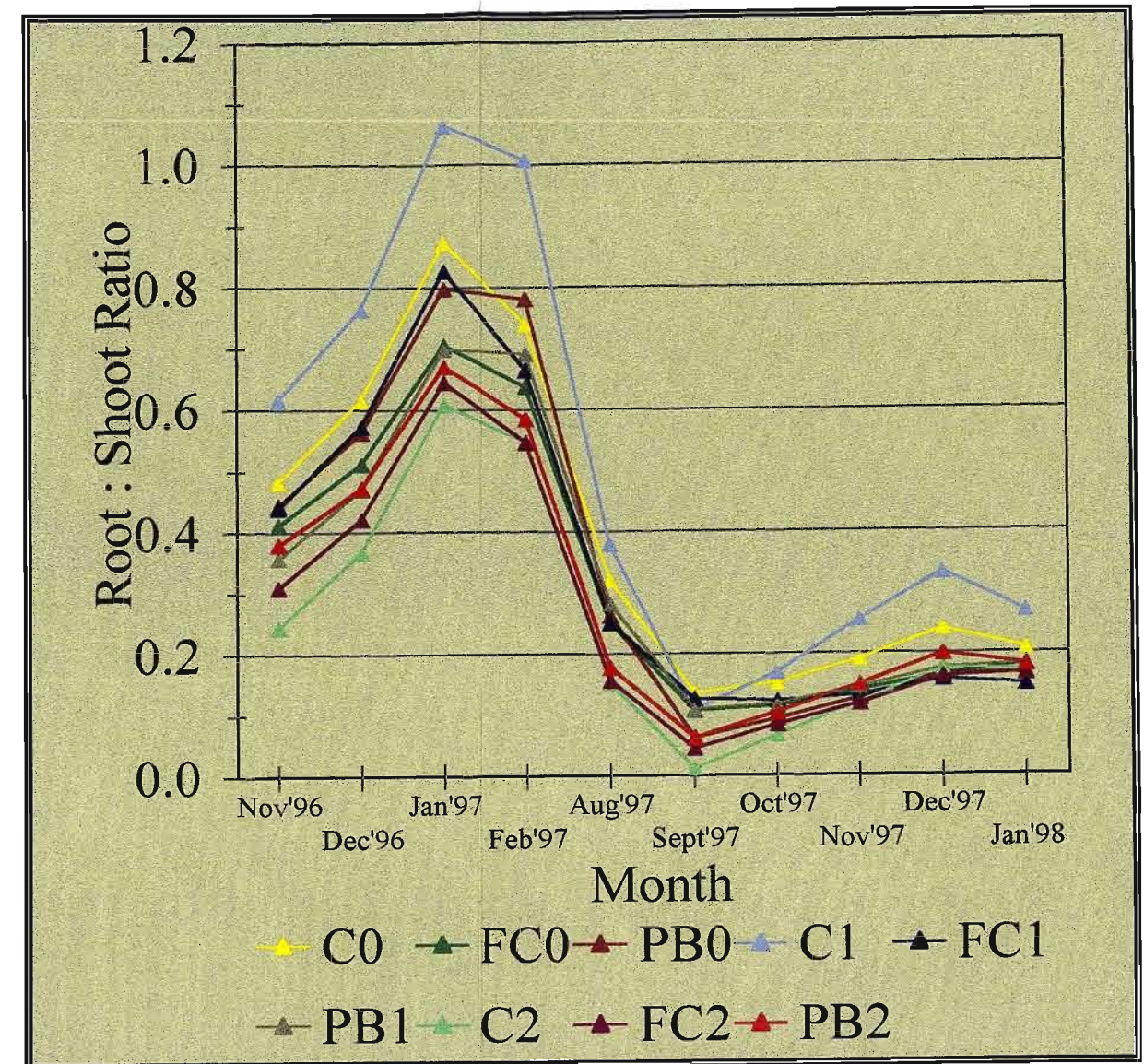
From Fig. 3.5 it is clear that the root : shoot ratio for the first season (January 1997) was far greater than the second season (December 1997). Since shoot growth for both flushes was fairly consistent (Fig. 3.2), this is indicative of the higher root growth observed in January compared to the December root flush (Fig. 3.4). The trend amongst treatments was however much the same for both flushes, and for simplicity comparisons will be made for the January 1997 flush (Fig. 3.5).

Of the control treatments, C1 (1.064) and C0 (0.874) trees produced a greater root/shoot ratio peak than C2 (0.608) trees. Similarly in filtercake treatments, the peak root/shoot ratio was found in FC1 (0.827) trees, followed by FC0 (0.705) and FC2 (0.645) trees. A linear trend in response to K occurred for pinebark treated trees, where PB0 (0.798) trees produced the peak root : shoot ratio, followed by PB1 (0.700) and PB2 (0.671) trees. From an overall perspective, the C1 and C0 trees produced a larger root/shoot ratio than all other treatments, with the opposite being true for FC2 and C2 trees (Fig. 3.5 and Table 3.4).

**Table 3.4 Mean Root : Shoot Ratio. Values are means of 8 trees over ten months of coincidental root and shoot growth. SE (diff) = 0.25.**

Treatment	Mean Root : Shoot Ratio
C0	0.396
C1	0.497
C2	0.247
FC0	0.323
FC1	0.344
FC2	0.266
PB0	0.346
PB1	0.323
PB2	0.298

Although less pronounced in the second season, the highest rate of K application always produced the lowest root/shoot ratio, irrespective of mulch treatment (Fig. 3.5 and Table 3.4), indicating that K played a greater role in reducing root growth than shoot growth.



**Fig. 3.5 Mean growth of roots compared to shoots (Root : Shoot ratio) for the months of coincidental growth from November 1996 to January 1998. Values are means of eight trees. SE (diff) = 0.25.**



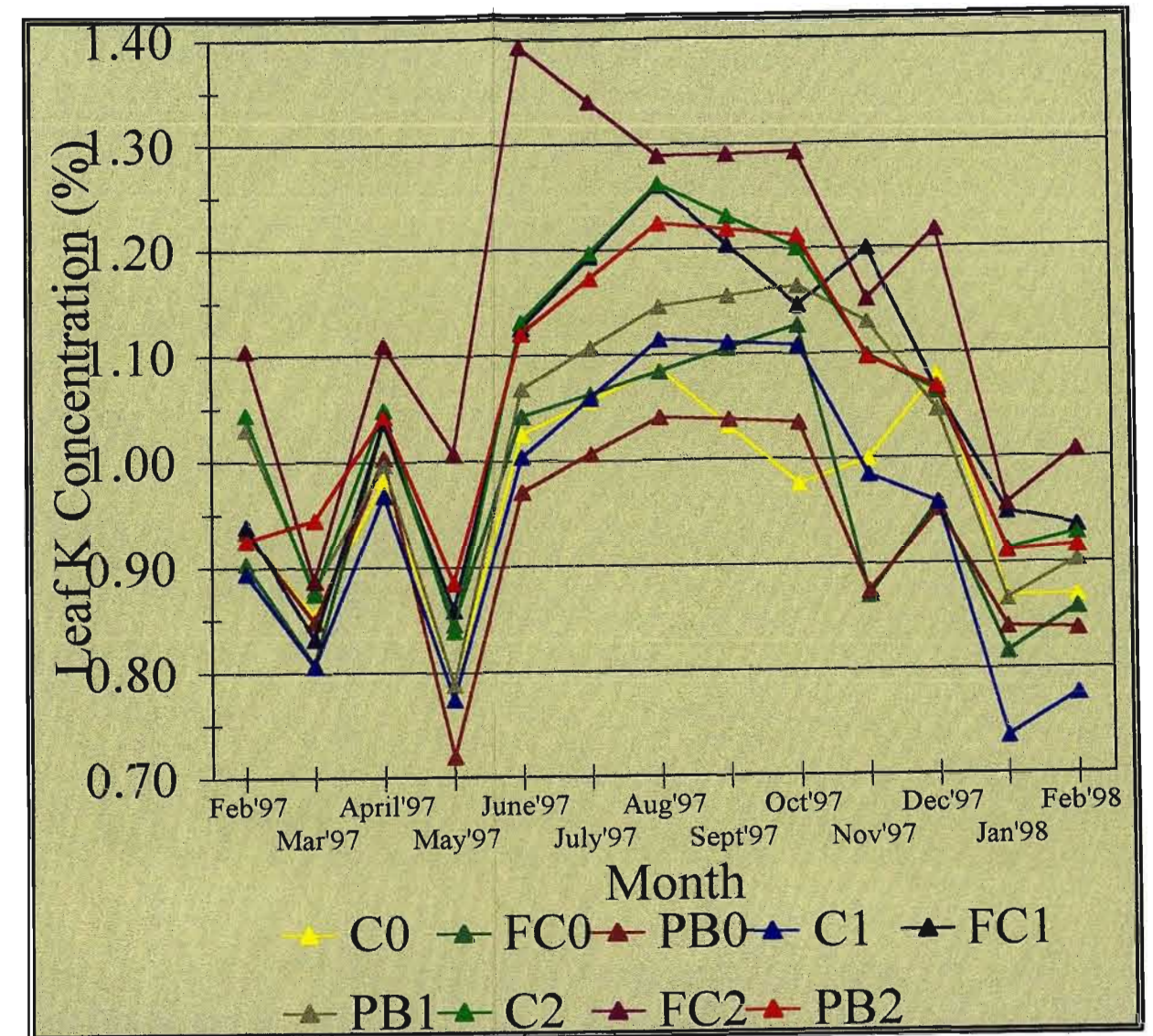
### 3.1.7 MINERAL ANALYSIS

Monthly leaf K content was analysed in order to monitor absolute leaf levels of K during the phenological cycle, so as to evaluate the effectiveness of treatments. These results are presented in Figure 3.6, whilst mean leaf K content values are presented in Table 3.5.

In Figure 3.6 a similar trend in K leaf content changes occurred between treatments, with peaks in April and August to October 1997. Although two split dressings of K had taken place prior to the April peak, K levels remained relatively low with no dramatic differences occurring between treatments. This was contrary to expectation and indicated a K deficiency in the orchard, which was verified by orchard soil analyses (Appendix 2). Clearer evidence of this K deficiency can be seen in the August to October K treatment peaks, where the zero rate K treated trees C0 and PB0 peaked at much the same levels as they had done in April, whilst other trees exhibited dramatically improved leaf K levels (Fig. 3.6).

FC0 trees were the exception to these zero rate K treatments, and exhibited a greater level of leaf K in October than April which can only be attributed to the inherently high K levels found in the filtercake mulch (Table 3.1). This data indicates that the C1, C2, PB1, PB2 and filtercake treatments corrected the existing K deficiency to various extents, thereby supplying enough K to the trees to raise leaf concentrations. Nevertheless, a small K peak occurred in December for C0, FC0 and PB0 trees. This was not the case for K treated trees, indicating that zero rate K trees had not taken up sufficient K for their physiological requirements by November.

According to expectation, the highest K treatment levels (C2, PB2 and FC2) produced the highest corresponding leaf K concentrations (Fig. 3.6 and Table 3.5), with FC2 leaf K concentrations being greater than all other treatments from April to October (Fig. 3.6). Interestingly, the FC1 treatment produced similar mean leaf K concentrations to those found in C2 and PB2 treated trees, indicating once again that the inherently high K concentration of the filtercake mulch had a marked effect in raising leaf K concentrations (Table 3.5).



**Fig. 3.6 Mean monthly leaf K concentrations for February 1997 to February 1998. Values are means of eight trees. SE (diff) = 0.14.**



**Table 3.5** Mean leaf K content from February 1997 to February 1998. Values are means of 8 trees over 12 months. SE (diff) = 0.14.

Treatment	Mean Leaf K Content (%)
C0	0.966
C1	0.946
C2	1.064
FC0	0.963
FC1	1.158
FC2	1.058
PB0	0.931
PB1	1.022
PB2	1.058

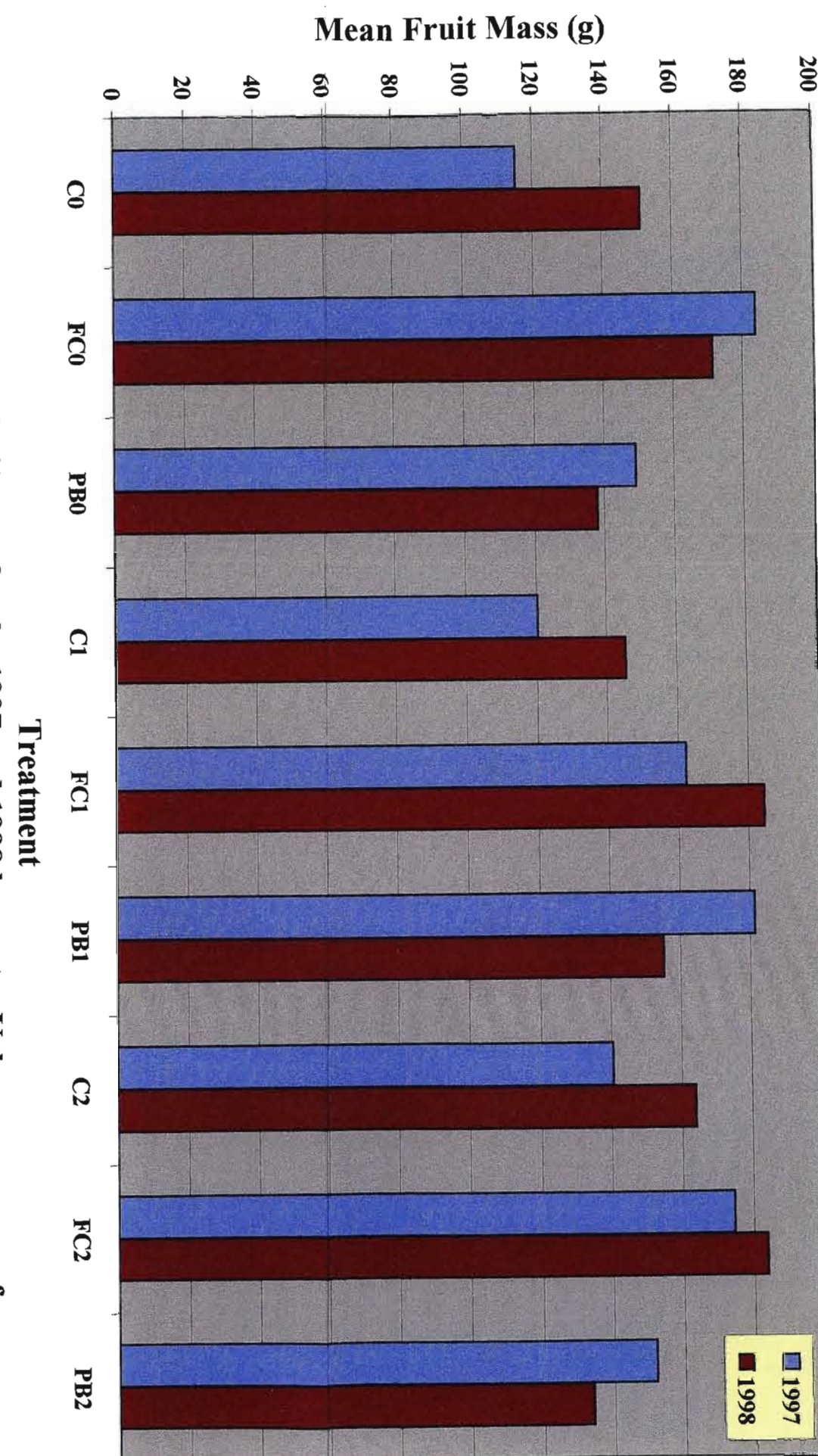
## 3.2 YIELD RESULTS

### 3.2.1 MEAN FRUIT MASS

A mean fruit mass comparison has been made in order to obtain the mean fruit count size for each treatment, including reject fruit. This is a useful additional comparison to total yield (t/ha) in that it allows one to establish whether trees at different treatment levels are responding through increasing/decreasing fruit number or size. These results are presented in Figure. 3.7, which shows the mean fruit mass for the 1997 and 1998 harvests.

Due to logistical problems, treatments for the 1996/97 season were only applied in October 1996. This was after floral initiation and fruit set, and no significant effects of the mulch or K treatments were therefore expected for the 1997 harvest. Nevertheless, control trees produced larger fruit at the C2 treatment rate (140 g) than at the C1 (120 g) and C0 (115 g) rates. A similar trend occurred for the 1998 harvest, where C2 trees again produced the largest mean

**Fig. 3.7** Mean fruit mass for the 1997 and 1998 harvests. Values are means of eight trees. SE (diff) = 67.41.



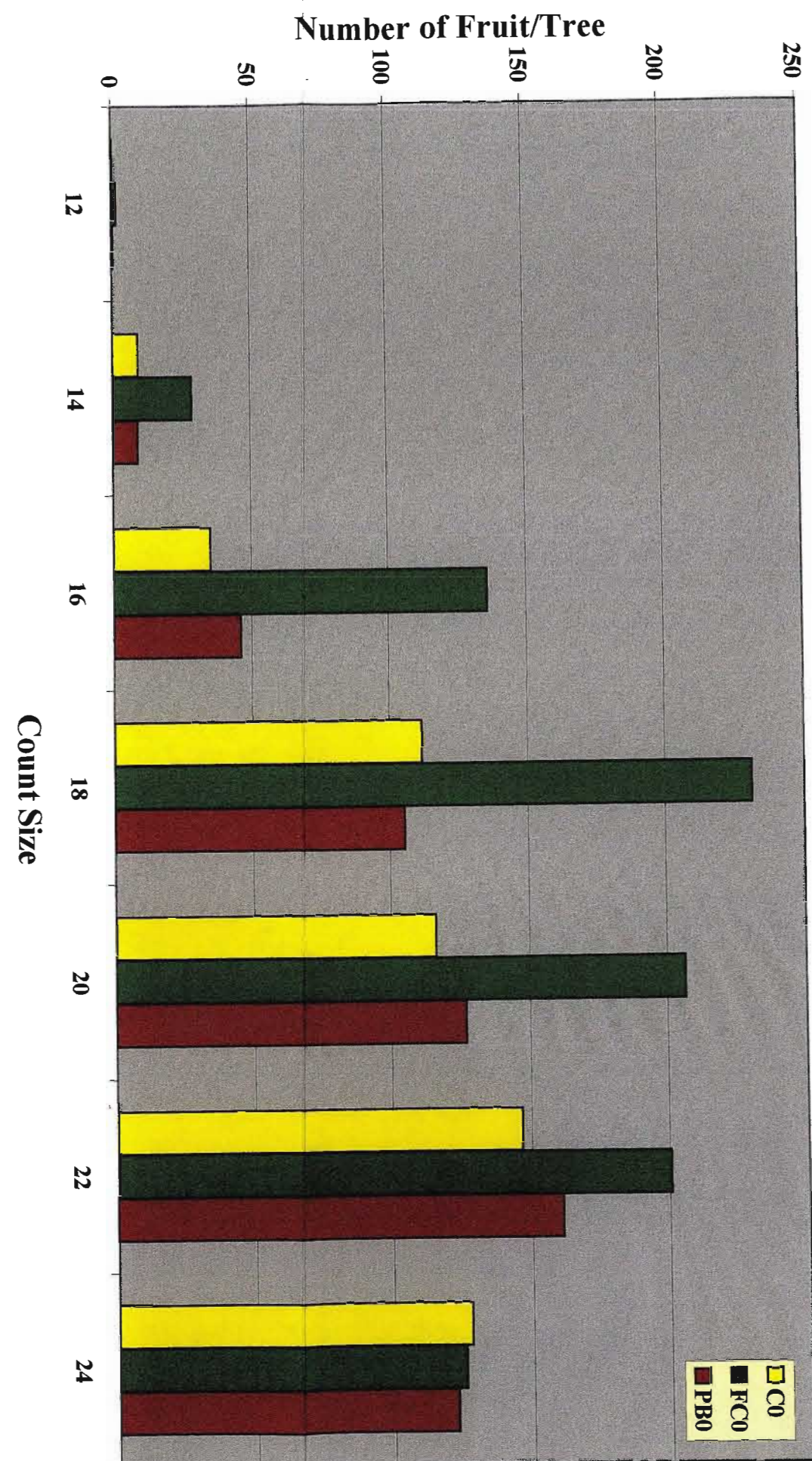


fruit mass (164 g) of the control trees, but in this case C0 trees produced fruit of a slightly larger mean mass than C1 trees. Cumulatively this resulted in no significant difference ( $p \leq 0.1$ ) in mean fruit mass between C0 and C1 treated trees, whilst C2 trees produced significantly larger ( $p \leq 0.1$ ) fruit than either of these treatments. This indicates that the 5.0 kg K treatment (C2) caused a shift toward larger fruit being produced in control trees, either through reducing the number of small fruit, and/or allowing for fruit to fill better. Nevertheless, all control fruit were graded into the above count size 24 category ( $\leq 170$  g), and hence classed as reject.

In filtercake treatments, FC0 and FC2 treated trees yielded fruit of a slightly higher mean mass than FC1 trees (162 g) for the 1997 harvest, resulting in FC1 fruit being classed into the above count size 24 category (reject), whilst FC0 and FC2 fruit were classed as count size 22 (171 to 190 g). This relatively poor performance of FC1 trees did not re-occur in the 1998 harvest, with all filtercake treated trees producing fruit of a mean mass equivalent to count size 22. The mean fruit mass of trees supplied a pinebark mulch was significantly the greatest ( $p \leq 0.1$ ) for PB1 trees for both harvests, with no significant difference ( $p \leq 0.1$ ) occurring between the PB0 and PB2 treatments over this time period. The only time the mean fruit mass for all pinebark treatments was not in the reject range ( $\leq 170$  g) over the two harvests, was for the PB1 treated trees in the 1997 harvest, which were categorized to count size 22.

From an overall perspective, filtercake treatments resulted in significantly ( $p \leq 0.1$ ) larger fruit being produced than all other treatments except for PB1 (Fig. 3.7; Table 3.6). In addition, all filtercake treatments produced fruit with an average mass greater than 170 g (count size 22), whilst all other treatments except for PB1 produced fruit in the reject range ( $\leq 170$  g) (Table 3.6). Except for the PB2 tree harvest, all mulch treatments resulted in significantly larger fruit ( $p \leq 0.1$ ) than their respective control trees (Fig. 3.7), again proving beyond doubt that mulching is a beneficial practice in improving avocado fruit size. In addition, the large mean fruit mass differences between seasons in control trees exemplifies the distinct alternate bearing cycle that was evident in the field (Fig. 3.7).

**Fig. 3.8 Additive mean zero K rate count size distribution for the 1997 and 1998 harvests. Values are means of eight trees added for two years. SE (diff) = 40.81.**





**Table 3.6 Mean fruit mass over the two harvests (1997 and 1998). Values are means of 8 trees over 2 harvests. SE (diff) = 33.71.**

Treatment	Mean Fruit Mass (g)
C0	133.146
C1	132.891
C2	152.106
FC0	177.621
FC1	173.227
FC2	179.037
PB0	143.540
PB1	168.193
PB2	142.929

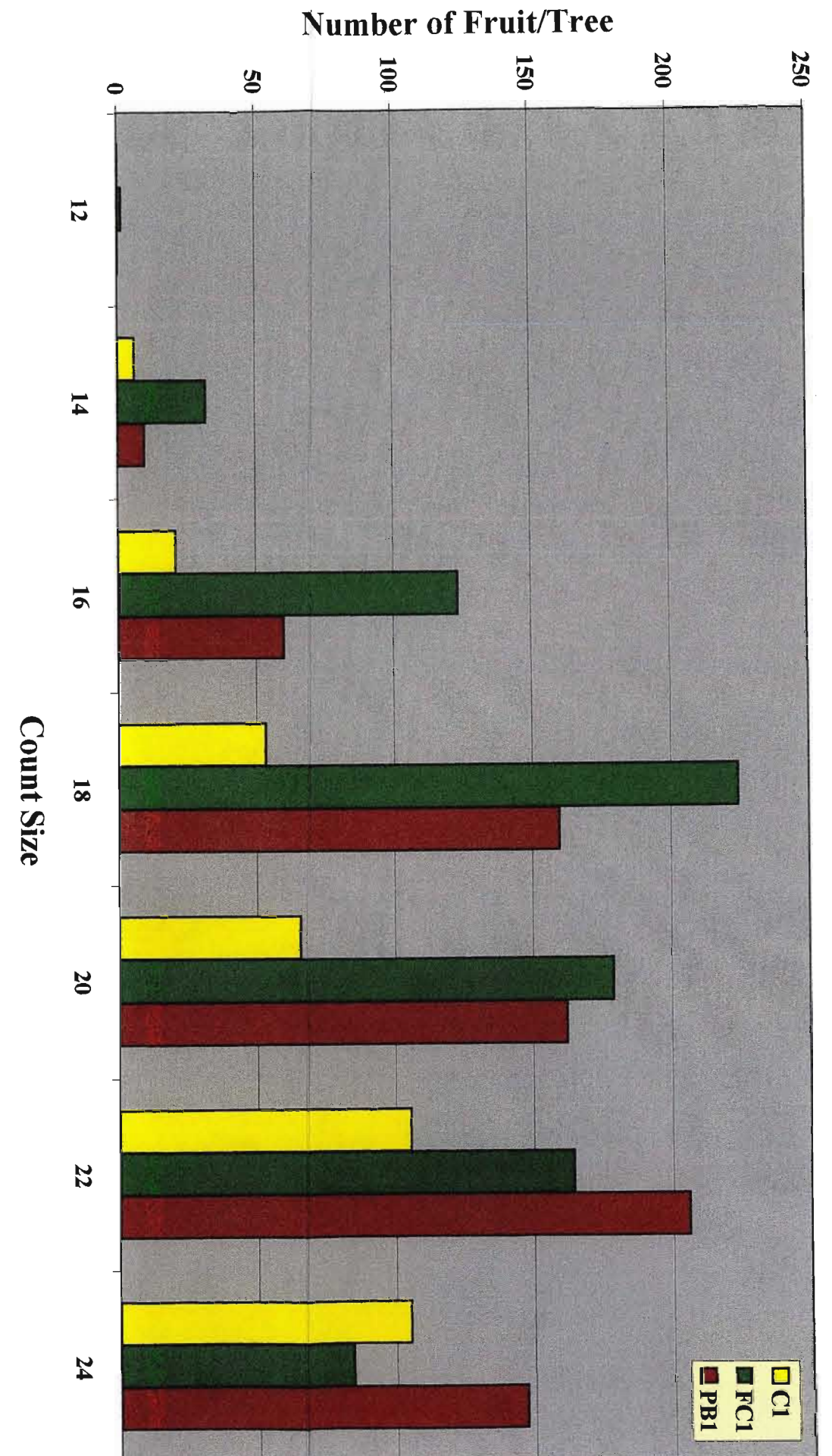
### 3.2.2 COUNT SIZE DISTRIBUTION

An additive fruit count size comparison (excluding reject fruit smaller than count size 24) over the two harvests has been made in order to obtain more detailed data on the fruit size distribution than the mean fruit mass categories discussed for Figure 3.7. Additive values have been chosen as these are most representative of a total yield per tree over the two harvests. More detailed count size distributions for each season are presented in Appendix 4.

Figure 3.8 shows the mean additive count size distribution at the zero rate of K application. Control and pinebark trees (C0 and PB0) were seen to yield a similar number of fruit in the different count size categories, with the distribution curve for both treatments peaking at count size 22 (Fig. 3.8). In contrast, filtercake treated trees yielded more fruit in count size categories 14 to 22 than C0 and PB0 trees, with a distribution curve that peaked at count size 18. This data shows a two count shift toward larger fruit size for FC0 trees compared to C0 and PB0 trees, which is consistent with results obtained in Figure 3.7.

Figure 3.9 shows the mean additive count size distribution at the 2.5 kg K application rate. As was the case at the zero K rate (Fig. 3.8), control and pinebark treatments again produced a

**Fig. 3.9 Additive mean 2.5 kg K rate count size distribution for the 1997 and 1998 harvests. Values are means of eight trees added for two years. SE (diff) = 46.11.**



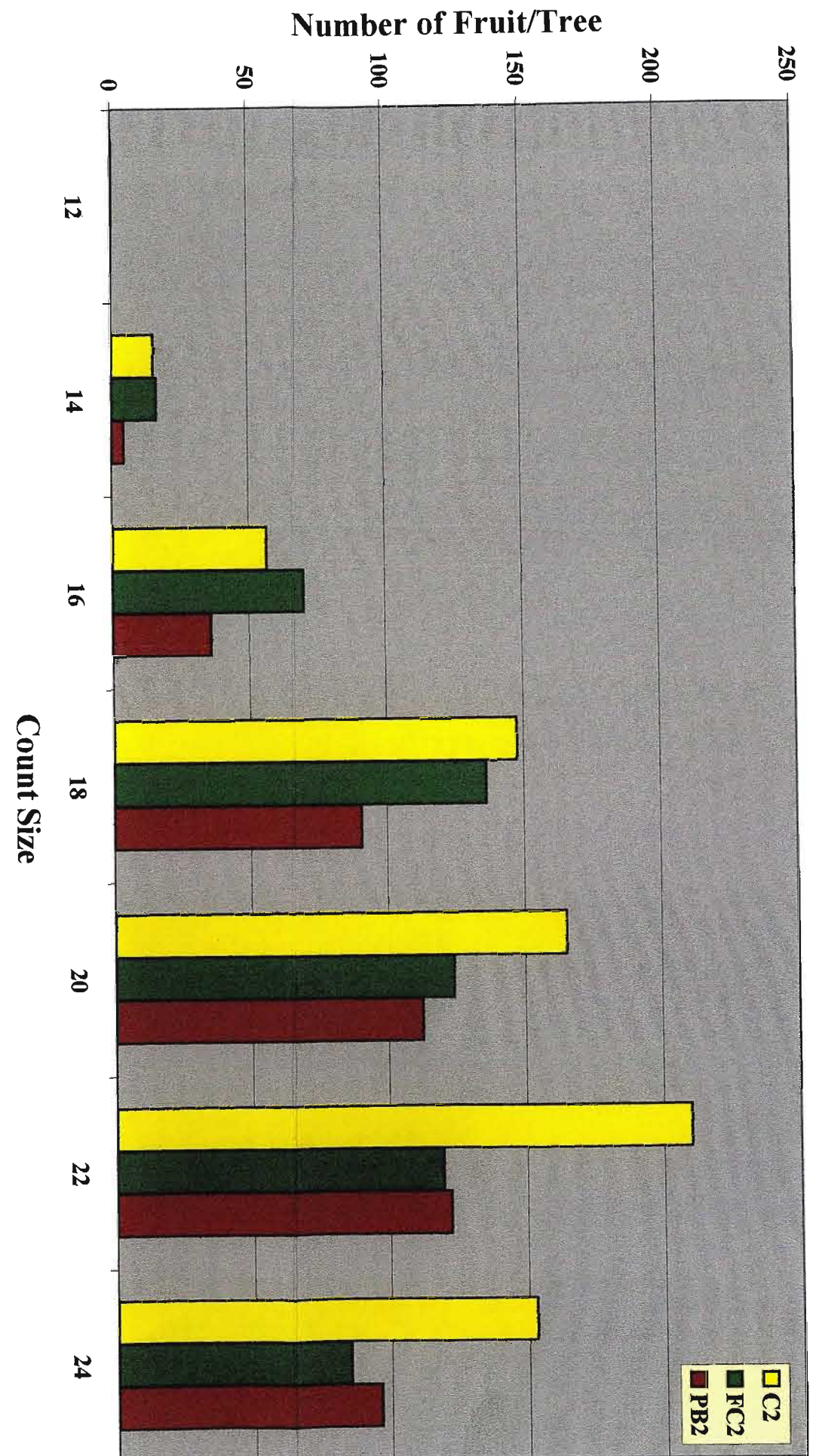


fruit size distribution that peaked at count size 22, whilst that of filtercake treated trees peaked at count size 18 (Fig. 3.9). Trees treated with pinebark and filtercake mulch however yielded more fruit than control trees, with much of this fruit being graded into the count size 16 to 20 categories (Fig. 3.9). In addition, FC1 treated trees (Fig. 3.9) yielded similar numbers of fruit for count sizes 12 to 18 to that of the FC0 treatment (Fig. 3.8), but produced less fruit than the FC0 treatment from count sizes 20 to 24. This indicates that K played a role in reducing the number of small fruit, whilst increasing the number of large fruit in the FC1 treatment.

Figure 3.10 shows the mean additive count size distribution at the 5.0 kg K application rate. Control trees yielded more fruit in all count size categories at the C2 treatment level (Fig. 3.10) than any other control (Figs. 3.8 and 3.9). In addition, C2 trees yielded more fruit than pinebark treated trees (Fig. 3.10) in all count size categories except 12. Although the high rate of K clearly had a significant effect on increasing fruit number for control trees, no shift in fruit size was apparent compared to other control treatments (Figs. 3.8 and 3.9), with the count size distribution curve for C2 treated trees (Fig. 3.10) similarly peaking at count size 22. The PB2 count size distribution (Fig. 3.10) was similar to the PB0 (Fig. 3.8) and PB1 (Fig. 3.9) distributions in that it peaked at count size 22, but PB2 trees produced significantly less fruit in all count size categories than PB0 and PB1 trees. This trend was also apparent in FC2 trees, where the distribution curve again peaked at count size 18 (Fig. 3.10), but showed a reduced yield to that obtained at FC0 (Fig. 3.8) and FC1 (Fig. 3.9) K treatment rates.

These results show that the 5.0 kg K rate impacted negatively on fruit number in both mulch treatments, whilst increasing fruit number in control trees (Figs. 3.8, 3.9 and 3.10). Interestingly, the increase in K seems to have had no significant impact on fruit size in any treatments (Figs. 3.8, 3.9 and 3.10), with count size distributions for control and pinebark trees peaking at 22, and filtercake at 18, for all levels of K application. It would therefore seem that high levels of K have a far more significant effect on fruit number than fruit size. This is however a contradiction in terms, since if we are able to reduce fruit number through applying higher levels of K, it would follow that remaining fruit should be of a larger size since more assimilates are now available per fruit. The result should therefore be one of fewer small and more larger fruit being produced. This is to some extent verified in C2 trees, where the mean fruit mass (Fig. 3.7) was significantly ( $p \leq 0.1$ ) larger than that of C0 and C1 trees, and yet the

**Fig. 3.10 Additive mean 5.0 kg K rate count size distribution for the 1997 and 1998 harvests. Values are means of eight trees added for two years. SE (diff) = 34.51.**





count size distribution remained unchanged. This can only mean that less reject and more saleable (larger) fruit with an unchanged distribution were produced at the high K treatment level.

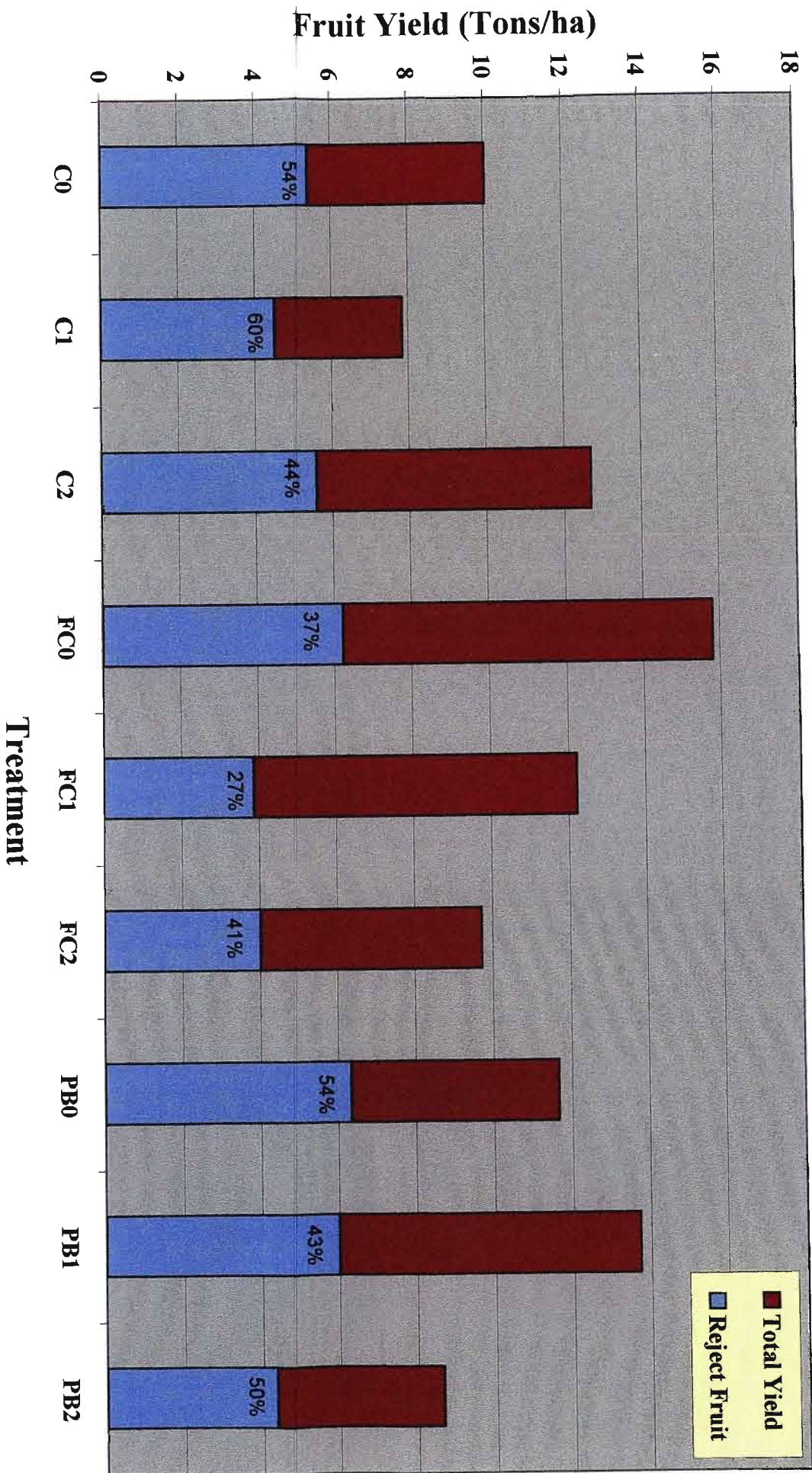
### 3.2.3 TOTAL FRUIT YIELD

One way of verifying whether fewer small and more larger fruit are in fact being produced by a tree is to measure the number of small or reject fruit as a percentage of total yield. These results are presented in Figure. 3.11, which shows the mean total fruit yield in tonnes ha<sup>-1</sup> for the 1997 and 1998 harvests.

Over the two harvests control trees were seen to yield higher at the C2 K treatment rate than at C0 and C1 treatment rates (Fig. 3.11). In addition, C2 trees produced the lowest percentage reject fruit (44 %) of all the control treatments (Fig. 3.11), indicating that the high level of K impacted significantly ( $p \leq 0.05$ ) on reducing the number of small (reject) fruit whilst increasing the saleable tonnage to 7.12 tonnes (Table 3.7). In filtercake treated trees the FC0 treatment produced a higher total yield than FC1 and FC2 treated trees (Fig. 3.11 and Table 3.7). Upon comparing the reject fruit yield (Fig. 3.11), it however becomes obvious that FC1 trees produced significantly ( $p \leq 0.05$ ) less reject fruit than FC0 and FC2 trees, resulting in a saleable yield close to that of FC0 treated trees (Table 3.7). This result once more implicates K in decreasing overall fruit number whilst increasing the saleable yield, which could only have occurred through a lower number of small fruit being produced. Similarly in pinebark treated trees a trend of a reduction in the number of reject fruit with K additions occurred, with the PB1 treatment producing the highest total yield and lowest reject fruit yield (Fig. 3.11), and so also the highest saleable yield of all pinebark treated trees.

From an overall perspective, the highest total yields were produced by C2, FC0, FC1, PB0 and PB1 trees, and the lowest by C0, C1, FC2 and PB2 trees (Fig. 3.11), indicating that the 5.0 kg K treatment rate was optimal for control trees, but above optimum for mulched trees. If one compares the saleable yields (Table 3.7) of the highest yielding treatments, the highest is FC0, then FC1, PB1 and finally C2. However, upon further investigation it becomes apparent that FC0 treated trees yielded a mere 1.26 tonnes ha<sup>-1</sup> more saleable fruit than FC1 trees, and did

Fig. 3.11 Total mean fruit yield for 1997 and 1998 harvests. Values are means of eight trees for two years. SE (diff) = 4.48.





so through an increased total yield of 3.61 tonnes compared to FC1 trees (Table 3.7). This means that only 34.9 % of the additional 3.61 tonnes of fruit were saleable, and 65.1 % reject. The most “efficient” yield of all treatments was therefore produced by FC1 trees.

**Table 3.7 Mean fruit yield over the two harvests (1997 and 1998). Values are means of 8 trees over 2 harvests. SE (diff) = 4.48.**

<b>Treatment</b>	<b>Total Yield (tonnes ha<sup>-1</sup>)</b>	<b>Reject Yield (tonnes ha<sup>-1</sup>)</b>	<b>Saleable Yield (tonnes ha<sup>-1</sup>)</b>
<b>C0</b>	10.03	5.39	4.63
<b>C1</b>	7.84	4.49	3.35
<b>C2</b>	12.69	5.57	7.12
<b>FC0</b>	15.82	6.21	9.61
<b>FC1</b>	12.21	3.86	8.35
<b>FC2</b>	9.71	3.99	5.72
<b>PB0</b>	11.65	6.32	5.33
<b>PB1</b>	13.72	5.99	7.73
<b>PB2</b>	8.65	4.33	4.31

## CHAPTER 4

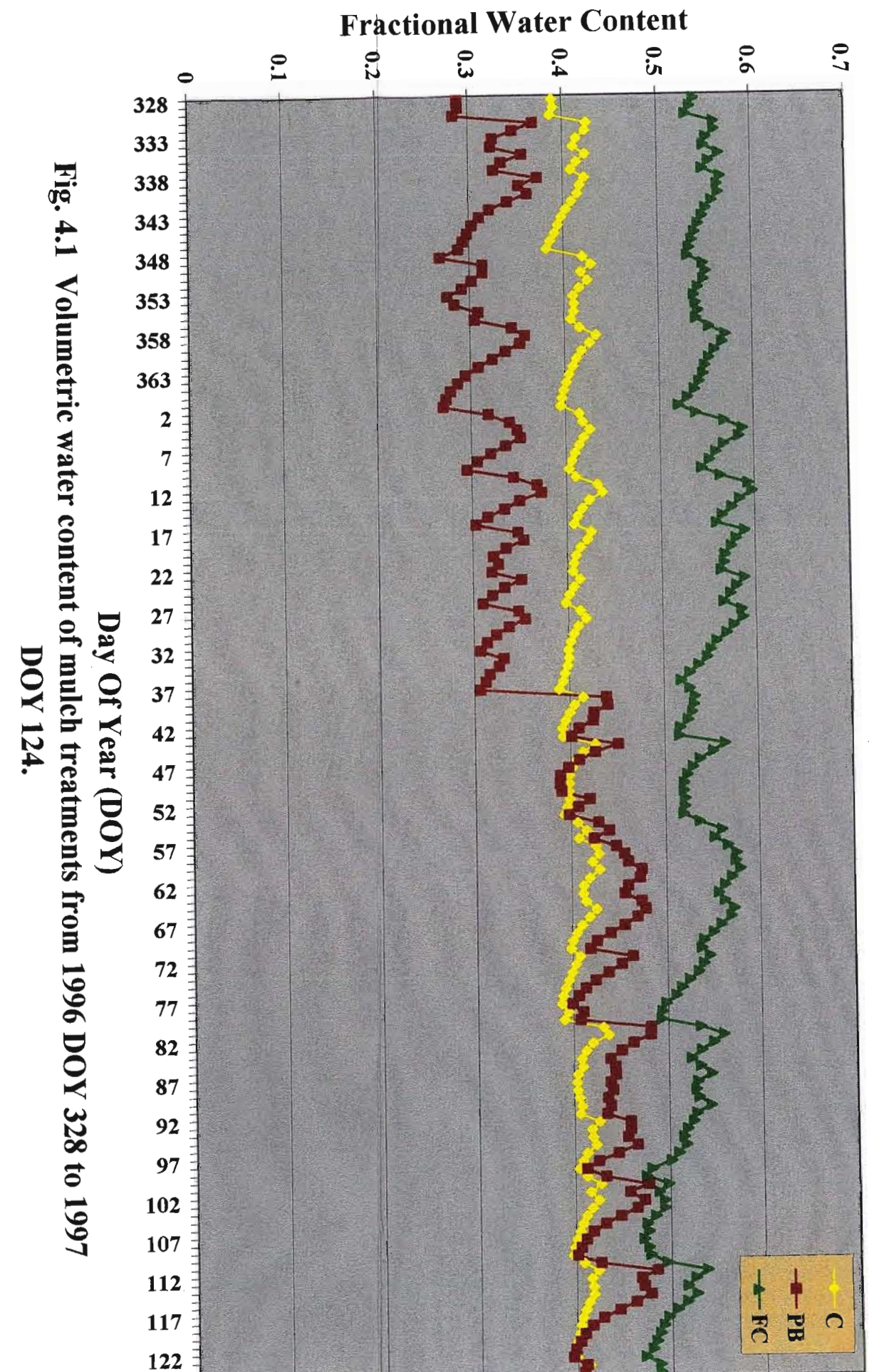
### ROOT-ZONE CLIMATE

#### 4.1 AGROMETEOROLOGICAL RESULTS

##### 4.1.1 VOLUMETRIC WATER CONTENT

Mean daily volumetric water content data for day of year (DOY) 328 of 1996 to DOY 124 of 1997 are presented in figure 4.1. Due to limitations in the equipment type and availability, ThetaProbes were not replicated within treatments, and results are therefore not statistically verifiable. It should be taken into account that the ThetaProbe placed in the pinebark mulch was moved to immediately below the mulch layer on day 37 of 1997, resulting in the apparent dramatic increase in water content from that day onward. This was done to try and establish to what extent the pinebark mulch was affecting the soil water content immediately below the mulch layer (in the soil), once it became apparent that the water content within the mulch was consistently lower than the control. It was considered unnecessary to repeat this exercise for the filtercake treatment, since the water content in the filtercake was consistently higher than the control and the soil below the filtercake would most likely have had an even higher water content. Water content in the filtercake treatment was therefore measured within the original mulch zone at all times.

Filtercake maintained the highest volumetric water content of all treatments throughout the measurement period, mostly ranging between 50 % - 60 % and producing a mean over the entire measurement period of 54 % (Fig. 4.1). Conversely, the pinebark mulch remained the driest of all treatments prior to the ThetaProbe being moved on DOY 37, and produced a mean volumetric water content of 32 % over this period. A large increase in water content was however measured upon the ThetaProbe being moved, with soil below the mulch having a mean water content of 44 % compared to a mean of 41 % in the control. In addition, the control (soil) exhibited the least day to day variation in water content, with the greatest change measured being a mere 4 % compared to 5 % in filtercake and 8 % in pinebark (Fig. 4.1).





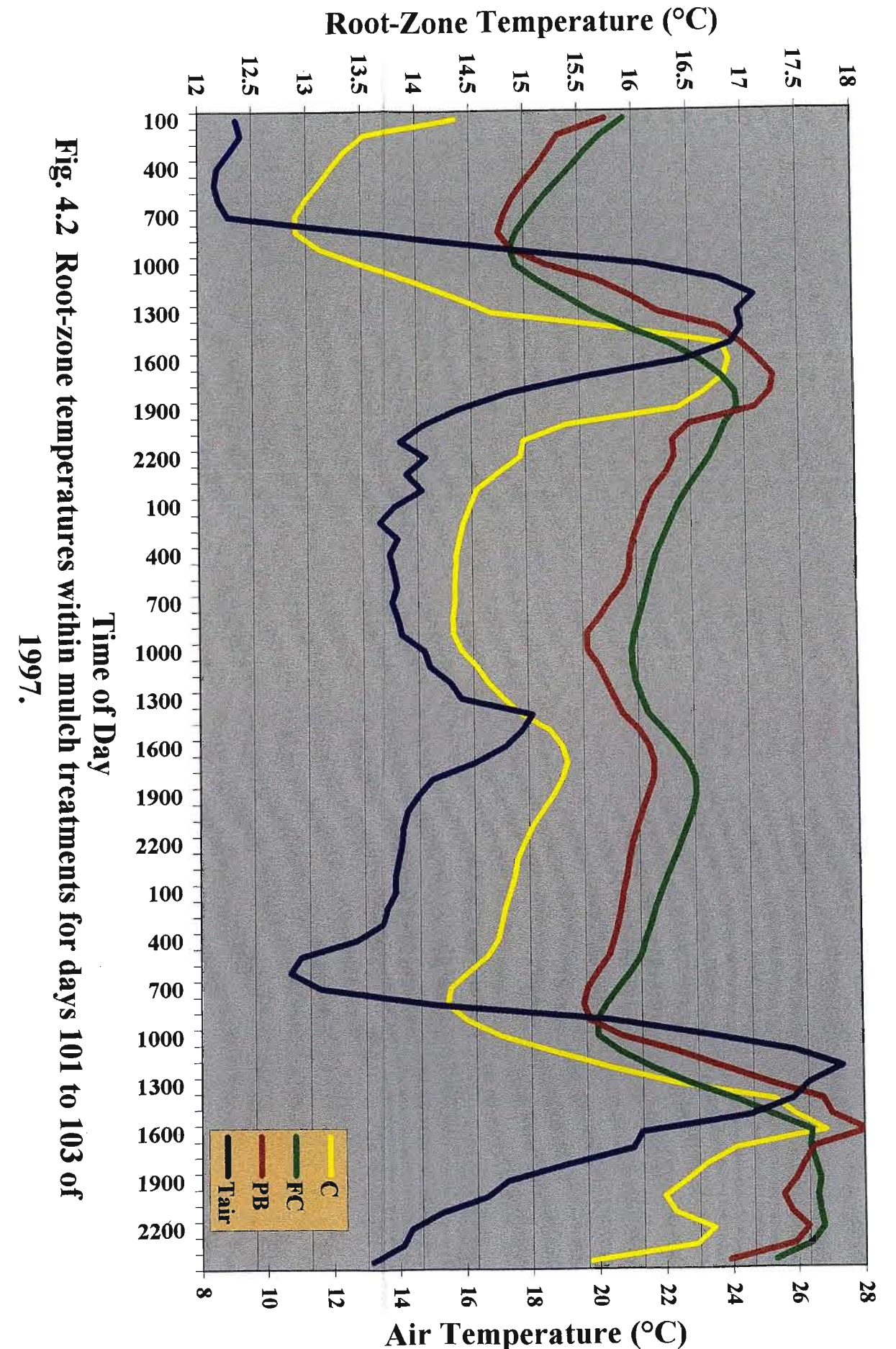
While this data provides no information in terms of the matric potentials and AFP's of the different treatments, it is clear that filtercake maintained a very high volumetric water content for a mulch, making it very unlikely that filtercake treated trees would have experienced any water stress throughout this time-frame. The reason for the filtercake mulch having a much higher water content than the pinebark, probably lies in the fact that it is a much finer material than pinebark, having smaller interparticle airspaces and hence a higher water holding capacity than pinebark.

#### 4.1.2 TEMPERATURE

Air and root-zone temperatures were measured for 198 days in order to establish what effect the mulch temperatures were having on root growth. Figures 4.2 and 4.3 show the mean hourly root-zone temperatures for two data sets within this period of measurement.

Figure 4.2 shows the root-zone temperatures over a relatively cool period in April 1997 (DOY 101 to 103), during which time air temperature fluctuated between 8.5 and 27.4 °C. The mean air temperature over this period was 16.3 °C, and root-zone temperatures 15.0 °C for the control, 16.2 °C for pinebark, and 16.3 °C for filtercake. The root-zone temperatures for both mulch types were very similar, with daily mulch temperature fluctuations never exceeding 2.5 °C. Nevertheless, pinebark temperatures decreased 0.5 °C more during the cooler periods and increased 0.5 °C more during the hotter periods compared to filtercake. The filtercake mulch produced the most even root-zone temperatures of the three treatments, with daily temperature fluctuations never exceeding 2.0 °C and total fluctuation over the entire three-day period never exceeding 2.8 °C. The control treatment exhibited reduced root-zone temperatures compared to mulch treatments over this relatively cool period, with daily temperature fluctuations of up to 4.0 °C occurring.

Figure 4.3 shows the root-zone temperatures over relatively warmer period than Fig. 4.2 in December 1996 (DOY 360 to 362), during which time air temperature fluctuated between 19.7 °C and 34.0 °C. The mean air temperature over this period was 25.4 °C, and root-zone temperatures 21.2 °C for the control, 21.7 °C for pinebark, and 21.9 °C for filtercake (Fig. 4.3). At these relatively warmer air temperatures pinebark root-zone temperatures followed

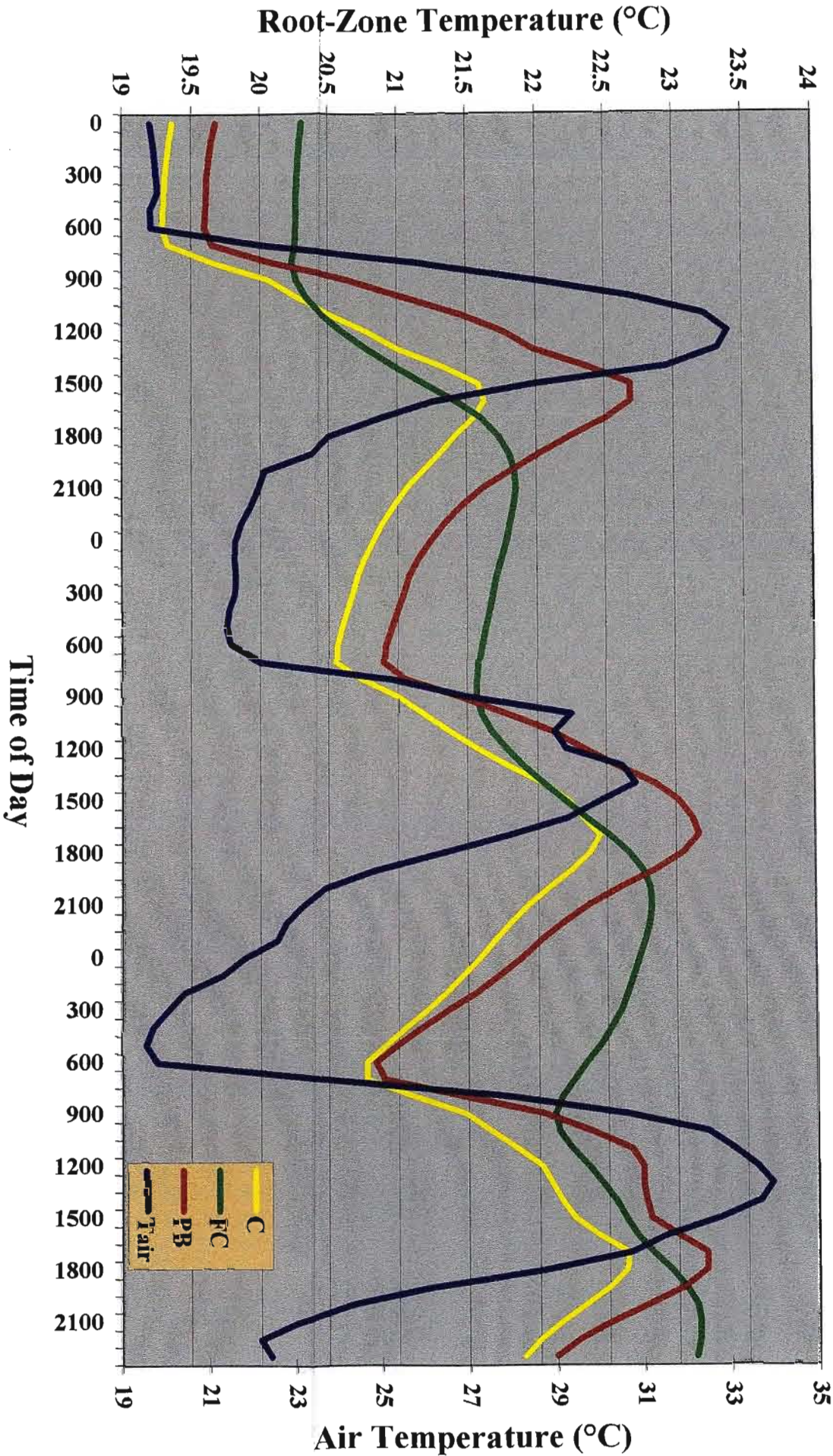




a similar trend to those observed in the control, with a maximum daily temperature fluctuation of 2.3 °C occurring in the control and 3.1 °C in pinebark. Nevertheless, on average pinebark was 0.52 °C warmer than the control, which again produced the lowest mean root-zone temperature (21.2 °C) of all treatments. The filtercake mulch again produced the most even root-zone temperatures of the three treatments, with daily temperature fluctuations never exceeding 1.6 °C and total fluctuation over the entire three-day period never exceeding 2.9 °C. In addition, the time taken for temperature increases and decreases to occur in the filtercake mulch was far longer than for the other two treatments, indicating that roots underwent a far more gradual change of temperature in filtercake.

From an overall perspective, filtercake was the warmest and the control the coolest of the applied treatments, and whilst pinebark reacted similarly to filtercake in response to temperature changes at cooler temperatures, it was inclined to react similarly to the control at higher temperatures. In addition the filtercake mulch displayed a far more gradual change in root-zone temperature in response to air temperature changes than either the control or pinebark treatments. It is likely that this generally deviant behaviour of the filtercake mulch when compared to the control and pinebark mulch is largely due to its inherent higher water content status (Fig. 4.1). Since water has a very high specific heat capacity (2.5 MJ kg<sup>-1</sup> at 0 °C) it takes a long time to heat up and cool down, giving rise to gradual temperature changes such as those observed in the filtercake mulch. Since control and pinebark treatments exhibited a lower water content status (Fig. 4.1) than filtercake, it is likely that under high temperature conditions such as those which occurred on DOY 360 to 362 of 1996 (Fig. 4.3) a higher evaporative demand would have caused these treatments to undergo a further water content reduction. This would in turn result in temperature changes being less gradual, with more severe peak root-zone temperatures being reached in these treatments compared to the filtercake mulch.

Fig. 4.3 Root-zone temperatures within mulch treatments for days 360 to 362 of 1996.



## DISCUSSION

For fruit size to be maximized, processes such as cell division and expansion must occur unhindered throughout fruit development (Valmayor, 1967; Coombe, 1976). Abiotic and biotic stress due to extremes in solar radiation, water and nutrient availability, as well as pathogenic factors will impact on whole plant physiology, affecting gene expression and subsequently the synthesis, transport and utilization of photoassimilate and plant growth regulators (Chapin, 1991). Moore-Gordon (1997) found this type of stress response to manifest itself primarily through a reduced CK:ABA ratio, resulting in ABA accumulation in aerial vegetative and reproductive tissues. Similarly, Chapin (1991) proposed stress response occurs through a reduced CK:ABA ratio, ultimately resulting through a cascade of events in less photoassimilate being available for fruit growth and so a reduction in fruit-size occurring. Since CK's are known to promote meristematic activity and affect cellular differentiation in plant tissues (Smith and Wood, 1992; Gillaspay *et al.*, 1993) and may largely be sourced in actively growing roots during the later stages of fruit development (Moore-Gordon, 1997), it would make sense that any steps taken to improve root health would have a positive impact not only on restoring a balanced root : shoot ratio (Wareing, 1970), but also on increasing the amount of available CK's.

Moore-Gordon (1997) applied this theory through the application of a pinebark mulch, and found it to be effective in reducing abiotic/biotic plant stress and increasing 'Hass' avocado fruit size. Mulches improve soil organic matter content (Haynes, 1980) and so soil structure and porosity (Gallardo-Laro and Nogales, 1987), and can increase water and nutrient availability (Stephenson and Schuster, 1945; Gregoriou and Raj Kumar, 1984), whilst narrowing the diurnal soil temperature range (Gregoriou and Raj Kumar, 1984; Wooldridge and Harris, 1991). In addition, mulching can contribute mineral nutrients through mineralization (Smith *et al.*, 1995; Wolstenholme and Wilely, 1995) and creates a suppressive environment to *Pc* root pathogen (Turney and Menge, 1994). Pinebark is however an expensive product, resulting in this study partially being done as a follow-up on the work done by Moore-Gordon (1997) using a much cheaper filtercake mulch. Filtercake has an inherently



high nutritional status for a mulch and is a waste-product of nearby sugarmills in the Kwazulu-Natal midlands, making it much cheaper than pinebark.

In addition,  $K^+$  has been found to play a number of indispensable roles in higher plant cells. These include: forming the principle inorganic constituent of the cytosol (Maathuis and Sanders, 1996); acting as the dominant counterion for the large excess of negative charge on proteins and nucleic acids (Maathuis and Sanders, 1996); being very compatible with the conformational integrity of proteins when present at high concentration due to its low tendency to order water through having a small hydration shell (Franks and Eagland, 1975); causing the activation of a wide range of cytosolic reactions, including some central to intermediary metabolism (Wyn-Jones and Pollard, 1983); contributing vastly to the osmotic pressure of the vacuole and cytosol and therefore cell turgor pressure which endows non-lignified plant cells with their structural rigidity, thereby forming up to 10 % of the total dry weight in plants grown under  $K^+$  replete conditions (Leigh and Wyn-Jones, 1984); affecting changes in the movement of cells and organs in higher plants through its role as a major contributor to turgor movements, allowing for processes such as the opening and closing of stomates to occur through the regulation of large inward and outward  $K^+$  fluxes in the guard cells (Raschke, 1975; MacRobbie, 1987). A study on the reduction of abiotic/biotic plant stress in an attempt to increase fruit size without considering this vital element in some way would therefore be incomplete. Potassium was thus applied at various rates in conjunction with the control, pinebark and filtercake treatments in order to determine what effect this element has on the pheno/physiology and yield of 'Hass' avocado.

Due to the inability of a plant to relocate itself in response to abiotic/biotic plant stresses, its growth and development will be largely determined by its location, and thus clearly root-zone or soil properties, which will ultimately impact on plant and fruit growth. Soil quality and the amelioration thereof by mulching are closely intertwined, and changes in any one factor may impact on one if not all of its properties changing. Couple to this the response of plants to such changes, and it becomes clear that discussing each factor of such a complex interaction in isolation is a very difficult task that will not necessarily provide the correct answers. In order to extract the relevant information in a somewhat clearer way a discussion on the general trends presented in Table 5.1 (page 69) has been performed. Where greater specificity is required the

results will be referred to directly from chapters 3 and 4. All the trends discussed will therefore be referring to Table 5.1 unless otherwise stated. In discussing these general trends it is important to remember from the outset that the main aim of this study was to improve ‘Hass’ avocado fruit size, while rejuvenating tree vigour and maintaining a consistent bearing habit and high yield from year to year.

The highest yields throughout the trial were produced by FC0, FC1, PB1 and C2 trees, with FC0 and FC1 treatments producing significantly less reject fruit than PB1 and C2 treated trees (section 3.2.3). In addition, the mean count size peak for FC0 and FC1 trees was 18 whilst that of PB1 and C2 trees was 22, indicating that the filtercake treated trees produced more larger fruit than the PB1 and C2 trees (section 3.2.2). It was also noted that the FC1 treatment produced the most “efficient” yield of the filtercake treated trees (section 3.2.3). The question to both these sets of results is why?

If we are firstly to consider the pheno/physiological differences between FC0 and FC1 trees it would seem that FC0 trees put more energy into vegetative growth in the form of roots and shoots than did FC1 trees (Fig. 3.1; Table 3.3), possibly resulting in surplus carbohydrates being available for storage through stem thickening in FC1 trees. Since the mean fruit masses (Fig. 3.7) for these two treatments were almost identical, the greater yield “efficiency” in FC1 trees had to have been through producing a lower number of reject fruit (Fig. 3.11) from an overall reduced yield compared to FC0 trees. It would seem that the higher vegetative growth observed in FC0 trees competed with developing fruit for assimilates to the detriment of fruit size and carbohydrate storage. It is therefore likely that the additional K in FC1 trees caused a reduction in vegetative growth in both roots and shoots, thereby still maintaining a root : shoot ratio almost identical to FC0 trees (Table 3.4), while allowing surplus assimilates to be used in fruit growth and carbohydrate storage.

In the case of PB1 and C2 trees, it is clear that although almost identical percentages of their total yield fell into the reject range, PB1 trees yielded higher than C2 trees (Fig. 3.11). This means PB1 trees yielded more larger fruit than C2 trees whilst producing the same percentage rejects. The reasons for this seem to be twofold. Firstly, the high K application rate in C2 may have caused a prioritisation of assimilates toward stem thickening (carbohydrate storage) (Fig.

3.3) to the detriment of root growth, as was the case for all 5.0 kg K treatments (Table 3.3). Nevertheless, C2 shoot growth remained high and a low root : shoot ratio ensued. To some extent this lower root : shoot ratio was beneficial, since surplus assimilates were evidently available for storage and fruit fill. The trade-off to this however is a lower ability to take-up water and nutrients from a root-zone environment already depleted in water content (Fig. 4.1), resulting in a reduced yield. Lahav and Kalmer (1977) report similar results of a 50 % reduction in yield in response to water stress in terms of increased irrigation intervals in 'Hass' avocado, and found the largest fruit to occur under the highest water regimes and smallest fruit to occur under the lowest water regimes. In addition, it is possible that high levels of K (Fig. 3.6) begin to compete with other elements such as nitrogen (N) for uptake over a now reduced root surface area. Importantly, this yield was still very respectable at a mean of 12.7 tons ha<sup>-1</sup> (Fig. 3.11), while producing a significantly lower percentage of reject fruit than the C0 and C1 treated trees. PB1 trees on the other hand maintained a root : shoot ratio identical to FC0 trees and very similar to FC1 trees (Table 3.4), but did so under less stable root-zone conditions with a lower water and inherent nutrient content than filtercake treated trees (Figs. 4.1 - 4.3). Although this allowed PB1 trees to sustain a higher yield than C2 trees, root-zone stress was still not minimised to the same extent as in FC0 and FC1 treated trees.

Some of these trends are more clearly defined when the lower yielding treatments of C0, C1, FC2, PB0 and PB2 (section 3.2.3) are considered. Of these, FC2 trees produced the highest saleable yield (Table 3.7) and so lowest percent reject fruit (Fig. 3.11), with a count size distribution that peaked at count size 18. This indicates that although the overall yield was reduced at the 5.0 kg K rate in filtercake treated trees, abiotic/biotic plant stress did not occur to any extent that compromised fruit size. Furthermore, evidence of surplus assimilates being available for fruit growth is given by the fact that the stem circumference increase was high for FC2 trees, showing that there were no physiological needs for these assimilates in overcoming any abiotic/biotic plant stresses. This is a similar response to that noted for C2 trees, where the high K application rate seemed to cause a prioritisation of assimilates toward stem thickening (carbohydrate storage) (Fig. 3.3) to the detriment of root growth. However, since a high water content status existed in FC2 tree root-zones, it is likely that the reduced root : shoot ratio would only have impacted through a lower nutrient uptake, resulting in a reduced yield. This could either have occurred due to less root surface area being available for that uptake and/or



through K competing with other elements for uptake due to its level of saturation in the root-zone (Fig. 3.6). Furthermore, this may suggest that K is playing a major role in counteracting the effects of N additions, resulting in reduced vegetative growth.

A similar trend is evident in PB2 trees, where the 5.0 kg K application again produced a high stem circumference increase to the detriment of root growth, resulting in a low root : shoot ratio. Since root-zone conditions were however less stable (Figs. 4.2 and 4.3) and the pinebark mulch retained a lower water content (Fig. 4.1) than filtercake, a combination of a reduced yield and increase in reject fruit percentage occurred due to the higher level of abiotic/biotic plant stress. Nevertheless, this resulted in a significantly reduced yield with more reject fruit than in C2 trees. A possible explanation for this lies in the fact that shoot growth in PB2 trees was significantly greater than C2 trees (Fig. 3.2), possibly compounding the abiotic/biotic plant stress by competing with developing fruit for already limited water and nutrients, resulting in a large number of setting or set fruit being abscised, whilst the strongest sinks in terms of remaining fruit were able to take advantage of the surplus assimilates for fruit fill. This result indicates that it is hugely disadvantageous to partially release stress within a complex pheno/physiological system such as exists in the 'Hass' avocado. A partial release of stress is likely to "unbalance" a stressed but "balanced" system, resulting in pheno/physiological changes that impact negatively on the tree and fruit growth and yield.

The C1 treated trees produced the least "efficient" yield of all treatments through bearing a large number of reject fruit within an already reduced crop (Table 3.7). When considering the reasons for this, it is immediately evident that the root : shoot ratio in C1 trees was significantly greater than for any other treatments (Table 3.4). It would seem then that a high level of abiotic/biotic plant stress within the root-zone due to unstable temperatures and a low water and/or nutrient content status resulted in a large proportion of assimilates being partitioned toward root growth, to the detriment of shoot and fruit growth and yield. A similar trend is also evident in C0 trees, where a very high but somewhat lower root : shoot ratio than C1 trees seemed to allowed for a greater proportion of assimilates to be partitioned toward shoot growth and stem circumference increase, thereby producing a slightly higher yield with less reject fruit than in C1 trees. A further alleviation of this same abiotic/biotic plant stress response is apparent in PB0 trees, where a fairly high root : shoot ratio (Table 3.4) is again an

indication of unfavourable root-zone conditions existing, but to a lesser extent than was the case for C1 and C0 treated trees, resulting in an improved yield (Fig. 3.11) but not reject fruit percentage in comparison to C0 trees.

Responses of plants in this manner to abiotic/biotic plant stress are not unique. According to Thornley (1977), any organ has the potential to function either as a source or a sink. The source-sink status of that organ at a given time will depend upon its internal composition and environmental stress status at that time. In accordance with this, the underlying principle is one of the tree attempting to overcome the most growth limiting factor by partitioning assimilates and resources to the limited region. Fiscus and Markhart (1979) found that under mesic conditions *Phaseolus* plants produced new conductive root tissue roughly in proportion to leaf tissue, but that under dry soil conditions, the root growth was far greater than the aerial vegetative growth. Whiley (1994) cited Kozlowski *et al.* (1991) as showing that during times of soil water or nutrient depletion, assimilates and more specifically carbon are allocated preferentially to the roots rather than the shoots increasing the root : shoot ratio, whilst stress alleviation by irrigation or fertilisation resulted in the opposite being true (Ledig, 1983; Axelsson and Axelsson, 1986). Ledig (1983) also noted that a reduced photosynthetic photon flux may be followed by a greater allocation of carbon to shoots than roots thus decreasing the root : shoot ratio. Furthermore Cannell (1989) reported that an improvement in mineral nutrition was seen to decrease the rate of turnover of fine roots and promote shoot growth in trees. This indicates that under sub-optimal root-zone conditions the plant is reducing the aerial vegetative growth and putting more “energy” into root growth in order to find enough water and/or mineral nutrients to sustain it.

From observations made in the field regarding root and canopy health in terms of the proportion of white feeder roots present and canopy density, the author noted no visual evidence that *Pc* was affecting filtercake treated trees detrimentally as a result of its high water content (Fig. 4.1). The filtercake mulch teemed with macrofauna such as earthworms and beetles, and it is likely that this ecological system would have included many microflora and fauna, which as a whole may have formed a very suppressive environment to *Pc* fungal growth. This is no surprise, as filtercake dressings have been shown to improve sugarcane yields by partially eliminating nematodes and aluminium toxicity, whilst increasing the number of

beneficial microbes (Alexander, 1971). The mechanisms of root disease and nematode control by mulching have been discussed in depth by Turney and Menge (1994). These include increased populations of soil microorganisms which compete with or inhibit fungal pathogens; the production of *Pc* inhibitory volatiles such as ammonia and nitrite, and toxins such as saponins and organic acids; encystment of *Pc* zoospores by organic matter; increased host resistance by induced phytoalexin production; and an improved root growth environment in terms of aeration, drainage and soil temperature not suitable for *Pc* survival.

From an overall perspective, it would seem then that too much vegetative growth in roots and shoots results in vegetative-reproductive competition for assimilates, which affects yield “efficiency” by resulting in a higher number of small or reject fruit. In retrospect, too little vegetative growth results in reduced yields, although not necessarily through a reduction in fruit size. Also, too low a root : shoot ratio results in a reduction in the number of fruit the tree can support, and in cases where K has not been applied in sufficient quantities, an increase in the percentage of reject fruit. This is particularly the case in unmulched trees, where a lower soil water content compounds the stress of having fewer roots for water and nutrient uptake. K could therefore be a very important manipulative tool in regulating vegetative growth by counteracting the effects of N additions, resulting in more controlled vegetative growth. On the other hand, too high a root : shoot ratio resulting from root-zone stress impacts negatively on both total yield and fruit size through requiring a high percentage of assimilates that would otherwise be used in shoot and reproductive growth. In addition, a high water content within the soil profile is imperative if tree stress is to be minimized. This is achievable through a mulch application, which not only reduces water stress, but improves the soil physical properties and seemingly provides a highly antagonistic environment to *Pc* in the case of filtercake.

Further studies using filtercake should be done to try and quantify more clearly the root-zone conditions that this mulch is bringing about. These could include a measure of oxygen and carbon dioxide within the root-zone as well as possible tracer studies to determine to what extent if any the mulch is changing the root-depth-distribution of the tree, and to what extent roots at different depths are contributing to the various physiological organs, and in what manner. In addition, a measure of both soluble and insoluble sugar fractions within the trunk bark and possibly leaves will provide a clearer understanding of the seasonal fluctuations in

carbohydrate levels in response to mulching and K additions. It would also be vastly beneficial to determine the optimal K : N ratio for maximum fruit growth and yield, and to what extent increasing the K content affects N uptake and/or utilisation and carbohydrate allocation within the tree.

Futhermore, the measure of water content used in this study should be quantified in terms of soil matric potential, as this will provide a better benchmark for irrigation regimes both with and without the use of mulches. A study on the biological activity within filtercake and the suppressiveness of this mulch to *Pc* through such activity and its inherent organic properties would also be invaluable in determining to what extent water content within the soil and mulch may be increased to minimize water stress, without increasing populations of this fungus.

**Table 5.1 A summary of results from chapter three and four. The following symbols have been used: ↑ for High; ↔ for Intermediate and ↓ for low.**

Fig. #	Treatment	C0	C1	C2	FC0	FC1	FC2	PB0	PB1	PB2
3.1	Canopy Extension	↑	↓	↑	↑	↔	↑	↔	↑	↑
3.2	Vegetative Shoot Flush	↔	↓	↑	↑	↔	↑	↔	↔	↑
3.3	Stem Circumf. Increase	↔	↓	↑	↔	↑	↑	↔	↔	↑
3.4	Root Growth	↑	↑	↓	↑	↔	↔	↑	↑	↔
3.5	Root/Shoot Ratio	↑	↑	↓	↔	↔	↓	↔	↔	↓
3.6	Mean Leaf K Concentration	↔	↔	↑	↔	↑	↑	↔	↑	↑
3.7	Mean Fruit Mass	↓	↓	↔	↑	↑	↑	↔	↑	↔
3.8 to 3.10	Mean Count Size Peak	22	22	22	18	18	18	22	22	22
3.11	Mean Total Yield	↔	↓	↑	↑	↑	↔	↔	↑	↔
3.11	Mean Reject Fruit %	↑	↑	↔	↓	↓	↓	↑	↔	↔
4.1	Volumetric Water Content	↓	↓	↓	↑	↑	↑	↔	↔	↔
4.2 & 4.3	Root Zone Temperature	↓	↓	↓	↑	↑	↑	↔	↔	↔

## SUMMARY AND CONCLUSIONS

The 'Hass' avocado is preferred by overseas consumers due to its excellent internal keeping quality and superior taste, thereby providing local farmers with an opportunity to potentially earn a premium price for their product in foreign currency. 'Hass' trees however bear a large number of unacceptably small fruit, which are often randomly interspersed with large fruit on the same flowering stem of what looks like a healthy tree. The problem seemingly increases under stressful growing conditions and with increasing tree age, and is particularly noticeable in orchards situated in warmer and/or drier climates.

Mulching with filtercake minimised this stress, through providing a climatically stable root-zone environment that was high in nutrient and water content and seemingly suppressed *Pc*. This resulted in a significant two-count increase in fruit size for filtercake treated trees compared to pinebark and control trees, and a 4.98 ton ha<sup>-1</sup> increase in saleable fruit through a 5.79 ton ha<sup>-1</sup> yield increase that contained 16.4 % less reject fruit than control trees.

Mulching with pinebark also reduced tree stress and increased saleable yield compared to control trees, but was not as effective as filtercake in doing so due to its much lower nutrient and water content, and resultant less stable root-zone environment.

A potassium deficient situation existed prior to trial implementation, at least partially giving rise to some of the observed responses of trees to K additions. Nevertheless, the 5.0 kg K application played a key role in improving yield and to some extent fruit size in control trees, but significantly reduced yield in both filtercake and pinebark treated trees. A 2.5 kg K application was however beneficial in improving yield in filtercake and pinebark treated trees, with FC1 trees producing the most "efficient" yield of all treatments. The opposite was true for C1 trees, which produced the lowest yield of all treatments as well as the highest reject fruit percentage, indicating that a partial release of stress is extremely detrimental to the pheno/physiological balance that exists within a tree, even if that tree is stressed.

When looking at reasons for the best yielding treatments of FC0, FC1, PB1 and C2 performing so well, one of the most important factors to consider is the root : shoot ratio, and the amount of vegetative growth each parameter contributes toward that ratio. In considering these factors, the best mean annual root : shoot ratio approximates 0.32, with an annual mean white feeder root growth of 33 % to 38 %, but never exceeding 65 %, and an annual mean shoot growth approximating 100 mm. In addition, a mean annual leaf K content of approximately 1 % should be maintained, if fruit size and yield are to be maximized. Whilst this falls within industry norms, it is important that this level of leaf K content is maintained throughout all months of the year, and not simply achieved during a single leaf analysis.

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## APPENDICES

**Appendix 1 Long term rainfall data (mm) for Cooling farm over 35 years.**

<b>Year</b>	<b>Jan</b>	<b>Feb</b>	<b>Mar</b>	<b>Apr</b>	<b>May</b>	<b>Jun</b>	<b>Jul</b>	<b>Aug</b>	<b>Sep</b>	<b>Oct</b>	<b>Nov</b>	<b>Dec</b>	<b>Total</b>
1964	245	28	103	72	76	0	31	8	63	86	52	69	833
1965	62	0	49	40	39	163	19	69	49	92	153	89	824
1966	163	104	45	52	66	0	2	35	34	68	122	75	766
1967	183	139	188	100	31	9	25	0	8	81	107	69	940
1968	198	74	135	26	4	0	0	0	43	59	95	114	748
1969	89	79	211	48	66	31	38	3	55	140	67	95	922
1970	67	85	51	19	39	28	3	32	112	143	78	105	762
1971	75	143	111	65	121	30	20	63	37	58	46	132	901
1972	156	166	39	29	45	8	5	12	5	61	109	72	707
1973	148	90	87	77	0	0	9	0	149	152	83	68	863
1974	251	65	128	44	70	80	3	14	6	27	105	106	899
1975	142	143	55	68	25	0	0	6	157	46	110	116	868
1976	233	173	242	40	24	0	7	24	58	152	83	84	1120
1977	208	104	190	19	0	0	0	46	52	79	115	58	869
1978	230	126	123	135	7	2	0	34	87	110	111	130	1095
1979	139	101	59	27	35	0	41	31	38	70	109	107	757
1980	88	45	26	33	19	0	3	11	181	46	150	66	668
1981	71	51	18	64	26	9	60	62	62	46	112	58	639
1982	89	66	145	55	7	7	5	5	36	128	77	104	724
1983	70	51	64	20	31	8	31	31	32	83	182	115	718
1984	184	302	74	139	16	24	21	37	12	116	103	70	1098
1985	145	166	78	0	0	9	21	0	31	139	104	126	839
1986	85	55	158	31	31	0	0	29	28	111	87	175	790
1987	96	129	167	41	16	64	15	56	63	50	87	71	1425
1988	113	284	181	46	45	0	15	18	13	76	104	124	1019
1989	66	288	44	50	25	28	0	0	25	87	232	78	923
1990	74	78	154	49	15	0	0	85	23	150	58	189	875

<b>1991</b>	133	141	136	18	46	12	18	17	81	126	68	90	884
<b>1992</b>	107	77	45	36	0	0	14	19	29	60	84	61	532
<b>1993</b>	60	89	87	35	10	0	0	29	49	109	94	207	769
<b>1994</b>	135	32	192	41	10	0	55	54	4	97	30	141	791
<b>1995</b>	49	30	154	77	29	63	8	13	9	90	151	249	922
<b>1996</b>	169	249	172	51	21	8	178	16	10	97	91	63	1125
<b>1997</b>	145	77	81	108	36	107	23	19	68	100	154	97	1015
<b>1998</b>	142	183	72	25	48	4	2	29	31	78	133	157	904
<b>Total</b>	4608	4033	3864	1780	1079	694	672	907	1740	3213	3644	3730	29964
<b>Mean</b>	131	115	110	51	31	20	19	26	50	92	104	107	856
<b>Max.</b>	251	302	242	139	121	163	178	85	181	152	232	249	1125
<b>Min.</b>	449	0	18	0	0	0	0	0	4	27	30	58	532



**Appendix 2a Soil analysis for trial prior to trial implementation (21/05/1996). Analysis conducted in the laboratory of the department of agriculture, Cedara, Kwazulu-Natal.**

Sample Type	Sample Density (g/mL)	P (mg/L)	K (mg/L)	Ca (mg/L)	Mg (mg/L)	Zn (mg/L)	Acidity (Al+H) (CMol/L)	Total cations (CMol/L)	Acid Sat. (%)	pH (KCl)	NIRS Organic Carbon (%)
Topsoil	1.03	6	101	494	160	2.1	1.03	5.08	20	4.17	2.8
Subsoil	1.07	1	39	362	146	0.8	1.61	4.72	34	4.06	2.9

**Appendix 2b Soil analysis norms for avocado (SAAGA, 1990).**

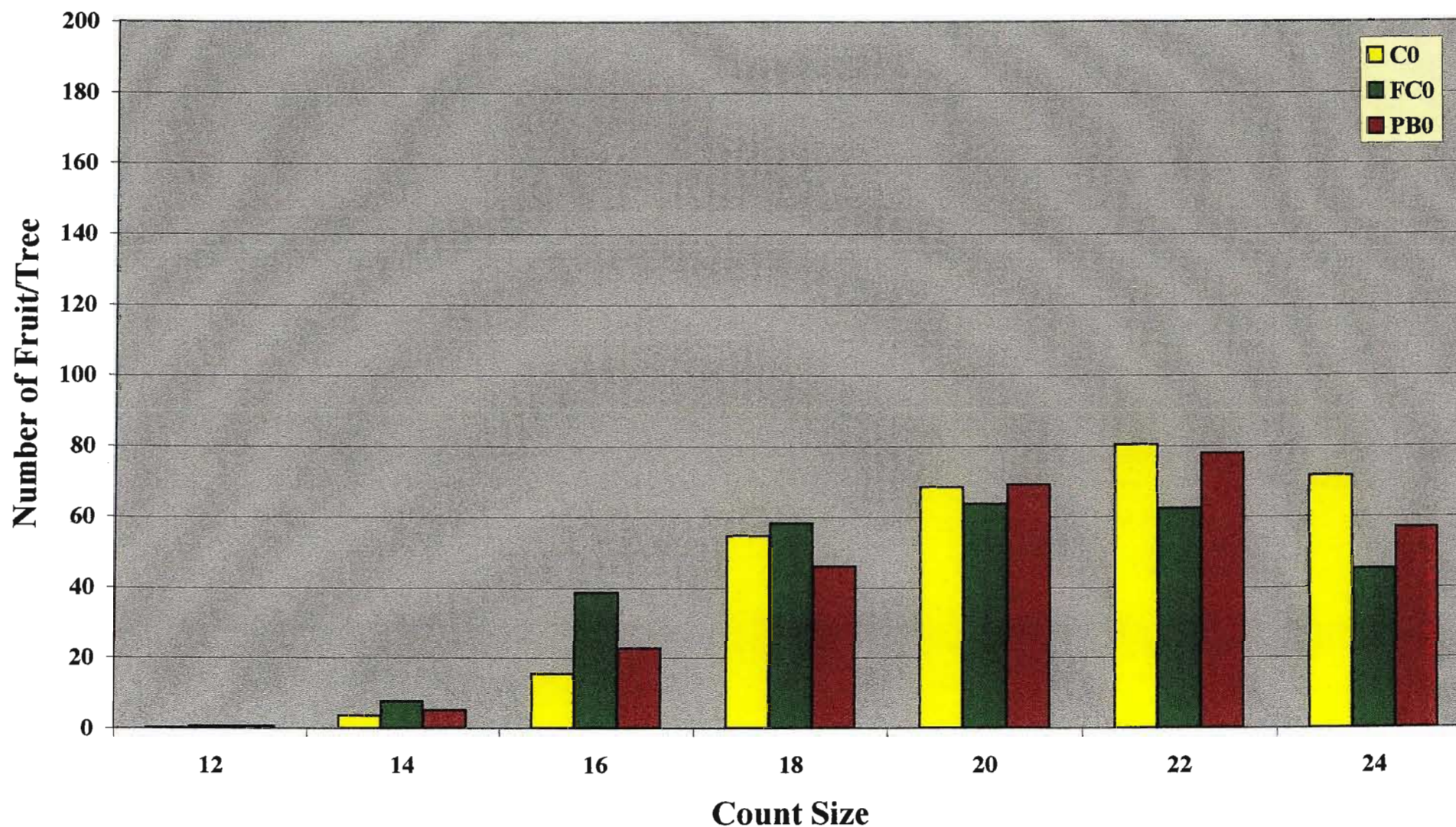
P (mg/L)	K (mg/L)	Ca (mg/L)	Mg (mg/L)	Acid Sat. (%)	pH (KCl)
8 - 27	150 - 250	750 - 1000	100 - 300	0 - 30	5.5 - 6.5

**Appendix 3a Leaf analysis for trial prior to implementation (21/05/96).**

N (%)	Ca (%)	Mg (%)	K (%)	Na (%)	P (%)	Zn (mg kg <sup>-1</sup> )	Cu (mg kg <sup>-1</sup> )	Mn (mg kg <sup>-1</sup> )	B (mg kg <sup>-1</sup> )
1.74	0.92	0.74	0.65	0.05	0.16	41	221	219	28

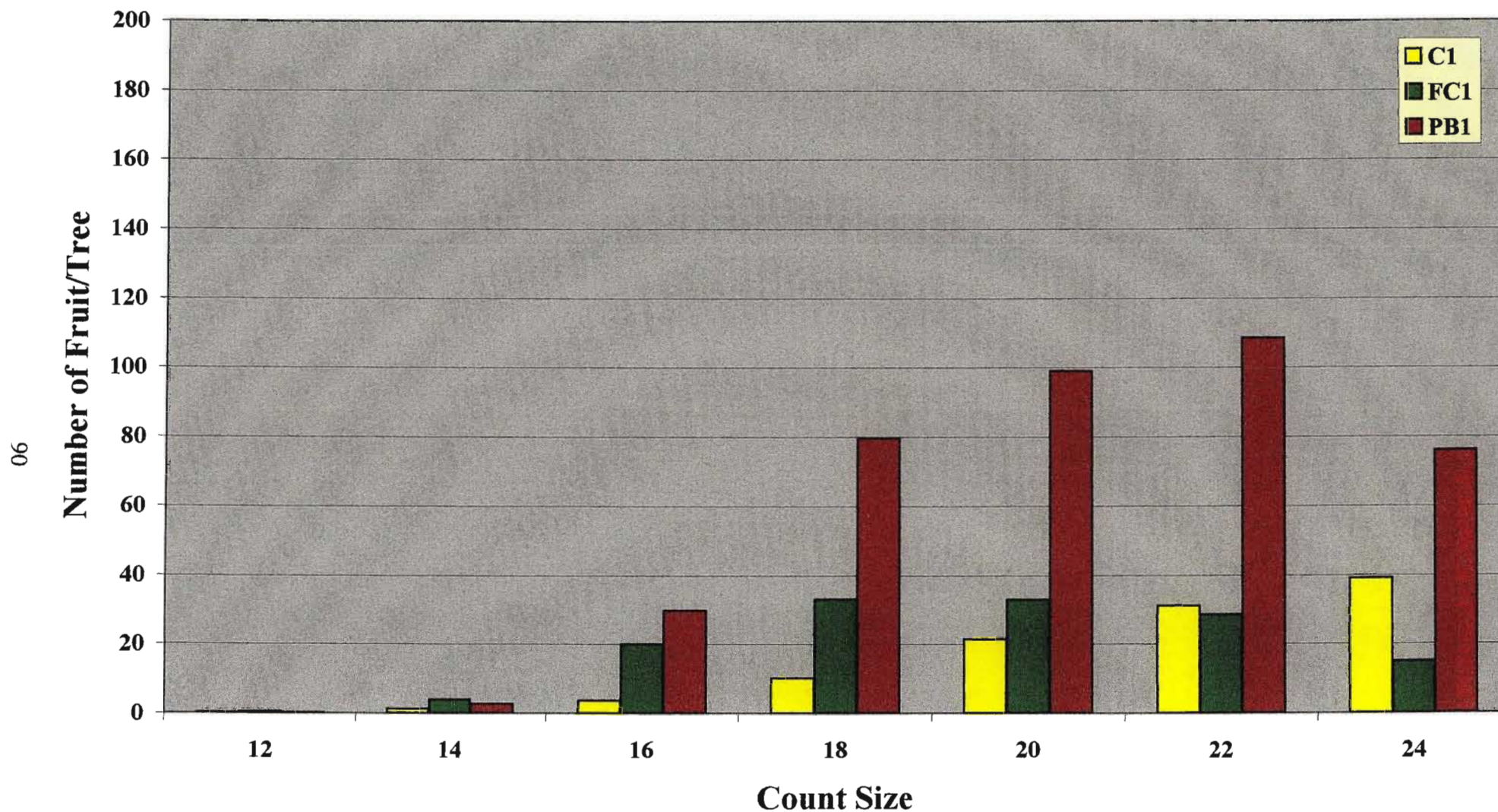
**Appendix 3b Leaf analysis norms for avocado (SAAGA, 1990).**

N (%)	Ca (%)	Mg (%)	K (%)	Na (%)	P (%)	Zn (mg kg <sup>-1</sup> )	Cu (mg kg <sup>-1</sup> )	Mn (mg kg <sup>-1</sup> )	B (mg kg <sup>-1</sup> )
2.20 - 2.40	1.00 - 2.00	0.40 - 0.80	0.75 - 1.25	0.01 -0.06	0.08 - 0.15	25 - 100	5 - 15	50 - 250	50 - 80



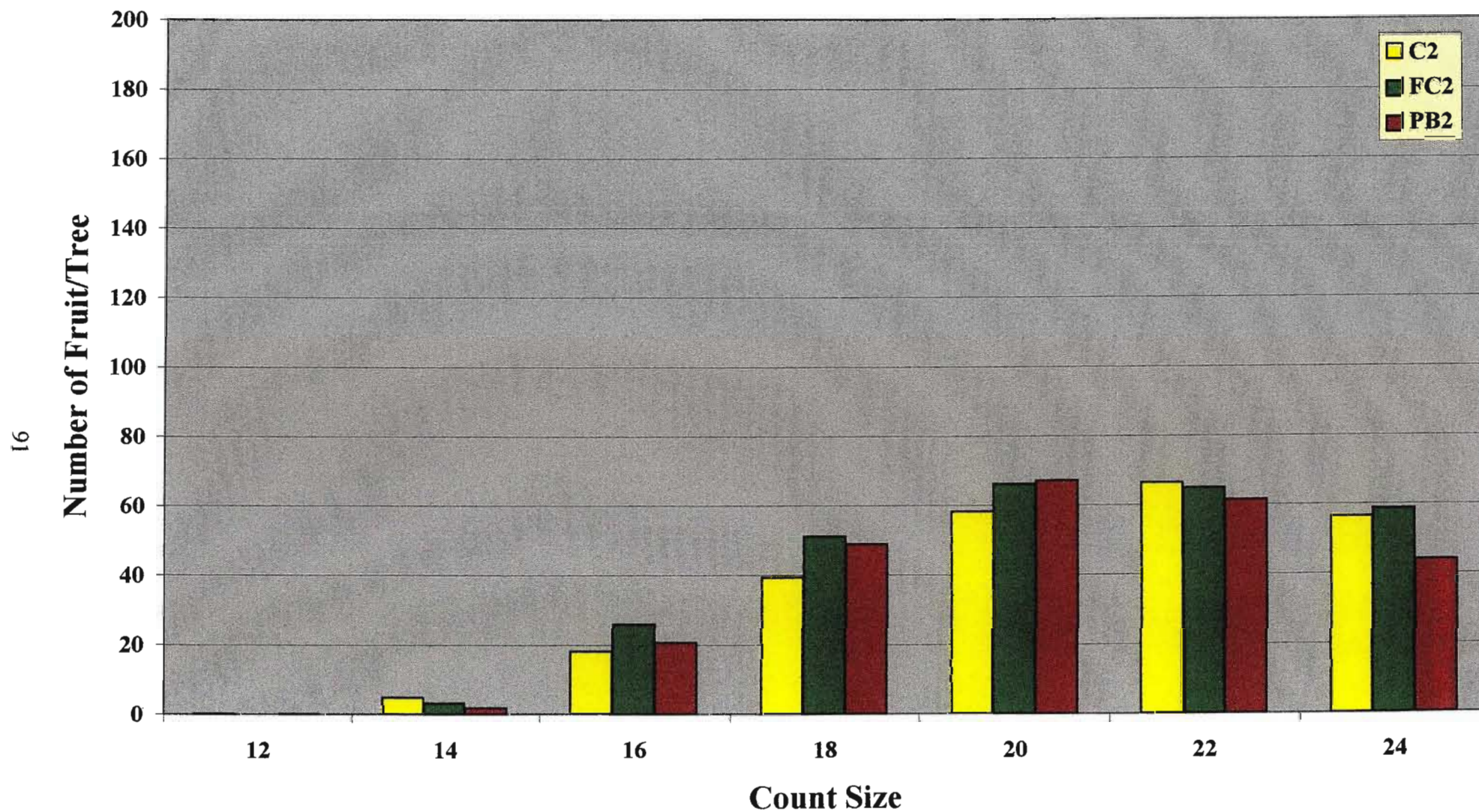
**Appendix 4a Mean zero K rate count size distribution for the 1997 harvest. Values are means of eight trees. SE (diff) = 12.42.**





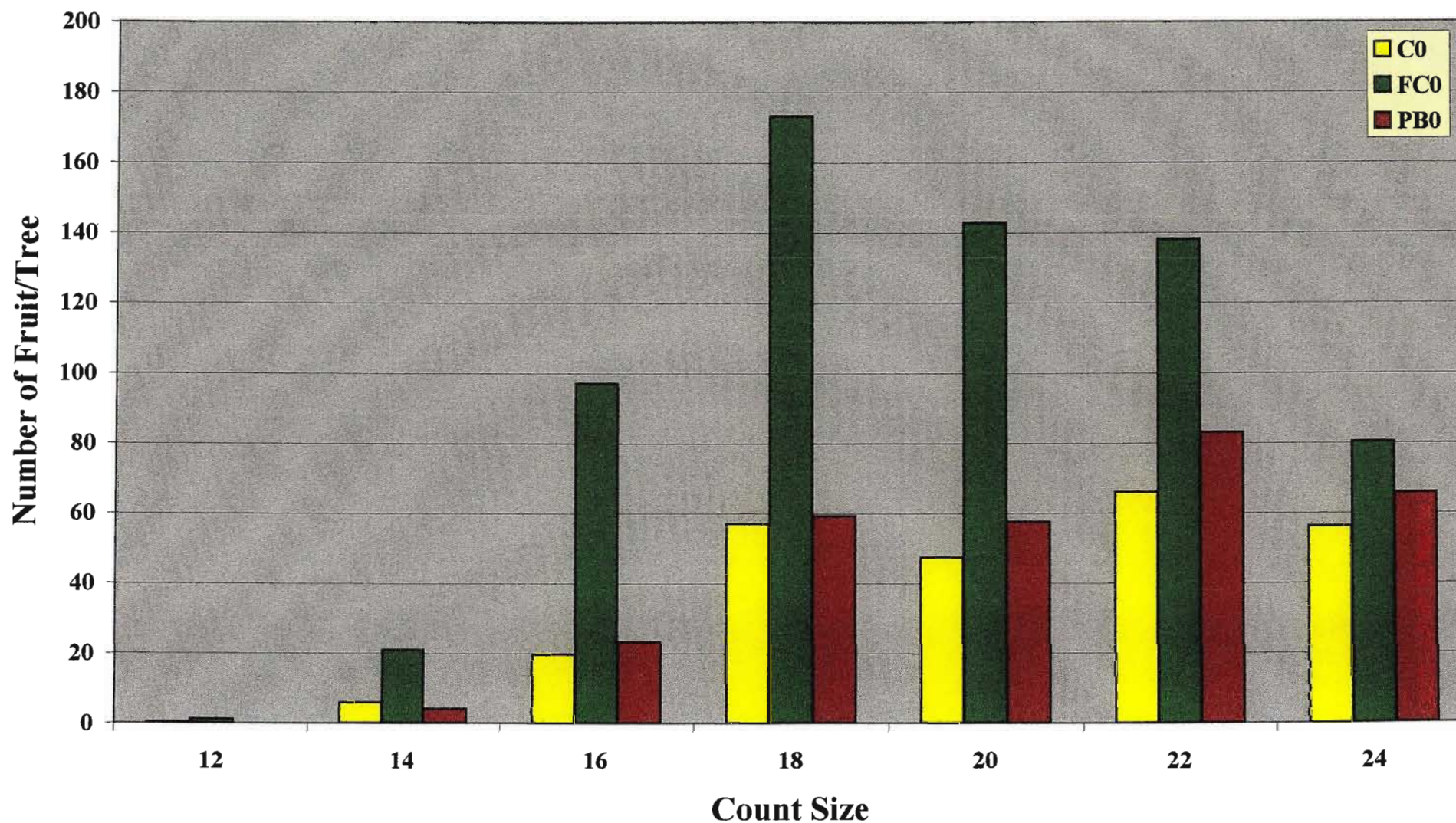
**Appendix 4b Mean 2.5 kg K rate count size distribution for the 1997 harvest.**  
**Values are means of eight trees. SE (diff) = 14.20.**





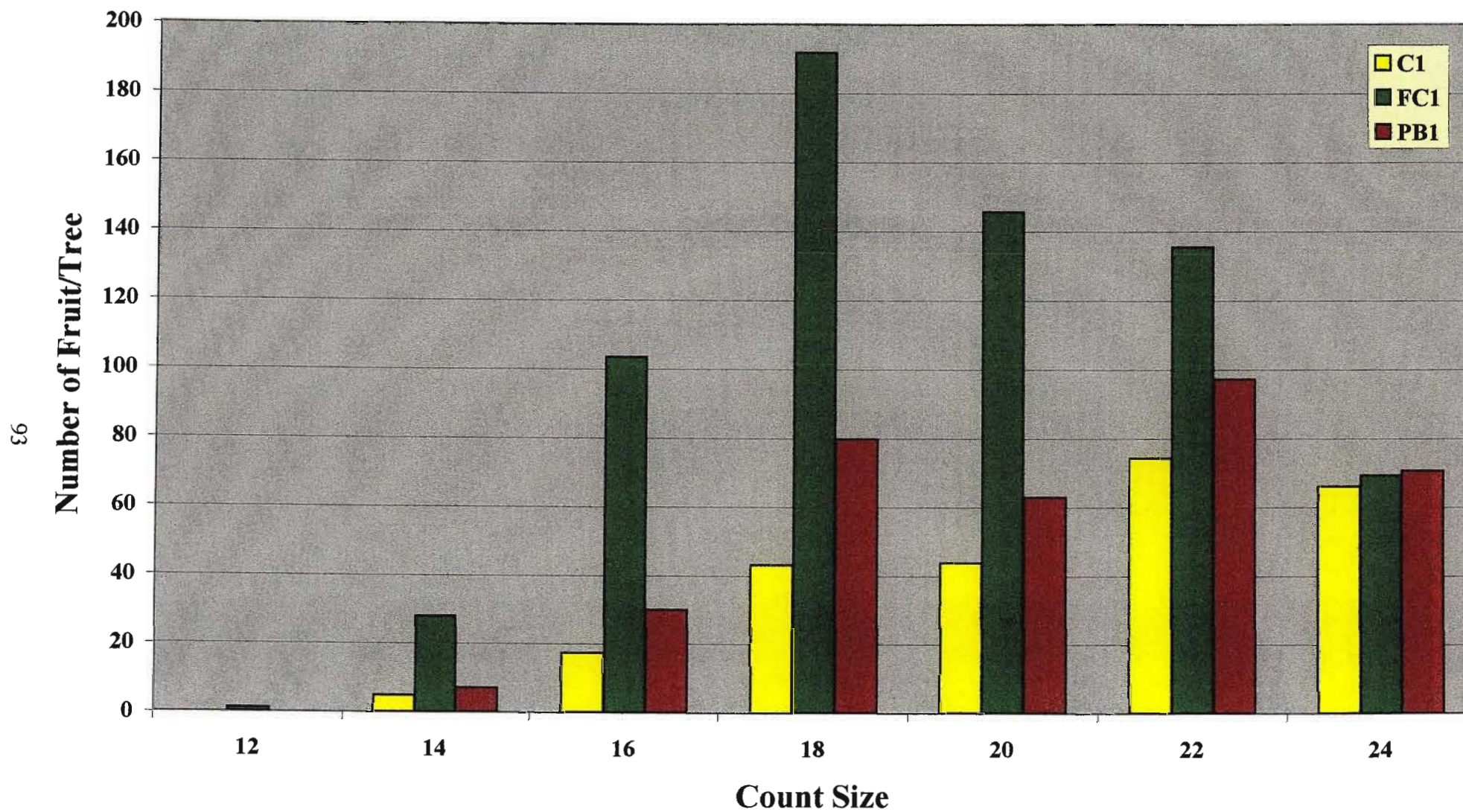
**Appendix 4c Mean 5.0 kg K rate count size distribution for the 1997 harvest.**  
Values are means of eight trees. SE (diff) = 11.27.





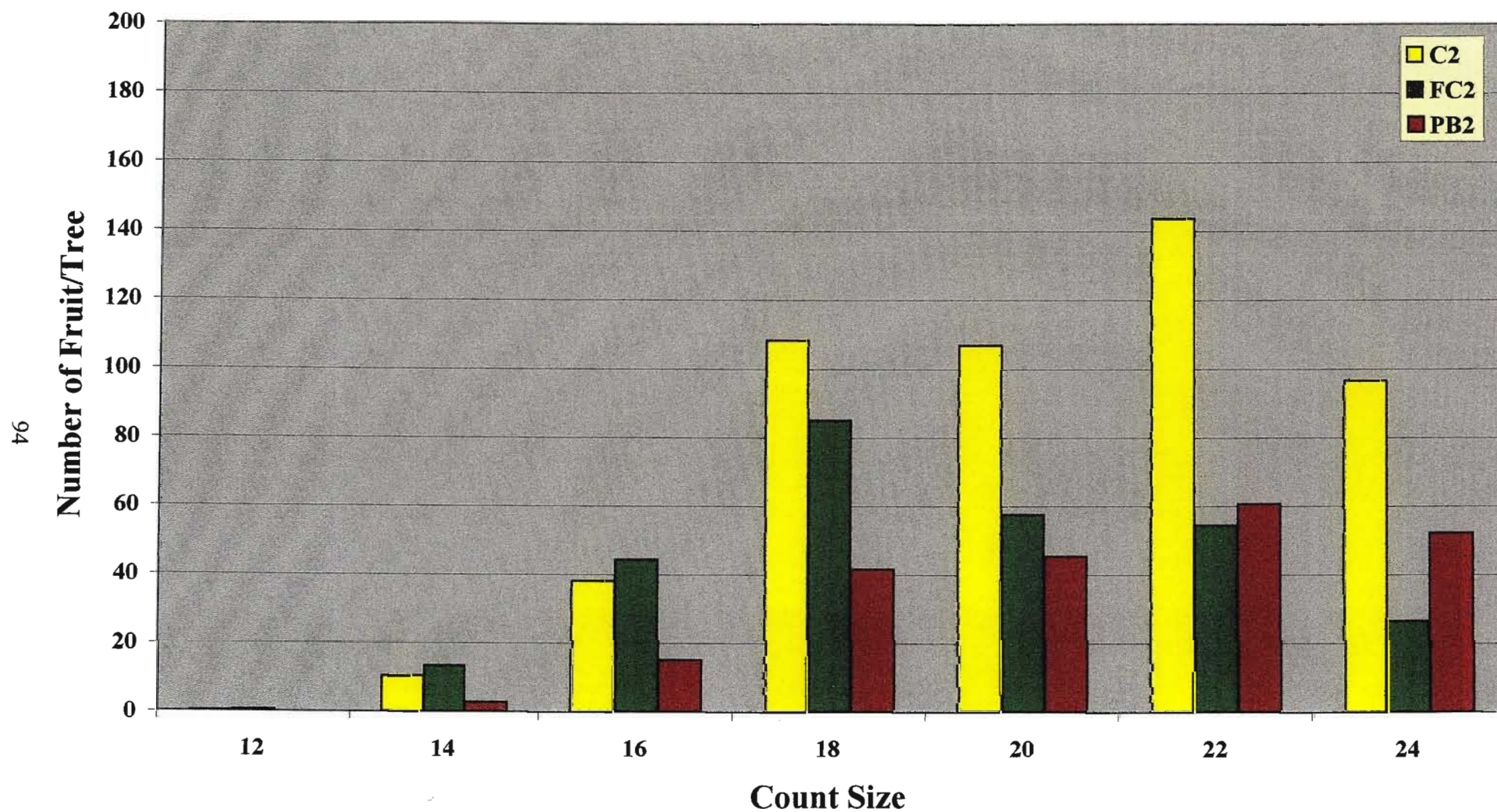
**Appendix 4d Mean zero K rate count size distribution for the 1998 harvest.**  
Values are means of eight trees. SE (diff) = 21.25.





**Appendix 4e Mean 2.5 kg K rate count size distribution for the 1998 harvest.**  
Values are means of eight trees. SE (diff) = 22.50.





**Appendix 4f Mean 5.0 kg K rate count size distribution for the 1998 harvest.**  
**Values are means of eight trees. SE (diff) = 17.51.**

**Appendix 5 Paper(s) published.**

# Mulching and Potassium Relationships in Hass Avocados to Increase Yield and Fruit Size

W van Niekerk, B N Wolstenholme, MA Johnston

Horticultural Science, School of Agricultural Science and Agribusiness, University of Natal, Private Bag X01, Pietermaritzburg 3209

## ABSTRACT

The Hass cultivar is important to the South African avocado industry as it is preferred by consumers, and is late maturing so filling a niche market overseas. Hass yields, although higher than most other cultivars, are still unacceptably low and a high percentage of fruit are too small to fetch good prices. The application of a thick composted filterpress mulch was investigated as an alternative to composted pinebark, as a strategy to help alleviate stress and increase yield and fruit size. In addition, the effect of potassium on the biennial bearing habit and mean yield of trees was investigated. Trees were evaluated over two years (three harvests) for: yield, fruit size, shoot growth, root growth, root zone temperature, root zone water content, leaf nutrient level, stem circumference and canopy diameter. Average fruit mass from mulched trees increased, whilst number of reject (small) fruit decreased, with a less pronounced biennial bearing pattern being evident when compared to controls. Trees mulched with filterpress produced higher yields and fruit size than all other treatments. Application of 5 kg potassium to trees mulched with filterpress showed a reduced yield but improved fruit size. Addition of 5 kg potassium to unmulched trees significantly increased yield and reduced the number of reject (small) fruit by 13%.

## INTRODUCTION

The Hass avocado is preferred by overseas consumers due to its excellent internal keeping quality and superior taste. It is furthermore important to the South African avocado industry as it is late maturing and so fills a niche market locally and abroad. It is common knowledge that Hass trees bear a large number of unacceptably small fruit (Kremer-Köhne & Köhne, 1995). The poor consumer acceptance of these small fruit (Moore-Gordon *et al.*, 1997) in a predominantly export orientated market (Cutting, 1993) causes considerable financial losses, estimated to be over R30 million in 1994 (Moore-Gordon and Wolstenholme, 1996).

The problem seemingly increases under stressful growing conditions (Moore-Gordon and Wolstenholme, 1996) and with increasing tree age. The long-term solution to this problem lies in one of two strategies, i.e. to find

the physiological mechanism for the random development of small fruit and thereby manipulate the tree through the application of growth regulators or hormones, or to breed new large-fruited black-skinned cultivars. Both "processes" are time-consuming and so an interim amelioration of the problem through mulching with pinebark has been suggested in the short-term (Moore-Gordon *et al.*, 1997). The benefits derived from mulching include increased water and nutrient availability (Gregoriou & Rajkumar, 1984), improved soil structure and porosity (Gallardo-Laro & Nosgales, 1987) and a narrowing of the diurnal soil temperature range (Gregoriou & Rajkumar, 1984). In addition, mulching creates a suppressive environment to the *Phytophthora cinnamomi* root rot fungus, therefore reducing the impact of this phytopathogen (Turney and Menge, 1994). On the whole mulching promotes a healthier, even root growth

that not only ameliorates stressful conditions for the roots, but ultimately alleviates stressful growing conditions for the tree as a whole. The highly beneficial effect of mulching with composted pinebark, in both 'Hass' fruit size and especially yield, has been summarized by Moore-Gordon *et al.* (1997).

The current project was commissioned by Mr Werner Seele of 'Cooling' farm, Bruyns Hill, primarily to test the viability of using sugarcane filterpress or filtercake as an alternative mulch to composted pinebark. Pinebark is an expensive mulch, whilst filterpress, which is a wasteprodukt of the sugar milling process, is often allocated free of charge to a specified tonnage. Transport to the farm however, is an additional cost. Mr Seele also noted that whenever a large crop had been harvested in the current season, a corresponding large loss of potassium occurred due to removal of the fruit. This was followed by low leaf potassium levels the following season, with an associated loss in yield. Leaves in the following season would again have sufficiently high potassium levels, and a resultant high yield. Mr Seele therefore requested that a potassium trial be superimposed on the mulching trial to determine whether extra potassium additions would have a beneficial effect on fruit size, yield and the alternate bearing habit of the trees.

## MATERIALS AND METHODS

### Treatments

The study was conducted at Cooling farm (Mr W.P. Seele) near Bruyns Hill in the KwaZulu-Natal midlands. A block of 72 eight-year-old Hass trees

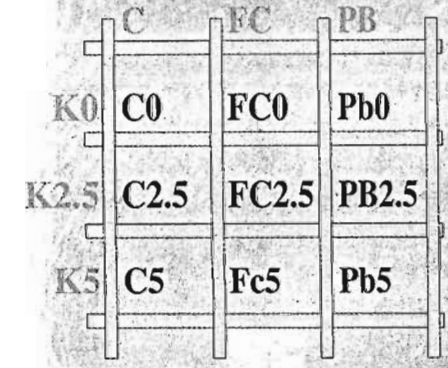




(in 1996) on clonal Duke 7 rootstocks at a planting density of 100 trees ha<sup>-1</sup> were used. The trees are situated on a South-East facing slope on soils of the Inanda form. Nine treatments were applied (2 trees/treatment/replication) and each was replicated four times (18 trees/replication). All the experimental trees received standard cultural treatment, including weed control and microjet irrigation based on tensiometer measurements.

Treatments are represented as follows:  
 C = Control  
 FC = Filtercake/Filterpress  
 PB = Pinebark  
 K0 = 0 kg Potassium/Tree (K Rate 0)  
 K2.5 = 2.5 kg Potassium/Tree (K Rate 1)  
 K5 = 5 kg Potassium/Tree (K Rate 2)

The experimental design was a 3x3 factorial giving the nine treatments applied to eight trees/treatment.



In figures to follow potassium rates are simply referred to as 0, 1 and 2 (e.g. FC1 instead of FC 2.5).

The filterpress mulch was composted for six months prior to application (in October 1996) of a 100 mm thick layer from tree trunk to canopy drip zone. Composted pinebark (Gromed® coarse potting mix) was applied in a similar fashion. Approximately 2.5 m<sup>3</sup> of mulch/tree was therefore applied. The control trees were left "as is" in the orchard, with the natural leaf litter mulch left undisturbed.

Potassium was applied at rates of 0 kg, 2.5 kg and 5 kg active potassium/tree. Applications were done in two split dressings annually in October 1996 and 1997 and January 1997 and 1998. To prevent "chloride leaf burn" KCl was used in the first season, and K<sub>2</sub>SO<sub>4</sub> in the second season.

**Data collection**

Tree diameter and stem circumferences (above and below the graft union) were measured once a year. Shoot flush was measured at monthly intervals from the beginning to the end of the spring flush, by measuring 10 marked shoots on each tree. No pronounced summer flush was noted. Root growth was monitored by visually rating the area covered by white feeder roots, on a scale of 1 to 10, under a newspaper mulch layer (Whiley et al., 1988) on the south-west side of each tree to avoid direct sunlight (Moore-Gordon et al., 1996). Leaf samples were taken for mineral analysis to determine the levels of potassium and other minerals over the season. At the end of each season fruit was harvested and fruit count size distributions determined gravimetrically, according to the number of fruit per 4 kg export carton.

Fruit was graded as follows:

- Count 10: 366-450 g
- Count 12: 306-365 g
- Count 14: 266-305 g
- Count 16: 236-265 g
- Count 18: 211-235 g
- Count 20: 191-210 g
- Count 22: 171-190 g
- Count 24: 156-170 g

Fruit of count sizes above 24 were regarded as rejects since they were not of an exportable size.

Total tree yield was calculated and all the fruit for each tree were weighed in lug boxes and counted, allowing for average fruit mass for each tree and ultimately each treatment to be determined.

Agrometeorological measurements including air temperature, root zone temperature and root zone water content for each treatment, discussed by van Niekerk, Savage et al. (Paper in preparation) were monitored over a period of approximately 18 months. Thermocouple sensors were used for temperature measurements and were placed at a depth where the mulch or leaf mulch, in the case of the controls, met the soil layer (roughly 70-100 mm).

Thetaprobos (Model ML1 from Delta T, United Kingdom) were used to measure soil water content, and were buried horizontally and inserted into the side-profile at approximately the same depth as the thermocouples. All sensors were connected to a datalogger. Only yield and fruit size data are reported in this paper.

**RESULTS AND DISCUSSION**

Fig.1A and 1B show the average fruit mass for the 1996-1997 and 1997-1998 seasons. It is important to remember the treatments for the 1996-1997 season were only applied in October, which is after floral initiation and fruit set. Control trees produced fruit of 115 g for C0 (Fig.1A), and average fruit mass increased with increasing rates of K. Even so, all fruit were in the above count size 24 category, and hence reject. Nevertheless, this result indicated a potassium deficiency in the orchard, which was verified by orchard soil analyses (data not shown). Control trees produced larger fruit of 151 g for C0 (Fig.1B), with no observable trend in response to rate of K applied. These differences between seasons exemplify the heavy alternate bearing cycle evident in control trees. Without exception, there were significant differences in mean fruit mass between control treatments and filterpress mulch treatments (Fig.1A & 1B). In the field, filterpress treated trees all exhibited renewed vigour through dramatically improved vegetative growth and produced fruit with an average mass of 183 g (Fig.1A) for FC0 and 184 g (Fig.1B) for FC1. However no trend was apparent with an increase in the amount of potassium applied. The lowest rate (FC0) proved to be best in the 1996-1997 season and the intermediate rate (FC1) in the 1997-1998 season, perhaps due to a better nutritional balance/ratio between potassium and the other elements

present in the filterpress on application. Average fruit mass of trees supplied a pinebark mulch was greater than that of the controls (as expected), but not as

high as fruit from trees mulched with filterpress. Again no observable trend was apparent in response to rate of potassium applied. The relatively poorer performance of pinebark mulched trees suggests that the major limiting factor in this trial was nutritional.

For the data presented in the following graphs it is important to note that the relatively high number of reject fruit was not only size related, but also due to an untimely hail storm which damaged approximately 20% of the fruit.

Fig. 2A and 2B show the average count size distribution in 1998 of fruit from trees treated with and without either pinebark or filterpress mulch and increasing rates of potassium application. Control trees show a typical fruit size distribution for the Hass cultivar on Cooling farm with 67% of the fruit in the reject range (Fig. 2A & B). Not only were there fewer fruit on the tree, but a large percentage were small fruit. The count size distribution for fruit from filterpress mulched trees was shifted in favour of larger fruit. The distribution peaks at count size 18 for filterpress, with 173 fruit (Fig. 2A) and 192 fruit (Fig. 2B) respectively. A substantial number of count size 16, (97 fruit in Fig. 2A & 104 fruit in Fig. 2B), 20 and 22 fruit were also found. In addition, a decline in reject fruit from the control percentage of 67% to 51% (Fig. 2A) and 41% (Fig. 2B) is evident for the filterpress.

The 2.5 kg rate of potassium applied to filterpress thereby producing the lowest reject percentage fruit of all treatments. Not only were more fruit produced by trees mulched with filterpress, but they were generally larger. Pinebark mulch-treated trees produced more fruit than control trees but 66% (Fig. 2A) and 63% (Fig. 2B) of these fruit were in the reject range. In the authors opinion this is largely due to the fact that 1997/8 was a dry season and pinebark often becomes even drier under these conditions thereby limiting root proliferation in the surface layer of the mulch and further disadvantaging the tree from a nutritional point of view. No significant

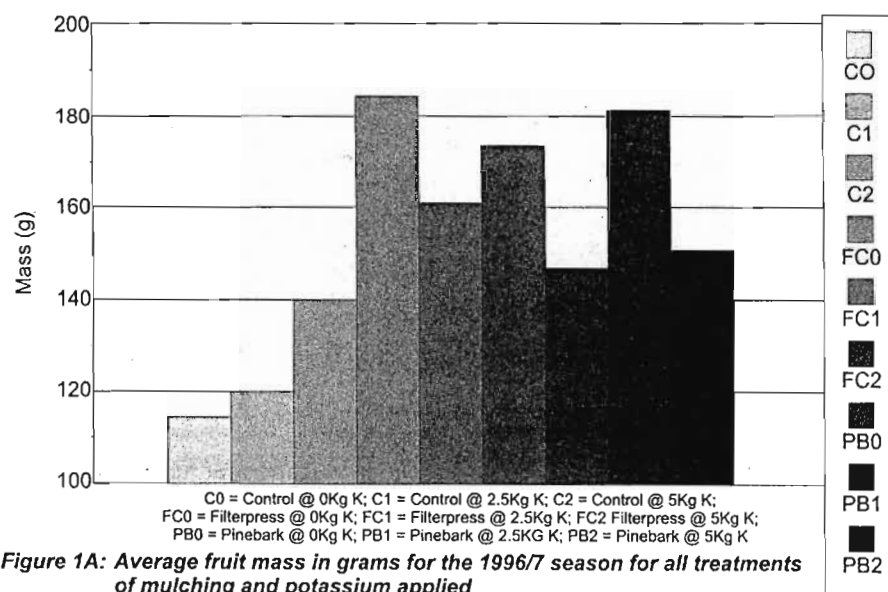


Figure 1A: Average fruit mass in grams for the 1996/7 season for all treatments of mulching and potassium applied

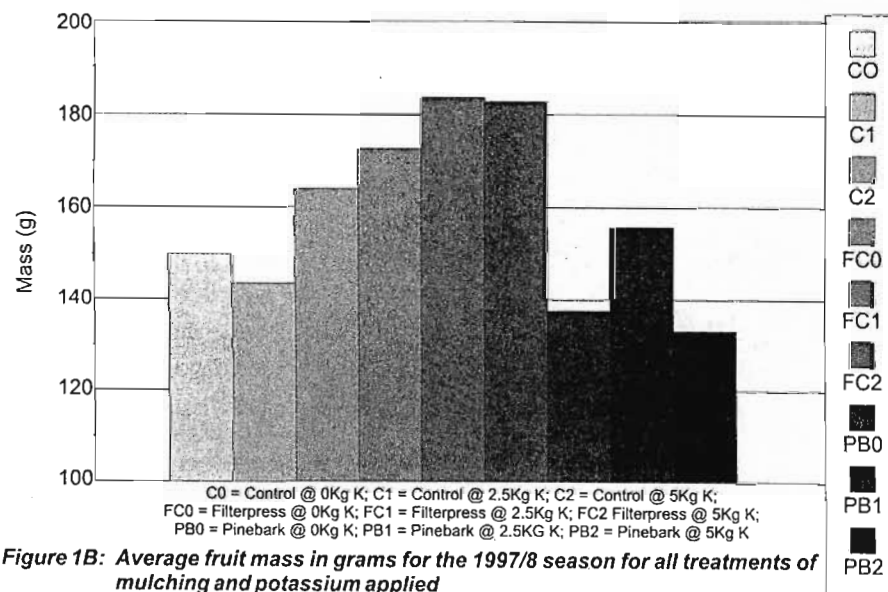


Figure 1B: Average fruit mass in grams for the 1997/8 season for all treatments of mulching and potassium applied

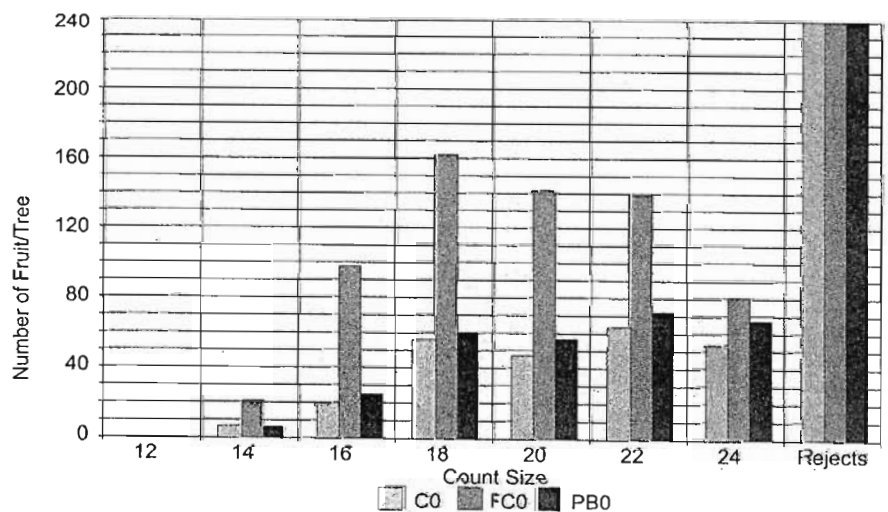


Figure 2A: Count size distribution curves for mulch treatments for the 1997/8 season showing the number of fruit harvested per tree in each count size category at a zero rate of potassium applied per tree





difference in percentage reject fruit is apparent for the potassium treatments applied to the control and pinebark trees.

Fig. 2C shows the average fruit count size distribution from trees supplied 5 kg of potassium. Control trees produced more fruit than other treatments. Of the 1109 fruit, 606 were reject (54%). This was the lowest reject percentage of all control treatments indicating that trees supplied high potassium levels supported more fruit with less small fruit. In filterpress mulch treated trees it is evident that the very high rate of potassium applied in FC2 reduced fruit number and yield, although the majority of fruit was large. Count size peaked at 18 for fruit from filterpress treated trees as opposed to the count size 22 for the control, with 46% fruit being reject. Pinebark treated trees performed poorly at the high rate of potassium with both a low yield of fairly small fruit and 481 of the 699 fruit produced proving to be reject (68%).

Fig. 3 shows the total yield in tonnes ha<sup>-1</sup> for the 1997-1998 season.

CO and C1 produced a relatively low yield of 11.6 and 11.1 t ha<sup>-1</sup> respectively. By comparison, C2 showed a significantly higher yield (18.2 t ha<sup>-1</sup>), indicating that the high rate of potassium applied had a positive impact on yield for control trees. FC2 showed a reduced yield (9.8 t ha<sup>-1</sup>), whilst FC0 and FC1 yielded very well with 23.2 and 21.2 t ha<sup>-1</sup> respectively. This was significantly higher than for any other treatment indicating that up to 2.5 kg potassium/tree applied to filterpress was advantageous in increasing yield. PB1 yielded significantly more (14.6 t ha<sup>-1</sup>) than PBO and PB2. The lowest yield of all treatments (9.4 t ha<sup>-1</sup>) was exhibited by the PB2 treatment indicating that the high rate of potassium applied became a yield limiting factor when applied in combination with the pinebark mulch.

### CONCLUSIONS

Yield and fruit size are determined by a multitude of endogenous and environmental factors. Mulching has

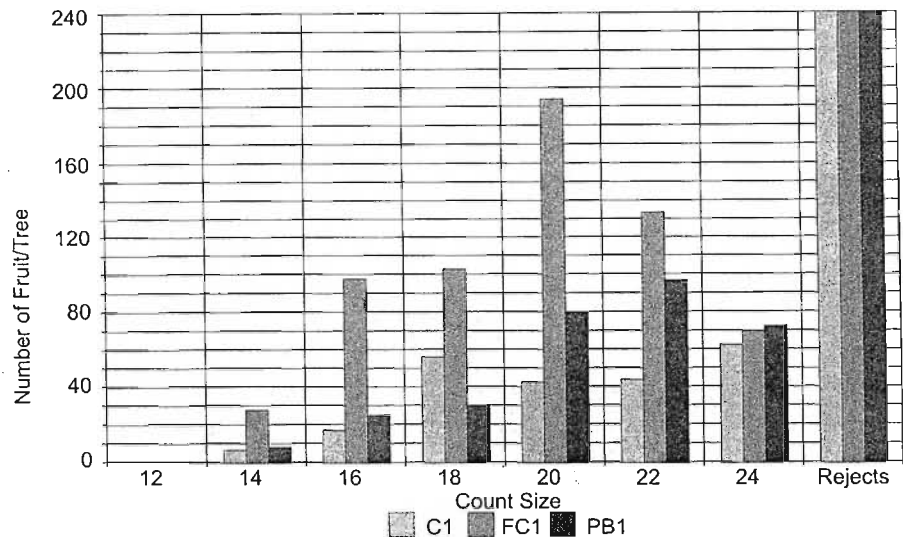


Figure 2B: Count Size distribution curves for mulch treatments for the 1997/8 season showing the number of fruit per tree in each count size category on a 2.5 kg rate of potassium applied per tree

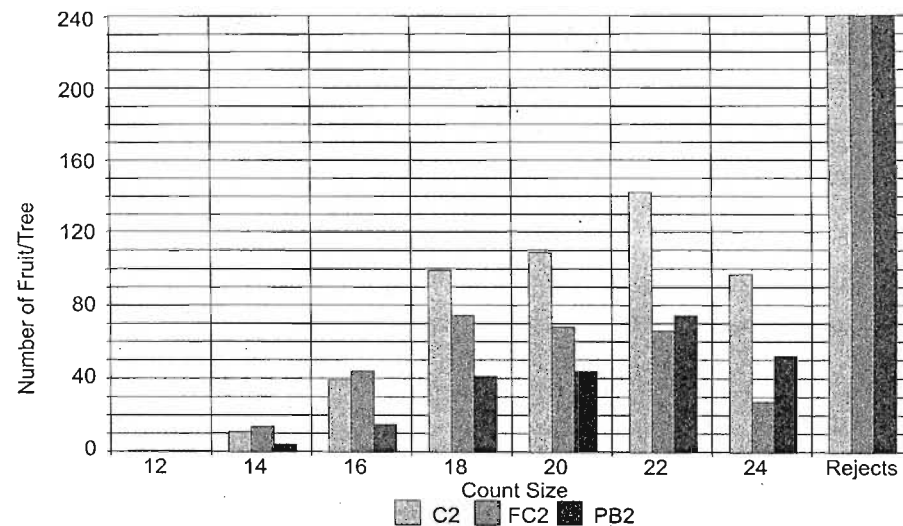


Figure 2C: Count Size distribution curves for mulch treatments for the 1997/8 season showing the number of fruit harvested per tree in each count size category at a 5kg rate of potassium applied per tree.

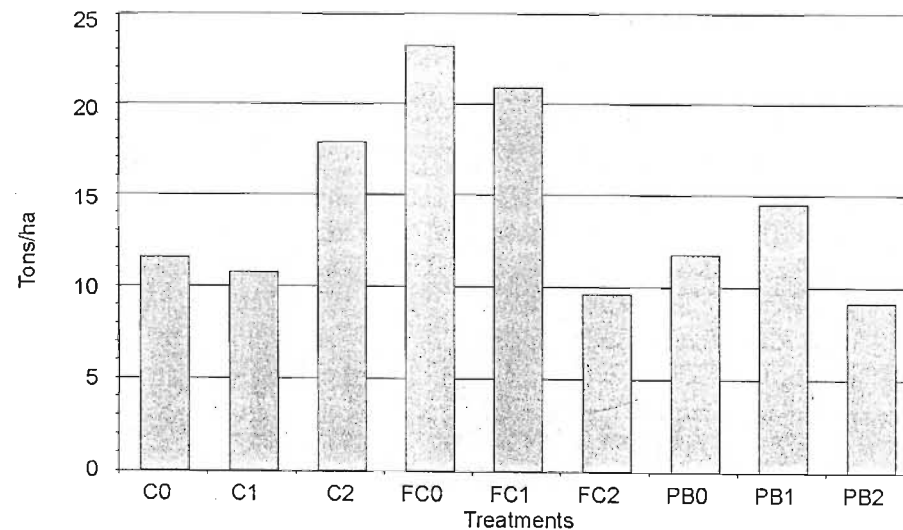


Figure 3: Total Yield in tons ha<sup>-1</sup> for the 1997/8 season for all applied treatments.

been shown to increase fruit size and yield, whilst reducing the number of small, reject fruit. In doing so, a short term solution to improving yield and fruit size in Hass avocado has been achieved. Irrespective of potassium additions, filterpress has been shown to be an excellent mulch for use on Hass avocado due to its inherent nutritional properties, higher water holding capacity and apparent suppressiveness to the *Phytophthora cinnamomi* root rot fungus. Of the filterpress treatments, the 2.5 kg potassium treatment (FC1) produced higher yields of larger fruit than were evident for any of the other treatments. The lowest percentage rejects (41%) was also produced by FC1. Filterpress and pinebark both performed best at the 2.5 kg potassium rate. Control trees produced significantly more, larger fruit at the 5 kg potassium rate, indicating this to be the best rate of potassium for unmulched trees. The relatively poorer performance of pinebark mulched trees as compared to filterpress mulched trees suggests that nutrition was lacking in the orchard. The fact that filterpress is not only a mulch but also an organic fertilizer suggests it alleviated nutritional stress better than pinebark.

## ACKNOWLEDGEMENTS

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James Arnott and Karrin Bamber who were subjected to everything from root rating and leaf sampling to measuring shoot lengths and harvesting. Without their help a project of this magnitude would not have been possible. Personal thanks also to Mrs Teri Dennison for her assistance in the laboratory work, Prof. M.J. Savage, Mr Peter Dovey and Ms Joithi Moodley for their Agrometeorology assistance and Prof. A.K. Cowan for his guidance and many stimulating discussions.

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