MANIPULATION OF INTERNAL FRUIT QUALITY IN CITRUS

BY

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DECLARATION

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

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SUMMARY

Internal fruit quality in citrus is becoming an important issue in the deregulated marketing environment. Fruit with poor and variable taste would lead to low prices on the markets and loss of market share. Internal fruit quality is determined by a few parameters such as the sugar content (determined as total soluble solids (TSS)), titratable acid (TA) content, the TSS:TA ratio and juice percentage. The objective of this study was to manipulate these parameters by means of cultural practices in order to improve the internal quality of citrus fruit.

The separate and combined effects of summer trunk girdling and deficit irrigation on internal fruit quality of 'Delta' Valencia and 'Marisol' Clementine trees were investigated over two consecutive seasons. On 'Marisol' Clementines, four trials were conducted over two seasons, at two different sites, Somerset West and Citrusdal. Girdling increased the TSS, although not always significantly, but there were no trends observed for TA and TSS:TA ratios. Deficit irrigation increased the TSS and the TA levels in both seasons and at both sites. On 'Delta' Valencias, deficit irrigation increased the TSS of fruit in 1998, but decreased the TSS in 1999. Deficit irrigation decreased the TA levels and increased the TSS:TA ratio in both years. Summer trunk girdling, performed at different times after the physiological fruit drop period, had no significant effect on the TSS and TA levels and consequently the TSS:TA ratios in both years.

The timing of summer trunk girdling, performed at different times after the physiological fruit drop period on the internal fruit quality of 'Temple' tangor trees, was evaluated over two consecutive years. Girdling significantly decreased the TSS in the first year, but had no significant effect on the TA level and the TSS:TA ratio of the fruit. In the second year there was, however, a tendency towards an increase in TSS and TA levels with the later girdling treatments, although this was not significant.

The effect of exposing internally-borne fruit to direct sunlight, by means of summer pruning, on the internal fruit quality of these normally-shaded fruit was evaluated on 'Mihowase' Satsuma and 'Nules' Clementine trees over two consecutive years. Summer pruning had no significant effect on fruit quality of 'Mihowase' Satsumas in the first year. In the second year, pruning significantly decreased TA levels and increased the TSS:TA ratio, but had no significant effect on fruit colour and TSS. Pruning on 'Nules' Clementines significantly increased the TSS:TA ratio of fruit in the first year, but had no significant effect on the colour, TSS and TA levels. In the second year, pruning had no significant effect on the colour, but significantly decreased the TA levels and increased the TSS levels and the TSS:TA ratio.

Fruit quality differences between fruit from different sectors of 'Mihowase' Satsuma, 'Nules' Clementine, 'Fairchild' and 'Temple' tangor trees were investigated. In Satsumas, Clementines and 'Temple' tangors the top fruit were the largest and inside bottom fruit the smallest, but the opposite was true in 'Fairchild'. The TSS in all four cultivars was the highest in top fruit and the lowest in inside bottom fruit. Outside bottom fruit (Satsumas) or top fruit (Clementines, 'Fairchild' and 'Temple') had the highest TSS:TA ratios and inside bottom fruit had the lowest ratios. The north sector in all the cultivars had higher TSS:TA ratios than the south sector.

The accumulation of reducing and non-reducing sugars in 'Mihowase' Satsuma and 'Nules' Clementine fruit from physiological fruit drop to maturation were quantified. In Satsumas, reducing and non-reducing sugars increased linearly over time, but plateaued out towards the last sampling date. In Clementines, reducing sugars increased cubically over time with a rapid decrease towards maturity and non-reducing sugars also increased over time until maturity.

The timing of girdling and the type of girdling tool used on the healing ability of the girdle on 'Nules' Clementine trees were investigated in two trials. Slow healing and essentially at the same rate, took place when trees were girdled with a Stanley carpet knife in September, October and November, faster healing when girdled in December and January (the hottest period), followed by slower healing when girdled in February. The Outspan girdling tool resulted in girdles which took more days to heal than the Stanley carpet knife.

The effect of ridging on the internal quality of fruit from 'Bahianinha' Navel trees was evaluated over two consecutive years. Ridging increased the TSS and the TSS:TA ratio of fruit in both years.

OPSOMMING

Manipulasie van interne vrugkwaliteit by sitrus

Interne vrugkwaliteit by sitrus is besig om belangrik te word in die gedereguleerde bemarkingsomgewing. Vrugte met swak en variërende smaak lei tot lae pryse op die markte en 'n verlies aan markaandeel. Interne vrugkwaliteit word bepaal deur 'n paar parameters, nl. suikerinhoud (bepaal as totale oplosbare vaste stowwe (TOVS)), titreerbare suur (TS) vlakke, die TOVS:TS-verhouding en sappersentasie. Die doel van hierdie studie was om hierdie parameters te manipuleer deur verbouingspraktyke en so die interne kwaliteit van sitrusvrugte te verbeter.

Die effek van somerringelering, stresbesproeiing en die kombinasie van beide op die interne vrugkwalitiet van 'Marisol' Clementine en 'Delta' Valencias bome is ondersoek oor twee agtereenvolgende seisoene. Vier proewe is uitgevoer op 'Marisol' Clementines oor twee seisoene en by twee lokaliteite, t.w. Somerset-Wes en Citrusdal. Ringelering het die TOVS verhoog, alhoewel nie altyd betekenisvol nie, maar daar was geen tendense vir TS en TOVS:TS-verhouding nie. Stresbesproeiing het die TOVS-en die TS-vlakke in albei seisoene en by beide lokaliteite verhoog. Op 'Delta' Valencias het stresbesproeiing die TOVS van vrugte verhoog in 1998, maar dit verlaag in 1999. Stresbesproeiing het die TS-vlakke verlaag en die TOVS:TS-verhouding verhoog in albei jare. Somerringelering, uitgevoer op verskillende tye na die fisiologiese vrugvalperiode, het geen betekeisvolle verhoging in TOVS gehad nie en geen betekenisvolle effek op die TS-vlakke en die TOVS:TS-verhouding in albei jare.

Die effek van somerringelering, uitgevoer op verskillende tye na die fisiologiese vrugvalperiode op die interne vrugkwaliteit van 'Temple' tangor bome, is ondersoek oor twee agtereenvolgende jare. Ringelering het die TOVS betekenisvol verlaag in die eerste jaar, maar het geen betekenisvolle effek op die TS-vlakke en die TOVS:TS-verhouding van vrugte gehad nie. In die tweede jaar was daar egter 'n tendens na verhoogde TOVS- en TS-vlakke, met die latere behandelings, alhoewel dit nie betekenisvol was nie.

Die effek van blootstelling van binnevrugte aan direkte sonlig, deur somersnoei, op die

interne vrugkwaliteit van hierdie skaduvrugte is ondersoek op 'Mihowase' Satsuma en 'Nules' Clementine bome oor twee agtereenvolgende jare. Somersnoei in die eerste jaar het vrugkwaliteit van 'Mihowase' Satsumas nie betekenisvol beïnvloed nie. In die tweede jaar het snoei die TS-vlakke betekenisvol verlaag en die TOVS:TS-verhouding verhoog, maar het geen betekenisvolle effek op kleur en TOVS gehad nie. Snoei op 'Nules' Clementines het die TOVS:TS-verhouding in die eerste jaar betekenisvol verhoog, maar het geen betekenisvolle effek op kleur-, TOVS-en TS-vlakke gehad nie. In die tweede jaar het snoei geen betekenisvolle effek op kleur gehad nie, maar het die TS-vlakke verlaag en die TOVS en TOVS:TS-verhouding verhoog.

Vrugkwaliteitsverskille tussen vrugte vanaf verskillende posisies in 'Mihowase' Satsuma, 'Nules' Clementine, 'Fairchild' and 'Temple' tangor bome is ondersoek. In Satsumas, Clementines, en 'Temples' was vrugte uit die boonste posisies die grootste en binnevrugte in die onderkant van die boom die kleinste, maar die teenoorgestelde het voorgekom by 'Fairchilds'. In al vier kultivars was die TOVS die hoogste in vrugte uit die boonste posisies en die laagste in binnevrugte aan die onderkant van die boom. Buitevrugte aan die onderkant van die boom (Satsumas) of vrugte in die boonste posisies (Clementines, 'Fairchilds' en 'Temples') het die hoogste TOVS:TS-verhoudings gehad en binnevrugte aan die onderkant van die boom die laagste verhoudings. Die noordelike sektor in al die kultivars het hoër TOVS:TS-verhoudings gehad as die suidelike sektor.

Die akkumulasie van reduserende en nie-reduserende suikers in 'Mihowase' Satsuma en 'Nules' Clementine vrugte vanaf fisiologiese vrugval tot rypwording is gemonitor. In Satsumas het reduserende en nie-reduserende suikers lineêr toegeneem oor tyd, maar het later afgeplat. In Clementines het reduserende suikers kubies toegeneem oor tyd met 'n skerp afname tot by rypwording en nie-reduserende suikers het ook toegeneem oor tyd tot by rypwording.

Die effek van die tyd van ringelering en die tipe ringeleermes wat gebruik is op 'Nules' Clementine bome, op die tyd en tempo van wondgenesing, is ondersoek in twee studies. Stadige genesing, en teen dieselfde tempo, vind plaas wanneer bome geringeleer word met 'n Stanley-matmes in September, Oktober en November, vinniger genesing wanneer in Desember en Januarie (die warmste periode) geringeleer word, gevolg deur stadiger genesing wanneer in Februarie geringeleer word. Die Outspan-ringeleermes veroorsaak ringeleerwonde wat langer neem om te genees as die Stanley-matmes.

Die effek van operdwalle op die interne vrugkwaliteit van 'Bahianinha' nawelbome is ondersoek oor twee agtereenvolgende jare. Vrugte van bome op operdwalle het verhoogde TOVS en TOVS:TS-verhoudings in albei jare gehad.

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CONTENTS

1 LITERATURE REVIEW

INTERNAL FRUIT QUALITY IN CITRUS AND THE MANIPULATION THEREOF

1. INTRODUCTION

Internal fruit quality in citrus is becoming an important issue in a deregulated marketing environment. Other countries in the southern hemisphere that compete with South Africa on the markets commercially utilise better quality rootstocks and also in many instances have better climatic conditions. Fruit of marginal quality (low total soluble solids (TSS) content) is a big problem, especially in early-maturing 'Mihowase' Satsumas grown in the Western Cape. Fruit with poor and variable taste would lead to low prices on the markets and loss of market share.

Internal fruit quality is determined by a few parameters such as the sugar content (determined as TSS), titratable acid (TA) content, the TSS:TA ratio, juice percentage and fibre strength.

This review will only define the parameters which determine the taste and palatability of citrus fruit, i.e. the sugar and acid content and the sugar:acid ratio. The ratio of TSS (measured by a refractometer or hydrometer) and the percent TA (measured as citric acid by titration) is probably the most important parameter of internal fruit quality in the citrus industry. The TSS:TA ratio is used to determine optimum maturity for harvesting of the fruit. The 'sweetness' of the sugars and the 'sourness' of the acids and their relative amounts determines the taste of the fruit (Kimball, 1984b). In California this ratio must be at least 8:1 at harvest (Kimball, 1984a) and 9:1 in Florida, but only once a minimum TSS value is attained (Reuther *et al.*, 1969). Japanese consumers demand a TSS:TA ratio for Satsumas of at least 10:1 (Richardson *et al.*, 1991). It is this minimum TSS value that creates problems. The eating quality of non-climacteric fruit, such as citrus, never improves after harvest. Therefore, only once a certain minimum TSS and TSS:TA ratio is attained, can harvesting start. To attain high maturity standards, internal fruit quality, especially the TSS, has to be improved.

The first part of the seminar consists of a definition of internal fruit quality and the different parameters comprising internal fruit quality. Since the balance (ratio) of sugars and acids determine the taste and palatability of citrus fruit, the different sugars and acids in citrus fruit, as well as their metabolism, translocation and distribution in the fruit will be discussed. The factors influencing internal fruit quality will also be discussed. The second part deals with the use of orchard manipulations, like irrigation, girdling and ridging, to maximise the internal quality of citrus fruit.

2. SUGARS AND ACIDS

2.1 SUGARS

The concentration of sugars and acids in citrus fruit juice has been the main criterion for evaluating internal quality, which is correlated with maturity (Tadeo *et al.*, 1987; Yamanishi, 1995). Eating quality of citrus is often equated with the TSS:TA ratio (Beever, 1990). Citrus fruit are deemed to be marketable when a certain minimum TSS:TA ratio is attained (Beever, 1990; Davies & Albrigo, 1994). The minimum ratio varies, but generally ranges from 7-9:1 for oranges and mandarins, and 5-7:1 for grapefruit (Davies & Albrigo, 1994). Fruit or juice with high TSS:TA ratios and high TSS, taste very sweet, whereas those with low ratios and TSS are tart. Fruit with a high ratio and low TSS taste insipid (Davies & Albrigo, 1994).

The TSS include carbohydrates, organic acids, proteins, amino acids (Erickson, 1968) and various minerals (Davies & Albrigo, 1994). Bartholomew & Sinclair (1943), Sinclair (1961a) and Davies & Albrigo (1994) reported that 75-85 % of the TSS of orange juice are sugars (carbohydrates). TA may constitute 8-23 % of the TSS of the citrus juice (Yamanishi, 1995). Increases in TSS are not necessarily changes in the fruit's simple sugar content (Echeverria & Ismail, 1990), but juice loss can also be responsible for increased solids in citrus juice (Rasmussen *et al.*, 1965).

The major sugar and the major translocatable carbohydrate in citrus is sucrose (non-reducing) (McCready *et al.*, 1950; Davies & Albrigo, 1994; Yamanishi, 1995) followed by the reducing sugars, glucose and fructose, which occur in an approximate ratio of 2:1:1 (Ting & Attaway, 1971; Garcia-Luis *et al.*, 1991; Tzur *et al.*, 1992). Garcia-Luis *et al.* (1991) found that exposing leaves to $^{14}CO_2$ led to [^{14}C] sugar accumulation in the juice sacs, mainly as [^{14}C] sucrose. Fructose is sweeter than sucrose, while sucrose is sweeter than glucose (Yamanishi, 1995). Clementines have a juice sucrose content somewhat higher than in Navel oranges, but a lower content of reducing sugars (Tadeo *et al.*, 1987). Citrus fruit are low in starch reserves, but usually starch is converted to sucrose, fructose and glucose (Davies & Albrigo, 1994). Trace amounts of galactose, rhamnose (McCready *et al.*, 1950) and mannose have also been found in citrus juice (Davies & Albrigo, 1994). Additional sugars that may contribute to the increase in TSS could arise from the conversion of organic acids to sugars through gluconeogenesis (Echeverria & Valich, 1989).

2.2 ACIDS

Total acidity is an important attribute, because a balanced sour taste is a major factor in the acceptability of citrus fruit juices (Kefford & Chandler, 1970). In most citrus-growing regions the ratio of TSS to TA determines whether fruit are harvestable and the palatability of the fruit (Davies & Albrigo, 1994) and is used as a criterion to prevent low quality fruit entering the market (Ting & Attaway, 1971)

Organic acids contribute significantly to overall juice acidity (Davies & Albrigo, 1994). The vacuoles appear to store the acids (Kimball, 1984a), of which citric acid is the primary one (70-90 % of total) (Bitters, 1961; Sinclair, 1961b; Rasmussen *et al.*, 1965; Erickson, 1968). The total acidity of citrus juice is due primarily to citric acid (Sinclair, 1961b; Clements, 1964a, 1964b; Ting & Attaway, 1971; Shaw *et al.*, 1983; Kimball, 1984a) and variations in acidity are due mainly to changes in the citric acid concentration (Sinclair & Ramsey, 1944; Sinclair, 1961b; Cancalon, 1994), whereas the malic acid concentration in the juice remains uniform during the season (Sinclair & Ramsey, 1944; Kimball, 1984a). These low, but significant levels of malic acid (Clements, 1964a, 1964b) appears to be independent of the citrate concentration (Clements, 1964b). Citric and malic acids make up 80-95 % of the total organic acids in citrus juice (Sinclair & Ramsey, 1944; Rasmussen *et al.*, 1965). Trace amounts of oxalic, tartaric, malonic and quinic acids have also been reported (Sinclair, 1961b; Davies & Albrigo, 1994). These minor organic acids make up less than 2 % of all the organic acids in citrus juice (Yamanishi, 1995). Organic acid levels generally decrease as citrus fruit mature (Kefford & Chandler, 1970; Davies & Albrigo, 1994) in spite of the rapid acid accumulation in young fruit (Erickson, 1968).

Mandarins have about the same acidity range as oranges, but grapefruit are more acidic. In the juice of lemons, citric acid may account for 60-70 % of the TSS. Calamondin juice is also characterised by its high acidity, as reflected by the high citric acid content (Nisperos-Carriedo *et al.*, 1992).

2.3 SUGAR METABOLISM

Fruit sugar content depends on import of photosynthetic products from leaves, fruit photosynthesis and respiration (Huang *et al.*, 1992). Most of the solids accumulate in the fruit after the fruit has attained 60-75 % of its ultimate size (Reuther, 1988). Closer to maturity the level of reducing sugars decreases in relation to total sugars, but the level of sucrose increases rapidly (Tzur *et al.*, 1992).

Citrus fruit depend on continued import of sugars while attached to the plant. The accumulation of soluble sugars during ripening is not as a result of starch breakdown (Tzur *et al.*, 1992). Echeverria & Valich (1989) found that *de novo* synthesis of sugars from organic acids can explain the continuous increase in sugars during the late stages on the tree.

Respiration reduces the amount of carbon available for accumulation of dry matter and sugars (Koch, 1988b). According to Koch (1988b) as much as 30 % of the sugars moving into fruit could be lost through CO_2 during respiration.

Even though sucrose is the main sugar in citrus it is apparently broken down and resynthesised as it moves into the fruit to maintain a 'down-hill' concentration gradient from the leaves to the fruit (Koch, 1988a). Sucrose breakdown to glucose and fructose is usually caused by acid and neutral invertases (Tzur *et al.*, 1992). Tzur *et al.* (1992) found that juice sacs can synthesise and degrade sucrose, and that the presence of sucrose in the juice sacs is derived not only from sucrose import.

In acid limes, sucrose is hydrolysed enzymatically as well as nonenzymatically at a pH of 2.5 or lower (Echeverria & Burns, 1989; Echeverria, 1990; Echeverria & Burns, 1990). During the early stages of fruit growth, sucrose is catabolised enzymatically by sucrose synthase (in cytosol), acid invertase (in vacuole, 4-5,3 pH) and/or alkaline invertase (in cytosol, neutral pH) (Kato & Kubota, 1978; Echeverria & Burns, 1989; 1990). In mature acid limes a high vacuolar citric acid concentration results in such a low pH that sucrose is hydrolysed nonenzymatically (Lee & Nagy, 1988; Echeverria & Burns, 1989; Echeverria, 1990; Echeverria & Burns 1990).

2.4 ACID METABOLISM

The accumulation of citric acid in the juice vesicles of citrus fruit directly affects the quality and palatability of the juice. Citric acid is the main organic acid in citrus juice vesicles. The acid was thought to be synthesised in the leaves or fruit peel and then translocated to the juice vesicles, or formed directly in the juice vesicles (Ting & Attaway, 1971). Subsequent results showed that the synthesis of citric acid occurs in the pulp, since leaves do not directly synthesise citric acid (Kefford & Chandler, 1970; Ting & Attaway, 1971). Juice vesicles produce organic acids (including citric acid) through the normal glycolytic pathway by which carbohydrates are oxidised and the products enter the Krebs cycle (Ting & Attaway, 1971; Koch, 1988b). PEP carboxylase, the enzyme involved in organic acid synthesis, is present in peel tissues and juice vesicles (Koch, 1988b). On the basis of the high fixation activity of the juice vesicles, Bean & Todd (1960), suggested that the vesicles have an important function in the synthesis and storage of acids.

The rate of citric acid utilisation affects its levels and the enzyme aconitase is responsible for its breakdown. The decline in organic acids towards ripening is linked to their use as energy substrates, translocation to the peel, or their use as building blocks for *de novo* synthesis of sugars (Echeverria & Valich, 1989).

2.5 CHANGES IN TSS AND ACIDS DURING THE SEASON

Citrus fruit growth can be divided into three different stages: phase I of slow growth (cell division), phase two of exponential growth (cell enlargement) and phase III when maturation occurs (Bain, 1958). TSS, juice content and TA increase during the early stage II of fruit development (Davies, 1986). This build-up of acids is because of the early blockage of the citric acid cycle, either by a lack of, or the inhibition of the aconitase enzyme, which normally catabolises citric acid (Kimball, 1984a). As citric acid increases in concentration, malic and quinic acid declines rapidly, but malic acid concentration rises toward the end of the maturation phase (Ting & Attaway, 1971). Citric acid reaches a peak concentration in the early stage of fruit development (Sinclair & Ramsey, 1944), depending on the cultivar, e.g. 5 months after fruit set in Valencias (Kefford & Chandler, 1970). TSS and juice content continue to increase during stage II, while acidity decreases (Sinclair & Ramsey, 1944; Bain, 1958; Clements, 1964b; Erickson, 1968; Kimball, 1984a; Davies, 1986; Yamanishi, 1995). Erickson (1968) found that during maturation (Stage III), fruit growth rate slows down and TSS (reducing, non-reducing and thus total sugars) increase (Sinclair, 1961a; Ting & Attaway, 1971), while citric acid decreases more gradually (Clements, 1964b). The total sugars in the juice increase during ripening, mainly due to an accumulation of sucrose in the juice (Ting & Attaway, 1971; Tadeo *et al.*, 1987). Cancalon (1994) found that glucose and fructose concentrations increase exponentially in Valencia oranges from April to September (northern hemisphere), decrease slightly during the next three months (October to December) and then plateau out in the winter. The sucrose concentration then rises sharply, apparently due to the formation of sucrose from the pre-existing glucose and fructose (Cancalon, 1994). In May, the sugar concentration, especially sucrose increases significantly (Cancalon, 1994). The decrease in TA is considered to be due to dilution as the fruit increase in size and juice content (Sinclair, 1961b; Rasmussen *et al.*, 1965; Ting & Attaway, 1971; Kimball, 1984a) or a loss of citric acid by translocation or metabolic conversion (Rasmussen *et al.*, 1965; Kefford & Chandler, 1970).

Citrus fruit are considered mature and harvest begins when a favourable balance (ratio) between TSS and acids is attained (Davies, 1986; Tadeo *et al.*, 1987). This decrease in the concentration of acid with the increase in total sugars during maturation results in an increase in the TSS:TA ratio (Cancalon, 1994), which is the basis for determining legal maturity (8:1 for oranges in California) for determining harvest date and palatability (Erickson, 1968; Yamanishi, 1995). It should be noted that all fruit on a given tree are not at the same stage of maturity at one time.

According to Yamanishi (1995), Hilgeman (1941) found that a high percentage of TSS is usually accompanied by a high percentage of TA.

2.6 TRANSLOCATION

2.6.1 METABOLISM

Metabolic processes are required to load photosynthetic products into the phloem, maintain long-distance movement (Geiger & Savonick, 1975 cited by Koch, 1984a) and transfer assimilates into sink tissues (Thorne, 1982 cited by Koch, 1984a). Assimilate entry into a sink may be influenced by hydrolytic enzymes, sugar compartmentation and end-product synthesis (Koch, 1984b). Metabolic conversions occur in the vacuoles of the juice sac-cells. The high concentration of organic acids within the vacuoles of the sac-cells in the early stages of import could result in low pH values, which would lead to non-enzymatic acid hydrolysis of sucrose (Garcia-Luis *et al.*, 1991). Photosynthesis drops rapidly with the onset of low winter temperatures (Goldschmidt & Koch, 1996). Koch (1988a) also found that there is no transport from the leaves to the fruits when the nights are cold.

2.6.2 THE PATH OF TRANSPORT

The transport of photo-assimilates from source leaves to developing citrus fruit involves the movement of sucrose as the major translocate (Kriedemann, 1969) via the phloem to the albedo, where unloading occurs (Garcia-Luis *et al.*, 1991). The primary way of phloem transport to juice sacs are three groups of vascular bundles outside the segment epidermis: the central, the septal and the dorsal vascular bundles (Koch & Avigne, 1990). Central vascular bundles supply only the seeds (Koch, 1988a). Koch & Avigne (1990) suggested that there is one dorsal and two septal vascular bundles per segment. The major path of assimilate entry into the fruit is via the dorsal vascular system (Koch, 1984b; Lowell *et al.*, 1989). The sucrose is then transported through the albedo tissues into the juice sacs through the thread-like, non-vascularised stalks of the juice sacs (Garcia-Luis *et al.*, 1991). The vascular tissue is restricted to the albedo and subsequent movement must be symplastic (cell-to-cell via plasmodesmata) and/or apoplastic (extracellular) into the juice sacs (Koch & Avigne, 1990; Garcia-Luis *et al.*, 1991). Each juice vesicle has a thread-like stalk between phloem cells and the final site of photosynthate deposition (Koch, 1984b). These nonvascular stalks are attached to the interior of the segment epidermis (Koch, 1984b; Lowell *et al.*, 1989) at a point near one of the three major vascular strands (Koch & Avigne, 1990).

The pathway and driving forces for the nonvascular transport of sucrose are not known (Garcia-Luis *et al.*, 1991).

2.6.3 SINK-SOURCE RELATIONSHIPS

Actively-growing organs are strong sinks (Goldschmidt & Koch, 1996). It has long been known that specific source leaves supply specific sink tissues (Murray *et al.*, 1982 in Koch, 1984a). Active transport of sugars may involve a proton pumping ATPase (Garcia-Luis *et al.*, 1991). It is postulated that the gradient is maintained by the hydrolysis and metabolic conversions of imported sucrose and the products accumulate in the vacuoles of the juice sac-cells (Garcia-Luis *et al.*, 1991). Koch & Avigne (1990) found that sucrose hydrolysis does not seem to be directly involved in phloem unloading or nonvascular translocation. However, they found a descending sucrose gradient between the site of phloem unloading and the juice sacs. However, fruit are not always strong sinks at the early stage of fruit development (Kadoya & Tanaka, 1972), because there is an ascending sugar gradient during this time (Koch & Avigne, 1990).

Koch (1984a, 1984b) and Koch & Avigne (1984; 1990) found that the fruit sector in direct vertical alignment with the source leaf receives the majority of translocated ^{14}C-labeled photosynthates. Borras *et al.* (1984) found that carbohydrate demand in the fruit stimulates photosynthesis in the nearest leaves (sink effect). Borras *et al.* (1984) found that Navel fruit increases its sugar levels from May to June (northern hemisphere) (stage of intense growth) and this increase coincides with a decrease in sugars in young leaves in vegetative shoots and in shoots with a terminal fruit.

Koch & Avigne (1984) found that on a girdled branch, a leaf of eight nodes distance from a terminal fruit, partition the same proportion of assimilates to the fruit as one adjacent to the fruit. This is because roots are no longer a sink for photosynthates of girdled branches (Koch & Avigne, 1984). Kadoya & Tanaka (1972) found that as the number of fruit per tree increased, there is an increase in the total amount of ^{14}C

distributed to the fruit parts. Basipetal movement of ^{14}C to the roots decreases with increased fruiting (Kadoya & Tanaka, 1972). In the absence of fruit or a vegetative flush to act as a sink, mature leaves tend to export assimilates to the root system (Posssingham & Kriedemann, 1969). Citrus leaves become exporters of photosynthates only once they are fully expanded (Goldschmidt & Koch, 1996). New leaf flushes can thus compete strongly with other sinks for photosynthates (Goldschmidt & Koch, 1996).

2.6.4 DISTRIBUTION AFTER TRANSLOCATION

According to Koch (1984a), sugars translocated into citrus fruit will persist in that segment, because vascular connections between segments are lacking. Layers of suberin also surround each juice vesicle which is impermeable to solutes and photosynthates (Koch, 1984a). This asymmetrical translocation could therefore be the reason for the uneven distribution of sugars within fruit (Koch, 1984a; Koch & Avigne, 1984).

Purvis & Yelenosky (1983) found that there is no transport of soluble carbohydrates between the flavedo, albedo and juice vesicles at low temperatures. Application of GA_3 on the fruit surface, increase the movement of photosynthates into the fruit (Kadoya & Tanaka, 1972). Wallerstein *et al.* (1978b) found two forms of transport in citrus: a rapid flow system (for 1 h after labelling) and a slow flow system thereafter. Girdling almost completely inhibits the slow ^{14}C phloem transport, but cannot block the rapid transport (Wallerstein *et al.*, 1978b).

2.7 DISTRIBUTION OF SUGARS AND ACIDS IN THE JUICE SACS

Most of the sugars and nearly all the citric acid of the citrus fruit occur in the juice vesicles (Ting & Attaway, 1971). These vesicles enlarge as the fruit develops (Ting & Attaway, 1971). In plant cells, the major fluid compartments are the vacuolar sap and the cytosol (Echeverria & Valich, 1988).

Echeverria & Valich (1988) found that in Valencia oranges the vacuole of the juice sac cells contains 70 % of the malic acid, 75 % of the fructose and glucose, 89 % of the citric acid and 100 % of the sucrose. The rest occurs in the cytosol. The vacuolar sugars are the major form of carbohydrate supplying energy to the mature juice sac cells (Echeverria & Valich, 1988). Echeverria & Valich (1988) also found that the juice sac cells can metabolise sugars. The decline of citric acid content is mostly the result of translocation of the acid to the peel tissue. Sinclair & Ramsey (1944) suggested that the unequal distribution of soluble solids in different portions of the fruit is strong evidence that the acids are also not uniformly distributed in the fruit.

2.8. DISTRIBUTION IN THE FRUIT

Koch (1988b) showed that the most acidic part of a Valencia fruit is its center. TA is lower at both ends and increases toward the central region (Ting, 1969). Oranges and grapefruit have higher concentrations of TSS and total sugars in the stylar-end-half than in thc stcm-cnd-half (Haas & Klotz, 1935; Sinclair, 1961a; Ting, 1969; Kefford & Chandler, 1970; Syvertsen & Albrigo, 1980; Kimball, 1984a). The reducing sugars, however, are lower and non-reducing sugars higher at the stem and stylar ends than at the central regions (Ting, 1969). The TSS:TA ratio is therefore lowest in the middle of the fruit (Koch, 1988b).

Ting (1969) and Kefford & Chandler (1970) found an increasing TA and decreasing soluble solids from the periphery (near the rind) of the segments towards the core (inside). The ratio of TSS:TA was higher around the periphery of the segments than at the core (Ting, 1969). Both reducing and non-reducing sugars were highest in the periphery and decreased toward the core areas (Ting, 1969).

The distribution of the sugars and acids in the fruit may be due to the location of the vascular bundles or can be explained by the mode of transport.

3. FACTORS AFFECTING FRUIT QUALITY

3.1 CLIMATE

3.1.1 TEMPERATURE

Temperature appears to be one of the main climatic factors that influences fruit quality (Jones, 1961). Levy *et al.* (1978a) indicated that acid levels in citrus fruit are related to environmental conditions. According to Richardson *et al.* (1993) low temperatures in Satsuma mandarin orchards have been linked to poor internal fruit quality, like low TSS and high TA (Levy *et al.*, 1978b) and therefore a low TSS:TA ratio in the fruit. Susanto *et al.* (1992) and Yamanishi (1995) found that a higher temperature regime resulted in pummelo fruit with a higher internal quality (higher TSS and lower citric acid content) and earlier maturation than at lower temperatures. Internal fruit quality can be altered by temperature, even very early in the season (Davies, 1986).

Kefford & Chandler (1970) suggested that accumulation of citric acid is accelerated by warm nights and spring rains. High day and night temperatures before harvest (throughout fruit growth) and moderate temperatures after the fruit begin to colour, encourage early accumulation of soluble solids (Richardson *et al.*, 1991) and accelerate the loss of acids (Kefford & Chandler, 1970; Richardson *et al.*, 1991; Davies & Albrigo, 1994). Davies (1986) found that as heat units increased during a season, TA decreased and the TSS:TA ratio increased. High availability of heat units in August (northern hemisphere), when acid begins to form, is therefore considered to be conducive to low acidity (Jones *et al.*, 1962; Kefford & Chandler, 1970). With high temperatures in April, May and August (northern hemisphere), TSS and acid levels of Navel fruit increase (Jones *et al.*, 1962). The decrease in acids is primarily a function of the high temperatures (Reuther *et al.*, 1969), but also the rapid respiration of organic acids (Kimball, 1984a; Davies & Albrigo, 1994), more rapid utilisation of the acids in metabolism and excessive rainfall or irrigation (Davies & Albrigo, 1994).

Most citrus cultivars have lower soluble solids and acids in hot, tropical climates (Reuther & Rios-Castano, 1969), having no cool temperature or drought-induced dormant periods (Reuther, 1973; 1988). This lower TSS may be due to the combination of high night temperatures, heavy respiration losses, and the competition of vegetative growth with fruit for carbohydrates (Reuther, 1973). At elevations higher than 2100 meters insufficient heat units result in poor fruit quality (Reuther & Rios-Castano, 1969).

Richardson *et al.* (1993) used a reflective foil mulch which increased the maximum daily temperatures in the canopy of the tree with up to 3°C. These trees accumulated more heat units from flowering until harvest. Fruit from trees mulched with the reflective foil had significantly higher TSS levels, lower acidity and a significantly higher TSS:TA ratio throughout fruit maturation and harvest. Kuriyama *et al.* (1981) found in Satsuma mandarins that when an orchard was mulched with vinyl mulch from October to November (northern hemisphere) the content of sugars and citric acid were higher in the fruit.

3.1.2 EFFECT OF SUNLIGHT/POSITION OF FRUIT IN THE TREE

According to Levy *et al.* (1978a) environmental factors will influence citrus juice quality. Differences in juice quality (TSS) are associated with positional differences in canopy microclimate and exposure to light and temperature of individual fruit (Sites & Reitz, 1949; Levy *et al.*, 1978a; Syvertsen & Albrigo, 1980). All quality parameters are influenced by factors such as fruit size, harvest date, location on the tree, rootstocks, and climatic conditions (Cohen, 1988). It is these factors that cause variation in internal quality among fruit from the same tree. Light level is either the principal factor affecting the TSS or highly correlated with these factors (Sites & Reitz, 1949). Sites & Reitz (1949), Erickson (1968) and Iwagaki (1981) showed that the TSS content in fruit increases with increased light intensity. A light level of about 25-30 % of full sunlight is needed to sustain net photosynthesis (Reuther, 1988; Goldschmidt & Koch, 1996). Shading reduces sugar content (TSS) of fruit by reducing net photosynthesis and dark respiration of these shaded leaves (Reuther, 1988; Yamanishi & Hasegawa, 1995).

3.1.2.1 INSIDE/OUTSIDE

Kimball (1984a) and Koch (1988a) stated that fruit on the outside of a tree may reach maturity long before those on the inside. In grapefruit (Syvertsen & Albrigo, 1980; Fallahi & Moon, 1989), mandarins and oranges (Sites & Reitz, 1949; Erickson, 1968; Koch, 1988a; Fallahi & Moon, 1989) fruit from external canopies had significantly higher soluble solids than the internal fruit, which resulted in a higher TSS:TA ratio for the external fruit than for the internal fruit (Syvertsen & Albrigo, 1980), except for mandarins (Fallahi & Moon, 1989). Syvertsen & Albrigo (1980) found with grapefruit that external fruit in the canopy had a lower percentage acid than internal fruit. A reduction in acid levels and an increase in TSS will lead to an increase in TSS:TA ratio and subsequently improved fruit taste (Cohen, 1988). Contrary to

Syvertsen & Albrigo (1980), Fallahi & Moon (1989) found that TA of external fruit of mandarin and grapefruit was higher compared to internal fruit.

3.1.2.2 TOP/BOTTOM

Sun-exposed fruit in the upper sectors of the canopy have a higher quality than fruit in shaded lower or inside canopy sectors (Syvertsen & Albrigo, 1980). The TSS in the fruit increases with an increase in height of the fruit on the tree (Sites & Reitz, 1949; Erickson, 1968). Syvertsen & Albrigo (1980) also found that ranking the TSS:TA ratio for grapefruit from highest to lowest corresponds with the canopy positions from the top to the bottom. The percentage acids in grapefruit remain lowest in the upper canopy positions (Syvertsen & Albrigo, 1980). The quality of fruit at the bottom of a tree is inferior to those of the middle and the top due to lower light intensities and air temperatures (Suzuki *et al.*, 1973).

3.1.2.3 SOUTH/NORTH

Oranges from southern canopy sectors (northern hemisphere) tend to have higher concentrations of soluble solids (Sites & Reitz, 1949; Erickson, 1968; Syvertsen & Albrigo, 1980; Koch, 1988a, 1988b) and acids (Erickson, 1968; Koch, 1988a, 1988b). According to Syvertsen & Albrigo (1980) and Cohen (1988) fruit from the southern side of the tree are more mature than fruit from the northern side (northern hemisphere). This is probably due to microclimate conditions such as the amount and intensity of light or the higher temperature to which external or upper fruit is exposed to.

The higher temperatures experienced by the more exposed fruit would result in higher internal respiration rates (Syvertsen & Albrigo, 1980). Syvertsen & Albrigo (1980) speculated that these higher respiration rates in the early season could result in lower concentrations of carbohydrates from which the acids in fruit are derived. According to Fallahi & Moon (1989) the higher soluble solids in fruit from external canopy positions are due to two factors: 1) higher CO_2 assimilation rates, higher leaf to fruit ratio, and efficient transport of photosynthetic products to fruit in external canopy positions and/or 2) fruit from internal canopy positions are closer to the main limbs (main xylem tissues) and may receive more water which may result in more dilution of soluble solids compared to external fruit. The latter assumption is, however, questioned.

Fallahi & Moon (1989) concluded that a more uniform light penetration would result in a more uniform photosynthate distribution among the fruit in a tree. Koch (1988a) stated that hedging and topping trees increase colour and internal quality of the fruit. Maintenance pruning may improve light penetration into the tree (Lewis & McCarty, 1973). The efficiency, however, depends on the amount of internal shading prior to pruning (Koch, 1988a).

3.2 ROOTSTOCK EFFECTS

Vigorous rootstocks, like rough lemon, tend to give high yields of larger fruit with a low juice content, while the juice is low in soluble solids content (Bitters, 1961; Hilgeman, 1966) and acidity (Bitters, 1961; Kefford & Chandler, 1970; Davies, 1986) due to a dilution effect from a better tree water status (Albrigo, 1977). Trifoliate orange and its hybrids tend to give lower yields of fruit with a high juice content, while the juice is high in soluble solids and acidity (Kefford & Chandler, 1970; Davies, 1986). These adverse effects of rough lemon rootstock on internal quality were shown for oranges, Murcott tangors, tangelos, grapefruit and limes (Kefford & Chandler, 1970). Where no minimum TSS is required, fruit will attain a minimum TSS:TA ratio on rough lemon first, due to a dilution of acidity (Davies, 1986). Wutscher (1988) found that a high-quality variety, such as Valencia has adequate quality on any rootstock, but marginal varieties may not. In selecting rootstocks, yield, soil adaptation, and disease resistance are still the key factors (Wutscher, 1988). Fruit quality effects will remain a secondary selection criterion when a rootstock is chosen, but cannot be neglected, especially with varieties of marginal quality, where the rootstock can determine if the fruit would be saleable or unsaleable (Wutscher, 1988). Rootstock effects sometimes vary from year to year, from area to area, and with cultural practices (Wutscher, 1988).

3.3 EFFECT OF FRUIT SIZE

It is well known that small oranges are sweeter than large ones. There is an inverse relation between fruit size and soluble solids content (Erickson & Richards, 1955;

Kefford & Chandler, 1970; Ketsa, 1988) and TA (Ting, 1969; Ketsa, 1988). Large fruit from the same position on the tree have lower total soluble solids and acids (Sites & Reitz, 1949; Krezdorn, 1988). Cohen (1988) found that in 'Minneola' tangelos the acid content was 1.2% in small fruit and 1.1% in large ones. Ketsa (1988) found, in tangerines, a direct relationship between fruit size and juice content.

3.4 NUMBER OF SEEDS

Krezdorn (1988) found that more seedy fruit have higher total soluble solids and acid than less seedy fruit.

3.5 TREE AGE

As trees advance in age, the fruit decrease in size and increase in soluble solids content (Kefford & Chandler, 1970).

3.6 CULTURAL PRACTICES

3.6.1 MINERAL NUTRITION (FERTILIZATION)

Nitrogen and potassium are two principal nutrient elements in citrus fertilisation (Embleton *et al.*, 1973; Koo, 1988). Nitrogen is the dominant nutrient element that affects fruit quality (Koo, 1988). The effect of nitrogen, potassium and phosphorus applications on internal fruit quality, however, gave contradictory results.

3.6.1.1 NITROGEN

Bouma (1956) and Embleton *et al.* (1973) stated that an increase in nitrogen would generally have an adverse effect on fresh fruit quality of grapefruit and oranges. Jones & Embleton (1959) found that a high nitrogen level in the summer in Valencia trees would adversely affect fruit quality by decreasing the TSS levels and increasing the acidity (Reuther & Smith, 1952; Reitz & Koo, 1960). Reuther & Smith (1952) and Reitz & Koo (1960) found delayed maturity (colour development) with high nitrogen application. Kefford & Chandler (1970), however, found that increasing rates of nitrogen fertilisation give increasing yields of smaller fruit, with increasing soluble solids and acidity, but the TSS:TA ratio decreased. Ammonium nitrogen, applied as ammonium salts, produce fruit with higher soluble solids content than other sources of nitrogen (Kefford & Chandler, 1970; Koo, 1988). Lee & Chapman (1988) found that the TSS and acid contents of 'Ellendale' mandarins were unaffected by nitrogen applications.

3.6.1.2 PHOSPHORUS

High phosphate levels give a slight decrease in soluble solids content (Embleton *et al.*, 1956; Jones, 1961; Smith *et al.*, 1963; Anderson, 1966; Kefford & Chandler, 1970) and a delay in colour break of the fruit (Smith *et al.*, 1963). Koo (1988) found that phosphorus have no effect on the soluble solids and will therefore give a higher TSS:TA ratio. Embleton *et al.* (1956) and Anderson (1966) found that an increase in phosphorus increased the TSS:TA ratio.

High phosphate levels, give a slight decrease in acidity (Embleton *et al.*, 1956; Jones, 1961; Smith *et al.*, 1963; Anderson, 1966; Kefford & Chandler, 1970), while Jones & Parker (1949) noted no effect.

It is therefore clear that phosphorus application give contradictory results in terms of internal fruit quality.

3.6.1.3 POTASSIUM

Trees with a high potassium status yield large fruit with low soluble solids and high acidity (Reuther & Smith, 1952; Sites & Deszyck, 1952; Reitz & Koo, 1960; Jones, 1961; Kefford & Chandler, 1970; Ting & Attaway, 1971) and potassium will therefore decrease the TSS:TA ratio (Sites & Deszyck, 1952; Reitz & Koo, 1960; Jones, 1961; Koo, 1988). Trees supplied with large amounts of potassium also produce more poorly-coloured fruit (Reuther & Smith, 1952; Sites & Deszyck, 1952; Reitz & Koo, 1960). Lee & Chapman (1988) found that TSS levels in 'Ellendale' mandarins were unaffected by potassium applications. They also found the increased acid content with potassium applications.

Reduced supply of potassium will result in better quality fruit, but it must be remembered that potassium is an essential element for plant growth. According to Sites & Deszyck (1952) the effects of potassium on internal fruit quality appears to be due to the effect of potassium on fruit size.

3.6.1.4 MICRONUTRIENTS

Koo (1988) found that most micronutrient elements do not affect fruit quality.

3.6.2 ARSENICAL SPRAYS

Arsenical sprays (lead or calcium arsenate) have been used on grapefruit shortly after bloom to reduce fruit acidity (Deszyck & Ting, 1958; Hilgeman, 1966; Erickson, 1968; Ting & Attaway, 1971; Koch, 1988a). A lead arsenate spray is usually most effective when applied about two months after fruit set (Ting & Attaway, 1971). According to Kefford & Chandler (1970), Pretorius (1966) found that calcium arsenate also decreases acidity in Valencia oranges. The arsenate partly substitutes for phosphate in the ATP-ADP energy transfer system (Gilfillan, 1990) and partially uncouples the reaction in the Krebs cycle which leads to citric acid formation (Kefford & Chandler, 1970; Gilfillan, 1990). Acidity is therefore not actually reduced, but a proportion of the acid is not synthesised (Gilfillan, 1990). Arsenical sprays, therefore, affect the citrate synthase enzyme system. During periods of high rainfall arsenical sprays are more effective than during dry periods (Deszyck & Ting, 1958).

3.6.3 IRRIGATION MANAGEMENT

According to Davies & Albrigo (1994) a mature citrus tree generally requires from 1000 to 1563 mm of water each year to replace the loss by evapotranspiration (ET). Irrigation scheduling should be based on the concept of replenishing daily water losses by evapotranspiration (Davies & Albrigo, 1994). Deficit irrigation is the deliberate and systematic under-irrigation of crops and is a common practice in many areas of the world, especially in arid countries (English & Raja, 1996). Grape growers use deficit irrigation to reduce vegetative growth of vines and improve grape quality (Wardle, 1991). High soil water stimulates vegetative growth (Hilgeman & Sharp, 1970; Dasberg, 1992). In citrus, deficit irrigation is conducted in an attempt to enhance internal fruit quality, mainly by increasing TSS. Peng & Rabe (1996) found in 'Mihowase' Satsumas that deficit irrigation i.e. irrigation when soil water tension at 70 cm soil depth reached -70 kPa induced earlier harvesting than when using normal irrigation i.e. irrigation when soil water tension at 70 cm soil depth reached -30 kPa. Reduced irrigation can be achieved by reducing the irrigation surface area and/or reducing the irrigation frequency and water amounts. The effects of water deficits on fruit quality may depend on the intensity and duration of the water stress period, as well as the stage when the deficit is introduced.

3.6.3.1 TIMING OF DEFICIT IRRIGATION

Citrus fruit are very sensitive to the plant water deficits (Davidson & David, 1975). Adequate water supply is of major importance during citrus flowering and fruit set to prevent abscission of flowers and fruitlets (Goell, 1988; Sardo & Germana, 1988; Domingo *et al.*, 1996) and subsequent yield loss. In the rapid fruit growth period (stage II) a shortage of water may cause small fruit (Davidson & David, 1975; Sardo & Germana, 1988; Domingo *et al.*, 1996). The response of citrus trees to water stress is therefore dependent on the phenological phase (I, II or III) in which water stress is applied (Shalhevet & Bielorai, 1978; Sanchez-Blanco *et al.*, 1989; Castel & Buj, 1990). Ginestar & Castel (1996) found in Clementines that fruit quality was affected mainly during period III (final fruit growth and beginning of ripening-maturation phase (August to October in northern hemisphere)) by deficit irrigation, increasing sugar content and acidity. Cruse *et al.* (1982) found in 'Marrs' oranges, harvested in November (northern hemisphere), that water conditions in the summer (May to August) affected TSS the most. Therefore, Peng & Rabe (1998) introduced deficit irrigation only after the physiological fruit drop period.

3.6.3.2 EFFECT ON TSS, ACID AND TSS:ACID RATIO

In general, water shortage (especially during summer and ripening period) or a decrease in the amount of water applied (Hilgeman, 1977) causes an increase in concentration of TSS in the juice (Erickson & Richards, 1955; Reuther & Rios-Castano, 1969; Goell & Levy, 1970; Goell & Cohen, 1981; Goell, 1988; Castel & Buj, 1990; Dasberg, 1992; Peng & Rabe, 1996; 1997), increases juice acidity (Goell & Levy, 1970; Levy *et al.*, 1978a; Goell & Cohen, 1981; Kuriyama *et al.*, 1981; Cruse *et al.*, 1982; Koo & Smajstrla, 1984; Goell, 1988; Sardo & Germana, 1988; Sanchez Blanco *et al.*, 1989; Peng & Rabe, 1997), smaller fruit (Hilgeman & Sharples, 1957; Goell & Levy, 1970; Barbera *et al.*, 1988; Peng & Rabe, 1996) and a lower juice content (Goell & Levy, 1970). Under conditions of heat or moisture stress, water can move from citrus fruit to leaves, as well as being lost directly from the fruit (Kefford & Chandler, 1970; Koch, 1988a) and the soluble solids content in the fruit increases (Kefford & Chandler, 1970). Deficit irrigation also enhances earlier fruit colouration

(Peng & Rabe, 1996) and earlier commercial maturity (Peng & Rabe, 1997). Levy *et al.* (1979) showed the same results in grapefruit. They found that trees receiving a 40-day irrigation interval had significantly higher TSS and sugar levels. Acidity may increase more than the TSS, lowering the TSS:TA ratio and thereby diminishing fruit quality (Levy *et al.*, 1978b). Levy *et al.* (1978b) reported that the effect of summer water stress on acid accumulation in Marsh grapefruit lasted long after the stress was relieved and was more pronounced than the effect of stress on TSS. Grapefruit may be more sensitive to deficit irrigation than oranges (Levy *et al.*, 1978b).

Excess irrigation or precipitation (especially during the ripening period) affects fruit quality by decreasing fruit TSS (Hilgeman & Sharples, 1957; Hilgeman, 1966; 1977; Kimball, 1984a; Barbera *et al.*, 1988; Koch, 1988a; Koo, 1988; Dasberg, 1992; Sepaskhah & Kashefipour, 1994), total sugars (Sanchez Blanco *et al.*, 1989) and total acidity (mainly citric acid)(Hilgeman & Sharples, 1957; Kefford & Chandler, 1970; Davidson & David, 1975; Hilgeman, 1977; Cruse *et al.*, 1982; Barbera *et al.*, 1988; Koch, 1988a; Koo, 1988; Sepaskhah & Kashefipour, 1994) by a dilution effect (Koch, 1988a; Davies & Albrigo, 1994), increasing fruit size, and producing fruit of a low keeping quality (Dasberg, 1992). Levy *et al.* (1978a) also reported an inverse relationship between mean acid content in grapefruit and rainfall. In unusually wet years this can cause problems in meeting industry standards. Excessive irrigation (water application above the ET demand) therefore may not only decrease fruit quality, but produce larger fruit with a higher juice % (Davidson & David, 1975; Dasberg, 1992) and cause excessive vegetative growth (Hilgeman, 1977; Dasberg, 1992).

3.6.3.3 IRRIGATION SYSTEM

The irrigation technique also affects the fruit quality (Shalhevet & Levy, 1990). Drip irrigation increased acid and TSS in Valencia orange when compared with microjet irrigation in Florida (Koo & Smajstrla, 1984). On the other hand Bravdo *et al.* (1992) found that drip compared to microjet irrigation had no effect on fruit quality, when similar amounts of water were applied. Deidda *et al.* (1992) compared two irrigation systems (drip and microsprinkler) and found that Valencia fruit from drip treatments showed significantly less acidity than those from microjet treatments if trees of both treatments received the same amount of water.

Irrigation methods that wet only a portion of the soil surface tend to increase the TSS:TA ratio of Valencia oranges (Shalhevet & Levy, 1990). Moreshet *et al.* (1983) compared the quality of fruit from trees where 100% of the soil volume was irrigated, with trees where only 40 % of the volume was irrigated. Fruit from the partially irrigated plot had a higher percentage of TSS and acids, but the TSS:TA ratio was unaffected (Moreshet *et al.*, 1983). The partially irrigated plot received 6 m^3 water/tree/year and six irrigations less than the fully irrigated plot (Moreshet *et al.*, 1983). Koo & Smajstrla (1984) found that for Valencia oranges both soluble solids and acid concentration decreased with increase in ground coverage and irrigation rates due to the dilution effect water has on juice solids.

3.6.3.4 PHYSIOLOGICAL CHANGES

Deficit irrigation seems to positively influence the assimilate partitioning into fruit (Peng & Rabe, 1998; Yakushiji *et al.*, 1998), because the increase in TSS implies that a higher percentage of carbohydrates was partitioned into fruit in trees subjected to the deficit irrigation regime. The increase in the sugar content caused by deficit irrigation could be attributable to physiological changes rather than a concentration effect (Kuriyama *et al.*, 1981). This increase in the sugar content has been assumed to be the inhibition of polysaccharide synthesis from photosynthates and hydrolysis of polysaccharides in the fruit pulp (Kuriyama *et al.*, 1981). Yakushiji *et al.* (1996; 1998), however, found that the sugar accumulation (increase in total sugars per fruit) in Satsuma mandarin fruit due to water stress was not caused by dehydration, but rather that sugars were accumulated by active osmoregulation. The monosaccharides, glucose and fructose, were largely responsible for the active osmoregulation (Yakushiji *et al.*, 1996).

It is important to note that severe water stress can cause lower rates of photosynthesis caused by lower leaf diffusive conductance to water vapor and CO_2 (Levy *et al.*, 1978b) due to reduced transpiration because of closure of the stomata (Levy, 1983; Goldschmidt & Koch, 1996). This leads to less photosynthetic fixation of ambient CO_2 (Vu & Yelenosky, 1988; Davies & Albrigo, 1994; Goldschmidt & Koch, 1996) and results in the inhibition of vegetative and/or fruit growth (Davies & Albrigo, 1994). It is during these severe stress periods when oranges such as Valencias show significant shifts in carbohydrate reserves (Yelenosky, 1991). Peng & Rabe (1998) found that an irrigation regime of -100 kPa at 30 cm depth produced a lower TSS in the fruit than the -70 kPa regime, probably due to the negative effect of the -100 kPa regime on leaf CO_2 assimilation rate.

3.6.3.5 RECOMMENDATIONS RELATIVE TO IRRIGATION MANAGEMENT

Hilgeman & Sharples (1957), Hilgeman & Sharp (1970), Davidson & David (1975), Hilgeman (1977) and Kuriyama *et al.* (1981) recommended high soil moisture between March and July (between bloom and until the fruit become larger than 25 mm in diameter), followed by low soil moisture in August and October (northern hemisphere)(maturation period). Peng & Rabe (1998) suggested that deficit irrigation (-60 kPa at 60 cm soil depth) on 'Mihowase' Satsumas should be initiated at 0-4 weeks after the physiological fruit drop period (APFD) (clay-loam soil type) or 0-2 weeks APFD (sandy-loam soil type). Erickson & Richards (1955) introduced their reduced soil moisture regime from July (northern hemisphere) in Valencia oranges. Levy *et al.* (1978b) suggested that differential irrigation treatments should be applied only during the summer months. Goell & Cohen (1981) found in Marsh grapefruit and Shamouti orange that midbloom girdling (3/4 of the branches were girdled) intensified moisture stress.

3.6.4 GIRDLING

Girdling is a very old horticultural practice with a history of erratic results regarding fruit set and fruit size increase, better juice quality and the alleviation of alternate bearing (Krezdorn, 1960). A girdled tree is one in which the phloem is completely severed either by a narrow incision or by the removal of a cylinder of bark from the trunk (Noel, 1970). Citrus productivity and tree response to girdling depends on girdling date, girdling procedures and techniques like girdle width and position, i.e. on the trunk or branches, cultivar and climatic differences. For the most significant effect, girdling is carried out during the season of active growth (Noel, 1970).

3.6.4.1 GIRDLING TECHNIQUES AND GIRDLING WIDTHS

Girdling is usually carried out by removing a 2-3 mm wide ring of bark 10 cm above the bud union (Monselise *et al.*, 1972; Cohen, 1981), or by making a single cut through the bark of the trunk or branches (Cohen, 1981).

Cohen (1977) stated that the girdles have to be rather wide to have the desired effects, but that wide girdles may cause damage to the girdled branches or trees. The girdle must be around the whole circumference of the trunk or branch (Cohen, 1981). Hochberg *et al.* (1977) suggested that the effect of girdling can be enhanced by reopening the scar a month later, because the beneficial effects of girdling last as long as the girdle remains open (Cohen, 1984a, 1984b). Cohen (1984a, 1984b) also found that double girdling (repetition of narrow girdle at same site three weeks later), had a greater effect than a single girdle, even if it is a wide one.

3.6.4.1.1 TRUNK STRANGULATION

The trunks of citrus trees can be strangulated with a steel wire. The wire is removed a few months after strangulation. Trunk strangulation has almost the same effect on the tree as girdling (Yamanishi, 1995; Yamanishi & Hasegawa, 1995).

3.6.4.2 TIMING AND EFFECTS OF GIRDLING

3.6.4.2.1 SPRING GIRDLING FOR BETTER YIELDS

Girdling is used in citriculture mainly during the spring (beginning of bloom) to increase yields (Wallerstein *et al.*, 1978a) by increasing fruit number (fruit set) rather than fruit size (Goren & Monselise, 1971; Monselise *et al.*, 1972; Erner, 1988).

3.6.4.2.2 SUMMER GIRDLING FOR BETTER FRUIT SIZE

Summer girdling (June and August in northern hemisphere) increases fruit size (Hochberg *et al.*, 1977; Cohen, 1981; 1984a, 1984b). According to Cohen (1981) summer girdling should be carried out as soon as possible after cessation of the physiological fruit drop period.

3.6.4.3 EFFECT OF GIRDLING ON INTERNAL FRUIT QUALITY

Girdling of various varieties affect fruit quality and ripening date (Cohen, 1977; 1984a), but some of the effects are too small to justify the use of girdling as a commercial treatment (Iwahori *et al.*, 1977; Cohen, 1981).

3.6.4.3.1 SPRING GIRDLING

Goren & Monselise (1971) found that girdling late in the bloom period, reduced the TSS:TA ratio. Barry & Veldman (1997) found that when Ambersweet trees were girdled in the spring during fullbloom, the TSS was higher, the acid content was lower and the external colour was more advanced.

3.6.4.3.2 SUMMER GIRDLING

Peng & Rabe (1996) reported that girdling at 2-4 weeks after the physiological fruit drop period (December drop in southern hemisphere; 'June drop'in northern hemisphere) increased TSS levels and TSS:TA ratios in 'Mihowase' Satsumas for trees receiving both deficit and normal irrigation. Hochberg *et al.* (1977) found that girdling on grapefruit trees (June in northern hemisphere) produce fruit with higher acidity and caused some delay in fruit maturation. On the other hand, Cohen (1984b) found that summer girdling on 'Marsh' grapefruit had no effect on internal fruit quality, but colour break occurred earlier. Pummelo trees strangulated in July (northern hemisphere) with a steel wire 5-10 cm above the bud union showed significantly higher levels of the three main sugars, sucrose, glucose and fructose, as well as citric acid content (Yamanishi & Hasegawa, 1995). The wires were removed two months later (Yamanishi & Hasegawa, 1995).

Trunk strangulation of 'Tosa Buntan' pummelo in October (northern hemisphere) with a steel wire (removed after four months) increased TSS content of the juice due to an increased sucrose content two months after imposing the treatment (Yamanishi, 1995). The decrease in TA was due to the decrease in citric acid concentration and led to an increase in the TSS:TA ratio (Yamanishi, 1995). Church (1933) found an increase in TSS, reducing sugars, and total sugar content in Navel fruit after girdling (girdling date unknown).

Noel (1970) stated that the season of girdling will affect the healing ability, thus trees girdled during the dormant phase will not heal or heal very slowly. Girdling in consecutive years on 'Mihowase' Satsumas led to a negative yield response and smaller fruit and did not increase TSS and the TSS:TA ratio significantly in the second year (Peng & Rabe, 1996). Trees girdled under deficit irrigation have smaller leaves and less vegetative growth than trees girdled under normal irrigation (Peng & Rabe, 1996).

3.6.4.4 PHYSIOLOGICAL CHANGES DUE TO GIRDLING

Cohen (1981) found that girdling mainly affects the rate of existing processes, but does not alter them significantly. Girdling does not completely prevent the movement of surplus food from the foliage to the roots (Noel, 1970). Auxin is transported in the cambium and phloem (Noel, 1970). When a tree is girdled, the sieve tubes above the girdle degenerates (older sieve tubes first and younger ones later) and cease to transport materials (Schneider, 1954). Carbohydrates therefore accumulate above the girdle (Schneider, 1954). Noel (1970) suggested that the early fruit maturity due to girdling is due to reduced water supply.

Girdling temporarily prevents the upward transport of certain forms of nitrogen and the downward transport of carbohydrates, and other plant materials, including growth regulators (Goldschmidt & Koch, 1996). Girdling is known to affect fruit quality, probably by interfering with the hormonal balance (Goren *et al.*, 1971). In evergreen trees there is a continuous downward movement of carbohydrates through the trunk phloem to the roots (Schneider, 1954). Attempts to explain the various aspects of girdling and its effects on the trees have included studies of the changes in carbohydrates (Wallerstein *et al.*, 1974; 1978a).

The primary effect of girdling is due to the accumulation of photosynthates produced by the leaves above the girdle (Wallerstein *et al.*, 1974; 1978a). Girdling inhibits carbohydrate translocation (mostly sucrose) to the roots through phloem bundles in citrus seedlings immediately after girdling (Goren *et al.*, 1971; Agusti *et al.*, 1992) and induces starch accumulation in the leaves (Wallerstein *et al.*, 1974; Agusti *et al.*, 1992). Soluble sugar levels in the leaves reach saturation very early after girdling which leads to starch accumulation (Erner, 1988). Such leaves may abscise and affect the following crop (Agusti *et al.*, 1992).

Citrus roots become depleted of carbohydrates following girdling, especially when trees are girdled in the middle of the growing season (Schneider, 1954). In such trees, the only available sink for photosynthates are the fruit, since shoot growth ceases during fruit maturation (Yamanishi, 1995).

Other explanations suggest that girdling changes the hormonal balance, mainly auxin and gibberellins, and causes accumulation of gibberellin-like substances in the bark above the ring (Wallerstein *et al.*, 1973). The girdling of trunks of 'Shamouti' orange trees in March (northern hemisphere) promoted the accumulation of growth substances in the bark near the ring and in the leaves, and when ringing in August, gibberellins accumulated above the ring (Goren *et al.*, 1971). The increased gibberellin activity in the aerial parts increase fruit setting (Monselise *et al.*, 1972). The effect of girdling on root starvation may be due to the reduced level of gibberellins in the roots (Wallerstein *et al.*, 1973). By contrast, Goren *et al.* (1971) suggested that the effect of ringing on yield is not hormone-mediated.

3.6.4.5 NEGATIVE EFFECTS OF GIRDLING

Damage symptoms, such as leaf yellowing (inhibition of photosynthesis) following girdling might be due to an excessive accumulation of photosynthetic products above the girdle (Cohen, 1977; 1981; Goldschmidt & Koch, 1996). Yamanishi & Hasegawa (1995) found the same results in strangulated pummelo trees. Cohen (1977) stated that damage to trees can also occur due to decreased root development in trunk-girdled trees. The decrease is apparently caused by a deficiency in the root of materials produced by the leaves, probably carbohydrates and IAA (auxin) (Cohen, 1977).

Erner (1988) stated that annual girdling causes severe damage and therefore biennial girdling is preferred. Girdled trees need adequate irrigation and fertilisation, because improperly irrigated orchards show more injury to girdled trees (Cohen, 1984b). Krezdorn (1960) stated that trees low in vigour and very young trees should not be girdled. Girdling of weak, unhealthy trees might also be disadvantageous to the trees (Goren & Monselise, 1971; Cohen, 1981; 1984b). Therefore, only trees in optimum health should be girdled.

After girdling there is formation of wound callus (Noel, 1970). Regeneration, leading to girdle healing, occurs from secondary vascular cambium and phellogen, differentiating in callus tissue (Noel, 1970).

3.6.5 RIDGING OF SOILS

Ridging soils is a rediscovery of a practice used by the ancient Romans to utilise soils that became useless because of waterlogging. Ridging was generally used in Europe and England with the cultivation of vegetables. With the introduction of underground drainage the industry moved away from ridging soils (Du Preez, 1985).

The key reason for ridging soils is to improve internal drainage of the soils (Du Preez, 1985; Snyman, 1991; Coetzee, 1995) and thereby increasing the soil temperature. Ridging also improves the surface drainage of soils with a low infiltration rate (Du Preez, 1985). Ridged soils dry out more quickly and rainfall will be less effectively used, because the roots in the ridges are limited to the ridged part of the soils (Abercrombie, 1996). Especially in summer, the root zone dries out quickly and conditions similar to deficit irrigation develop. When there is no rainfall one can regulate the exact amount of water each tree receives through irrigation. These drier soils, especially during the maturation phase, would increase the internal quality (TSS) of the fruit. Moist soils during the maturation period would result in a lower TSS in the fruit due to a dilution effect.

Kuriyama *et al.* (1981) found in Satsuma mandarin that after laying drainage pipes, the total sugar and citric acid contents at harvest were slightly higher in the drained areas.

4. CONCLUSION

Citrus fruit with a low TSS content and therefore a low TSS:TA ratio is sometimes a problem in the citrus industry. Such fruit have a tart taste. The high internal quality standards demanded for export force producers of citrus to enhance the TSS levels of the fruit in some way.

In commercial orchards, climate is difficult to regulate, but producers can manipulate other factors in order to increase the TSS of the fruit. When choosing a rootstock, rough lemon should be avoided if possible. However, the performance of the rootstock in the soil should not be neglected. Fertilisation should be used judiciously. Adequate light levels are important for the formation of soluble solids and increases with better exposure of the leaves to sunlight. Pruning can be done to increase light penetration into the tree.

Deficit irrigation would increase the TSS content of fruit, but only if applied during the maturation period (stage III) and after the physiological fruit drop period. During bloom, deficit irrigation would lead to abscission of flowers and during fruit growth it would lead to small fruit. I would think that deficit irrigation would have a better effect on early-maturing mandarins than on Navels and Valencias picked after the winter rains.

Girdling cuts off the roots as a sink for carbohydrates. The carbohydrates accumulate above the girdle and are thought to be preferentially partitioned to the fruit. Girdling should be carried out when the tree and roots are active and carbohydrates are translocated out of the leaves. This happens after the physiological fruit drop period.

Ridged soils allow quicker drainage. The practical effect of ridging is probably resembling deficit irrigation. Therefore, by reducing the amount of water each tree receives and by girdling, the TSS content in the fruit will increase. The timing of these practices are however very important.

5. REFERENCES

ABERCROMBIE, R.A., 1996. Rifverbouing by sitrus. *Subtropica* **17**, 12-16.

AGUSTI, M., ALMELA, V. & PONS, J., 1992. Effects of girdling on alternate bearing in citrus. *J. Hortic. Sci.* **67**, 203-210.

ALBRIGO, L.G., 1977. Rootstocks affect 'Valencia' orange fruit quality and water balance. *Proc. Int. Soc. Citric.* **1**, 62-65.

ANDERSON, C.A., 1966. Effects of phosphate fertilizer on yield and quality of 'Valencia' oranges. *Proc. Fla. State Hortic. Soc.* **79**, 36-40.

BAIN, J.M., 1958. Morphological, anatomical, and physiological changes in the developing fruit of the Valencia orange, *Citrus sinensis* (L.) Osbeck. *Aust. J. Bot.* **6**, 1-28.

BARBERA, G., CARIMI, F. & LEONE, F., 1988. Effects of different levels of water stress on yield and quality of lemon trees. *Proc. VIth Int. Citrus Congr.*, 717-722.

BARRY, G. & VELDMAN, F., 1997. A preliminary study on the effect of girdling on fruit set and quality of Ambersweet mandarin hybrid. *Citrus J.* **7**, 25.

BARTHOLOMEW, E.T. & SINCLAIR, W.B., 1943. Soluble constituents and buffer properties of orange juice. *Plant Physiol.* **18**, 185-206.

BEAN, R.C. & TODD, G.W., 1960. Photosynthesis and respiration in developing fruits I. $^{14}CO_2$ uptake by young oranges in light and in dark. *Plant Physiol.* **35**, 425-429.

BEEVER, D.J., 1990. Export quality satsumas need careful handling. *Orchard. N. Z.* March, 24-25.

BITTERS, W.P., 1961. Physical characters and chemical composition as affected by scions and rootstocks. Chapter 3, 56-96. In: W.B. SINCLAIR (ed.), The Orange: Its Biochemistry and Physiology. University of California, Division of Agricultural Sciences, Berkeley, USA.

BORRAS, R., TADEO, J.L. & PRIMO MILLO, E., 1984. Seasonal carbohydrate changes in two sweet orange varieties of the navel group. *Sci. Hortic.* **24**, 143-149.

BOUMA, D., 1956. Studies in citrus nutrition. II. Phosphorus deficiency and fruit quality. *Aust. J. Agric. Res.* **7**, 261-271.

BRAVDO, R., SALOMON, E., ERNER, Y., SAADA, D., SHUFMAN, E. & OREN, Y., 1992. Effect of drip and microsprinkler fertigation on citrus yield and quality. *Proc. Int. Soc. Citric.* **2**, 646-648.

CANCALON, P.F., 1994. Changes in the saccharide composition of citrus juice and anatomical fractions during fruit maturation. *Proc. Fla. State Hortic. Soc.* **107**, 253-256.

CASTEL, J.R. & BUJ, A., 1990. Response of Salustiana oranges to high frequency deficit irrigation. *Irrig. Sci.* **11**, 121-127.

CHURCH, C.G., 1933. Composition of juice of oranges from girdled and normal trees. *Calif. Citrogr.* **18**, 348-349.

CLEMENTS, R.L., 1964a. Organic acids in citrus fruits. I. Varietal differences. *J. Food Sci.* **29**, 276-280.

CLEMENTS, R.L., 1964b. Organic acids in citrus fruits. II. Seasonal changes in the orange. *J. Food Sci.* **29**, 281-286.

COETZEE, J.G.K., 1995. Ridging soils for new citrus plantings. *Citrus J.* **5**, 22-24.

COHEN, A., 1977. Girdling effects on tree performance. *Proc. Int. Soc. Citric.* **1**, 178-181.

COHEN, A., 1981. Recent developments in girdling of citrus trees. *Proc. Int. Soc. Citric.* **1**, 196-199.

COHEN, A., 1984a. Citrus fruit enlargement by means of summer girdling. *J. Hortic. Sci.* **59**, 119-125.

COHEN, A., 1984b. Effect of girdling date on fruit size of Marsh seedless grapefruit. *J. Hortic. Sci.* **59**, 567-573.

COHEN, E., 1988. The chemical composition and sensory flavour quality of 'Minneola' tangerines. I. Effects of fruit size and within-tree position. *J. Hortic. Sci.* **63**, 175-178.

CRUSE, R.R., WIEGAND, C.L. & SWANSON, W.A., 1982. The effects of rainfall and irrigation management on citrus juice quality in Texas. *J. Am. Soc. Hortic. Sci.* **107**, 767-770.

DASBERG, S., 1992. Irrigation management and citrus production. *Proc. Int. Soc. Citric.* **3**, 1307-1310.

DAVIDSON, M. & DAVID, B., 1975. Mineral nutrition and irrigation in citrus crops, 14-20. In: E. HAFLIGER (ed.), Citrus. Technical Monograph, No. 4. Ciba-Geigy Ltd., Basle, Switzerland.

DAVIES, F.S., 1986. The navel orange. *Hortic. Rev.* **8**, 129-180.

DAVIES, F.S. & ALBRIGO, L.G., 1994. Plant husbandry. Chapter 3, 79-82. Chapter 7, 202-224. In: F.S. DAVIES & L.G. ALBRIGO (eds.), Citrus, Crop Production Science in Horticulture 2. CAB International, Wallingford, Oxon, UK.

DEIDDA, P., FILIGHEDDU, M.R., DETTORI, S., 1992. Progress report on the influence of irrigation system on yield and fruit quality in 'Valencia' orange [*Citrus sinensis* (L.) Osbeck]. *Proc. Int. Soc. Citric.* **2**, 643-645.

DESZYCK, E.J. & TING, S.V., 1958. Seasonal changes in acid content of Ruby Red grapefruit as affected by lead arsenate sprays. *Proc. Am. Soc. Hortic. Sci.* **72**, 304-308.

DOMINGO, R., RUIZ-SANCHEZ, M.C., SANCHEZ-BLANCO, M.J. & TORRECILLAS, A., 1996. Water relations, growth and yield of Fino lemon trees under regulated deficit irrigation. *Irrig. Sci.* **16**, 115-123.

DU PREEZ, M., 1985. Ridging of orchard soil. *Decid. Fruit Grow.* **35**, 22-31.

ECHEVERRIA, E, 1990. Developmental transition from enzymatic to acid hydrolysis of sucrose in acid limes (*Citrus aurantifolia*). *Plant Physiol.* **92**, 168-171.

ECHEVERRIA, E. & BURNS, J.K., 1989. Vacuolar acid hydrolysis as a physiological mechanism for sucrose breakdown. *Plant Physiol.* **90**, 530-533.

ECHEVERRIA, E. & BURNS, J.K., 1990. Sucrose breakdown in relation to fruit growth of acid lime (*Citrus aurantifolia*). *J. Exp. Bot.* **41**, 705-708.

ECHEVERRIA, E. & ISMAIL, M., 1990. Sugars unrelated to Brix changes in stored citrus fruits. *HortScience* **25**, 710.

ECHEVERRIA, E. & VALICH, J., 1988. Carbohydrate and enzyme distribution in protoplasts from Valencia orange juice sacs. *Phytochemistry* **27**, 73-76.

ECHEVERRIA, E. & VALICH, J., 1989. Enzymes of sugar and acid metabolism in stored 'Valencia' oranges. *J. Am. Soc. Hortic. Sci.* **114**, 445-449.

EMBLETON, T.W., JONES, .W.W. & KIRKPATRICK, J.D., 1956. Influence of applications of dolomite, potash, and phosphate on quality, grade, and composition of Valencia orange fruit. *Proc. Am. Soc. Hortic. Sci.* **67**, 191-201.

EMBLETON, T.W., REITZ, H.J. & JONES, W.W., 1973. Citrus Fertilization. Chapter 5, 122-182. In: W. REUTHER (ed.), The Citrus Industry. Vol III, University of California, Riverside, California.

ENGLISH, M. & RAJA, S.N., 1996. Perspectives on deficit irrigation. *Agric. Water Manag.* **32**, 1-14.

ERICKSON, L.C., 1968. The general physiology of citrus. Chapter 2, 86-126. In: W. REUTHER, H.J. WEBBER & L.D. BATCHELOR (eds.), The Citrus Industry. Univ. of California Press, Berkeley.

ERICKSON, L.C. & RICHARDS, S.J., 1955. Influence of 2,4-D and soil moisture on size and quality of Valencia oranges. *Proc. Am. Soc. Hortic. Sci.* **65**, 109-112.

ERNER, Y., 1988. Effects of girdling on the differentiation of inflorescence types and fruit set in 'Shamouti' orange trees. *Isr. J. Bot.* **37**, 173-180.

FALLAHI, E. & MOON, J.W. Jr., 1989. Fruit quality and mineral nutrients from exposed versus internal canopy positions of four citrus varieties. *J. Plant Nutr.* **12**, 523-534.

GARCIA-LUIS, A., DIDEHVAR, F., GUARDIOLA, J.L. & BAKER, D.A., 1991. The transport of sugars in developing fruits of satsuma mandarin. *Ann. Bot.* **68**, 349-357.

GEIGER, D.R. & SAVONICK, S.A., 1975. Effects of temperatures, anoxia and other metabolic inhibitors of translocation, 256-286. In: M.H. ZIMMERMAN & J.A. MILBURN (eds.). Transport in Plants. I. Phloem Transport. Springer Verlag. Berlin, Heidelberg, New York.

GILFILLAN, I.M., 1990. Crop manipulation: Fruit acid reduction with calcium arsenate sprays, 7-9. In: R.M. NETTERVILLE (ed.). Production Guidelines for Export Citrus, Vol. II, S.A. Co-op Citrus Exchange, Hennopsmeer, South Africa.

GINESTAR, C. & CASTEL, J.R., 1996. Responses of young clementine citrus trees to water stress during different phenological periods. *J. Hortic. Sci.* **71**, 551-559.

GOELL, A., 1988. Citrus irrigation in Israel-making do with less water. *Proc. VIth Int. Citrus Congr.*, 699-706.

GOELL, A. & COHEN, A., 1981. Combining irrigation regimes with girdling techniques in citrus trees (a new experimental mode). *Proc. Int. Soc. Citric.* **2**, 514-518.

GOELL, A. & LEVY, Y., 1970. The effects of irrigation stress on fruit quality. *Proc. XVIIIth Int. Hortic. Congr.* **1**, 221-222 [Abstr.].

GOLDSCHMIDT, E.E. & KOCH, K.E., 1996. Citrus. Chapter 34, 797-823. In: E. ZAMSKI & A.A. SCHAFFER (eds.), Photoassimilate Distribution in Plants and Crops. Marcel Dekker Inc., New York.

GOREN, R. & MONSELISE, S.P., 1971. Effects of ringing on yields of low-bearing orange trees (*Citrus sinensis* (L.) Osbeck). *J. Hortic. Sci.* **46**, 435-441.

GOREN, R., GOLDSCHMIDT, E.E. & MONSELISE, S.P., 1971. Hormonal balance in bark and leaves of Shamouti orange trees (*Citrus sinensis* (L.) Osbeck) in relation to ringing. *J. Hortic. Sci.* **46**, 443-451.

HAAS, A.R.C. & KLOTZ, L.J., 1935. Physiological gradients in citrus fruits. *Hilgardia* **9**, 181-217.

HILGEMAN, R.H., 1941. Studies of the ripening of Marsh grapefruit in Arizona, with special reference to the improvement of maturity measurements. *Ariz. Agric. Exp. Stn. Tech. Bull.* **89**, 95-168.

HILGEMAN, R.H., 1966. Effect of climate of Florida and Arizona on grapefruit fruit enlargement and quality; apparent transpiration and internal water stress. *Proc. Fla. State Hortic. Soc.* **79**, 99-106.

HILGEMAN, R.H., 1977. Response of citrus trees to water stress in Arizona. *Proc. Int. Soc. Citric.* **1**, 70-74.

HILGEMAN, R.H., & SHARP, F.O., 1970. Response of 'Valencia' orange trees to four soil water schedules during 20 years. *J. Am. Soc. Hortic. Sci.* **95**, 739-745.

HILGEMAN, R.H., & SHARPLES, G.C., 1957. Irrigation trials with Valencias in Arizona. *Calif. Citrogr.*. Sep., 404-407.

HOCHBERG, R., MONSELISE, S.P. & COSTO, J., 1977. Summer girdling and 2,4-D effects on grapefruit sizes. *HortScience* **12**, 228.

HUANG, T-B., DARNELL, R.L. & KOCH, K.E., 1992. Water and carbon budgets of developing citrus fruit. *J. Am. Soc. Hortic. Sci.* **117**, 287-293.

IWAGAKI, I., 1981. Tree configuration and pruning of Satsuma mandarin in Japan. *Proc. Int. Soc. Citric.* **1**, 169-172.

IWAHORI, S., MATSUMOTO, R. & OOHATA, J.T., 1977. Effects of trunk ringing and defoliation on maturation of Ponkan (*Citrus reticulata* Blanco) fruit. *Bull. Fac. Agric. Kagoshima Univ.* **27**, 1-6.

JONES, W.W., 1961. Environmental and cultural factors influencing the chemical composition and physical characters. Chapter 2, 25-55. In: W.B. SINCLAIR (ed.), The Orange: Its Biochemistry and Physiology. University of California, Division of Agricultural Sciences, Berkeley, USA.

JONES, W.W. & EMBLETON, T.W., 1959. The visual effect of nitrogen nutrition on fruit quality of Valencia oranges. *Proc. Am. Soc. Hortic. Sci.* **73**, 234-236.

JONES, W.W. & PARKER, E.R., 1949. Effects of nitrogen, phosphorus, and potassium fertilizers and of organic materials on the composition of Washington navel orange juice. *Proc. Am. Hortic. Sci.* **53**, 91-102.

JONES, W.W., EMBLETON, T.W. & CREE, C.B., 1962. Temperature effects on acid, Brix in Washington Navel oranges. *Calif. Citrogr.* **47**, 132-134.

KADOYA, K. & TANAKA, H., 1972. Studies on the translocation of photosynthates in satsuma orange. I. Effect of summer cycle shoot and bearing fruit on the translocation and distribution of ^{14}C. *J. Jpn. Soc. Hortic. Sci.* **41**, 23-28.

KATO, T. & KUBOTA, S., 1978. Properties of invertases in sugar storage tissues of citrus fruit and changes in their activities during maturation. *Physiol. Plant.* **42**, 67-72.

KEFFORD, J.F. & CHANDLER, B.V., 1970. General composition of citrus fruit. Chapter 2, 5-22. Carbohydrates. Chapter 3, 23-30. Acids. Chapter 4, 31-37. In: C.O. CHICHESTER, E.M. MRAK & G.F. STEWART (eds.), The Chemical Constituents of Citrus Fruits. Academic Press, Inc., New York.

KETSA, S., 1988. Effects of fruit size on juice content and chemical composition of tangerine. *J. Hortic. Sci.* **63**, 171-174.

KIMBALL, D.A., 1984a. Factors affecting the rate of maturation of citrus fruits. *Proc. Fla. State Hortic. Soc.* **97**, 40-44.

KIMBALL, D.A., 1984b. Brix/acid ratio: Brix/acid ratio correlation with climatic data for California Navel and Valencia oranges. *Citrus Ind.*. Aug., 26-29.

KOCH, K.E., 1984a. Translocation of photosynthetic products from source leaves to aligned juice segments in citrus fruit. *HortScience* **19**, 260-261.

KOCH, K.E., 1984b. The path of photosynthate translocation into citrus fruit. *Plant Cell Environ.* **7**, 647-653.

KOCH, K.E., 1988a. Production and environmental factors affecting the Brix/acid ratio, 78-81. In: J.J. FERGUSON & W.F. WARDOWSKI (eds.), Factors Affecting Fruit Quality. Proceedings, Citrus Short Course. Citrus Research and Education Center, Lake Alfred, Florida.

KOCH, K.E., 1988b. Sugar and acid metabolism in citrus fruit, 59-66. In: J.J. FERGUSON & W.F. WARDOWSKI (eds.), Factors Affecting Fruit Quality. Proceedings, Citrus Short Course. Citrus Research and Education Center, Lake Alfred, Florida.

KOCH, K.E. & AVIGNE, W.T., 1984. Localized photosynthate deposition in citrus fruit segments relative to source-leaf position. *Plant Cell Physiol.* **25**, 859-866.

KOCH, K.E. & AVIGNE, W.T., 1990. Postphloem, nonvascular transfer in citrus. *Plant Physiol.* **93**, 1405-1416.

KOO, R.C.J., 1988. Fertilization and irrigation effects on fruit quality, 35-42. In: J.J. FERGUSON & W.F. WARDOWSKI (eds.), Factors Affecting Fruit Quality. Proceedings, Citrus Short Course. Citrus Research and Education Center, Lake Alfred, Florida.

KOO, R.C.J. & SMAJSTRLA, A.G., 1984. Effects of trickle irrigation and fertigation on fruit production and juice quality of 'Valencia' orange. *Proc. Fla. State Hortic. Soc.* **97**, 8-10.

KREZDORN, A.H., 1960. The influence of girdling on the fruiting of Orlando tangelos and navel oranges. *Proc. Fla. State Hortic. Soc.* **73**, 49-52.

KREZDORN, A.H., 1988. Pollination and related factors affecting fruit quality, 43-48. In: J.J. FERGUSON & W.F. WARDOWSKI (eds.), Factors Affecting Fruit Quality. Proceedings, Citrus Short Course. Citrus Research and Education Center, Lake Alfred, Florida.

KRIEDEMANN, P.E., 1969. ^{14}C Translocation in orange plants. *Aust. J. Agric. Res.* **20**, 291-300.

KURIYAMA, T., SHIMOOSAKO, M., YOSHIDA, M. & SHIRAISHI, S., 1981. The effect of soil moisture on the fruit quality of Satsuma mandarin (*Citrus unshiu* Marc.). *Proc. Int. Soc. Citric.* **2**, 524-527.

LEE, H.S. & NAGY, S., 1988. Relationship of sugar degradation to detrimental changes in citrus juice quality. *Food Technol.* Nov., 91-94, 97.

LEE, L.S. & CHAPMAN, J.C., 1988. Yield and fruit quality responses of Ellendale mandarins to different nitrogen and potassium fertiliser rates. *Aust. J. Exp. Agric.* **28**, 143-148.

LEVY, Y., 1983. Acclimation of citrus to water stress. *Sci. Hortic.* **20**, 267-273.

LEVY, Y., BAR-AKIVA, A. & VAADIA, Y., 1978a. Influence of irrigation and environmental factors on grapefruit acidity. *J. Am. Soc. Hortic. Sci.* **103**, 73-76.

LEVY, Y., BIELORAI, H. & SHALHEVET, J., 1978b. Long-term effects of different irrigation regimes on grapefruit tree development and yield. *J. Am. Soc. Hortic. Sci.* **103**, 680-683.

LEVY, Y., SHALHEVET, J. & BIELORAI, H., 1979. Effect of irrigation regime and water salinity on grapefruit quality. *J. Am. Soc. Hortic. Sci.* **104**, 356-359.

LEWIS, L.N. & McCARTY, C.D., 1973. Pruning and girdling of citrus. Chapter 7, 211-229. In: W. REUTHER (ed.), The Citrus Industry. Vol III, University of California, Riverside, California.

LOWELL, C.A., TOMLINSON, P.T. & KOCH, K.E., 1989. Sucrose-metabolizing enzymes in transport tissues and adjacent sink structures in developing citrus fruit. *Plant Physiol.* **90**, 1394-1402.

McCREADY, R.M., WALTER, E.D. & MACLAY, W.D., 1950. Sugars of citrus juices. *Food Technol.* Jan., 19-20.

MONSELISE, S.P., GOREN, R. & WALLERSTEIN, I., 1972. Girdling effects on orange fruit set and young fruit abscission. *HortScience* **7**, 514-515.

MORESHET, S., COHEN, Y. & FUCHS, M., 1983. Response of mature 'Shamouti' orange trees to irrigation of different soil volumes at similar levels of available water. *Irrig. Sci.* **3**, 223-236.

MURRAY, B.J., MAUK, C. & NOODEN, L.D., 1982. Restricted vascular pipelines (and orthostichies) in plants. *What's new in Plant Physiol.* **13**, 33-36.

NISPEROS-CARRIEDO, M.O., BALDWIN, E.A., MOSHONAS, M.G. & SHAW, P.E., 1992. Determination of volatile flavor components, sugars, and ascorbic, dehydroascorbic, and other organic acids in calamondin (*Citrus mitis* Blanco). *J. Agric. Food Chem.* **40**, 2464-2466.

NOEL, A.R.A., 1970. The girdled tree. *Bot. Rev.* **36**, 162-195.

PENG, Y.H. & RABE, E., 1996. Effect of summer trunk girdling on fruit quality, maturation, yield, fruit size and tree performance in 'Mihowase' satsumas. *J. Hortic. Sci.* **71**, 581-589.

PENG, Y.H. & RABE, E., 1997. Postharvest storage behaviour, respiration rate and ethylene evolution of fruit from deficit and normal irrigation in 'Mihowase Satsuma' trees. *J. S. Afr. Soc. Hortic. Sci.* **7**, 44-47.

PENG, Y.H. & RABE, E., 1998. Effect of differing irrigation regimes on fruit quality, yield, fruit size and net CO_2 assimilation of 'Mihowase' Satsuma. *J. Hortic. Sci. Biotechnol.* **73**, 229-234.

POSSINGHAM, J.V. & KRIEDEMANN, P.E., 1969. Environmental effects on the formation and distribution of photosynthetic assimilates in citrus. *Proc. Ist Int. Citrus Symp.* **1**, 325-332.

PRETORIUS, A., 1966. Influence of trace elements on the effectiveness of calcium arsenate sprays. *S. A. Citrus J.* **395**, 5-7.

PURVIS, A.C. & YELENOSKY, G., 1983. Translocation of carbohydrates and proline in young grapefruit trees at low temperatures. *Plant Physiol.* **73**, 877-880.

RASMUSSEN, G.K., REECE, P.C. & HENRY, W.H., 1965. Seasonal changes in fruit quality factors of Robinson, Osceola, Lee and Dancy tangerines. *Proc. Fla. State Hortic. Soc.* **78**, 51-55.

REITZ, H.J.& KOO, R.C.J., 1960. Effect of nitrogen and potassium fertilization on yield, fruit quality, and leaf analysis of Valencia orange. *Proc. Am. Soc. Hortic. Sci.* **75**, 244-252.

REUTHER, W., 1973. Climate and citrus behaviour. Chapter 9, 280-337. In: W. REUTHER (ed.), The Citrus Industry. Vol III, University of California, Riverside, California.

REUTHER, W., 1988. Climate and fruit quality, 9-23. In: J.J. FERGUSON & W.F. WARDOWSKI (eds.), Factors Affecting Fruit Quality. Proceedings, Citrus Short Course. Citrus Research and Education Center, Lake Alfred, Florida.

REUTHER, W. & RIOS-CASTANO, D., 1969. Comparison of growth, maturation and composition of citrus fruits in subtropical California and tropical Colombia. *Proc. Ist Int. Citrus Symp.* **1**, 277-300.

REUTHER, W., RASMUSSEN, G.K., HILGEMAN, R.H., CAHOON, G.A. & COOPER, W.C., 1969. A comparison of maturation and composition of 'Valencia' oranges in some major subtropical zones of the United States. *J. Am. Soc. Hortic. Sci.* **94**, 144-157.

REUTHER, W. & SMITH, P.F., 1952. Relation of nitrogen, potassium, and magnesium fertilization to some fruit qualities of Valencia orange. *Proc. Am. Soc. Hortic. Sci.* **59**, 1-12.

RICHARDSON, A., ANDERSON, P. & DAWSON, T., 1991. More heat needed for high quality satsuma mandarins. *Orchard. N. Z.* Dec., 26-30.

RICHARDSON, A., MOONEY, P., DAWSON, T., ANDERSON, P., KILLEN, W.J. & ASTILL, M., 1993. Satsuma mandarin quality is improved using a reflective mulch. *Orchard. N. Z.* Febr., 36-38.

SANCHEZ BLANCO, M.J., TORRECILLAS, A., LEON, A. & DEL AMOR, F., 1989. The effect of different irrigation treatments on yield and quality of Verna lemon. *Plant Soil* **120**, 299-302.

SARDO, V. & GERMANA, C., 1988. Water stress and orange yield. *Acta Hortic.* **228**, 245-251.

SCHNEIDER, H., 1954. Effect of trunk girdling on phloem of trunk of sweet orange trees on sour orange rootstock. *Hilgardia* **22**, 593-601.

SEPASKHAH, A.R. & KASHEFIPOUR, S.M., 1994. Relationship between leaf water potential, CWSI, yield and fruit quality of sweet lime under drip irrigation. *Agric. Water Manag.* **25**, 13-22.

SHALHEVET, J. & BIELORAI, H., 1978. Crop water requirement in relation to climate and soil. *Soil Sci.* **125**, 240-247.

SHALHEVET, J. & LEVY, Y., 1990. Citrus trees. Chapter 32, 951-986. In: B.A. STEWART & D.R. NIELSEN (eds.), Irrigation of Agricultural Crops. American Society of Agronomy, Inc., Crop Science Society of America, Inc., Soil Science Society of America, Inc., Madison, Wisconsin, USA.

SHAW, P.E., BUSLIG, B.S. & WILSON, C.W., 1983. Total citrate content of orange and grapefruit juices. *J. Agric. Food Chem.* **31**, 182-184.

SINCLAIR, W.B., 1961a. Principal juice constituents. Chapter 5, 131-160. In: W.B. SINCLAIR (ed.), The Orange: Its Biochemistry and Physiology. University of California, Division of Agricultural Sciences, Berkeley, USA.

SINCLAIR, W.B., 1961b. Organic acids and buffer properties. Chapter 6, 161-190. In: W.B. SINCLAIR (ed.), The Orange: Its Biochemistry and Physiology. University of California, Division of Agricultural Sciences, Berkeley, USA.

SINCLAIR, W.B. & RAMSEY, R.C., 1944. Changes in the organic-acid content of Valencia oranges during development. *Bot. Gaz.* Dec., 140-148.

SITES, J.W. & DESZYCK, E.J., 1952. Effect of varying amounts of potash on yield and quality of Valencia and Hamlin oranges. *Proc. Fla. State Hortic. Soc.* **65**, 92-98.

SITES, J.W. & REITZ, H.J., 1949. The variation in individual Valencia oranges from different locations of the tree as a guide to sampling methods and spot-picking for quality. I. Soluble solids in the juice. *Proc. Am. Soc. Hortic. Sci.* **54**, 1-10.

SMITH, P.F., SCUDDER, G.K. Jr. & HRNCIAR, G., 1963. Twenty years of differential phosphate application on Pineapple oranges. *Proc. Fla. State Hortic. Soc.* **76**, 7-12.

SNYMAN, N., 1991. Ridge for top soybean yields. *Farmer's Weekly.* March 22, 16-17.

SUSANTO, S., NAKAJIMA, Y., HASEGAWA, K. & OZAWA, Y., 1992. Effect of early season day/night temperatures on vegetative and reproductive growth of cultivar 'Tosa Buntan' pummelo (*Citrus grandis* (L.) Osbeck). *Sci. Hortic.* **50**, 147-151.

SUZUKI, T., OKAMOTO, S. & SEKI, T., 1973. Effects of micro-meteorological elements and positions in the tree crown on the development of shoots, leaves and fruits of satsuma mandarin. *J. Jpn. Soc. Hortic. Sci.* **42**, 201-209.

SYVERTSEN, J.P. & ALBRIGO, L.G., 1980. Some effects of grapefruit tree canopy position on microclimate, water relations, fruit yield, and juice quality. *J. Am. Soc. Hortic. Sci.* **105**, 454-459.

TADEO, J.L., ORTIZ, J.M. & ESTELLES, A., 1987. Sugar changes in clementine and orange fruit during ripening. *J. Hortic. Sci.* **62**, 531-537.

THORNE, J.H., 1982. Temperature and oxygen effects on ^{14}C-photosynthate unloading and accumulation in developing soybean seeds. *Plant Physiol.* **69**, 48-53.

TING, S.V., 1969. Distribution of soluble components and quality factors in the edible portion of citrus fruits. *J. Am. Soc. Hortic. Sci.* **94**, 515-519.

TING, S.V. & ATTAWAY, J.A., 1971. Citrus fruits. Chapter 3, 107-159. In: A.C. HULME (ed.), The Biochemistry of Fruits and Their Products, Vol. I, Academic Press, New York.

TZUR, A., GOREN, R. & ZEHAVI, U., 1992. Carbohydrate metabolism in developing citrus fruits. *Proc. Int. Soc. Citric.* **1**, 405-411.

VU, J.C.V. & YELENOSKY, G., 1988. Solar irradiance and drought stress effects on the activity and concentration of ribulose bisphosphate carboxylase in 'Valencia' orange leaves. *Isr. J. Bot.* **37**, 245-256.

WALLERSTEIN, I., GOREN, R. & MONSELISE, S.P., 1973. Seasonal changes in gibberellin-like substances of Shamouti orange (*Citrus sinensis* (L.) Osbeck) trees in relation to ringing. *J. Hortic. Sci.* **48**, 75-82.

WALLERSTEIN, I., GOREN, R. & MONSELISE, S.P., 1974. The effect of girdling on starch accumulation in sour orange seedlings. *Can. J. Bot.* **52**, 935-937.

WALLERSTEIN, I., GOREN, R. & BEN-TAL, Y., 1978a. Effect of ringing on root starvation in sour orange seedlings. *J. Hortic. Sci.* **53**, 109-113.

WALLERSTEIN, I., GOREN, R. & MONSELISE, S.P., 1978b. Rapid and slow translocation of ^{14}C-sucrose and ^{14}C-assimilates in *Citrus* and *Phaseolus* with special reference to ringing effect. *J. Hortic. Sci.* **53**, 203-208.

WARDLE, P., 1991. Science and water smooth growing. *Orchard. N. Z.*. Dec., 20-22.

WUTSCHER, H.K., 1988. Rootstock effects on fruit quality, 24-34. In: J.J. FERGUSON & W.F. WARDOWSKI (eds.), Factors Affecting Fruit Quality. Proceedings, Citrus Short Course. Citrus Research and Education Center, Lake Alfred, Florida.

YAKUSHIJI, H., MORINAGA, K. & NONAMI, H., 1998. Sugar accumulation and partitioning in Satsuma mandarin tree tissues and fruit in response to drought stress. *J. Am. Soc. Hortic. Sci.* **123**, 719-726.

YAKUSHIJI, H., NONAMI, H., FUKUYAMA, T., ONO, S., TAKAGI, N. & HASHIMOTO, Y., 1996. Sugar accumulation enhanced by osmoregulation in Satsuma mandarin fruit. *J. Am. Soc. Hortic. Sci.* **121**, 466-472.

YAMANISHI, O.K., 1995. Trunk strangulation and winter heating effects on fruit size, internal quality and maturation of 'Tosa Buntan' pummelo grown in a plastic house. *J. Hortic. Sci.* **70**, 65-74.

YAMANISHI, O.K. & HASEGAWA, K., 1995. Trunk strangulation responses to the detrimental effect of heavy shade on fruit size and quality of 'Tosa Buntan' pummelo. *J. Hortic. Sci.* **70**, 875-887.

YELENOSKY, G., 1991. Responses and adaptations of citrus trees to environmental stresses. *Isr. J. Bot.* **40**, 239-250.

PAPER 1.1: THE EFFECT OF DEFICIT IRRIGATION AND SUMMER TRUNK GIRDLING ON THE INTERNAL FRUIT QUALITY OF 'DELTA' VALENCIAS

Abstract

Fruit of marginal quality can be a problem in the South African citrus industry. The separate and joint effects of summer trunk girdling and deficit irrigation on internal fruit quality were investigated over two consecutive seasons, 1998 and 1999. The trial was carried out with 'Delta' Valencia trees on rough lemon rootstock in the Clanwilliam area (32°20'S 18°50'E) in South Africa. Deficit irrigation was conducted in both years by using two adjacent irrigation blocks. One block received normal irrigation and one block deficit irrigation. Girdling, performed at different times, was carried out under normal and deficit irrigation in both years. Deficit irrigation in 1999 had no effect on fruit colour, but fruit from the deficit block were larger and had a lower juice content (%) than fruit from the normal block. Deficit irrigation increased the total soluble solids (TSS) of fruit in 1998, but decreased the TSS in 1999. Deficit irrigation decreased the titratable acid (TA) levels and increased the TSS:TA ratio in both years. Summer trunk girdling had no effect on the fruit colour, diameter and juice content (%) in 1999. Girdling had no significant effect on the TSS in the normal and deficit blocks in 1998 and in the normal block in 1999, but significantly decreased the TSS in the deficit block in 1999. Girdling also had no significant effect on the TA levels and the TSS:TA ratios in both normal and deficit blocks in 1998 and 1999. At this stage, our data do not support the use of deficit irrigation and summer trunk girdling on 'Delta' Valencias as cultural practices to improve internal fruit quality.

Introduction

Girdling is a very old horticultural practice (Krezdorn, 1960) and has a history of affecting fruit quality and the date of maturity (Barry & Veldman, 1997). Church (1933) found an increase in total soluble solids (TSS), reducing sugars, and total sugar content in Navel fruit after girdling (girdling date unknown). Peng & Rabe (1996) reported that girdling 2-4 weeks after the physiological fruit drop period (December drop in southern hemisphere-'June drop' in northern hemisphere) increased TSS levels and TSS:TA ratios. Cohen (1984) detected no effect on internal fruit quality following summer girdling.

Deficit irrigation is the deliberate and systematic under-irrigation of crops and is a common practice in many areas of the world, especially in arid countries (English & Raja, 1996). Grape growers use deficit irrigation to reduce vegetative growth of vines and improve grape quality (Wardle, 1991). In citrus, deficit irrigation is used in an attempt to enhance internal fruit quality, mainly by increasing the total soluble solids (TSS) (Erickson & Richards, 1955; Goell & Levy, 1970; Goell & Cohen, 1981; Castel & Buj, 1990; Peng & Rabe; 1997). Yakushiji *et al.* (1996; 1998) found that the sugar accumulation (increase in total sugars per fruit) in Satsuma mandarin fruit due to water stress was not caused by dehydration, but rather that sugars were accumulated by active osmoregulation. The monosaccharides, glucose and fructose, were largely responsible for the active osmoregulation (Yakushiji *et al.*, 1996).

Citrus productivity and tree response to girdling depend on girdling date, girdling procedures and techniques like the girdle width and the position, i.e. on the trunk or branches, cultivar and climatic differences (Peng & Rabe, 1996). The effects of water deficits on fruit quality also depend on the intensity and duration of the water stress period, as well as the phenological phase when the deficit is introduced (Shalhevet & Bielorai, 1978; Castel & Buj, 1990). Ginestar & Castel (1996) found in Clementines that fruit quality was affected by deficit irrigation mainly during the final fruit growth period and the beginning of the ripening period/maturation (August to October in northern hemisphere). The result was an increase in sugar content and acidity. Therefore, Peng & Rabe (1998) introduced deficit irrigation only after the physiological fruit drop period. According to Goell & Cohen (1981) girdling also intensifies moisture stress. Therefore, it is expected that the combination of deficit irrigation and girdling would promote internal fruit quality more than deficit irrigation or girdling on its own.

Fruit of marginal quality (low TSS) will lead to a reduction in the amount of exportable fruit (Peng & Rabe, 1996), low prices on the markets and a loss of market share. The objective of this study was to evaluate the separate and joint effects of deficit irrigation and girdling, performed at different times, on the internal fruit quality of 'Delta' Valencia fruit in two consecutive years. The irrigation levels used in this study could also be used to establish an irrigation schedule, especially for the summer months, that will maximise internal fruit quality.

Materials and Methods

Plant material

'Delta' Valencia trees on rough lemon rootstock were used for this study in 1998 and 1999. The orchard was planted in 1985 and is situated in the Clanwilliam area, South Africa (32°20'S 18°50'E; winter rainfall area (±550 mm per annum)). The soil was a sandy loam/sand. Tree spacing was 6 m between rows and 4 m in row. The row direction of the orchard was north-south. Only healthy trees with uniform canopy size were used for the study. The trial consisted of two parts, an irrigation part and a girdling part.

Irrigation procedures and treatments

The orchard consisted of two irrigation blocks. In both irrigation blocks, tensiometers were used for irrigation scheduling. The microjets of the irrigation system delivered 4 mm or 104 ℓ water/hour. Treatments in both years consisted of a block with normal irrigation (control) and a block with deficit irrigation. The control block (normal irrigation) in 1998 had a sandy soil, which was shallower and more rocky than the deficit irrigation block. In the second year (1999) the shallow, sandy block was used for the deficit irrigation. In 1998 the control block received 4337 m^3 water/ha from 10 February 1998 to 27 April 1998 and the deficit block received 2906 m^3 water/ha (67% of normal irrigation) during the same period. In 1999 the control block received 5725 m^3 water/ha from 19 January 1999 to 20 April 1999 and the deficit block received 4836 m^3 water/ha (84% of normal irrigation) during the same period. This probably did not result in enough stress; however, the extreme summer heat of 1999 resulted in the grower being cautious. The introduction of deficit irrigation in both years, was timed to coincide with the end of the normal physiological fruit drop period for 'Delta' Valencias.

Normal irrigation (Treatment 1.): The blocks were irrigated when the soil water tension dropped below -40kPa.

Deficit irrigation (Treatment 2.): Two tensiometers were used, a shallow (30 cm) and a deeper one (60 cm). When the shallow tensiometer dropped to between -55 and -60 kPa, only half the normal irrigation cycle was given (i.e. not to wet the whole profile); once the deeper tensiometer dropped between -55 and -60 kPa a full irrigation was given. A normal irrigation cycle was usually 6 hours (24 mm) of irrigation.

Girdling procedures and treatments

Girdling was carried out in each irrigation block in both years by using a Stanley carpet knife. A single cut was made through the bark of the main trunk about 10 cm above the bud union. No strip of bark was removed. Treatments in both years consisted of a control (no girdling) and three girdling treatments at different times. Treatments were two weeks apart in 1998 and 20 days apart in 1999. The girdling dates for both years are provided in Table 2. The same trees were used for girdling in the second year of the study. The girdling cut in 1999 was made about 1 cm above the girdling cut of 1998. The earliest girdling dates in both years were timed to coincide with the end of the normal physiological fruit drop period for 'Delta' Valencias.

[Table 1]

Statistical layout (girdling)

The trial consisted of a randomised complete block design with four treatments and ten single tree replicates per treatment in both irrigation blocks for both years.

Fruit quality measurements

At harvest, 17 August 1998, fruit samples were picked randomly from the outside of the canopy, at shoulder height around the tree. Two samples of 12 fruit each (one consisting of large and one of small fruit) were picked per tree (replicate) in both blocks. In 1999 at harvest (16 August), fifty fruit per single-tree replicate were picked from the outside of the canopy at shoulder height on the western side of the tree. Fruit colour was determined in 1999 based on the no. 34 Outspan colour chart for oranges, with eight being dark green and one being fully coloured (orange). Fruit diameter (measured by electronic calliper) of each fruit was also measured in 1999. Of the fifty fruit picked in 1999, a subsample of 12 fruit of average diameter was used for further quality determinations. In both years, juice was extracted using a citrus juicer. Juice was filtered through a layer of cheesecloth in 1998, and through two layers of muslin cloth in 1999, and juice content (%) was determined in 1999 by subtracting the weight of reamed peel from the original fruit weight and dividing by the original fruit weight. The juice was then used in both years for the determination of the TSS by using a hand-held refractometer (Atago N1). Titratable acidity (TA), expressed as citric acid content, was determined by titration against 0.1 N sodium hydroxide, using phenolphthalein as an indicator. The TSS:TA ratio was calculated by dividing the TSS values by the TA values.

Statistical analysis

Analyses of variance were performed using the GLM (General Linear Models) procedure in the SAS (Statistical Analysis System) computer program (SAS Inc., 1990).

Results

Deficit irrigation. Deficit irrigation in 1999 had no major effect on fruit colour, but fruit from this block (deficit block) were larger than fruit from the normal block (Table 1). Fruit from the deficit-irrigated block in 1999 had a lower juice content (%) than fruit from the normal block. Fruit from the deficit-irrigated block had a higher TSS than fruit from the normal block in 1998, but the opposite was true in 1999 (Table 2). The average TA content of fruit from the deficit-irrigated block was lower than fruit from the normal block in both years (Table 3). Fruit from the deficit-irrigated block had a higher average TSS:TA ratio than fruit from the normally irrigated block in both years (Table 4).

[Tables 2, 3 and 4]

Girdling. There were no definite trends in 1999 in fruit colour, diameter and juice content (%) due to girdling (Table 1). None of the girdling treatments had a significant effect on the TSS of the fruit from the normal and deficit blocks in 1998 and from the normal block in 1999 (Table 2), but all the girdling treatments significantly decreased the TSS of fruit from the deficit block in 1999 (P=0.0071). The girdling treatments also had no significant effect on the TA content of fruit from the normal and deficit blocks in both years (1998 and 1999), except for a quadratic trend in TA in 1999 in the normal block (Table 3). In general, the girdling treatments decreased the TA levels, although not significant. The girdling treatments also had no significant effect on the TSS:TA ratio of fruit from the normal and deficit blocks in both years, except for a quadratic trend in 1999 in the normal block (Table 4).

Differentiation between fruit sizes was only done in 1998. There was a significant fruit size effect. Small fruit had a higher TSS (P=0.0347) than large fruit in the normal block (Table 2). Small fruit, however, had a significantly higher TA content in both the normal (P=0.0003) and the deficit block (P=0.0001) (Table 3) and a lower TSS:TA ratio in the normal (P=0.0040) and the deficit block (P=0.0001), than large früit (Table 4).

Discussion

According to Hilgeman & Sharples (1957), Goell & Levy (1970), Sardo & Germana (1988), Domingo *et al.* (1996) and Peng & Rabe (1996) a shortage of water (deficit irrigation) may cause smaller fruit. This was, however, not the case in 1999, because trees in the deficit block had fewer fruit of larger diameter and trees in the normal block had a lot of small fruit (pers. obs.). The deficit in irrigation was, however, not very large in 1999 (84% of normal). Similar results on the effect of deficit irrigation on juice content have been reported by Goell & Levy (1970). Previous studies (Goell & Levy, 1970; Levy *et al.*, 1978; Goell & Cohen, 1981; Kuriyama *et al.*, 1981; Cruse *et al.*, 1982; Koo & Smajstrla, 1984; Sardo & Germana, 1988; Peng & Rabe, 1997) contradict our results on TA, since they report that deficit irrigation increased juice acidity. Other studies (Erickson & Richards, 1955; Goell & Levy, 1970; Goell & Cohen, 1981; Castel & Buj, 1990; Peng & Rabe; 1997) indicated that deficit irrigation would increase the TSS. Possible reasons for the positive, but inconsistent effects on TSS in this study may be related to the fact that the deficit irrigation was not extreme enough. The summer was dry and very hot in both years, especially in 1999, which made management of irrigation more critical. The producer did not dry the soil enough before each irrigation, because of fear of permanent damage to the trees. It is also difficult to introduce deficit irrigation to a cultivar harvested after the winter rainfall period. Inconsistent results, especially on TSS, may also be due to soil differences between irrigation blocks. According to our first year's results, deficit irrigation can be used as a cultural practice to improve internal fruit quality, especially for cultivars producing fruit of marginal quality. Further studies should, however, be conducted on late cultivars and in blocks with similar soil types. The timing of introduction of the deficit irrigation is, however, very important.

None of the girdling treatments improved the internal fruit quality of 'Delta' Valencias significantly in both blocks of both years of the study. Possible reasons for these results may be the timing and the severity of the girdling cut. Peng & Rabe (1996) found that girdling increased the TSS and TSS:TA ratio when performed soon after the physiological fruit drop period in Satsumas. This fruit drop period was approximately near the end of December in 1997 and 1998. In our Valencia trials, girdling was only carried out from 29 January 1998 in the first year. Therefore, girdling was probably carried out too late in the season in 1998. In the second season, girdling was carried out from 12 January 1999, but still did not provide the expected results. It is also important that the girdling cut should be completely through the bark. Valencia trees possibly do not respond that well after a girdling cut, or heal over very fast. Therefore, the possibility of using a wider girdle-width or reopening the scar a few weeks later should be considered for Valencias as was also suggested for 'Temple' tangors (paper 1.3).

The higher TSS and TA content, and the lower TSS:TA ratio in small fruit, compared to larger fruit, were expected and has been reported previously (Sites & Reitz, 1949; Krezdorn, 1988).

At this stage, due to a lack of consistent positive results, our data do not support deficit irrigation and girdling on 'Delta' Valencias as cultural practices in order to improve internal fruit quality. Further girdling studies using other girdling methods and an increased girdle-width should be conducted on 'Delta' Valencias. More extreme deficits should be investigated in further irrigation studies. These studies should be conducted using irrigation blocks with similar soil types or a proper statistical design to minimise soil differences.

References

BARRY, G. & VELDMAN, F., 1997. A preliminary study on the effect of girdling on fruit set and quality of Ambersweet mandarin hybrid. *Citrus J.* **7**, 25.

CASTEL, J.R. & BUJ, A., 1990. Response of Salustiana oranges to high frequency deficit irrigation. *Irrig. Sci.* **11**, 121-127.

CHURCH, C.G., 1933. Composition of juice of oranges from girdled and normal trees. *Calif. Citrogr.* **18**, 348-349.

COHEN, A., 1984. Effect of girdling date on fruit size of Marsh seedless grapefruit. *J. Hortic. Sci.* **59**, 567-573.

CRUSE, R.R., WIEGAND, C.L. & SWANSON, W.A., 1982. The effects of rainfall and irrigation management on citrus juice quality in Texas. *J. Am. Soc. Hortic. Sci.* **107**, 767-770.

DOMINGO, R., RUIZ-SANCHEZ, M.C., SANCHEZ-BLANCO, M.J. & TORRECILLAS, A., 1996. Water relations, growth and yield of Fino lemon trees under regulated deficit irrigation. *Irrig. Sci.* **16**, 115-123.

ENGLISH, M. & RAJA, S.N., 1996. Perspectives on deficit irrigation. *Agric. Water Manag.* **32**, 1-14.

ERICKSON, L.C. & RICHARDS, S.J., 1955. Influence of 2,4-D and soil moisture on size and quality of Valencia oranges. *Proc. Am. Soc. Hortic. Sci.* **65**, 109-112.

GINESTAR, C. & CASTEL, J.R., 1996. Responses of young clementine citrus trees to water stress during different phenological periods. *J. Hortic. Sci.* **71**, 551-559.

GOELL, A. & COHEN, A., 1981. Combining irrigation regimes with girdling techniques in citrus trees (a new experimental mode). *Proc. Int. Soc. Citric.* **2**, 514-518.

GOELL, A. & LEVY, Y., 1970. The effects of irrigation stress on fruit quality. *Proc. XVIIIth Int. Hortic. Congr.* **1**, 221-222 [Abstr.].

HILGEMAN, R.H., & SHARPLES, G.C., 1957. Irrigation trials with Valencias in Arizona. *Calif. Citrogr.*. Sep., 404-407.

KOO, R.C.J. & SMAJSTRLA, A.G., 1984. Effects of trickle irrigation and fertigation on fruit production and juice quality of 'Valencia' orange. *Proc. Fla. State Hortic. Soc.* **97**, 8-10.

KREZDORN, A.H., 1960. The influence of girdling on the fruiting of Orlando tangelos and navel oranges. *Proc. Fla. State Hortic. Soc.* **73**, 49-52.

KREZDORN, A.H., 1988. Pollination and related factors affecting fruit quality, 43-48. In: J.J. FERGUSON & W.F. WARDOWSKI (eds.), Factors Affecting Fruit Quality. Proceedings, Citrus Short Course. Citrus Research and Education Center, Lake Alfred, Florida.

KURIYAMA, T., SHIMOOSAKO, M., YOSHIDA, M. & SHIRAISHI, S., 1981. The effect of soil moisture on the fruit quality of Satsuma mandarin (*Citrus unshiu* Marc.). *Proc. Int. Soc. Citric.* **2**, 524-527.

LEVY, Y., BAR-AKIVA, A. & VAADIA, Y., 1978. Influence of irrigation and environmental factors on grapefruit acidity. *J. Am. Soc. Hortic. Sci.* **103**, 73-76.

PENG, Y.H. & RABE, E., 1996. Effect of summer trunk girdling on fruit quality, maturation, yield, fruit size and tree performance in 'Mihowase' satsumas. *J. Hortic. Sci.* **71**, 581-589.

PENG, Y.H. & RABE, E., 1997. Postharvest storage behaviour, respiration rate and ethylene evolution of fruit from deficit and normal irrigation in 'Mihowase Satsuma' trees. *J. S. Afr. Soc. Hortic. Sci.* **7**, 44-47.

PENG, Y.H. & RABE, E., 1998. Effect of differing irrigation regimes on fruit quality, yield, fruit size and net CO_2 assimilation of 'Mihowase' Satsuma. *J. Hortic. Sci. Biotechnol.* **73**, 229-234.

SARDO, V. & GERMANA, C., 1988. Water stress and orange yield. *Acta Hortic.* **228**, 245-251.

SAS INSTITUTE INC., 1990. SAS/STAT User's Guide, Version 6. 4th ed. Vol. 1 and 2, Cary, NC, USA.

SHALHEVET, J. & BIELORAI, H., 1978. Crop water requirement in relation to climate and soil. *Soil Sci.* **125**, 240-247.

SITES, J.W. & REITZ, H.J., 1949. The variation in individual Valencia oranges from different locations of the tree as a guide to sampling methods and spot-picking for quality. I. Soluble solids in the juice. *Proc. Am. Soc. Hortic. Sci.* **54**, 1-10.

WARDLE, P., 1991. Science and water smooth growing. *Orchard. N. Z.* Dec., 20-22.

YAKUSHIJI, H., MORINAGA, K. & NONAMI, H., 1998. Sugar accumulation and partitioning in Satsuma mandarin tree tissues and fruit in response to drought stress. *J. Am. Soc. Hortic. Sci.* **123**, 719-726.

YAKUSHIJI, H., NONAMI, H., FUKUYAMA, T., ONO, S., TAKAGI, N. & HASHIMOTO, Y., 1996. Sugar accumulation enhanced by osmoregulation in Satsuma mandarin fruit. *J. Am. Soc. Hortic. Sci.* **121**, 466-472.

Table 1. The effect of summer trunk girdling and deficit irrigation during the late summer months of 1999 on the fruit colour, diameter and juice content (%) of 'Delta' Valencias on rough lemon rootstock in the Clanwilliam area, South Africa.

	Girdling date	**COLOUR**		**DIAMETER**		**JUICE %**	
		NORMAL	**DEFICIT**	**NORMAL**	**DEFICIT**	**NORMAL**	**DEFICIT**
Treatment:							
Control(no girdling)		1.2b[z]	1.3ab	72.28a	73.38b	46.31ab	43.23a
Girdling	12/01/99	1.2b	1.2b	73.06a	93.87a	48.42a	44.68a
Girdling	02/02/99	1.2b	1.3a	65.51a	85.75ab	45.76b	41.81a
Girdling	23/02/99	1.3a	1.2ab	67.69a	84.72ab	47.63ab	44.98a
	MEAN	**1.2**	**1.3**	**69.63**	**84.43**	**47.03**	**43.68**
LSD		0.103	0.140	9.197	18.559	2.351	3.311
SE		0.0356	0.0482	3.170	6.396	0.8103	1.141
Source:	df						
Treatment	3	0.0279	0.1491	0.2909	0.1833	0.1061	0.2051
Control vs girdling	1	0.3015	0.2409	0.3441	0.0562	0.3138	0.6561
Girdling linear	1	0.0061	0.4691	0.2409	0.3208	0.4975	0.8549
Girdling quadratic	1	0.4295	0.0616	0.2208	0.6547	0.0306	0.0399

[z]Means with the same letter are not significantly different at the 5% level (LSD)

Table 2. The effect of summer trunk girdling and deficit irrigation during the late summer months of 1998 and 1999 on the TSS (total soluble solids) of 'Delta' Valencias on rough lemon rootstock in the Clanwilliam area, South Africa.

			TSS			
			NORMAL		DEFICIT	
	Girdling dates		**1998**	**1999**	**1998**	**1999**
Treatment:	1998	1999				
Control (no girdling)			9.38 a[z] ±0.132	10.53 a ±0.164	9.69 a ±0.108	10.26 a ±0.183
Girdling	29/01/98	12/01/99	9.47 a ±0.132	10.51 a ±0.164	9.65 a ±0.108	9.49 b ±0.183
Girdling	12/02/98	02/02/99	9.37 a ±0.123	10.42 a ±0.164	9.62 a ±0.108	9.43 b ±0.183
Girdling	26/02/98	23/02/99	9.18 a ±0.123	10.16 a ±0.164	9.42 a ±0.108	9.42 b ±0.183
	MEAN		**9.35**	**10.41**	**9.60**	**9.65**
LSD			0.359	0.477	0.304	0.531
Fruit size[y]:						
	Small		9.49 a ±0.090	-	9.69 a ±0.0762	-
	Large		9.21 b ±0.090	-	9.50 a ±0.0762	-
LSD			0.253	-	0.215	-
Source:	df					
Treatment	3		0.4302	0.3766	0.3107	0.0071
Control vs girdling	1		0.7682	0.3872	0.3317	0.0007
Girdling linear	1		0.1153	0.1434	0.1360	0.7888
Girdling quadratic	1		0.7674	0.6759	0.5217	0.9120
Size	1		0.0347	-	0.0787	-
Treatment*size	3		0.7872	-	0.9429	-

[z]Means with the same letter are not significantly different at the 5% level (LSD)
[y]No differentiation between fruit sizes in 1999

Table 3. The effect of summer trunk girdling and deficit irrigation during the late summer months of 1998 and 1999 on the titratable acid levels of 'Delta' Valencias on rough lemon rootstock in the Clanwilliam area, South Africa.

			ACID			
			NORMAL		DEFICIT	
	Girdling dates		1998	1999	1998	1999
Treatment:	1998	1999				
Control (no girdling)			1.80 a[z] ±0.0564	1.94 ab ±0.0504	1.68 a ±0.0313	1.84 a ±0.0786
Girdling	29/01/98	12/01/99	1.80 a ±0.0564	1.81 b ±0.0504	1.66 a ±0.0313	1.69 a ±0.0786
Girdling	12/02/98	02/02/99	1.70 a ±0.0526	2.02 a ±0.0504	1.62 a ±0.0313	1.72 a ±0.0786
Girdling	26/02/98	23/02/99	1.72 a ±0.0526	1.89 ab ±0.0504	1.62 a ±0.0313	1.66 a ±0.0786
	MEAN		**1.76**	**1.91**	**1.65**	**1.61**
LSD			0.153	0.146	0.0885	0.228
Fruit size[y]:						
	Small		1.86 a ±0.0383	-	1.77 a ±0.0221	-
	Large		1.65 b ±0.0384	-	1.52 b ±0.0221	-
LSD			0.108	-	0.0626	-
Source:	df					
Treatment	3		0.4591	0.0547	0.4476	0.4204
Control vs girdling	1		0.3890	0.6223	0.1890	0.1140
Girdling linear	1		0.3126	0.2544	0.4387	0.8447
Girdling quadratic	1		0.3672	0.0133	0.5725	0.6514
Size	1		0.0003	-	0.0001	-
Treatment*size	3		0.9840	-	0.7042	-

[z]Means with the same letter are not significantly different at the 5% level (LSD)
[y]No differentiation between fruit sizes in 1999

Table 4. The effect of summer trunk girdling and deficit irrigation during the late summer months of 1998 and 1999 on the TSS:TA ratio of 'Delta' Valencias on rough lemon rootstock in the Clanwilliam area, South Africa.

			RATIO[x]			
			NORMAL		DEFICIT	
	Girdling dates		1998	1999	1998	1999
Treatment:	1998	1999				
Control (no girdling)			5.30 a[z] ±0.160	5.52 ab ±0.148	5.82 a ±0.0879	5.62 a ±0.200
Girdling	29/01/98	12/01/99	5.36 a ±0.160	5.84 a ±0.148	5.90 a ±0.0879	5.71 a ±0.200
Girdling	12/02/98	02/02/99	5.61 a ±0.149	5.22 b ±0.148	6.00 a ±0.0879	5.57 a ±0.200
Girdling	26/02/98	23/02/99	5.40 a ±0.149	5.39 b ±0.148	5.90 a ±0.0879	5.75 a ±0.200
	MEAN		**5.42**	**5.49**	**5.91**	**5.66**
LSD			0.434	0.429	0.248	0.579
Fruit size[y]:						
	Small		5.19 b ±0.109	-	5.53 b ±0.061	-
	Large		5.65 a ±0.109	-	6.29 a ±0.061	-
LSD			0.3062	-	0.176	-
Source:	df					
Treatment	3		0.4953	0.0402	0.5570	0.9197
Control vs girdling	1		0.3937	0.8344	0.2738	0.8153
Girdling linear	1		0.8432	0.0394	0.9744	0.8939
Girdling quadratic	1		0.2094	0.0374	0.3538	0.5234
Size	1		0.0040	-	0.0001	-
Treatment*size	3		0.9438	-	0.4511	-

[z]Means with the same letter are not significantly different at the 5% level (LSD)
[y]No differentiation between fruit sizes in 1999
[x]Rounding off causes TSS/acid values to differ from actual ratio values

PAPER 1.2: THE EFFECT OF DEFICIT IRRIGATION AND SUMMER TRUNK GIRDLING ON THE INTERNAL FRUIT QUALITY OF 'MARISOL' CLEMENTINES

Abstract

Fruit of marginal quality can be a problem in the South African citrus industry. Girdling, deficit irrigation, and a combination of girdling and deficit irrigation were conducted over two seasons, 1998 and 1999, at two different sites. The trials were conducted to investigate the separate and joint effects of deficit irrigation and girdling, performed at different times, on the internal fruit quality. The trials were carried out with 'Marisol' Clementine trees on Carrizo citrange rootstock in Somerset West (34°S 19°E) and Citrusdal (32°30'S 19°E) in South Africa. Four trials were conducted over a two year period. Girdling was carried out during 1998 at Somerset West on trees in the same irrigation block (Trial A1). During 1998, at Citrusdal, a deficit irrigation trial was conducted by using two adjacent irrigation blocks (Trial B1). One block received normal irrigation and one block deficit irrigation. Girdling and deficit irrigation were combined in 1999, at both sites, Somerset West (Trial A2) and Citrusdal (Trial B2), using two adjacent irrigation blocks. Girdling was carried out in each irrigation block (both normal and deficit blocks). Girdling increased the total soluble solids (TSS), although not always significantly, but there were no trends observed for external fruit colour, fruit diameter, juice content (%), titratable acidity (TA) and TSS:TA ratios due to girdling. Deficit irrigation increased the TSS and the TA levels in both seasons and at both sites, increased the TSS:TA ratio at Somerset West in 1998, and decreased the TSS:TA ratio in the second season (1999) at both sites due to the increased acidity levels. Deficit irrigation had no major effects on external fruit colour and juice content in 1999, but decreased fruit diameter at Citrusdal. According to these results, deficit irrigation, summer trunk girdling, or a combination of both, can be used as cultural practices to improve internal fruit quality, especially in cultivars producing fruit of marginal quality. The combination of girdling and deficit irrigation increased the TSS more than when the practices are executed on its own.

Introduction

Girdling is a very old horticultural practice (Krezdorn, 1960) and has a history of affecting fruit quality and the date of maturity (Hochberg *et al.*, 1977; Iwahori *et al.*, 1977; Barry & Veldman, 1997). Church (1933) found an increase in total soluble solids (TSS), reducing sugars, and total sugar content in Navel fruit after girdling (girdling date unknown). Peng & Rabe (1996) reported that girdling at 2-4 weeks after the physiological fruit drop period (December drop in southern hemisphere-'June drop' in northern hemisphere) increased TSS levels and TSS:TA ratios. Goren & Monselise (1971) and Cohen (1984) detected that summer girdling had no effect on internal fruit quality.

Deficit irrigation is the deliberate and systematic under-irrigation of crops and is a common practice in many areas of the world, especially in arid countries (English & Raja, 1996). Grape growers use deficit irrigation to reduce vegetative growth of vines and improve grape quality (Wardle, 1991). In citrus, deficit irrigation is conducted in an attempt to enhance internal fruit quality, mainly by increasing the total soluble solids (TSS) (Erickson & Richards, 1955; Goell & Levy, 1970; Goell & Cohen, 1981; Goell, 1988; Castel & Buj, 1990; Dasberg, 1992; Peng & Rabe, 1997; 1998). Yakushiji *et al.* (1996; 1998) found that the sugar accumulation (increase in total sugars per fruit) in Satsuma mandarin fruit due to water stress was not caused by dehydration, but rather that sugars were accumulated by active osmoregulation. The monosaccharides, glucose and fructose, were largely responsible for the active osmoregulation (Yakushiji *et al.*, 1996).

Citrus productivity and tree response to girdling depend on girdling date, girdling procedures and techniques like the girdle width and the position, i.e. on the trunk or branches, cultivar and climatic differences (Peng & Rabe, 1996). The effects of water deficits on fruit quality also depend on the intensity and duration of the water stress period, as well as the phenological phase when the deficit is introduced (Shalhevet & Bielorai, 1978; Sanchez-Blanco *et al.*, 1989; Castel & Buj, 1990). Ginestar & Castel (1996) found in Clementines that fruit quality was affected mainly during the final fruit growth period and the beginning of the ripening period [the maturation phase (August to October in northern hemisphere)] by deficit irrigation, increasing the sugar content and acidity. Therefore, Peng & Rabe (1998) introduced deficit irrigation only after the physiological fruit drop period. According to Goell & Cohen (1981) girdling also intensifies moisture stress. Therefore, it is expected that the combination of deficit irrigation and girdling would promote internal fruit quality more than deficit irrigation and girdling executed on its own.

Fruit of marginal quality (low TSS) will lead to a reduction in the number of exportable fruit (Peng & Rabe, 1996), low prices on the markets and a loss of market share. The objective of this study is to evaluate the separate and joint effects of deficit irrigation and girdling, performed at different times, on the internal fruit quality of 'Marisol' Clementine fruit. 'Marisol' is an early-maturing Clementine selection which tends to produce fruit of inherently lower sugar levels. The trials were performed at two sites, Somerset West and Citrusdal. The irrigation levels used in this study may also be used to establish an irrigation schedule, especially for the summer months, which should maximise internal fruit quality.

Materials and Methods

Plant material

Four trials were conducted over two seasons. The studies were conducted at two sites, Somerset West (Site A) (34°S 19°E) and Citrusdal (Site B) (32°30'S 19°E), South Africa. 'Marisol' Clementine trees on Carrizo citrange rootstock were used for both studies. The orchard at Site A was planted in 1993. The soil in the orchard consisted of a clay loam. Tree spacing was 4.5 m between rows and 2.0 m in row with a north-south row direction. Trees in the same irrigation block were girdled in the first year (1998) of the study, but trees in two adjacent irrigation blocks were used in the second year (1999) for a combination of girdling and deficit irrigation.

At Site B, trees in two adjacent irrigation blocks were used over two consecutive years of the study. In the first year (1998) the trees were used for a deficit irrigation study and in the second year (1999) for a combination of girdling and deficit irrigation. Both blocks were planted in 1993 with a spacing of 5.0 m between rows and 2.5 m in row and a north-south row direction. Only healthy trees with uniform canopy size were used.

Girdling procedures and treatments

Girdling was carried out by using a Stanley carpet knife. A single cut was made through the bark of the main trunk about 10 cm above the bud union. No strip of bark was removed. Treatments in 1998 at Somerset West and in 1999 at Somerset West and Citrusdal consisted of an ungirdled control and three girdling treatments. In 1998 at Somerset West the girdling treatments were two weeks apart and in 1999 at both sites the treatments were 20 days apart, starting end of December and ending mid February. The actual girdling dates are provided in Table 2 (Somerset West, 1999), Table 3 (Citrusdal, 1999) and Table 4 (Somerset West, 1998).

The earliest girdling dates at both sites were timed to coincide with the end of the normal physiological fruit drop period for 'Marisol' Clementines. All the girdling trials consisted of a randomised complete block design with four treatments and ten two-tree replicates per treatment at Somerset West in 1998 and ten single-tree replicates per treatment in both irrigation blocks at Somerset West and Citrusdal in 1999.

Irrigation procedures and treatments

In Citrusdal, deficit irrigation studies were conducted over two consecutive years. The deficit irrigation blocks in both years were based on approximately 66% of the amount of water the normal blocks received.

In Somerset West, deficit irrigation studies were conducted only in the second year (1999). The theoretical deficit irrigation was based on approximately 60% of the amount of water the normal block received.

Treatments at both sites consisted of a block with normal irrigation (control) and a block with deficit irrigation. All the deficit irrigation studies were based on reducing the amount of water the trees in the deficit block receive. While the irrigations in both the deficit and normal blocks were done at the same time, the amounts given to each block differed. In their study, Peng & Rabe (1998) irrigated once a certain stress level was attained. Therefore, different treatments were irrigated at shorter or longer intervals, depending on the desired level of stress. Additional irrigation information for both sites is presented in Table 1. The start of the deficit irrigation period at both sites was timed to coincide with the end of the normal physiological fruit drop period for 'Marisol' Clementines.

[Table 1]

Fruit quality measurements

At harvest (14 April 1998), fruit samples were picked at Somerset West in 1998 (girdling trial) from the outside of the canopy, at shoulder height. The samples consisted of twelve fruit (six small and six large fruit) from a four-tree replicate (fruit picked randomly around the tree).

Fruit samples were picked at Citrusdal in 1998 (deficit irrigation) in both blocks at harvest (7 April 1998), from the outside of the tree canopy at shoulder height. In each irrigation block five samples of 24 fruit (12 small and 12 large fruit) were picked per three-tree replicate (randomly around tree), trees randomly selected in the orchard. Fruit were only picked from healthy trees with uniform canopy size.

In 1999, fifty fruit per single-tree replicate were harvested at both sites (5 May 1999 for Somerset West and 26 April 1999 for Citrusdal) from the outside of the canopy at shoulder height at random around the tree. Fruit colour was determined based on the no. 36 Outspan colour chart for soft citrus, with eight being dark green and one being fully coloured (orange). Fruit diameter (measured by electronic calliper) of each fruit was also measured. From the fifty fruit, a subsample of twelve fruit of average diameter was used for further quality determinations. In both years, juice was extracted using a citrus juicer. Juice was filtered through a layer of cheesecloth in 1998, and through two layers of muslin cloth in 1999 and juice content (%) was determined in 1999 by subtracting the weight of reamed peel from the original fruit weight and dividing by the original fruit weight. The juice was then used for the determination of the TSS by using a hand-held refractometer (Atago N1). Titratable acidity (TA), expressed as citric acid content, was determined by titration against 0.1 N sodium hydroxide, using phenolphthalein as an indicator. The TSS:TA ratio was calculated by dividing the TSS values by the TA values.

Statistical analysis

Analyses of variance were performed using the GLM (General Linear Models) procedure in the SAS (Statistical Analysis System) computer program (SAS Inc., 1990). For the irrigation studies values for the different parameters in both blocks, were averaged and their standard errors were determined since it was not a randomised block design. Therefore, the two blocks were compared with each other by using the averages and standard errors.

Results

Girdling. There were no significant trends in external fruit colour development due to girdling in both normal and deficit blocks at both sites in 1999 (Table 2 and Table 3). At Citrusdal, fruit from girdled trees were slightly larger, although not always significant (Table 3). In the deficit irrigation block, however, a quadratic trend was observed indicating a smaller stimulation in fruit size with later girdling. At Somerset West there was no trend in fruit diameter due to the girdling treatments (Table 2). Girdling in 1999 also had no significant effect on juice content (%) in both normal and deficit irrigation blocks at both sites.

[Tables 2 and 3]

Most of the girdling treatments in both years and at both sites increased the TSS, although not always significantly. Girdling carried out on 18 February 1998 at Somerset West significantly increased the TSS compared to the control, but there was no significant difference in TSS between different fruit sizes (P=0.7622) (Table 4).

[Table 4]

Girdling at Somerset West in 1999 significantly increased the TSS in the normal block when girdled on 8 February 1999 (Table 2), and girdling at Citrusdal in 1999 significantly increased the TSS (P=0.0603) in the normal block when girdled on 29 December 1998, and in the deficit block when girdled on 19 January 1999 (Table 3). There were no other significant differences in TSS due to girdling at both sites.

There were no general trends in TA levels and TSS:TA ratios due to girdling in 1998 at Somerset West (Table 4) and in 1999 in normal and deficit blocks at both sites, except for a TA increase and a TSS:TA ratio decrease in the deficit block at Citrusdal. In 1998 at Somerset West small fruit had a significantly higher TA content (P=0.0001) and a lower TSS:TA ratio (P=0.0001) than large fruit (Table 4).

Deficit Irrigation. Deficit irrigation had no major effect on fruit colour development and juice content (%) in 1999, at both sites (Table 2 and Table 3). Deficit irrigation also had no major effect on fruit diameter in 1999, except at Citrusdal (Table 3), where deficit irrigation slightly decreased fruit diameter. Deficit irrigation increased TSS and TA levels in the small and large fruit samples in 1998 at Citrusdal (Table 5) and in 1999 at Citrusdal and Somerset West (Table 2 and Table 3). The TSS:TA ratio increased in 1998 at Citrusdal due to deficit irrigation, but deficit irrigation decreased the TSS:TA ratio in 1999 at Somerset West and Citrusdal. Neutron probe values for the normal and deficit irrigation blocks at Somerset West in 1999 are provided in Fig. 1.

[Table 5 and Figure1]

Discussion

Significant increases in TSS due to girdling have been reported by Church (1933) on Navels and by Peng & Rabe (1996) on Satsumas. Although the increased TSS due to girdling was not always significant, our results confirm that girdling can be used to manipulate TSS levels in 'Marisol' Clementines as well.

The higher TA content and the lower TSS:TA ratio in small fruit, compared to larger fruit in 1998 at Somerset West, were expected according to Sites & Reitz (1949) and Krezdorn (1988).

Previous studies reported that deficit irrigation increases TSS levels on 'Salustiana' orange (Castel & Buj, 1990) and on Satsumas (Peng & Rabe, 1998), increases juice acidity (Goell & Levy, 1970; Goell & Cohen, 1981; Goell, 1988; Sanchez Blanco *et al.*, 1989; Peng & Rabe, 1997), results in smaller fruit (Goell & Levy, 1970; Peng & Rabe, 1996) and a lower juice content (Goell & Levy, 1970). In the three deficit irrigation trials, the deficit irrigation resulted in no marked effects on the fruit colour and juice content, cause a slight decrease in fruit diameter, an increase in TSS and TA levels and a slight decrease in TSS:TA ratios. The reason for the large differences between the studies in 1998 and 1999, especially in the TSS:TA ratios, may be related to more representative fruit sampling in 1999. Deficit irrigation can therefore be utilised as a cultural practice to improve internal fruit quality, especially for cultivars producing fruit of marginal quality. The timing of introduction of the deficit irrigation, however, seems to be important, i.e. it should commence as soon as possible after the physiological fruit drop period.

No major differences between the water content of the deficit and normal blocks is evident from Fig. 1. This is unexpected, since the deficit block received 66% of the normal block. Therefore, the normal block was probably continuously over-irrigated with excess being lost to drainage. The "deficit" of 66% of normal irrigation thus still resulted in adequate moisture levels in the root zone and the trees were never really subjected to stress levels.

The combination of girdling and deficit irrigation could also be used as a cultural practice, since, according to Goell & Cohen (1981), girdling intensifies moisture stress. Judging from our results in 1999 at both sites, it seems that although girdling and deficit irrigation conducted on its own increased the TSS, the combination of girdling and deficit irrigation enhanced the TSS increase. Therefore, the combination of deficit irrigation and girdling would be advisable for cultivars where perennial fruit quality problems are experienced.

References

BARRY, G. & VELDMAN, F., 1997. A preliminary study on the effect of girdling on fruit set and quality of Ambersweet mandarin hybrid. *Citrus J.* **7**, 25.

CASTEL, J.R. & BUJ, A., 1990. Response of Salustiana oranges to high frequency deficit irrigation. *Irrig. Sci.* **11**, 121-127.

CHURCH, C.G., 1933. Composition of juice of oranges from girdled and normal trees. *Calif. Citrogr.* **18**, 348-349.

COHEN, A., 1984. Effect of girdling date on fruit size of Marsh seedless grapefruit. *J. Hortic. Sci.* **59**, 567-573.

DASBERG, S., 1992. Irrigation management and citrus production. *Proc. Int. Soc. Citric.* **3**, 1307-1310.

ENGLISH, M. & RAJA, S.N., 1996. Perspectives on deficit irrigation. *Agric. Water Manag.* **32**, 1-14.

ERICKSON, L.C. & RICHARDS, S.J., 1955. Influence of 2,4-D and soil moisture on size and quality of Valencia oranges. *Proc. Am. Soc. Hortic. Sci.* **65**, 109-112.

GINESTAR, C. & CASTEL, J.R., 1996. Responses of young clementine citrus trees to water stress during different phenological periods. *J. Hortic. Sci.* **71**, 551-559.

GOELL, A., 1988. Citrus irrigation in Israel – making do with less water. *Proc. VIth Int. Citrus Congr.*, 699-706.

GOELL, A. & COHEN, A., 1981. Combining irrigation regimes with girdling techniques in citrus trees (a new experimental mode). *Proc. Int. Soc. Citric.* **2**, 514-518.

GOELL, A. & LEVY, Y., 1970. The effects of irrigation stress on fruit quality. *Proc. XVIIIth Int. Hortic. Congr.* **1**, 221-222 [Abstr.].

GOREN, R. & MONSELISE, S.P., 1971. Effects of ringing on yields of low-bearing orange trees (*Citrus sinensis* (L.) Osbeck). *J. Hortic. Sci.* **46**, 435-441.

HOCHBERG, R., MONSELISE, S.P. & COSTO, J., 1977. Summer girdling and 2,4-D effects on grapefruit sizes. *HortScience* **12**, 228.

IWAHORI, S., MATSUMOTO, R. & OOHATA, J.T., 1977. Effects of trunk ringing and defoliation on maturation of Ponkan (*Citrus reticulata* Blanco) fruit. *Bull. Fac. Agric. Kagoshima Univ.* **27**, 1-6.

KREZDORN, A.H., 1960. The influence of girdling on the fruiting of Orlando tangelos and navel oranges. *Proc. Fla. State Hortic. Soc.* **73**, 49-52.

KREZDORN, A.H., 1988. Pollination and related factors affecting fruit quality, 43-48. In: J.J. FERGUSON & W.F. WARDOWSKI (eds.), Factors Affecting Fruit Quality. Proceedings, Citrus Short Course. Citrus Research and Education Center, Lake Alfred, Florida.

PENG, Y.H. & RABE, E., 1996. Effect of summer trunk girdling on fruit quality, maturation, yield, fruit size and tree performance in 'Mihowase' satsumas. *J. Hortic. Sci.* **71**, 581-589.

PENG, Y.H. & RABE, E., 1997. Postharvest storage behaviour, respiration rate and ethylene evolution of fruit from deficit and normal irrigation in 'Mihowase Satsuma' trees. *J. S. Afr. Soc. Hortic. Sci.* **7**, 44-47.

PENG, Y.H. & RABE, E., 1998. Effect of differing irrigation regimes on fruit quality, yield, fruit size and net CO_2 assimilation of 'Mihowase' Satsuma. *J. Hortic. Sci. Biotechnol.* **73**, 229-234.

SANCHEZ-BLANCO, M.J., TORRECILLAS, A., LEON, A. & DEL AMOR, F., 1989. The effect of different irrigation treatments on yield and quality of Verna lemon. *Plant Soil* **120**, 299-302.

SAS INSTITUTE INC., 1990. SAS/STAT User's Guide, Version 6. 4th ed. Vol. 1 and 2, Cary, NC, USA.

SHALHEVET, J. & BIELORAI, H., 1978. Crop water requirement in relation to climate and soil. *Soil Sci.* **125**, 240-247.

SITES, J.W. & REITZ, H.J., 1949. The variation in individual Valencia oranges from different locations of the tree as a guide to sampling methods and spot-picking for quality. I. Soluble solids in the juice. *Proc. Am. Soc. Hortic. Sci.* **54**, 1-10.

WARDLE, P., 1991. Science and water smooth growing. *Orchard. N. Z.* Dec., 20-22.

YAKUSHIJI, H., MORINAGA, K. & NONAMI, H., 1998. Sugar accumulation and partitioning in Satsuma mandarin tree tissues and fruit in response to drought stress. *J. Am. Soc. Hortic. Sci.* **123**, 719-726.

YAKUSHIJI, H., NONAMI, H., FUKUYAMA, T., ONO, S., TAKAGI, N. & HASHIMOTO, Y., 1996. Sugar accumulation enhanced by osmoregulation in Satsuma mandarin fruit. *J. Am. Soc. Hortic. Sci.* **121**, 466-472.

Table 1. Irrigation information for deficit irrigation trials in 1998 at Somerset West and in 1999 at Somerset West and Citrusdal.

	Citrusdal 1998		Citrusdal 1999		Somerset West 1999	
	Normal	**Deficit**	**Normal**	**Deficit**	**Normal**	**Deficit**
Soil	sandy-loam with stone fraction	sandy	sandy-loam with stone fraction	sandy	clay-loam	clay-loam
$m^3 \cdot ha^{-1}$ water	5108	4338	3857	2206	5257	3445
% of normal irrigation	85		57		66	
Stress period	01/01/98 to 01/05/98		01/02/99 to 01/05/99		01/01/99 to 30/04/99	
Irrigation system	microjets		microjets		microjets	
Delivery rate	4 $mm \cdot h^{-1}$		4 $mm \cdot h^{-1}$		5.56 $mm \cdot h^{-1}$	
Scheduling	neutron probe		neutron probe		"Enviroscan" and neutron probe	

Table 2. The effects of summer trunk girdling and deficit irrigation during the summer months of 1999 on the internal fruit quality of 'Marisol' Clementines on Carrizo rootstock in the Somerset West area.

		COLOUR		**DIAMETER**		**JUICE %**		**TSS**		**ACID**		**RATIO[y]**	
		NORMAL	**DEFICIT**	**NORMAL**	**DEFICIT**	**NORMAL**	**DEFICIT**	**NORMAL**	**DEFICIT**	**NORMAL**	**DEFICIT**	**NORMAL**	**DEFICIT**
Treatment:	**Date**												
Control (no girdling)		3.5a[z]	2.9a	51.31a	48.68a	62.16a	61.95a	9.73b	10.15a	1.00a	1.15a	9.76a	8.94a
Girdling	28/12/98	3.5a	2.6a	51.11a	49.47a	62.21a	61.70a	9.58b	10.31a	1.00a	1.15a	9.65a	9.07a
Girdling	18/01/99	2.5b	2.5a	48.93a	49.31a	61.32a	59.34a	10.08b	10.56a	1.05a	1.12a	9.76a	9.54a
Girdling	8/02/99	3.0ab	2.7a	48.43a	49.73a	61.35a	60.16a	10.71a	10.64a	1.04a	1.17a	10.41a	9.13a
	MEAN	**3.1**	**2.7**	**49.95**	**49.30**	**61.76**	**60.79**	**10.03**	**10.42**	**1.02**	**1.15**	**9.90**	**9.17**
LSD		0.671	0.506	5.307	6.393	1.997	3.077	0.590	0.628	0.123	0.153	0.828	0.790
SE		0.231	0.174	1.829	2.203	0.688	1.060	0.203	0.216	0.0423	0.0527	0.285	0.272
Source:	df												
Treatment	3	0.0125	0.3979	0.5890	0.9887	0.6784	0.2682	0.0026	0.3706	0.7877	0.9401	0.2417	0.4511
Control vs girdling	1	0.0703	0.1754	0.3969	0.7487	0.5107	0.2154	0.1053	0.1687	0.5712	0.9092	0.5892	0.3379
Girdling linear	1	0.1168	0.6881	0.3101	0.9356	0.3820	0.3136	0.0005	0.2903	0.5745	0.7904	0.0704	0.8773
Girdling quadratic	1	0.0139	0.3338	0.7086	0.9152	0.5901	0.2320	0.7960	0.7508	0.5295	0.5815	0.4463	0.1980

[z]Means with the same letter are not significantly different at the 5% level (LSD)

[y]Rounding off causes TSS/acid values to differ from actual ratio values

Table 3. The effects of summer trunk girdling and deficit irrigation during the summer months of 1999 on the internal fruit quality of 'Marisol' Clementines on Carrizo rootstock in the Citrusdal area.

		COLOUR		DIAMETER		JUICE %		TSS		ACID		RATIO[y]	
		NORMAL	DEFICIT	NORMAL	DEFICIT	NORMAL	DEFICIT	NORMAL	DEFICIT	NORMAL	DEFICIT	NORMAL	DEFICIT
Treatment:	**Date**												
Control (no girdling)		5.1a[z]	5.1a	60.54b	53.88b	52.29a	54.25a	10.40b	10.50b	0.98a	0.98b	10.71a	10.75a
Girdling	29/12/98	5.0a	4.9a	63.81ab	63.06a	50.41a	52.29a	11.08a	10.46b	1.00a	1.03b	11.31a	10.31ab
Girdling	19/01/99	5.3a	5.1a	65.97a	54.01b	49.33a	53.13a	10.59ab	11.63a	0.98a	1.21a	10.82a	9.78b
Girdling	9/02/99	5.1a	5.2a	62.34ab	55.92b	50.15a	52.66a	10.83ab	11.27ab	0.97a	1.14ab	11.33a	10.07ab
	MEAN	**5.1**	**5.1**	**63.17**	**56.72**	**50.55**	**53.08**	**10.73**	**10.97**	**0.98**	**1.09**	**11.04**	**10.23**
LSD		0.431	0.506	4.530	6.072	4.104	4.212	0.555	1.055	0.111	0.180	0.889	0.835
SE		0.148	0.174	1.561	2.092	1.415	1.452	0.191	0.364	0.0382	0.0620	0.307	0.288
Source:	df												
Treatment	3	0.6205	0.8228	0.1148	0.0136	0.5146	0.7947	0.0923	0.0778	0.9445	0.0529	0.3602	0.1327
Control vs girdling	1	0.9233	0.7806	0.0627	0.1292	0.1659	0.3621	0.0603	0.1515	0.8811	0.0528	0.2210	0.0454
Girdling linear	1	0.5723	0.3804	0.5098	0.0229	0.8975	0.8568	0.3639	0.1270	0.5588	0.2085	0.9635	0.5601
Girdling quadratic	1	0.2368	0.8529	0.1417	0.0419	0.5887	0.7159	0.1311	0.0974	0.9662	0.0972	0.1940	0.2546

[z]Means with the same letter are not significantly different at the 5% level (LSD)
[y]Rounding off causes TSS/acid values to differ from actual ratio values

Table 4. The effect of summer trunk girdling performed in 1998 at different times on the internal fruit quality of 'Marisol' Clementines in the Somerset West area.

		TSS	ACID	RATIO[y]
Treatment:	**Date**			
Control (no girdling)		10.03bc[z]	1.18a	8.60a
Girdling	04/02/98	9.93c	1.18a	8.48a
Girdling	18/02/98	10.46a	1.22a	8.67a
Girdling	04/03/98	10.40ab	1.20a	8.67a
LSD		0.379	0.0656	0.467
Fruit size:				
	Small	10.19a	1.27a	8.04b
	Large	10.23a	1.12b	9.17a
LSD		0.268	0.0464	0.330
Source:	df			
Treatment	3	0.0161	0.4673	0.8073
Control vs girdling	1	0.1339	0.3349	0.9915
Girdling linear	1	0.0170	0.4601	0.4047
Girdling quadratic	1	0.0764	0.3049	0.6149
Size	1	0.7622	0.0001	0.0001
Treatment*size	3	0.8804	0.3975	0.2953

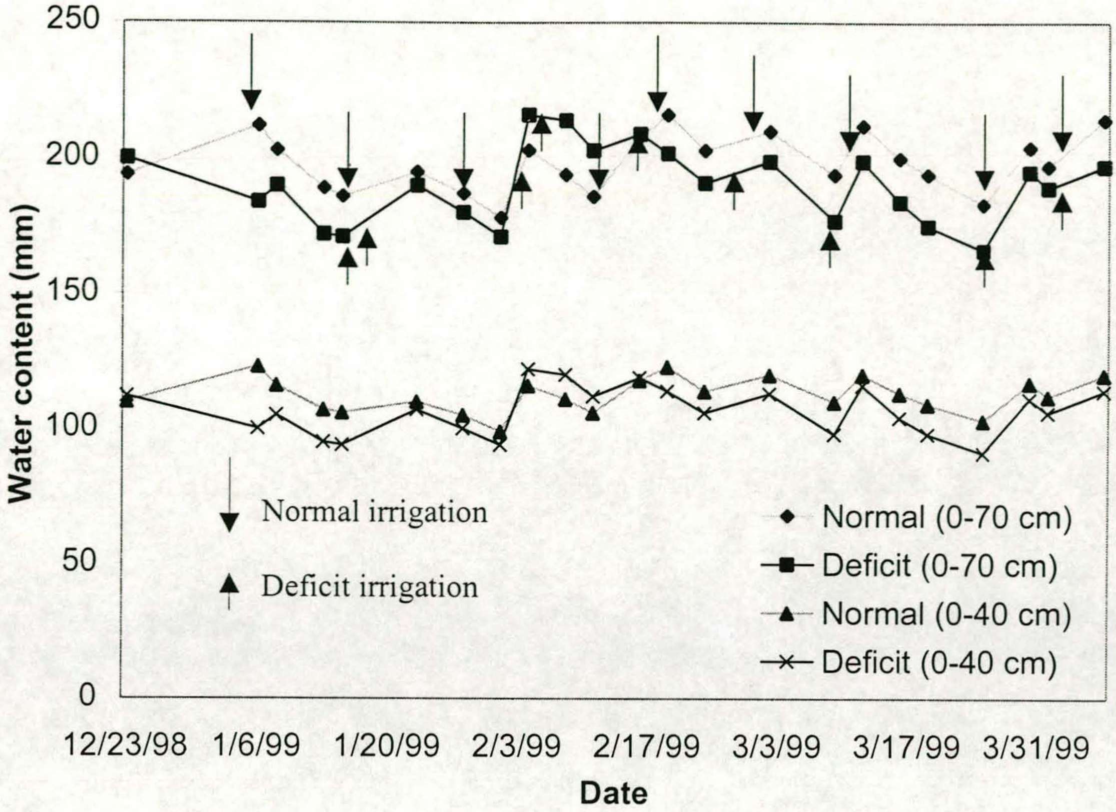
[z]Means with the same letter are not significantly different at the 5% level (LSD)
[y]Rounding off causes TSS/acid values to differ from actual ratio values

Table 5. The effect of deficit irrigation during the summer months in 1998 on the internal fruit quality of 'Marisol' Clementines on Carrizo rootstock in the Citrusdal area (Means ± standard errors).

	DIAMETER	TSS	ACID	RATIO[y]
Small fruit				
Normal irrigation	55.9±0.542	10.0±0.127	1.1±0.033	9.0±0.201
Deficit irrigation	51.9±0.223	11.7±0.282	1.2±0.048	9.7±0.324
% of control		117	109	108
Large fruit				
Normal irrigation	65.5±0.420	10.1±0.098	1.0±0.020	9.8±0.123
Deficit irrigation	62.9±0.934	11.6±0.244	1.1±0.126	10.2±0.486
% of control		114	110	104

[y]Rounding off causes TSS/acid values to differ from actual ratio values

Figure 1. Neutron probe values for 'Marisol' Clementines in 1999 at Somerset West in the normal and deficit irrigation blocks for 0-40 cm and 0-70 cm soil profiles from late December until time of harvest.



250
200
150
100
50
0
Water content (mm)
12/23/98
1/6/99
1/20/99
2/3/99
2/17/99
3/3/99
3/17/99
3/31/99
Date
Normal irrigation
Deficit irrigation
Normal (0-70 cm)
Deficit (0-70 cm)
Normal (0-40 cm)
Deficit (0-40 cm)

PAPER 1.3: EFFECT OF SUMMER TRUNK GIRDLING ON THE INTERNAL FRUIT QUALITY OF 'TEMPLE' TANGORS

Abstract

Fruit of marginal quality will lead to a reduction in the amount of exportable fruit, low prices on the markets and a loss of market share. The timing of summer trunk girdling, performed at different times after the physiological fruit drop period on total soluble solids (TSS), titratable acid (TA) content and the TSS:TA ratio of fruit were evaluated over two consecutive years. The trial was carried out with 'Temple' tangor trees on rough lemon rootstock near Citrusdal (32°30'S 19°E). Girdling significantly decreased the TSS, but had no significant effect on the TA level and the TSS:TA ratio of the fruit in the first year (1998). In the second year (1999) none of the girdling treatments had a significant effect on fruit colour, fruit diameter, juice content (%), TSS and TA levels of the fruit. Girdling on 12 January 1999 decreased the TSS:TA ratio significantly. According to these results, summer trunk girdling on 'Temple' tangors cannot be recommended as a practice to increase internal fruit quality, but further studies using an increased girdle-width or a double girdle should be conducted.

Introduction

Girdling is a very old horticultural practice (Krezdorn, 1960) and has long been known as a good way to increase citrus yields (Goren & Monselise, 1971; Wallerstein *et al.*, 1978; Erner, 1988; Rabe & van der Walt, 1992; Barry & Veldman, 1997). Girdling can successfully increase fruit size (Hochberg *et al.*, 1977; Cohen 1984a, 1984b), improve fruit quality, advance the date of maturity (Hochberg *et al.*, 1977; Iwahori *et al.*, 1977; Barry & Veldman, 1997) and alleviate alternate bearing in citrus (Agusti *et al.*, 1992). Girdling of citrus trees has been reviewed by Cohen (1981).

The effects of girdling are far from being fully understood (Lewis & McCarty, 1973). Attempts to explain the effect of girdling on trees have included studies of the changes in carbohydrates (Schneider, 1954; Wallerstein *et al.*, 1974; 1978; Fishler *et al.*, 1983;), mineral nutrients and respiration (Wallerstein *et al.*, 1978), and plant hormones (Noel, 1970; Goren *et al.*, 1971; Monselise *et al.*, 1972; Wallerstein *et al.*, 1973).

Citrus productivity and tree response to girdling depend on girdling date, girdling procedures and techniques e.g., the girdle width and the position, i.e. on the trunk or branches, cultivar and climatic differences (Peng & Rabe, 1996). According to Goell & Cohen (1981) girdling also intensifies moisture stress. Spring girdling (during the bloom period) is used to increase yields by increasing fruit number (fruit set) rather than fruit size (Goren & Monselise, 1971; Monselise *et al.*, 1972; Erner, 1988). Summer girdling (June and August in northern hemisphere) increases fruit size (Hochberg *et al.*, 1977; Cohen, 1981; 1984a, 1984b).

The effect of girdling on internal fruit quality shows contradictory results. Barry & Veldman (1997) found that when 'Ambersweet' trees were girdled in the spring during fullbloom, the total soluble solids (TSS) was higher, the acid content was lower and the external colour was more advanced. Peng & Rabe (1996) reported that girdling at 2-4 weeks after the physiological fruit drop period (December drop in southern hemisphere-'June drop'in northern hemisphere) increased TSS levels and TSS:acid ratios of 'Mihowase' Satsuma fruit. Hochberg *et al.* (1977) found that girdling on grapefruit trees (June in northern hemisphere) produced fruit with higher acidity and causes some delay in fruit maturation. On the other hand, Cohen (1984b) found that summer girdling on Marsh grapefruit had no effect on internal fruit quality, but colour break occurred earlier. Goren & Monselise (1971) also detected no differences in TSS levels and citric acid content. Church (1933) found an increase in TSS levels, reducing sugars, and total sugar content in Navel fruit after girdling (girdling date unknown). Girdling in consecutive years can lead to a negative yield response, smaller fruit size and no significant increase in TSS or TSS:TA ratio in the second year (Peng & Rabe, 1996).

Fruit of marginal quality (low TSS) will lead to a reduction in the number of exportable fruit (Peng & Rabe, 1996), low prices on the markets and a loss of market share. This study reports on the effect of summer trunk girdling, carried out at different times in two consecutive years, on the internal fruit quality of 'Temple' tangors.

Materials and Methods

Plant material

'Temple' tangor trees on rough lemon rootstock were used in both years, 1998 and 1999. The orchard was planted as 'Fairchild' scion in 1988, but topworked to 'Temple' in 1992. The orchard is situated in the Citrusdal area, South Africa (32°30'S 19°E). The soil in the orchard is sandy. Tree spacing is 5.0 m between row and 3.0 m in row. The row-direction of the orchard is east-west. Trees in the same irrigation block were used for the trial and only healthy trees with uniform canopy size were used.

Girdling procedures and treatments

Girdling was carried out by using a Stanley carpet knife by making a single cut through the bark of the main trunk about 10 cm above the bud union. No strip of bark was removed. Treatments consisted of an ungirdled control, and girdling on 26 February 1998 in the first year. In the second year of the study, the treatments consisted of an ungirdled control, girdling on 12 January 1999, 2 February 1999 and 23 February 1999. The earliest girdling date in 1999 was timed to coincide with the end of the normal physiological fruit drop period for 'Temple' tangors. Different trees were used for each year of the study.

Trial layout

The trial consisted of a randomised complete block design with two treatments and ten two-tree replicates per treatment in 1998 and four treatments and ten single-tree replicates per treatment in 1999.

Fruit quality measurements

At harvest (26 June 1998 and 21 June 1999), fruit samples were picked from the outside of the canopy, at shoulder height. The samples consisted of twelve fruit of average diameter from each two-tree replicate (six fruit on both northern and southern sides of the canopy) in the first year. In the second year, fifty fruit were picked per single-tree replicate on the southern side of the tree.

In the second year, fruit colour was determined based on the no. 36 Outspan colour chart for soft citrus, with eight being dark green and one being fully coloured (orange). Fruit diameter (measured by electronic calliper) of each fruit was also measured in 1999. From the fifty fruit picked in 1999, a subsample of 12 fruit of average diameter was used for further quality determinations. In both years juice was extracted using a citrus juicer. Juice was filtered through a layer of cheesecloth in 1998. In the second year (1999) juice was strained through two layers of muslin cloth and juice content (%) was determined by subtracting the weight of reamed peel from the original fruit weight and dividing by the original fruit weight. The juice was then used for the determination of the TSS by using a hand-held refractometer (Atago N1). Titratable acidity (TA), expressed as citric acid content, was determined by titration against 0.1 N sodium hydroxide, using phenolphthalein as an indicator. The TSS:TA ratio was calculated by dividing the TSS values by the TA values.

Statistical analysis

Analyses of variance were performed using the GLM (General Linear Models) procedure in the SAS (Statistical Analysis System) computer program (SAS Inc., 1990).

Results

Girdling significantly decreased the TSS (P=0.0309) of the fruit in the first year (Table 1). Girdling, however, had no significant effect on the TA content (P=0.8688) and the TSS:TA ratio (P=0.0697) of the fruit.

It is well known that the TSS on the northern side of a tree is higher than on the southern side of the tree in the southern hemisphere (Sites & Reitz, 1949). The effect of girdling on the difference between the north and south side values for TSS, TA content and the TSS:TA ratio was thus also evaluated (Table 1). Girdling had no significant effect on the difference in TSS (P=0.4803), significantly decreased this difference in TA (P=0.0244) and significantly increased the difference in the TSS:TA ratio (P=0.0373).

[Table 1]

In the second year of the study (1999), girdling had no significant effect on fruit colour (P=0.9096), fruit diameter (P=0.9683) and the juice content (%) (P=0.8180) of the fruit (Table 2).

[Table 2]

In the second year of the study (1999), none of the girdling treatments had a significant effect on the TSS (P=0.8215) and the TA levels (P=0.3988) (Table 2). Girdling significantly decreased the TSS:TA ratio (P=0.0296) in 1999.

Discussion

Girdling in the first year (1998) decreased internal fruit quality of 'Temple' tangor trees, due to a significant decrease in TSS (P=0.0309) and a decrease (although not significant) in the TSS:TA ratio (P=0.0697). In the second year (1999), girdling had no effect on the TSS and the TA levels, but decreased the TSS:TA ratio.

Possible reasons for the lack of expected improvement in internal fruit quality in 1998 and no real effect in 1999 after girdling, may be related to the timing and the severity of the girdling cut. Peng & Rabe (1996) reported that girdling increased the TSS and TSS:TA ratio when performed soon after the physiological fruit drop period in Satsumas. This fruit drop period was towards the end of December in 1997 and 1998. Girdling was only carried out on 26 February 1998 in the first year. Therefore, girdling was probably done too late in the season in 1998, although this view is contrasted by the fact that the late girdling date in 1999 gave the best result in terms of TSS. The reasons for the small effect on internal fruit quality in 1999 remains uncertain.

It is important that the girdling cut should be completely through the bark. Since the 'Temple' tangor is quite a vigorous tree, it may require a wider girdle in order to respond to girdling in a similar way as was reported for Satsumas (Peng & Rabe, 1996). At this stage our results with summer trunk girdling on 'Temple' tangors cannot support this practice as a way to enhance internal fruit quality in this cultivar. Further studies should be conducted, using increased girdle-width or a double girdle, i.e. re-open the girdle wound three to four weeks after the first girdling date.

References

AGUSTI, M., ALMELA, V. & PONS, J., 1992. Effects of girdling on alternate bearing in citrus. *J. Hortic. Sci.* **67**, 203-210.

BARRY, G. & VELDMAN, F., 1997. A preliminary study on the effect of girdling on fruit set and quality of Ambersweet mandarin hybrid. *Citrus J.* **7**, 25.

CHURCH, C.G., 1933. Composition of juice of oranges from girdled and normal trees. *Calif. Citrogr.* **18**, 348-349.

COHEN, A., 1981. Recent developments in girdling of citrus trees. *Proc. Int. Soc. Citric.* **1**, 196-199.

COHEN, A., 1984a. Citrus fruit enlargement by means of summer girdling. *J. Hortic. Sci.* **59**, 119-125.

COHEN, A., 1984b. Effect of girdling date on fruit size of Marsh seedless grapefruit. *J. Hortic. Sci.* **59**, 567-573.

ERNER, Y., 1988. Effects of girdling on the differentiation of inflorescence types and fruit set in 'Shamouti' orange trees. *Isr. J. Bot.* **37**, 173-180.

FISHLER, M., GOLDSCHMIDT, E.E. & MONSELISE, S.P., 1983. Leaf area and fruit size on girdled grapefruit branches. *J. Am. Soc. Hortic. Sci.* **108**, 218-221.

GOELL, A. & COHEN, A., 1981. Combining irrigation regimes with girdling techniques in citrus trees (a new experimental mode). *Proc. Int. Soc. Citric.* **2**, 514-518.

GOREN, R., GOLDSCHMIDT, E.E. & MONSELISE, S.P., 1971. Hormonal balance in bark and leaves of Shamouti orange trees (*Citrus sinensis* (L.) Osbeck) in relation to ringing. *J. Hortic. Sci.* **46**, 443-451.

GOREN, R. & MONSELISE, S.P., 1971. Effects of ringing on yields of low-bearing orange trees (*Citrus sinensis* (L.) Osbeck). *J. Hortic. Sci.* **46**,435-441.

HOCHBERG, R., MONSELISE, S.P. & COSTO, J., 1977. Summer girdling and 2,4-D effects on grapefruit sizes. *HortScience* **12**, 228.

IWAHORI, S., MATSUMOTO, R. & OOHATA, J.T., 1977. Effects of trunk ringing and defoliation on maturation of Ponkan (*Citrus reticulata* Blanco) fruit. *Bull. Fac. Agric. Kagoshima Univ.* **27**, 1-6.

KREZDORN, A.H., 1960. The influence of girdling on the fruiting of Orlando tangelos and navel oranges. *Proc. Fla. State Hortic. Soc.* **73**, 49-52.

LEWIS, L.N. & McCARTY, C.D., 1973. Pruning and girdling of citrus. Chapter 7, 211-229. In: W. REUTHER (ed.), The Citrus Industry. Vol III, University of California, Riverside, California.

MONSELISE, S.P., GOREN, R. & WALLERSTEIN, I., 1972. Girdling effects on orange fruit set and young fruit abscission. *HortScience* **7**, 514-515.

NOEL, A.R.A., 1970. The girdled tree. *Bot. Rev.* **36**, 162-195.

PENG, Y.H. & RABE, E., 1996. Effect of summer trunk girdling on fruit quality, maturation, yield, fruit size and tree performance in 'Mihowase' satsumas. *J. Hortic. Sci.* **71**, 581-589.

RABE, E. & Van der WALT, H.P., 1992. Effect of urea sprays, girdling and paclobutrazol on yield in 'Shamouti' sweet orange trees in a subtropical climate. *J. S. Afr. Soc. Hortic. Sci.* **2**, 77-81.

SAS INSTITUTE INC., 1990. SAS/STAT User's Guide, Version 6. 4th ed. Vol. 1 and 2, Cary, NC, USA.

SCHNEIDER, H., 1954. Effect of trunk girdling on phloem of trunk of sweet orange trees on sour orange rootstock. *Hilgardia* **22**, 593-601.

SITES, J.W. & REITZ, H.J., 1949. The variation in individual Valencia oranges from different locations of the tree as a guide to sampling methods and spot-picking for quality. I. Soluble solids in the juice. *Proc. Am. Soc. Hortic. Sci.* **54**, 1-10.

WALLERSTEIN, I., GOREN, R. & BEN-TAL, Y., 1978. Effect of ringing on root starvation in sour orange seedlings. *J. Hortic. Sci.* **53**, 109-113.

WALLERSTEIN, I., GOREN, R. & MONSELISE, S.P., 1973. Seasonal changes in gibberellin-like substances of Shamouti orange (*Citrus sinensis* (L.) Osbeck) trees in relation to ringing. *J. Hortic. Sci.* **48**, 75-82.

WALLERSTEIN, I., GOREN, R. & MONSELISE, S.P., 1974. The effect of girdling on starch accumulation in sour orange seedlings. *Can. J. Bot.* **52**, 935-937.

Table 1. The effect of summer trunk girdling on the internal fruit quality of 'Temple' tangors on rough lemon rootstock in 1998 in the Citrusdal area.

Average of north and south

		TSS	ACID	RATIO[y]
Treatment:				
	Control (no girdling)	9.41a[z]	1.17a	8.02a
	Girdling (26/02/98)	9.11b	1.18a	7.81a
LSD		0.266	0.0532	0.234
Source:	df			
Treatment	1	0.0309	0.8688	0.0697

Difference: North-south

		TSS		ACID		RATIO	
Treatment:							
	Control (no girdling)	0.43	a	0.061	a	-0.024	b
	Girdling (26/02/98)	0.32	a	-0.027	b	0.46	a
LSD		0.338		0.0737		0.451	
Source:	df						
Treatment	1	0.4803		0.0244		0.0373	

[z]Means with the same letter are not significantly different at the 5% level (LSD)
[y]Rounding off causes TSS/acid values to differ from actual ratio values

Table 2. The effect of summer trunk girdling performed in 1999 at different times on fruit colour, diameter, juice content (%), TSS, TA levels and the TSS:TA ratio of 'Temple' tangors on rough lemon rootstock in the Citrusdal area.

		COLOUR	DIAMETER	JUICE %	TSS	ACID	RATIO[y]
Treatment:	**Girdling date**						
Control (no girdling)		2.8a[z]	73.08a	58.15a	10.20a	1.32a	7.91a
Girdling	12/01/99	2.7a	74.02a	58.99a	10.18a	1.44a	7.11b
Girdling	02/02/99	2.8a	74.73a	58.96a	10.34a	1.44a	7.22ab
Girdling	23/02/99	2.7a	73.62a	59.38a	10.47a	1.45a	7.38ab
LSD		0.564	6.947	2.692	0.711	0.180	0.740
Source:	df						
Treatment	3	0.9096	0.9683	0.8180	0.8215	0.3988	0.1471
Control vs girdling	1	0.6595	0.7093	0.3778	0.6494	0.0925	0.0296
Girdling linear	1	0.7733	0.9080	0.7692	0.4098	0.9191	0.4704
Girdling quadratic	1	0.6183	0.7591	0.8469	0.9605	0.9221	0.9444

[z]Means with the same letter are not significantly different at the 5% level (LSD)
[y]Rounding off causes TSS/acid values to differ from actual ratio values

PAPER 2.1: PRUNING EFFECTS ON INTERNAL FRUIT QUALITY OF SATSUMAS AND CLEMENTINES

Abstract

Differences in citrus juice quality are associated with exposure to light and temperature of individual fruit. Fruit on the outside may have a higher total soluble solids (TSS) content due to higher light intensities and air temperatures. Shading of leaves reduces sugar content of nearby fruit by reducing net photosynthesis of these shaded source leaves. Pruning may improve light penetration into the tree. The effect on the internal fruit quality of exposing internally-borne, shaded fruit to direct sunlight by means of summer pruning, was evaluated over two consecutive years. The trial was carried out with 'Mihowase' Satsuma and 'Nules' Clementine trees on Troyer citrange rootstock in Stellenbosch (34°S 19°E). Summer pruning had no significant effect in the first year on fruit colour, TSS, titratable acid (TA) and TSS:TA ratio in 'Mihowase' Satsumas. In the second year, pruning significantly decreased TA levels and increased the TSS:TA ratio, but had no significant effect on the colour and TSS. Pruning on 'Nules' Clementines significantly increased the TSS:TA ratio of fruit in the first year, but had no significant effect on the colour, TSS and TA levels. In the second year, pruning had no significant effect on the colour, but significantly decreased the TA levels and increased the TSS levels and the TSS:TA ratio. Summer pruning may be used as a cultural practice in order to improve the internal fruit quality, especially in 'Nules' Clementines, but current data do not support this practice for 'Mihowase' Satsumas.

Introduction

The quality of citrus fruit is affected by the position of the fruit on the tree. Differences in juice quality (total soluble solids (TSS)) are associated with positional differences in canopy microclimate and exposure to light and temperature of individual fruit (Sites & Reitz, 1949; Levy *et al.*, 1978; Syvertsen & Albrigo, 1980). Kimball (1984) and Koch (1988) stated that fruit on the outside of a tree may reach maturity before those on the inside and have a higher TSS content (Fallahi & Moon, 1989), due to higher light intensities (Sites & Reitz, 1949; Iwagaki, 1981) and air temperatures (Suzuki *et al.*, 1973). A light level of about 25-30 % of full sunlight is needed to sustain full photosynthetic efficiency (Reuther, 1988; Goldschmidt & Koch, 1996). Fruit, together with its source leaves, on the inside of the canopy do not receive as much light. Shading reduces sugar content (TSS) of fruit by reducing net photosynthesis of these shaded source leaves (Reuther, 1988; Yamanishi & Hasegawa, 1995). Full exposure of leaves on fruit-bearing shoots is important for maximum production of soluble solids, which then results in greater translocation of solids to the fruit (Erickson, 1968).

The key reason for pruning is to ensure a balance between vegetative vigour and the fruitfulness needed for maximum production of high-quality fruit (Lewis & McCarty, 1973). Koch (1988) stated that hedging and topping trees increased colour and internal quality of the fruit, mainly because the pruning improved light penetration into the tree (Lewis & McCarty, 1973). The efficiency, however, depends on the extent of interior shading prior to pruning (Koch, 1988). Trees pruned too severely, would probably cause a decrease in the TSS of the fruit, because the source of photosynthetic assimilates is reduced. Severe pruning will also delay fruiting and reduce the yield of the trees (Lewis & McCarty, 1973).

The objective of this study was to determine the effect of exposing fruit borne in the interior of the tree to direct sunlight, on the internal quality of these previously shaded fruit.

Materials and Methods

Plant material

Healthy, uniform 'Mihowase' Satsuma and 'Nules' Clementine trees on Troyer citrange rootstock were used in two consecutive years (different trees used for each year). The orchard was planted in 1991 and is situated in the Stellenbosch area, South Africa (34°S 19°E). The soil in the orchard is a clay-loam. Tree spacing is 4.5 m between rows and 2.0 m in row (Satsumas) and 4.5 x 1.5 m (Clementines). The row-direction of the orchard is north-south.

Trial layout

Both trials consisted of a randomised complete block design with two treatments and five single-tree replicates per treatment in the first year and ten single-tree replicates per treatment in the second year. Ten shaded fruit per tree (replicate) were tagged in the first year and five shaded fruit per tree were tagged in the second year. Only fruit on the westerly side of the tree were used.

Treatments

Treatments consisted of an unpruned control, where the tagged fruit remained in the shaded position, or pruned sectors to expose the shaded (tagged) fruit to direct sunlight by cutting windows into the tree.

The 'Mihowase' Satsuma trees were pruned on 11 December 1997 in the first year and on 14 December 1998 in the second year. The 'Nules' Clementine trees were pruned on 19 January 1998 in the first year and on 11 January 1999 in the second year. The regrowth in both cultivars was removed after pruning. The pruning dates were chosen to coincide with the end of the normal physiological fruit drop period for each cultivar.

Fruit quality measurements

For both trials the light intensity (LI-189 light-meter with a quantum sensor) at the surface of each tagged fruit was measured every two weeks until harvest. The tagged fruit were harvested at the time of maturity (4 March 1998 and 15 March 1999, respectively, for 'Mihowase' Satsumas and 16 April 1998 and 10 May 1999, respectively, for 'Nules' Clementines). The following quality parameters were determined on each individual fruit: (1) Fruit colour, based on the no. 36 Outspan colour chart for soft citrus, with eight being dark green and one being fully coloured (orange); (2) fruit diameter, (3) juice was extracted using a citrus juicer, filtered through a layer of cheesecloth and then used for the determination of the total soluble solids (TSS) by using a hand-held refractometer (Atago N1) and titratable acidity (TA), expressed as citric acid content, determined by titration against 0.1 N sodium hydroxide, using phenolphthalein as an indicator; (4) and the TSS:TA ratio was calculated by dividing the TSS values by the TA values.

Statistical analysis

Analyses of variance were performed using the GLM (General Linear Models) procedure in the SAS (Statistical Analysis System) computer program (SAS Inc., 1990).

Results

In both cultivars in 1998 and in 1999 the fruit of pruned trees received much higher light levels throughout the season than the fruit of unpruned trees (Fig. 1a and Fig. 1b for 'Mihowase' Satsumas and Fig. 2a and Fig. 2b for 'Nules' Clementines). There was a decrease in the light level of pruned fruit throughout the season in Clementines in 1999. Changes in the light level at the surface of the tagged fruit occurred in both cultivars throughout the season due to bending of shoots as the fruit increased in size.

[Figures 1a, 1b, 2a and 2b]

Pruning of the 'Mihowase' Satsumas had no significant effect on fruit colour in both years of the study (P=0.7613 in 1998 and P=0.2345 in 1999), TSS (P=0.2767 in 1998 and P=0.2283 in 1999), TA in 1998 (P=0.2791) and TSS:TA ratio in 1998 (P=0.7809), compared to the fruit of the unpruned trees (control) (Table 1). Pruning, however, significantly decreased TA levels (P=0.0013) of fruit in 1999 and therefore significantly (P=0.0031) increased the TSS:TA levels.

[Table 1]

Pruning of the 'Nules' Clementines had no significant effect on fruit colour in both years (P=0.3308 in 1998 and P=0.0767 in 1999), the TSS in 1998 (P=0.2103) and the TA in 1998 (P=0.3151), compared to the fruit of the unpruned trees (control) (Table 2). Pruning significantly increased the TSS (P=0.0087) and decreased the TA (P=0.0135) of fruit compared to fruit from non-pruned trees in 1999. Pruning significantly increased the TSS:TA ratio of the fruit in both years of the study (P=0.0363 in 1998 and P=0.0058 in 1999). The increase in ratio for 1998 is due to a slight, although not significant, increase in TSS and a slight decrease in acid levels in the fruit of pruned trees. These effects were highly significant in 1999.

[Table 2]

Discussion

The increase in the TSS:TA ratio of fruit on the pruned 'Nules' Clementine trees was the only significant improvement in the internal fruit quality due to pruning and improved light levels, in both cultivars in the first year. Previous studies (Sites & Reitz, 1949; Erickson, 1968) indicated that higher light intensities should result in fruit with higher TSS. Therefore, it was expected that pruning would increase the TSS of fruit in both cultivars. Pruning in the second year, however, significantly improved the internal fruit quality of the fruit in both cultivars. A possible reason for the lack of consistent positive results with 'Mihowase' Satsumas may be the removal of too many of the source leaves. Also, the pruning in our trials resulted in regrowth which possibly competed with the fruit for newly-synthesised photosynthates by older source leaves. It has been shown that young citrus leaves remain a sink until virtually fully expanded (Goldschmidt & Koch, 1996). Syvertsen (1984) found in 'Pineapple' orange that shaded leaves acclimated photosynthetically (net CO_2 assimilation rates) six weeks after pruning. The time between pruning and harvesting was approximately 12 weeks for Clementines in 1998 and for Satsumas in both years, but 17 weeks for Clementines in 1999. Therefore, the timing of the pruning on Satsumas may also have been too late to maximise photosynthetic efficiency of these previously-shaded leaves and thus the transport of the photosynthates to the fruit. The longer acclimation period in Clementines after pruning may be a possible reason for the positive results obtained. Light measurements on adjacent leaves would have been more appropriate than measurements at the surface of each fruit, as photosynthesis depends on the level of light the leaves receive.

Summer pruning may be used as a cultural practice in order to improve the internal fruit quality, especially in 'Nules' Clementines. Regrowth should, however, be controlled after pruning. At this stage the inconsistent results, do not support summer pruning on 'Mihowase' Satsumas.

References

ERICKSON, L.C., 1968. The general physiology of citrus, 86-126. In: W. REUTHER, H.J. WEBBER & L.D. BATCHELOR (eds.), The Citrus Industry. Univ. of California Press, Berkeley.

FALLAHI, E. & MOON, J.W. Jr., 1989. Fruit quality and mineral nutrients from exposed versus internal canopy positions of four citrus varieties. *J. Plant Nutr.* **12**, 523-534.

GOLDSCHMIDT, E.E. & KOCH, K.E., 1996. Citrus. Chapter 34, 797-823. In: E. ZAMSKI & A.A. SCHAFFER (eds.), Photoassimilate Distribution in Plants and Crops. Marcel Dekker Inc., New York.

IWAGAKI, I., 1981. Tree configuration and pruning of Satsuma mandarin in Japan. *Proc. Int. Soc. Citric.* **1**, 169-172.

KIMBALL, D.A., 1984. Factors affecting the rate of maturation of citrus fruits. *Proc. Fla. State Hortic. Soc.* **97**, 40-44.

KOCH, K.E., 1988. Production and environmental factors affecting the Brix/acid ratio, 78-81. In: J.J. FERGUSON & W.F. WARDOWSKI (eds.), Factors Affecting Fruit Quality. Proceedings, Citrus Short Course. Citrus Research and Education Center, Lake Alfred, Florida.

LEVY, Y., BAR-AKIVA, A. & VAADIA, Y., 1978. Influence of irrigation and environmental factors on grapefruit acidity. *J. Am. Soc. Hortic. Sci.* **103**, 73-76.

LEWIS, L.N. & McCARTY, C.D., 1973. Pruning and girdling of citrus. Chapter 7, 211-229. In: W. REUTHER (ed.), The Citrus Industry. Vol III, University of California, Riverside, California.

REUTHER, W., 1988. Climate and fruit quality, 9-23. In: J.J. FERGUSON & W.F. WARDOWSKI (eds.), Factors Affecting Fruit Quality. Proceedings, Citrus Short Course. Citrus Research and Education Center, Lake Alfred, Florida.

SAS INSTITUTE INC., 1990. SAS/STAT User's Guide, Version 6. 4th ed. Vol.1 and 2, Cary, NC, USA.

SITES, J.W. & REITZ, H.J., 1949. The variation in individual Valencia oranges from different locations of the tree as a guide to sampling methods and spot-picking for quality. I. Soluble solids in the juice. *Proc. Am. Soc. Hortic. Sci.* **54**, 1-10.

SUZUKI, T., OKAMOTO, S. & SEKI, T., 1973. Effects of micro-meteorological elements and positions in the tree crown on the development of shoots, leaves and fruits of satsuma mandarin. *J. Jpn. Soc. Hortic. Sci.* **42**, 201-209.

SYVERTSEN, J.P., 1984. Light acclimation in citrus leaves. II. CO_2 assimilation and light, water, and nitrogen use efficiency. *J. Am. Soc. Hortic. Sci.* **109**, 812-817.

SYVERTSEN, J.P. & ALBRIGO, L.G., 1980. Some effects of grapefruit tree canopy position on microclimate, water relations, fruit yield, and juice quality. *J. Am. Soc. Hortic. Sci.* **105**, 454-459.

YAMANISHI, O.K. & HASEGAWA, K., 1995. Trunk strangulation responses to the detrimental effect of heavy shade on fruit size and quality of 'Tosa Buntan' pummelo. *J. Hortic. Sci.* **70**, 875-887.

Table 1. The effect of summer pruning (pruned on 11 December 1997 and 14 December 1998) on the internal fruit quality of 'Mihowase' Satsumas on Troyer citrange rootstock in the Stellenbosch area.

		COLOUR		TSS		ACID		RATIO[y]	
Treatment:		1998	1999	1998	1999	1998	1999	1998	1999
Control (no pruning)		5.0a[z]	6.1a	8.20a	7.38a	1.01a	1.62a	8.31a	4.65b
Pruning		5.2a	5.8a	7.74a	7.76a	0.94a	1.36b	8.51a	5.86a
LSD		1.537	0.444	1.015	0.665	0.151	0.130	1.866	0.678
SE		0.391	0.139	0.259	0.208	0.0384	0.0405	0.475	0.212
Source:	df								
Treatment	1	0.7613	0.2345	0.2767	0.2283	0.2791	0.0013	0.7809	0.0031

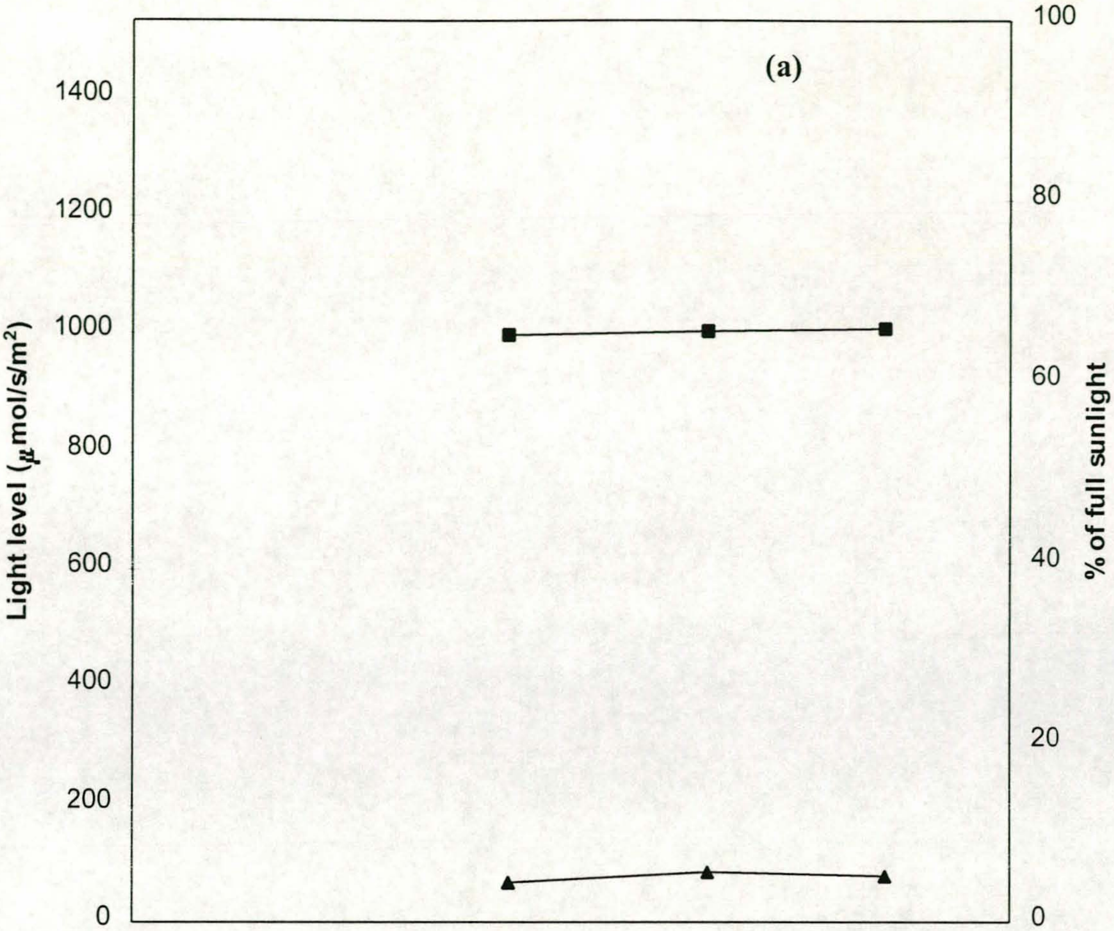
[z]Means with the same letter are not significantly different at the 5% level (LSD)
[y]Rounding off causes TSS/acid values to differ from actual ratio values

Table 2. The effect of summer pruning (pruned on 19 January 1998 and 11 January 1999) on the internal fruit quality of 'Nules' Clementines on Troyer citrange rootstock in the Stellenbosch area.

		COLOUR		TSS		ACID		RATIO[y]	
Treatment:		1998	1999	1998	1999	1998	1999	1998	1999
Control (no pruning)		5.9a[z]	4.9a	7.75a	8.15b	0.91a	1.02a	8.74b	8.19b
Pruning		6.2a	4.3a	8.01a	8.72a	0.89a	0.86b	9.14a	10.49a
LSD		0.784	0.713	0.489	0.386	0.0382	0.118	0.351	1.449
SE		0.200	0.223	0.125	0.121	0.00974	0.0370	0.0894	0.453
Source:	df								
Treatment	1	0.3308	0.0767	0.2103	0.0087	0.3151	0.0135	0.0363	0.0058

[z]Means with the same letter are not significantly different at the 5% level (LSD)
[y]Rounding off causes TSS/acid values to differ from actual ratio values

Figure 1. Light measurements at the surface of shaded and exposed fruit of 'Mihowase' Satsuma throughout the 1998 (a) and the 1999 (b) seasons, Stellenbosch.


(a)
Light level (μmol/s/m²)
% of full sunlight
0
200
400
600
800
1000
1200
1400
0
20
40
60
80
100

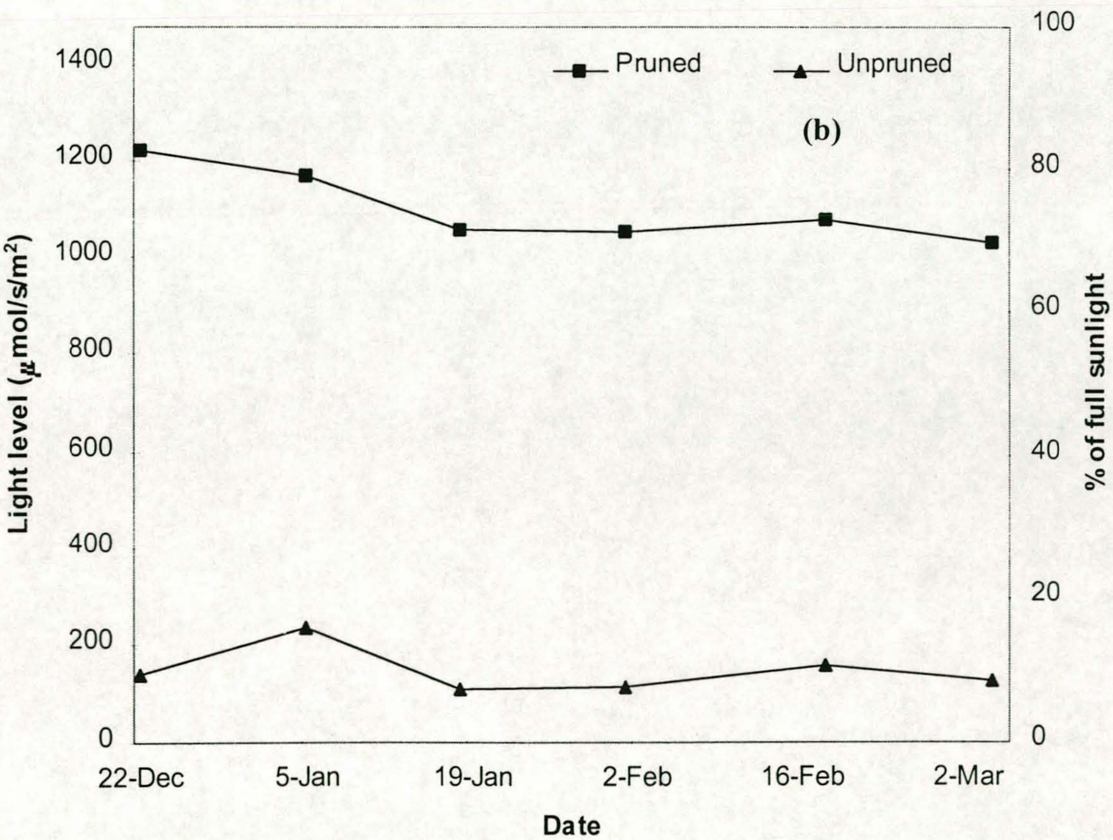
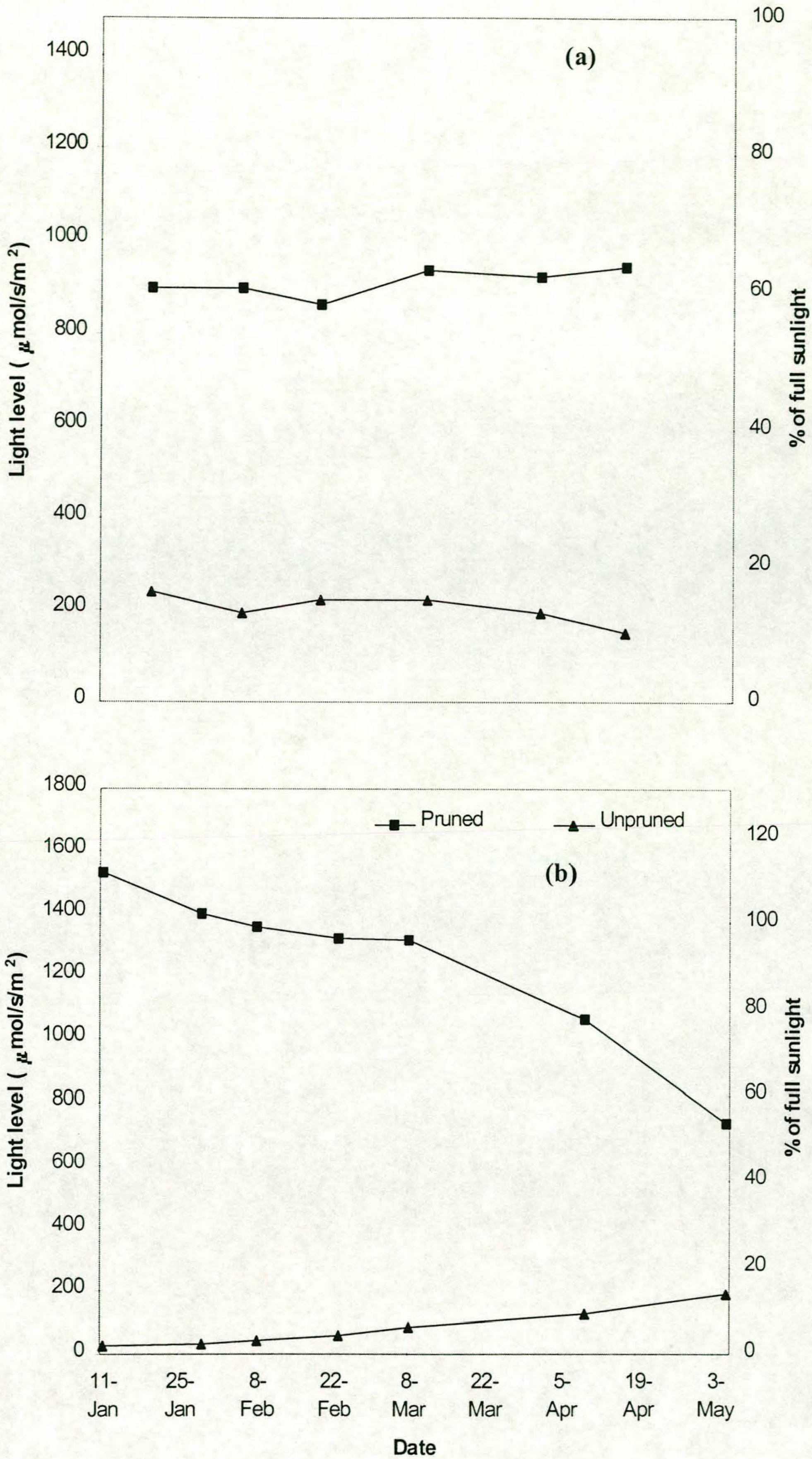

Pruned
Unpruned
(b)
Light level (μmol/s/m²)
% of full sunlight
0
200
400
600
800
1000
1200
1400
0
20
40
60
80
100
22-Dec
5-Jan
19-Jan
2-Feb
16-Feb
2-Mar
Date

Figure 2. Light measurements at the surface of shaded and exposed fruit of 'Nules' Clementine throughout the 1998 (a) and the 1999 (b) seasons, Stellenbosch.


(a)
Light level (μmol/s/m²)
% of full sunlight
1400
1200
1000
800
600
400
200
0
100
80
60
40
20
0
(b)
Pruned
Unpruned
1800
1600
1400
1200
1000
800
600
400
200
0
120
100
80
60
40
20
0
11-Jan
25-Jan
8-Feb
22-Feb
8-Mar
22-Mar
5-Apr
19-Apr
3-May
Date

PAPER 2.2: BEARING POSITION AFFECTS INTERNAL FRUIT QUALITY OF MANDARIN TYPES

Abstract

Differences in juice quality are associated with positional differences in canopy microclimate and exposure of individual fruit to light and temperature. Internal fruit quality differences between fruit from different sectors of the tree were investigated. The trials were carried out with 'Mihowase' Satsuma and 'Nules' Clementine trees on Troyer citrange rootstock in Stellenbosch (34°S 19°E) and 'Fairchild' and 'Temple' tangor trees on rough lemon rootstock in Citrusdal (32°30'S 19°E), South Africa. Fruit were harvested from four sectors in each tree, viz. north, south, east and west. Within each sector, fruit were harvested from three sub-sectors, i.e. the top, and the inside and outside bottom sub-sectors. Fruit from each sector were scored for colour, size, juice content (%), total soluble solids (TSS), titratable acidity (TA) and TSS:TA ratio. (i) Colour: 'Fairchild' fruit from all sub-sectors were fully coloured (orange) at harvest. There were also no fruit colour differences between the sub-sectors in each sector in the other cultivars. The north sector had significantly greener fruit than the south sector in Satsumas, Clementines and 'Temple'. (ii) Fruit size: In Satsumas, Clementines and 'Temple' top fruit were the largest and inside bottom fruit the smallest, but the opposite was true in 'Fairchild'. (iii) Juice content: The juice content (%) in all four cultivars was the lowest in top fruit and the highest in inside bottom fruit. (iv) Total soluble solids (TSS): The TSS in all four cultivars was the highest in top fruit and the lowest in inside bottom fruit. The TSS in fruit from the north sector were significantly higher than fruit from the south sector for 'Fairchild' and 'Temple', with no differences in Satsumas and Clementines. (v) Titratable acidity (TA): In Satsumas and Clementines inside bottom fruit had the highest TA levels and outside bottom fruit the lowest levels, with no trends in 'Fairchild' and 'Temple'. (vi) TSS:TA ratio: Outside bottom fruit (Satsumas) or top fruit (Clementines, 'Fairchild' and 'Temple') had the highest TSS:TA ratios and inside bottom fruit had the lowest ratios. The north sector in all the cultivars had higher TSS:TA ratios than the south sector. Top and outside bottom fruit had the best quality. This study provides information that can be used to set a standard for

sampling fruit for quality determinations, as a guide for spot-picking and harvesting, and in developing pruning strategies.

Introduction

Fruit quality is determined by fruit colour, fruit diameter, juice content (%), total soluble solids (TSS), titratable acidity (TA) and the TSS:TA ratio. According to Levy *et al.* (1978) environmental factors will influence citrus juice quality in terms of TSS. Differences in TSS are associated with positional differences in canopy microclimate and exposure to light and temperature of individual fruit (Sites & Reitz, 1949; Levy *et al.*, 1978; Syvertsen & Albrigo, 1980). All quality parameters are influenced by factors such as fruit size, harvest date, position in the tree, rootstocks, and climatic conditions (Cohen, 1988). It is these factors that cause variation in internal quality among fruit from the same tree.

Iwagaki (1981) found that fruit colour was better developed with higher light intensity in the periphery of the tree canopy, but found no differences in fruit colour between the top and bottom portion fruit. Sites & Reitz (1949) found that green fruit were associated with an inside location, yellow fruit with partially shaded conditions, and orange fruit with exposed conditions.

Cohen (1988) found that fruit from the top portion of the tree had a slightly larger diameter than fruit from bottom portions of the tree and that external fruit had a slightly larger diameter than internal fruit. Fruit from the warmer, southern side (northern hemisphere) of the tree were also larger than fruit from the northern side of the tree (Cohen, 1988).

Sites & Reitz (1949) and Cohen (1988) found that fruit from the top portion of the tree had a slightly higher juice content than fruit from bottom portions. Cohen (1988) and Fallahi & Moon (1989) found that the juice content (%) of internal fruit was higher than that of external fruit, but the opposite was reported by Syvertsen & Albrigo (1980). Fruit from the southern side (northern hemisphere) of the tree had a lower juice content (%) than fruit from the northern side of the tree (Cohen, 1988).

Sites & Reitz (1949), Erickson (1968) and Iwagaki (1981) reported that the TSS content in fruit increases with increased light intensity. Shading reduces sugar content (TSS) of fruit by reducing net photosynthesis and dark respiration of these shaded leaves (Reuther, 1988; Yamanishi & Hasegawa, 1995). TSS in the fruit increase with an increase in height of the fruit on the tree (Sites & Reitz, 1949; Erickson, 1968), due to higher light intensities and air temperatures (Suzuki *et al.*, 1973). In grapefruit (Syvertsen & Albrigo, 1980; Fallahi & Moon, 1989), mandarins and oranges (Sites & Reitz, 1949; Erickson, 1968; Koch, 1988a; Fallahi & Moon, 1989), fruit from external canopies have significantly higher TSS than the internal fruit, which results in a higher TSS:TA ratio (Syvertsen & Albrigo, 1980). Oranges from southern canopy sectors (northern hemisphere) tend to have higher concentrations of soluble solids (Sites & Reitz, 1949; Erickson, 1968; Syvertsen & Albrigo, 1980; Koch, 1988a, 1988b).

The percentage acids in grapefruit remain lowest in the upper canopy positions (Syvertsen & Albrigo, 1980). Syvertsen & Albrigo (1980) found with grapefruit that external fruit in the canopy had a lower percentage acid than internal fruit. Contrary to Syvertsen & Albrigo (1980), Fallahi & Moon (1989) found that titratable acid (TA) of external fruit of mandarin and grapefruit were higher compared to internal fruit. Oranges from southern canopy sectors (northern hemisphere) tend to have higher concentrations of acids (Erickson, 1968; Koch, 1988a, 1988b). This is probably due to microclimatic conditions such as the level and intensity of light or the higher temperature to which external or upper fruit are exposed.

Sun-exposed fruit in the upper sectors of the canopy have a higher quality (TSS:TA ratio) than fruit in shaded lower or inside canopy sectors (Syvertsen & Albrigo, 1980). Kimball (1984) and Koch (1988a) stated that maturity (based on TSS:TA ratio) of outside fruit was more advanced.

The aim of this study is to determine internal fruit quality differences between fruit from different sectors of 'Mihowase' Satsuma, 'Nules' Clementine, 'Fairchild' and 'Temple' tangor trees. The study would also provide information, which can be used in developing pruning and harvesting strategies.

Materials and Methods

Plant material

Healthy, uniform 'Mihowase' Satsuma and 'Nules' Clementine trees on Troyer citrange rootstock situated in the Stellenbosch area, South Africa (34°S 19°E) and 'Fairchild' and 'Temple' tangor trees on rough lemon rootstock situated in the Citrusdal area, South Africa (32°30'S 19°E) were used for this study. Additional information on the plant material used in the study is provided in Table 1.

[Table 1]

Trial layout and treatments

Each tree (replicate) was divided into four sectors, viz. north, south, west and east. In each sector, fruit were harvested from three different sub-sectors, the top of the tree, the inside bottom part (approximately 30 cm from the periphery of the tree) and the outside bottom part (until approximately 15 cm inside the tree) of the tree. The twelve positions (treatments) in each tree were replicated eight times.

Twelve fruit per sub-sector were sampled per tree (replicate) at harvest maturity (15 March 1999 for 'Mihowase' Satsumas, 10 May 1999 for 'Nules' Clementines, 7 June 1999 for 'Fairchild' and on 21 June 1999 for 'Temple' tangors.

Fruit quality measurements

The following quality measurements were done on each twelve-fruit sample: Fruit colour was determined based on the no. 36 Outspan colour chart for soft citrus, with eight being dark green and one being fully coloured (orange). Fruit diameter (measured by electronic calliper) of each fruit was measured. Juice was extracted using a citrus juicer. Juice was then strained through two layers of muslin cloth and juice content (%) was determined by subtracting the weight of reamed peel from the original fruit weight and dividing by the original fruit weight. The juice was then used for the determination of the total soluble solids (TSS) by using a hand-held refractometer (Atago N1). Titratable acidity (TA), expressed as citric acid content, was determined by titration against 0.1 N sodium hydroxide, using phenolphthalein as an indicator. The TSS:TA ratio was calculated by dividing the TSS values by the TA values.

Statistical analysis

Analyses of variance were performed using the GLM (General Linear Models) procedure in the SAS (Statistical Analysis System) computer program (SAS Inc., 1990).

Results and Discussion

Fruit colour. All the fruit from 'Fairchild' trees were fully coloured (orange) (Data not presented). There were no clear trends in fruit colour between the different sub-sectors of the sectors in Satsumas (Table 2a), Clementines (Table 3a) and 'Temple' tangors (Table 4a). In the south sector of 'Temple' tangor trees, fruit from the inside bottom sub-sector had significantly greener fruit than the outside sub-sector. Similar results have been reported by Sites & Reitz (1949). There were, however, significant differences in fruit colour between some of the sub-sectors in each sector in the other cultivars, but not commercially significant, since it would not make a difference in the percentage fruit picked at the given time.

[Tables 2a, 3a, 4a, and 5a]

On average, the north sector had significantly greener fruit than the south sector in Satsumas ($P=0.0347$), Clementines ($P=0.0035$) and in 'Temple' ($P=0.0001$). This may be due to the increased fruit temperature on the northern side of the tree (Syvertsen & Albrigo, 1980), because relatively low air temperature (<13°C) is required for fruit colour development (Goldschmidt, 1988). The east sector had significantly greener fruit than the west sector in Satsumas ($P=0.0161$). There were no significant differences between average outside and inside fruit in Satsumas ($P=0.6867$), Clementines ($P=0.4739$) and 'Temple' ($P=0.2809$) and between average top and bottom fruit ($P=0.1126$, $P=0.7172$ and $P=0.0613$, respectively). In general, the later maturing 'Fairchild' had the best colour development at harvest and the early-maturing Satsumas the worst.

Diameter. The general trend in 'Mihowase' Satsumas (Table 2a), 'Nules' Clementines (Table 3a) and 'Temple' tangors (Table 4a), was that fruit diameter was the largest in the top sub-sectors in each sector of the tree and the smallest in the inside bottom sub-sector, but the opposite was true in 'Fairchild' (Table 5a). The differences were, however, not always significant.

On average, fruit from the north sectors (warmer) were larger than fruit from south sectors in 'Temple' (P=0.0001). Studies by Cohen (1988) confirm these results. This may also be due to higher fruit temperatures in the northern side of the tree (Syvertsen & Albrigo, 1980). However, the north sector of Clementines (P=0.0001) and 'Fairchild' (P=0.0003) had significantly smaller fruit than the south sector. There were no significant differences in diameter between fruit from west and east sectors in Satsumas (P=0.1379), Clementines (P=0.0957) and 'Temple' (P=0.9583). In 'Fairchild', the west sector had significantly smaller fruit than the east sector (P=0.0002). Outside fruit were significantly larger than inside fruit in Satsumas (P=0.0001), Clementines (P=0.0001) and 'Temple' (P=0.0009), which is in agreement with studies by Cohen (1988). The opposite was true in 'Fairchild' (P=0.0001), which was more similar to oranges, where inside fruit are usually larger (pers.obs.). Fruit from top sub-sectors were significantly larger than fruit from bottom (outside and inside) sub-sectors in Satsumas (P=0.0001), Clementines (P=0.0001), and 'Temple' (P=0.0004), but the opposite was true in 'Fairchild' (P=0.0001). Cohen (1988) also reported that fruit from top portions were larger than from bottom portions. This is probably due to more light and heat in the exposed canopy.

Juice content. The general trend in all four cultivars was for the lowest juice content to be in fruit from the top sub-sectors in each sector and the highest juice content in fruit from the inside bottom sub-sectors (Tables 2a, 3a, 4a and 5a). Not all the differences in juice content were, however, significant.

On average, there were no significant differences between north and south sectors in Satsumas (P=0.6936), Clementines (P=0.3620), 'Fairchild' (P=0.3239) and 'Temple' (P=0.1653). There were also no significant differences between west and east sectors in Satsumas (P=0.5122), 'Fairchild' (P=0.9839) and 'Temple' (P=0.6758). Fruit from the west sector in Clementines had a significantly higher juice content than the east sector (P=0.0058). Inside fruit in all four cultivars had a significantly higher juice content than outside fruit (P=0.0001), which is in agreement with studies by Cohen (1988) and Fallahi & Moon (1989). In Satsumas, Clementines and 'Temple' the smallest fruit (inside bottom sub-sector) had the highest juice content, but in 'Fairchild' the largest fruit (also inside bottom sub-sector) had the highest juice content. Ketsa (1988) reported a direct relationship in tangerines between fruit size and juice content. Bottom (inside and outside) fruit had a significantly higher juice content than top fruit in all the cultivars (P=0.0005 for Satsumas, P=0.0001 for Clementine and 'Temple', and P=0.0004 for 'Fairchild'). Opposite results have been reported by Sites & Reitz (1949) and Cohen (1988).

TSS. The general trend in all four cultivars was the highest TSS in fruit from the top sub-sector in each sector and the lowest TSS in fruit from the inside bottom sub-sector (Tables 2b, 3b, 4b and 5b). Not all the differences in TSS were, however, significant.

[Tables 2b, 3b, 4b and 5b]

On average, there were no significant differences in TSS between north and south sectors in Satsumas (P=0.5524) and Clementines (P=0.1998). In 'Fairchild' (P=0.0001) and 'Temple' (P=0.0001), fruit from the north sector had a significantly higher TSS than the south sector. Similar results have been reported by previous studies (Sites & Reitz, 1949; Erickson, 1968; Syvertsen & Albrigo, 1980; Koch, 1988a). Fruit from the west sector had significantly lower TSS levels than fruit from the east sector in Satsumas (P=0.0038) and 'Fairchild' (P=0.0129), but there were no significant differences in TSS between west and east sectors in Clementines (P=0.7192) and 'Temple' (P=0.7382). Inside bottom fruit had significantly lower TSS levels than outside bottom fruit in all the cultivars (P=0.0001) as was also reported by Sites & Reitz (1949), Koch (1988a) and Fallahi & Moon (1989). Bottom (inside and outside) fruit also had significantly lower TSS levels than top fruit in all the cultivars (P=0.0001). Similar results have been reported by Sites & Reitz (1949) and Erickson (1968).

Titratable acidity (TA). The general trend in Satsumas (Table 2b) and Clementines (Table 3b) was the highest TA levels in fruit from the inside bottom sub-sector in each sector and the lowest TA levels in fruit from the outside bottom sub-sector. Not all the differences in TA levels were, however, significant. There were no trends in TA levels in 'Temple' (Table 4b) and 'Fairchild' (Table 5b).

On average, the north sector had significantly lower TA levels than the south sector in Satsumas (P=0.0009) and 'Temple' (P=0.0110), but in Clementines (P=0.1687) and 'Fairchild' (P=0.7914) there were no significant differences in TA levels between the north and the south sectors. Erickson (1968) and Koch (1988a) reported opposite results. There were no significant differences in TA levels between fruit from the west and the east sectors in Satsumas (P=0.3385) and 'Temple' (P=0.4503). Fruit from the west sector in Clementines (P=0.0013) and 'Fairchild' (P=0.0001) had significantly higher TA levels than the east sector. Inside bottom fruit in Satsumas (P=0.0001), Clementines (P=0.0076) and 'Fairchild' (P=0.0057) had significantly higher TA levels than outside bottom fruit. Similar results have been reported on grapefruit by Syvertsen & Albrigo (1980), but Fallahi & Moon (1989) found the opposite in mandarins and grapefruit. There were no significant differences in TA levels between inside and outside bottom fruit in 'Temple' (P=1.000). Bottom (inside and outside) fruit had significantly higher TA levels than top fruit in Satsumas (P=0.0045), but there were no significant differences in TA levels between bottom (inside and outside) fruit and top fruit in Clementines (P=0.2251), 'Fairchild' (P=0.3752), and 'Temple' (P=0.3175).

TSS:TA ratio. The general trend in all the cultivars was the highest TSS:TA ratios in fruit from the top and outside bottom sub-sectors in each sector and the lowest TSS:TA ratios in fruit from the inside bottom sub-sector. Not all the differences in TSS:TA ratios were, however, significant.

On average, the north sector in all the cultivars had significantly higher TSS:TA ratios than the south sector (P=0.0009 for Satsumas, P=0.0372 for Clementines, P=0.0001 for 'Fairchild' and 'Temple') due to the higher TSS and lower acid levels in the north sector. There were no significant differences in TSS:TA ratios between fruit from the west and the east sectors in Satsumas (P=0.9192) and 'Temple' (P=0.3888), but fruit from west sectors in Clementines (P=0.0188) and 'Fairchild' (P=0.0001) had significantly lower TSS:TA ratios than the east sectors. Outside fruit had significantly higher TSS:TA ratios than inside fruit in all the cultivars (P=0.0001 for Satsumas and Clementines, P=0.0006 for 'Fairchild', and P=0.0111 for 'Temple'). Similar results have been reported by Syvertsen & Albrigo (1980). Bottom (inside and outside) fruit had significantly lower TSS:TA ratios than top fruit (P=0.0002 for Satsumas and P=0.0001 for Clementines, 'Fairchild' and 'Temple'). Syvertsen & Albrigo (1980) reported similar results in their studies.

Most of the data in our trials confirm results by previous researchers. In all the cultivars used in the study, top and outside bottom fruit had the best quality and inside bottom fruit had the worst quality. There were only small variations between cultivars. Unexpected results were the large fruit from inside bottom sub-sectors of 'Fairchild', whereas the other cultivars had the smallest fruit in this position. These differences were not due to unsuitable climatic conditions. Possible differences in tree growth habit between the cultivars or the fact that these trees are all very well pruned may contribute to the small differences in fruit diameter between the different sub-sectors in the canopy. The results indicate that quality parameters differ in different positions on the tree, but also in the same positions for different cultivars. This study provides information which can be used to set a standard for sampling fruit for quality determinations. The information can also be used as a guide for spot-picking and harvesting, especially during the early stages of harvest. The lower quality inside fruit can be left on the tree and harvested later. The quality of the shaded inside fruit can also be improved by new pruning strategies. Windows can be pruned into the trees to improve light distribution towards the inner, shaded parts of the canopy.

References

COHEN, E., 1988. The chemical composition and sensory flavour quality of 'Minneola' tangerines. I. Effects of fruit size and within-tree position. *J. Hortic. Sci.* **63**, 175-178.

ERICKSON, L.C., 1968. The general physiology of citrus. Chapter 2, 86-126. In: W. REUTHER, H.J. WEBBER & L.D. BATCHELOR (eds.), The Citrus Industry. Univ. of California Press, Berkeley.

FALLAHI, E. & MOON, J.W. Jr., 1989. Fruit quality and mineral nutrient from exposed versus internal canopy positions of four citrus varieties. *J. Plant Nutr.* **12**, 523-534.

GOLDSCHMIDT, E.E., 1988. Regulatory aspects of chloro-chromoplast interconversions in senescing citrus fruit peel. *Isr. J. Bot.* **37**, 123-130.

IWAGAKI, I., 1981. Tree configuration and pruning of Satsuma mandarin in Japan. *Proc. Int. Soc. Citric.* **1**, 169-172.

KETSA, S., 1988. Effects of fruit size on juice content and chemical composition of tangerine. *J. Hortic. Sci.* **63**, 171-174.

KIMBALL, D.A., 1984. Brix/acid ratio: Brix/acid ratio correlation with climatic data for California Navel and Valencia oranges. *Citrus Ind.* Aug., 26-29.

KOCH, K.E., 1988a. Production and environmental factors affecting the Brix/acid ratio, 78-81. In: J.J. FERGUSON & W.F. WARDOWSKI (eds.), Factors Affecting Fruit Quality. Proceedings, Citrus Short Course. Citrus Research and Education Center, Lake Alfred, Florida.

KOCH, K.E., 1988b. Sugar and acid metabolism in citrus fruit, 59-66. In: J.J. FERGUSON & W.F. WARDOWSKI (eds.), Factors Affecting Fruit Quality. Proceedings, Citrus Short Course. Citrus Research and Education Center, Lake Alfred, Florida.

LEVY, Y., BAR-AKIVA, A. & VAADIA, Y., 1978. Influence of irrigation and environmental factors on grapefruit acidity. *J. Am. Soc. Hortic. Sci.* **103**, 73-76.

REUTHER, W., 1988. Climate and fruit quality, 9-23. In: J.J. FERGUSON & W.F. WARDOWSKI (eds.), Factors Affecting Fruit Quality. Proceedings, Citrus Short Course. Citrus Research and Education Center, Lake Alfred, Florida.

SAS INSTITUTE INC., 1990. SAS/STAT User's Guide, Version 6. 4th ed. Vol.1 and 2, Cary, NC, USA.

SITES, J.W. & REITZ, H.J., 1949. The variation in individual Valencia oranges from different locations of the tree as a guide to sampling methods and spot-picking for quality. I. Soluble solids in the juice. *Proc. Am. Soc. Hortic. Sci.* **54**, 1-10.

SUZUKI, T., OKAMOTO, S. & SEKI, T., 1973. Effects of micro-meteorological elements and positions in the tree crown on the development of shoots, leaves and fruits of satsuma mandarin. *J. Jpn. Soc. Hortic. Sci.* **42**, 201-209.

SYVERTSEN, J.P. & ALBRIGO, L.G., 1980. Some effects of grapefruit tree canopy position on microclimate, water relations, fruit yield, and juice quality. *J. Am. Soc. Hortic. Sci.* **105**, 454-459.

YAMANISHI, O.K. & HASEGAWA, K., 1995. Trunk strangulation responses to the detrimental effect of heavy shade on fruit size and quality of 'Tosa Buntan' pummelo. *J. Hortic. Sci.* **70**, 875-887.

Table 1. Additional information on the plant material used in the study.

	'Mihowase' Satsuma	'Nules' Clementine	'Fairchild'	'Temple' tangor
Planting date	1991	1991	1983	topworked to 'Temple' in 1992
Soil	clay-loam	clay-loam	sandy	sandy
Tree spacing (m)	4.5 x 2.5	4.5 x 2.5	6.0 x 4.0	5.0 x 3.0
Row-direction	north-south	north-south	north-south	east-west

Table 2a. Fruit colour, diameter and juice content (%) of 'Mihowase' Satsuma fruit borne in different positions in the canopy.

POSITION WITHIN TREE		COLOUR		DIAMETER		JUICE %	
North	Top	6.4	abc[z]	52.93	ab	50.84	c
	Outside	6.8	a	53.16	a	50.00	c
	Inside	6.3	bc	49.43	dc	56.18	ab
West	Top	6.0	c	53.54	a	50.16	c
	Outside	6.3	bc	50.85	bc	50.65	c
	Inside	6.1	bc	47.17	d	55.86	ab
South	Top	6.1	c	52.39	ab	51.14	c
	Outside	6.1	bc	51.32	abc	50.59	c
	Inside	6.5	ab	48.27	d	56.54	a
East	Top	6.4	abc	52.91	ab	50.40	c
	Outside	6.5	ab	52.45	ab	52.59	bc
	Inside	6.5	ab	49.17	dc	55.77	ab
	LSD	0.461		2.279		3.645	
	SE	0.164		0.809		1.294	
Average	Top	6.2		52.94		50.64	
	Outside	6.4		51.95		50.96	
	Inside	6.4		48.51		56.09	
Source:	df						
Treatment	11	0.0415		0.0001		0.0001	
North vs South	1	0.0347		0.0787		0.6936	
West vs East	1	0.0161		0.1379		0.5122	
Outside vs Inside	1	0.6867		0.0001		0.0001	
Top vs Bottom[y]	1	0.1126		0.0001		0.0005	

[z]Means with the same letter are not significantly different at the 5% level (LSD)
[y]Inside and outside sub-sectors combined

Table 2b. TSS, TA levels and the TSS:TA ratio of 'Mihowase' Satsuma fruit borne in different positions in the canopy.

POSITION WITHIN TREE		TSS		ACID		RATIO[x]	
North	Top	10.13	ab[z]	1.53	d	6.66	c
	Outside	10.28	ab	1.38	e	7.51	a
	Inside	9.44	de	1.69	bc	5.68	d
West	Top	10.00	bc	1.48	de	6.80	bc
	Outside	9.94	bc	1.39	e	7.23	ab
	Inside	9.55	de	1.76	b	5.50	d
South	Top	10.26	ab	1.58	dc	6.57	c
	Outside	10.06	bc	1.51	de	6.69	bc
	Inside	9.33	e	1.92	a	4.89	e
East	Top	10.44	a	1.51	de	7.00	abc
	Outside	10.24	ab	1.44	de	7.13	abc
	Inside	9.75	dc	1.79	ab	5.48	d
	LSD	0.361		0.136		0.565	
	SE	0.128		0.0482		0.201	
Average	Top	10.21		1.53		6.75	
	Outside	10.13		1.43		7.14	
	Inside	9.52		1.79		5.39	

Source:	df	TSS	ACID	RATIO
Treatment	11	0.0001	0.0001	0.0001
North vs South	1	0.5524	0.0009	0.0009
West vs East	1	0.0038	0.3385	0.9192
Outside vs Inside	1	0.0001	0.0001	0.0001
Top vs Bottom[y]	1	0.0001	0.0045	0.0002

[z]Means with the same letter are not significantly different at the 5% level (LSD)
[y]Inside and outside sub-sectors combined
[x]Rounding off causes TSS/acid values to differ from actual ratio values

Table 3a. Fruit colour, diameter and juice content (%) of 'Nules' Clementine fruit borne in different positions in the canopy.

POSITION WITHIN TREE		COLOUR		DIAMETER		JUICE %	
North	Top	4.6	a[z]	59.64	dc	51.69	defg
	Outside	4.5	a	57.99	d	53.52	cde
	Inside	4.5	ab	54.89	e	57.31	a
West	Top	4.0	bc	59.90	bdc	53.18	cdef
	Outside	3.9	c	59.31	dc	53.38	cde
	Inside	4.2	abc	54.83	e	56.27	ab
South	Top	3.9	c	61.53	abc	51.00	efg
	Outside	4.0	bc	62.17	ab	53.73	bcd
	Inside	4.4	abc	60.20	bdc	55.74	abc
East	Top	4.6	a	61.06	abc	50.73	fg
	Outside	4.3	abc	62.88	a	49.24	g
	Inside	4.0	bc	53.74	e	56.47	a
	LSD	0.553		2.485		2.588	
	SE	0.197		0.883		0.919	
Average	Top	4.3		60.53		51.65	
	Outside	4.2		60.59		52.47	
	Inside	4.3		55.92		56.45	
<u>Source:</u>	df						
Treatment	11	0.0208		0.0001		0.0001	
North vs South	1	0.0035		0.0001		0.3620	
West vs East	1	0.0905		0.0957		0.0058	
Outside vs Inside	1	0.4739		0.0001		0.0001	
Top vs Bottom[y]	1	0.7172		0.0001		0.0001	

[z]Means with the same letter are not significantly different at the 5% level (LSD)
[y]Inside and outside sub-sectors combined

Table 3b. TSS, TA levels and the TSS:TA ratio of 'Nules' Clementine fruit borne in different positions in the canopy.

POSITION WITHIN TREE		**TSS**		**ACID**		**RATIO**[x]	
North	Top	10.71	a[z]	0.93	de	11.53	a
	Outside	10.40	ab	0.91	e	11.47	a
	Inside	8.95	c	0.97	abcd	9.25	d
West	Top	10.75	a	0.99	abc	10.93	abc
	Outside	10.40	ab	1.02	a	10.26	c
	Inside	9.08	c	1.02	a	8.94	d
South	Top	10.53	ab	0.97	abcd	10.87	abc
	Outside	10.05	b	0.95	bcde	10.59	bc
	Inside	8.95	c	0.95	bcde	9.42	d
East	Top	10.84	a	0.94	cde	11.58	a
	Outside	10.49	ab	0.93	de	11.30	ab
	Inside	8.75	c	1.00	ab	8.80	d
	LSD	0.478		0.0517		0.740	
	SE	0.170		0.0184		0.283	
Average	Top	10.71		0.96		11.23	
	Outside	10.34		0.95		10.91	
	Inside	8.93		0.99		9.10	
Source:	df						
Treatment	11	0.0001		0.0003		0.0001	
North vs South	1	0.1998		0.1687		0.0372	
West vs East	1	0.7192		0.0013		0.0188	
Outside vs Inside	1	0.0001		0.0076		0.0001	
Top vs Bottom[y]	1	0.0001		0.2251		0.0001	

[z]Means with the same letter are not significantly different at the 5% level (LSD)
[y]Inside and outside sub-sectors combined
[x]Rounding off causes TSS/acid values to differ from actual ratio values

Table 4a. Fruit colour, diameter and juice content (%) of 'Temple' tangor fruit borne in different positions in the canopy.

POSITION WITHIN TREE		**COLOUR**		**DIAMETER**		**JUICE %**	
North	Top	4.9	a[z]	76.35	ab	56.33	b
	Outside	5.0	a	75.87	abc	57.57	b
	Inside	4.3	abc	74.38	bcd	60.70	a
West	Top	4.5	ab	78.01	a	56.42	b
	Outside	4.1	bc	75.57	abc	58.23	b
	Inside	3.5	cde	72.18	d	60.98	a
South	Top	2.6	fg	75.38	abc	57.38	b
	Outside	1.8	g	74.65	bcd	57.88	b
	Inside	3.2	ef	72.29	d	61.89	a
East	Top	3.9	bcde	76.79	ab	57.75	b
	Outside	3.2	def	76.07	ab	57.03	b
	Inside	4.0	bcd	73.04	cd	61.62	a
	LSD	0.791		2.958		2.105	
	SE	0.281		1.050		0.748	
Average	Top	4.0		76.63		56.97	
	Outside	3.5		75.54		57.68	
	Inside	3.8		72.97		61.30	
<u>Source:</u>	df						
Treatment	11	0.0001		0.0025		0.0001	
North vs South	1	0.0001		0.0994		0.1653	
West vs East	1	0.1451		0.9583		0.6758	
Outside vs Inside	1	0.2809		0.0009		0.0001	
Top vs Bottom[y]	1	0.0613		0.0004		0.0001	

[z]Means with the same letter are not significantly different at the 5% level (LSD)
[y]Inside and outside sub-sectors combined

Table 4b. TSS, TA levels and the TSS:TA ratio of 'Temple' tangor fruit borne in different positions in the canopy.

POSITION WITHIN TREE		TSS		ACID		RATIO[x]	
North	Top	10.76	a[z]	1.36	a	7.92	a
	Outside	10.66	a	1.38	a	7.80	ab
	Inside	10.33	bcd	1.36	a	7.60	abc
West	Top	10.56	abc	1.38	a	7.70	ab
	Outside	10.28	cd	1.40	a	7.40	bcd
	Inside	9.94	ef	1.42	a	7.00	de
South	Top	10.60	ab	1.43	a	7.48	abcd
	Outside	10.09	de	1.44	a	7.11	cde
	Inside	9.65	f	1.43	a	6.81	e
East	Top	10.70	a	1.36	a	7.93	a
	Outside	10.29	cd	1.39	a	7.45	abcd
	Inside	9.88	ef	1.40	a	7.08	de
	LSD	0.300		0.0871		0.489	
	SE	0.107		0.0309		0.174	
Average	Top	10.66		1.38		7.76	
	Outside	10.33		1.40		7.44	
	Inside	9.95		1.40		7.12	
Source:	df						
Treatment	11	0.0001		0.5481		0.0001	
North vs South	1	0.0001		0.0110		0.0001	
West vs East	1	0.7382		0.4503		0.3888	
Outside vs Inside	1	0.0001		1.0000		0.0111	
Top vs Bottom[y]	1	0.0001		0.3175		0.0001	

[z]Means with the same letter are not significantly different at the 5% level (LSD)
[y]Inside and outside sub-sectors combined
[x]Rounding off causes TSS/acid values to differ from actual ratio values

Table 5a. Fruit diameter and juice content (%) of 'Fairchild' fruit borne in different positions in the canopy (no fruit colour difference due to late harvest).

POSITION WITHIN TREE		**DIAMETER**		**JUICE%**	
North	Top	54.40	f[z]	56.89	cd
	Outside	55.78	ef	57.21	cd
	Inside	59.15	abc	60.42	a
West	Top	55.84	def	56.52	d
	Outside	55.78	ef	58.68	abc
	Inside	58.37	bc	60.45	a
South	Top	57.68	cd	58.58	abc
	Outside	58.22	bc	57.85	bcd
	Inside	59.62	ab	59.86	ab
East	Top	57.39	cde	57.63	cd
	Outside	58.35	bc	57.80	cd
	Inside	60.75	a	60.18	a
	LSD	1.881		2.053	
	SE	0.668		0.729	
Average	Top	56.33		57.41	
	Outside	57.03		57.89	
	Inside	59.47		60.23	
Source:	df				
Treatment	11	0.0001		0.0002	
North vs South	1	0.0003		0.3239	
West vs East	1	0.0002		0.9839	
Outside vs Inside	1	0.0001		0.0001	
Top vs Bottom[y]	1	0.0001		0.0004	

[z]Means with the same letter are not significantly different at the 5% level (LSD)
[y]Inside and outside sub-sectors combined

Table 5b. TSS, TA levels and the TSS:TA ratio of 'Fairchild' fruit borne in different positions in the canopy.

POSITION WITHIN TREE		TSS		ACID		RATIO[x]	
North	Top	13.50	a[z]	1.29	cde	10.69	a
	Outside	13.24	a	1.29	cde	10.32	a
	Inside	11.64	d	1.30	cde	8.98	bc
West	Top	12.71	bc	1.42	ab	8.95	bc
	Outside	12.71	bc	1.49	a	8.65	bc
	Inside	10.86	e	1.30	cde	8.44	c
South	Top	12.31	c	1.33	cd	9.34	b
	Outside	11.73	d	1.34	bc	8.79	bc
	Inside	10.69	e	1.24	de	8.70	bc
East	Top	13.13	ab	1.24	de	10.64	a
	Outside	12.73	bc	1.22	e	10.48	a
	Inside	11.36	d	1.22	e	9.35	b
	LSD	0.418		0.0975		0.767	
	SE	0.148		0.0346		0.272	
Average	Top	12.91		1.32		9.91	
	Outside	12.60		1.34		9.56	
	Inside	11.14		1.27		8.87	

Source:	df	TSS	ACID	RATIO
Treatment	11	0.0001	0.0001	0.0001
North vs South	1	0.0001	0.7914	0.0001
West vs East	1	0.0129	0.0001	0.0001
Outside vs Inside	1	0.0001	0.0057	0.0006
Top vs Bottom[y]	1	0.0001	0.3752	0.0001

[z]Means with the same letter are not significantly different at the 5% level (LSD)
[y]Inside and outside sub-sectors combined
[x]Rounding off causes TSS/acid values to differ from actual ratio values

PAPER 3: THE EFFECT OF RIDGING ON THE INTERNAL FRUIT QUALITY OF 'BAHIANINHA' NAVELS

Abstract

Ridging is a practice used to improve surface and internal drainage of soils. The root zone in the ridged part dries out quickly and conditions similar to deficit irrigation develop. The effect of ridging on the internal fruit quality of fruit from 'Bahianinha' Navel trees on rough lemon rootstock in the Robertson area (34°S 20°E), was evaluated in two consecutive years, 1998 and 1999. Ridging increased the total soluble solids (TSS) of fruit markedly in both years. Fruit from ridged trees had a slightly higher titratable acid (TA) level in 1998 but similar acid levels in 1999. Therefore, fruit from ridged trees had a higher TSS:TA ratio in both years. According to these results, ridging can be used as a cultural practice in citrus to promote internal fruit quality, especially where cultivars of inherently low internal quality is produced.

Introduction

Ridging is a process where suitable topsoil is heaped up above the unsuitable soil layers to form a continuous bench in which the trees can be planted. Ridging soils is a rediscovery of a practice used by the ancient Romans to utilise soils that became useless because of waterlogging (Coetzee, 1995), and was generally used in Europe and England with vegetable cultivation. With the introduction of internal drainage the industry moved away from ridging soils (Du Preez, 1985).

Ridging improves internal drainage of soils (Du Preez, 1985; Snyman, 1991; Coetzee, 1995) and increases soil temperature (Du Preez, 1985). Ridging also improves the surface drainage of soils with a low infiltration rate (Du Preez, 1985). Soil of the ridges dry out more quickly and rainfall will be less effectively used because the roots in the ridges are limited to the ridged parts of the soils (Abercrombie, 1996). The root zone dries out quickly, especially in summer, and conditions similar to deficit irrigation develop. When there is no rainfall one can regulate the exact amount of water each tree receives through irrigation. These drier soils (especially during the maturation phase) mimics deficit irrigation, and should increase the TSS in Satsumas (Peng & Rabe, 1998). Moist soils during the maturation period would result in a lower TSS in the fruit (Koch, 1988; Dasberg, 1992) due to a dilution effect (Koch, 1988; Davies & Albrigo, 1994).

There is no published data available that confirms that ridging has a positive effect on internal fruit quality (TSS) of citrus. Ridging, however, removes excess water quickly and efficiently from the root zone. This decreases the chance for dilution of the soluble solids in the fruit. This study investigates the effect that ridges have on the internal quality (TSS) of citrus compared to non-ridged soils. The possibility of ridging as a cultural practice to increase the internal quality (TSS) of citrus fruit will also be investigated.

Materials and Methods

Plant material and treatments

'Bahianinha' Navel trees on rough lemon rootstock, planted in 1993 in a sandy soil in the Robertson area, South Africa (34°S 20°E), were used in two consecutive years for this study. Trees in the same irrigation block were used for the trial. Tree spacing was 5 m between rows and 3 m in row. The row-direction of the orchard is almost north-south (slightly east of north). Only healthy trees with a uniform canopy size were used. Treatments consisted of an unridged control (normal, flat soil) and trees planted on ridges.

Trial layout

Ten replicates with six trees per replicate were used. The control trees were adjacent to the trees planted on ridges to try and minimise soil differences between the ridged and non-ridged trees (Fig. 1).

[Figure 1]

According to the soil texture analysis there were no major differences in texture between the flat soil and the ridged soil (Table 1). Samples were taken in the ridged and the non-ridged part of the block (Fig. 1).

[Table 1]

Fruit quality measurements

At harvest (21 May 1998 and 12 May 1999), fruit samples were picked from the outside of the canopy, at shoulder height. The samples consisted of twelve fruit of average diameter from each group of six trees (one fruit on both sides of each tree). Fruit were picked from the same trees in both years.

Fruit diameter of each fruit was measured (by electronic calliper), and juice was then extracted using a citrus juicer. The juice was filtered through a layer of cheesecloth in the first year and in the second year, through two layers of muslin cloth. Juice content (%) was determined by subtracting the weight of reamed peel from the original fruit weight and dividing by the original fruit weight. The juice was then used for the determination of the TSS by using a hand-held refractometer (Atago N1). Titratable acidity (TA), expressed as citric acid content, was determined by titration against 0.1 N sodium hydroxide, using phenolphthalein as an indicator. The TSS:TA ratio was calculated by dividing the TSS values by the TA values.

Statistical analysis

Analyses of variance were performed using the GLM (General Linear Models) procedure in the SAS (Statistical Analysis System) computer program (SAS Inc., 1990).

Results

Ridged trees had fruit with a higher TSS content than fruit from control trees in both years (P=0.0029 in 1998 and P=0.0038 in 1999) (Table 2). Fruit from ridged trees also had a slightly lower TA content, compared to the control in the first year (P=0.0576), but similar TA levels in the second year (P=0.9767). This increase in TSS in both years and the slight decrease in acid in 1998 and similar acid levels in 1999 led to an increase in the TSS:TA ratio in both years (P=0.004 in 1998 and P=0.0049 in 1999). The juice content (%) of fruit from ridged trees was also higher than of fruit from non-ridged trees in 1999 (P=0.0344) (Table 2).

[Table 2]

Discussion

The results of two consecutive years show that ridging increased the internal fruit quality of 'Bahianinha' Navels. The planting of trees on ridges did not only increase the TSS and the TSS:TA ratio, but it also decreased or had no effect on the acid content of the fruit. According to these results, ridging can also be used as a cultural practice in citrus to promote internal fruit quality, especially in selections with inherently low internal quality, and in wet soils or soils where internal drainage is a problem. Soil differences may however contribute to the differences in internal quality between fruit from ridged and non-ridged trees found in this study, but this is unlikely, since we attempted to minimise soil differences (as shown by the analyses) by the way of grouping of the trees from which the fruit samples were taken.

References

ABERCROMBIE, R.A., 1996. Rifverbouing by sitrus. *Subtropica* **17**, 12-16.

COETZEE, J.G.K., 1995. Ridging soils for new citrus plantings. *Citrus J.* **5**, 22-24.

DASBERG, S., 1992. Irrigation management and citrus production. *Proc. Int. Soc. Citric.* **3**, 1307-1310.

DAVIES, F.S. & ALBRIGO, L.G., 1994. Plant husbandry. Chapter 3, 79-82. Chapter 7, 202-224. In: F.S. DAVIES & L.G. ALBRIGO (eds.), Citrus, Crop Production Science in Horticulture 2. CAB International, Wallingford, Oxon, UK.

DU PREEZ, M., 1985. Ridging of orchard soil. *Decid. Fruit Grow.* **35**, 22-31.

KOCH, K.E., 1988. Production and environmental factors affecting the Brix/acid ratio, 78-81. In: J.J. FERGUSON & W.F. WARDOWSKI (eds.), Factors Affecting Fruit Quality. Proceedings, Citrus Short Course. Citrus Research and Education Center, Lake Alfred, Florida.

PENG, Y.H. & RABE, E., 1998. Effect of differing irrigation regimes on fruit quality, yield, fruit size and net CO_2 assimilation of 'Mihowase' Satsuma. *J. Hortic. Sci. Biotechnol.* **73**, 229-234.

SAS INSTITUTE INC., 1990. SAS/STAT User's Guide, Version 6. 4th ed. Vol. 1 and 2, Cary, NC, USA.

SNYMAN, N., 1991. Ridge for top soybean yields. *Farmer's Weekly.* March 22, 16-17.

Table 1. Soil texture analysis of flat and ridged soils.

	Depth (cm)	% Coarse sand	% Medium sand	% Fine sand	% Very fine sand	% Silt*	% Clay*
Non-ridged	0-30	7.48[z]	42.42	30.78	5.95	6.49	5.19
SE		2.477	5.405	3.360	0.543	3.037	2.991
Non-ridged	30-60	8.06	53.18	30.55	4.79	3.17	3.30
SE		1.316	2.102	1.518	1.080	1.022	1.455
Ridged	0-30	7.40	48.44	30.68	5.07	4.68	3.38
SE		0.502	0.248	1.068	0.104	0.196	1.144
Ridged	30-60	6.64	44.06	32.66	5.65	5.83	4.15
SE		0.624	0.901	1.853	0.456	1.143	0.745

*Sand->0.05 mm, Silt-0.05-0.002 mm, Clay-<0.002 mm particle size

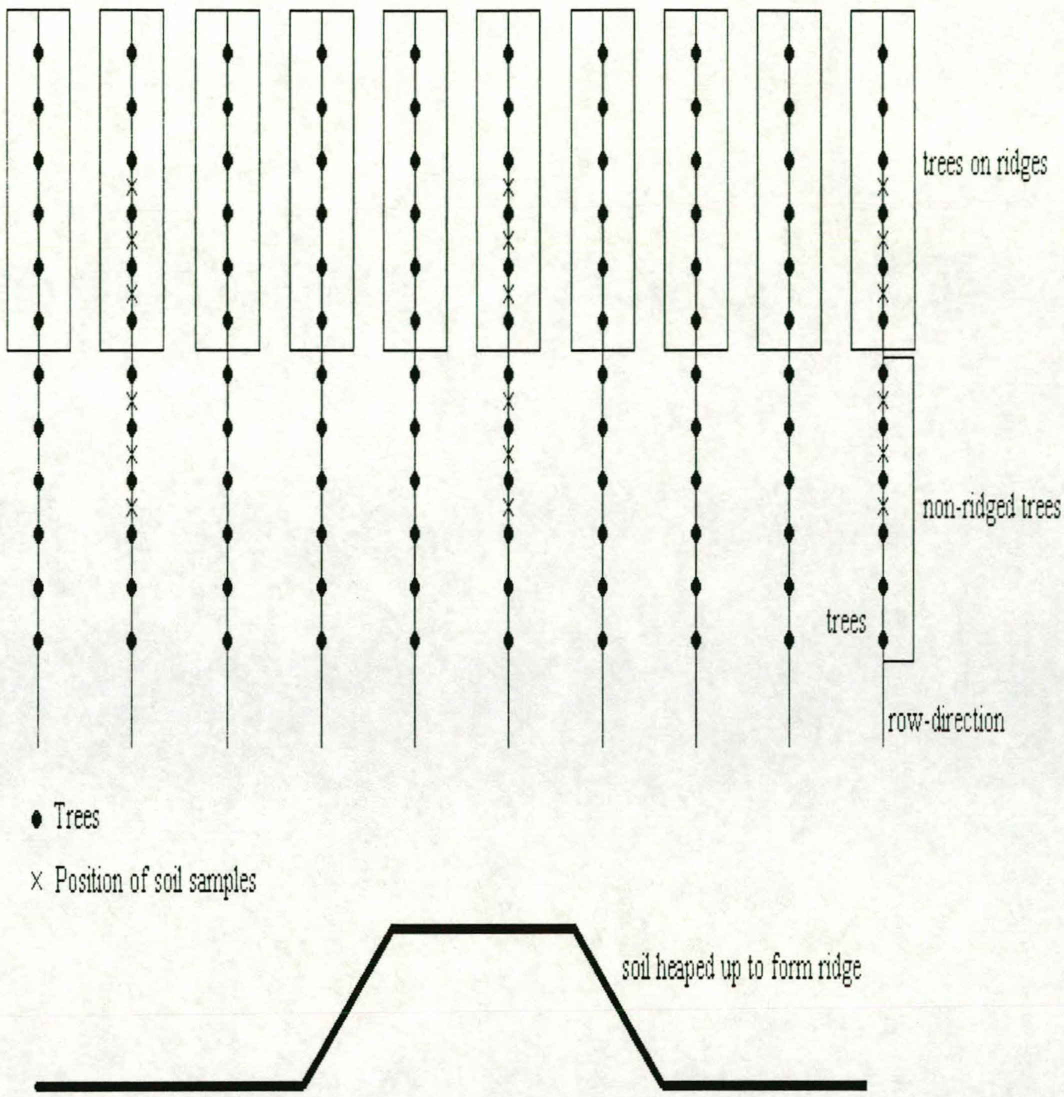
[z]Average of three samples (each sample consist of three subsamples)

Table 2. The effect of ridging on the internal fruit quality of 'Bahianinha' Navels on rough lemon rootstock in the Robertson area in 1998 and 1999.

		JUICE %	TSS		ACID		RATIO[y]	
		1999	1998	1999	1998	1999	1998	1999
Treatment:								
Control (no ridges)		48.32	9.62	8.85	1.04	1.08	9.28	8.22
Trees on ridges		50.64	10.05	9.61	1.00	1.08	10.10	8.91
	SE	0.661	0.0753	0.139	0.0137	0.0236	0.104	0.132
Source:	df							
Treatment	1	0.0344	0.0029	0.0038	0.0576	0.9767	0.0004	0.0049

[y]Rounding off causes TSS/acid values to differ from actual ratio values

Figure 1. Trial layout of ridged and non-ridged 'Bahianinha' Navel trees on rough lemon rootstock.


trees on ridges
non-ridged trees
trees
row-direction
Trees
Position of soil samples
soil heaped up to form ridge

PAPER 4: ACCUMULATION OF SUGAR DURING FRUIT GROWTH IN CITRUS: 'NULES' CLEMENTINES AND 'MIHOWASE' SATSUMAS

Abstract

The non-reducing sugar, sucrose, is the major sugar in citrus fruit followed by the reducing sugars, glucose and fructose. Total sugars in the juice increase during the ripening phase, mainly due to the accumulation of sucrose in the juice. The accumulation of reducing and non-reducing sugars (expressed as mg·g^{-1} and mg·fruit^{-1} dry mass) into fruit from physiological fruit drop to maturation were quantified. The trial was carried out on fruit from 'Mihowase' Satsuma and 'Nules' Clementine trees on Troyer citrange rootstock in Stellenbosch, South Africa (34°S 19°E). Fruit samples were picked every two weeks, starting on 15 December 1998 for Satsumas and on 11 January 1999 for Clementines, until harvest (19 March 1999 for Satsumas and 17 May 1999 for Clementines). Expressing reducing and non-reducing sugars on a whole fruit (mg·fruit^{-1} dry mass) or concentration (mg·g^{-1} dry mass) basis resulted in similar curves. In Satsumas, reducing and non-reducing sugars (mg·g^{-1} dry mass) increased linearly over time, but plateaued out towards the last sampling date (harvest). In Clementines, reducing sugars (mg·g^{-1} and mg·fruit^{-1} dry mass) increased cubically over time with a slower accumulation towards maturity. Non-reducing sugars increased quadratically (mg·g^{-1} dry mass) or linearly (mg·fruit^{-1} dry mass) over time until maturity. If manipulations to enhance sugar levels (e.g. summer girdling and/or water stress treatments) need to be done, the most effective timing would probably coincide with the period of rapid increase in sugars for Satsumas and Clementines.

Introduction

Citrus fruit are deemed to be marketable when a certain minimum total soluble solids (TSS):acid ratio is attained (Beever, 1990; Davies & Albrigo, 1994). This will only be attained by a decrease in the concentration of acid and an increase in total sugars during maturation (Cancalon, 1994). Bartholomew & Sinclair (1943), Sinclair (1961) and Davies & Albrigo (1994) reported that 75-85 % of the TSS of orange juice is sugars (carbohydrates). The transport of photo-assimilates from source leaves to developing citrus fruit involves the movement of sucrose as the major translocate (Kriedemann, 1969). Sucrose (non-reducing) is also the major sugar constituent in citrus fruit (McCready *et al.*, 1950; Davies & Albrigo, 1994; Yamanishi, 1995), followed by the reducing sugars, glucose and fructose, in an approximate ratio of 2:1:1 (Ting & Attaway, 1971; Garcia-Luis *et al.*, 1991; Tzur *et al.*, 1992).

Fruit sugar content depends on continued import of photosynthetic products (leaf-produced sugars) while attached to the plant (Tzur *et al.*, 1992), fruit photosynthesis and respiration (Huang *et al.*, 1992). Respiration reduces the amount of carbon available for accumulation of dry matter and sugars (Koch, 1988b). Most of the solids accumulate in the fruit after the fruit has attained 60-75 % of its ultimate size (Reuther, 1988). Closer to maturity the level of reducing sugars decreases in relation to total sugars, but the level of sucrose increases rapidly (Tzur *et al.*, 1992). Echeverria & Valich (1989) found that *de novo* synthesis of sugars from organic acids inside the fruit can explain the continuous increase in sugars during the late stages on the tree.

According to Koch (1988a), sucrose is apparently broken down and resynthesised as it moves into the fruit to maintain a 'down-hill' concentration gradient from the leaves to the fruit. Sucrose breakdown to glucose and fructose is usually caused by acid and neutral invertases (Tzur *et al.*, 1992). Echeverria & Valich (1988) and Tzur *et al.* (1992) found that juice sacs can synthesise and degrade sucrose, and that the presence of sucrose in the juice sacs is derived not only from sucrose import. Most of the sugars of the citrus fruit occur in the juice vesicles (Ting & Attaway, 1971). Echeverria & Valich (1988) found that in Valencia oranges the vacuole of the juice sac cells contains 75 % of the fructose and glucose and 100 % of the sucrose. The balance occurs in the cytosol (Echeverria & Valich, 1988).

Cancalon (1994) found that glucose and fructose concentrations increased exponentially in Valencia oranges from April to September (northern hemisphere), decreased slightly during the next three months (October to December) and then plateaued out in the winter. In May, the sugar concentration in these fruit, especially sucrose, increased significantly, apparently due to the formation of sucrose from the pre-existing glucose and fructose (Cancalon, 1994).

The objective of this trial was to quantify the accumulation of reducing and non-reducing sugars ($mg \cdot g^{-1}$ dry mass and $mg \cdot fruit^{-1}$ dry mass) in the fruit throughout the season in 'Mihowase' Satsumas and 'Nules' Clementines. These results should provide information that will enable horticulturists to best time manipulations of internal fruit quality by means of orchard practices.

Materials and Methods

Plant Materials

Healthy, uniform 'Mihowase' Satsuma and 'Nules' Clementine trees on Troyer citrange rootstock were used for this study. The orchard was planted in 1991 and is situated in the Stellenbosch area, South Africa (34°S 19°E). The soil in the orchard is a clay-loam. Tree spacing is 4.5 m between rows and 2.0 m in row (Satsumas) and 4.5 x 1.5 m (Clementines). The row direction of the orchard is north-south.

Trial layout

Fifteen trees per cultivar were used in the study. Twelve fruit per tree were tagged at the onset of the trial. Only fruit borne on the outside of the canopy on the western side of the tree with the same diameter and at the same height aboveground were tagged.

Sampling and preparation

Five samples of three fruit each (one fruit per tree) were picked for each cultivar every two weeks, starting after the physiological fruit drop period (15 December 1998 for Satsumas and 11 January 1999 for Clementines), until harvest (19 March 1999 for Satsumas and 17 May 1999 for Clementines). The fruit were peeled and the pulp blended with a Waring blender. The samples were then frozen at -20°C until lyophilising. The dry mass of each sample was determined, before milling.

Sugar extraction and analyses

A subsample of 500 mg per sample was dissolved in 50 ml 1% acetic acid, shaken overnight, an additional 50 ml of 1% acetic acid added, filtered through Whatman no. 2 filter paper and stored in airtight containers at -20°C until further analysis. Reducing and non-reducing sugars were then analysed on a Skalar Sanplus Segmented Flow Analyser. Reducing sugars were determined according to the 551-605 issue 012998/MH/97203 Skalar (1998) method. The non-reducing sugars were hydrolysed according to the 551-965w/r issue 070798/MH Skalar (1998) method, with the increase in reducing sugars representing the non-reducing fraction (sucrose) in the sample.

Statistical analysis

Analyses of variance were performed using the GLM (General Linear Models) procedure in the SAS (Statistical Analysis System) computer program (SAS Inc., 1990).

Results and Discussion

The end of the physiological fruit drop period for Satsumas was around the middle of December, and about three weeks later for Clementines. Reducing and non-reducing sugars ($mg \cdot g^{-1}$ dry mass) in Satsuma fruit increased linearly (P=0.0001) from the first sampling date to maturity (Fig. 1a). Both reducing and non-reducing sugars plateaus out towards the last sampling date. Reducing and non-reducing sugar accumulation ($mg \cdot fruit^{-1}$ dry mass) present almost the same curves (Fig. 1a), but with a quadratic increase over time (P=0.0170 for reducing and P=0.0094 for non-reducing sugars) (Fig. 1b), because the sugars increased rapidly, and plateaued towards maturity.

[Figures 1a and 1b]

In Clementines, reducing sugars ($mg \cdot g^{-1}$ and $mg \cdot fruit^{-1}$ dry mass) increased very slowly, rapidly thereafter, before a marked decrease towards maturity (Figs. 2a and

2b). Non-reducing sugars (mg·g^{-1} dry mass) increased rapidly, and then at a slower rate. Non-reducing sugars (mg·fruit^{-1} dry mass) increased linearly (P=0.0001) over time until harvest.

[Figures 2a and 2b]

The percentage contribution of reducing (±25%) and non-reducing (±75%) sugars to total sugars was similar for Satsumas and Clementines and the general trend of sugar accumulation (reducing and non-reducing) was also similar for the cultivars.

The rapid accumulation of sugars was earlier for the early-maturing Satsumas compared to the later-maturing Clementines. Tzur *et al.* (1992) found that closer to maturity the level of reducing sugars decreased and sucrose (main non-reducing sugar) increased. In Satsumas, both reducing and non-reducing sugars increased only slightly towards maturity, but in Clementines reducing sugars decreased and non-reducing sugars (sucrose) increased towards maturity. Although the increase in non-reducing sugars towards maturity in Clementines coincides with the decrease in reducing sugars, the decrease in reducing sugars may not solely be due to the formation of non-reducing sugars.

Cultural practices in the orchard, to improve internal fruit quality (summer trunk girdling, deficit irrigation, pruning etc.), are normally timed to coincide with the end of the physiological fruit drop period, but according to the sugar accumulation curves for Satsumas and Clementines, there is a rapid accumulation of sugars just after this fruit drop period. Therefore, if these manipulations to enhance sugar levels need to be done, the most effective timing would probably coincide with the period of rapid increase in sugars for both cultivars.

References

BARTHOLOMEW, E.T. & SINCLAIR, W.B., 1943. Soluble constituents and buffer properties of orange juice. *Plant Physiol.* **18**, 185-206.

BEEVER, D.J., 1990. Export quality satsumas need careful handling. *Orchard. N. Z.* March, 24-25.

CANCALON, P.F., 1994. Changes in the saccharide composition of citrus juice and anatomical fractions during fruit maturation. *Proc. Fla. State Hortic. Soc.* **107**, 253-256.

DAVIES, F.S. & ALBRIGO, L.G., 1994. Plant husbandry. Chapter 3, 79-82. Chapter 7, 202-224. In: F.S. DAVIES & L.G. ALBRIGO (eds.), Citrus, Crop Production Science in Horticulture 2. CAB International, Wallingford, Oxon, UK.

ECHEVERRIA, E. & VALICH, J., 1988. Carbohydrate and enzyme distribution in protoplasts from Valencia orange juice sacs. *Phytochemistry.* **27**, 73-76.

ECHEVERRIA, E. & VALICH, J., 1989. Enzymes of sugar and acid metabolism in stored 'Valencia' oranges. *J. Am. Soc. Hortic. Sci.* **114**, 445-449.

GARCIA-LUIS, A., DIDEHVAR, F., GUARDIOLA, J.L. & BAKER, D.A., 1991. The transport of sugars in developing fruits of satsuma mandarin. *Ann. Bot.* **68**, 349-357.

HUANG, T-B., DARNELL, R.L. & KOCH, K.E., 1992. Water and carbon budgets of developing citrus fruit. *J. Am. Soc. Hortic. Sci.* **117**, 287-293.

KOCH, K.E., 1988a. Production and environmental factors affecting the Brix/acid ratio, 78-81. In: J.J. FERGUSON & W.F. WARDOWSKI (eds.), Factors Affecting Fruit Quality. Proceedings, Citrus Short Course. Citrus Research and Education Center, Lake Alfred, Florida.

KOCH, K.E., 1988b. Sugar and acid metabolism in citrus fruit, 59-66. In: J.J. FERGUSON & W.F. WARDOWSKI (eds.), Factors Affecting Fruit Quality. Proceedings, Citrus Short Course. Citrus Research and Education Center, Lake Alfred, Florida.

KRIEDEMANN, P.E., 1969. ^{14}C Translocation in orange plants. *Aust. J. Agric. Res.* **20**, 291-300.

McCREADY, R.M., WALTER, E.D. & MACLAY, W.D., 1950. Sugars of citrus juices. *Food Technol.* Jan., 19-20.

REUTHER, W., 1988. Climate and fruit quality, 9-23. In: J.J. FERGUSON & W.F. WARDOWSKI (eds.), Factors Affecting Fruit Quality. Proceedings, Citrus Short Course. Citrus Research and Education Center, Lake Alfred, Florida.

SAS INSTITUTE INC., 1990. SAS/STAT User's Guide, Version 6. 4th ed. Vol. 1 and 2, Cary, NC, USA.

SINCLAIR, W.B., 1961. Principal juice constituents. Chapter 5, 131-160. In: W.B. SINCLAIR (ed.), The Orange: Its Biochemistry and Physiology. University of California, Division of Agricultural Sciences, Berkeley, USA.

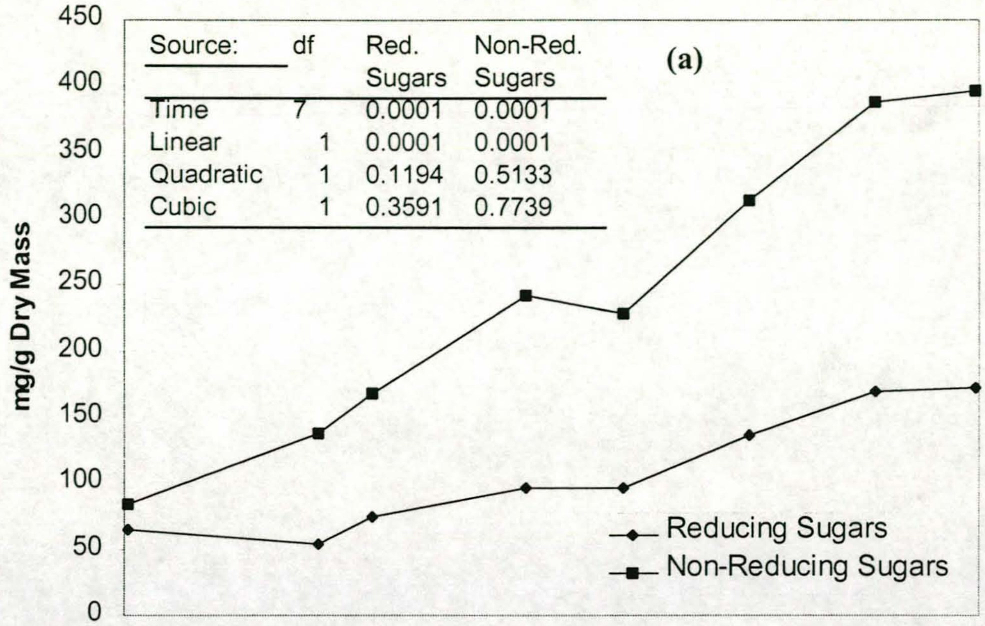
SKALAR, 1998. 12 Tin Street, 4823 AA, Breda, The Netherlands.

TING, S.V. & ATTAWAY, J.A., 1971. Citrus fruits. Chapter 3, 107-159. In: A.C. HULME (ed.), The Biochemistry of Fruits and Their Products, Vol. I, Academic Press, New York.

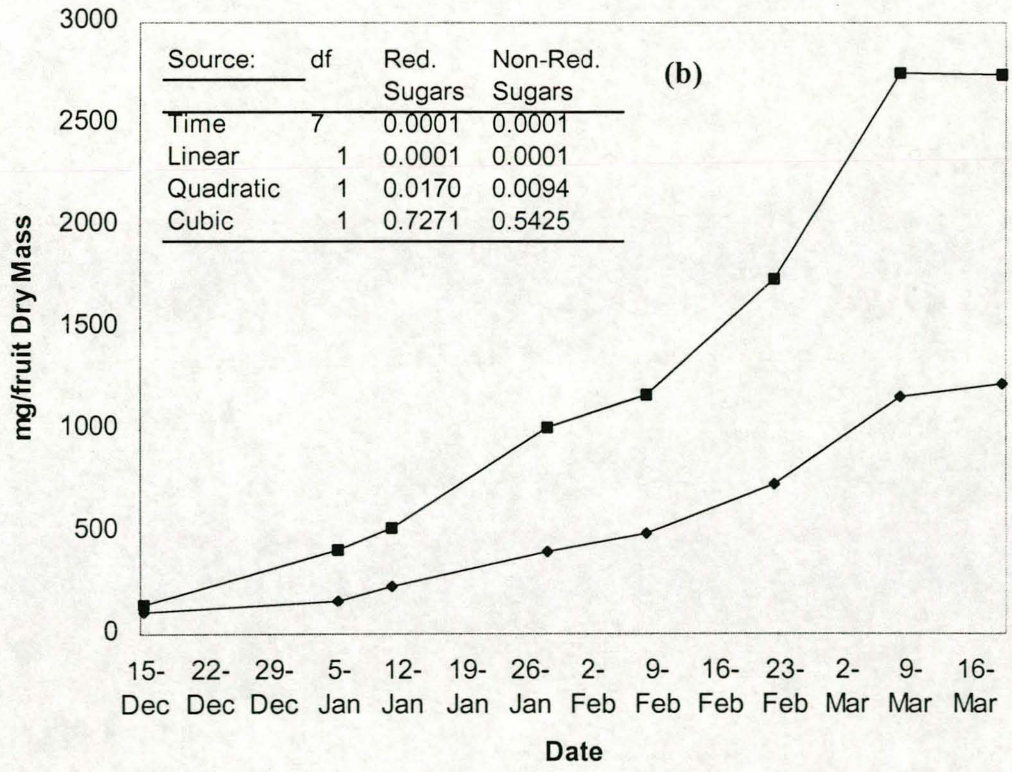
TZUR, A., GOREN, R. & ZEHAVI, U., 1992. Carbohydrate metabolism in developing citrus fruits. *Proc. Int. Soc. Citric.* **1**, 405-411.

YAMANISHI, O.K., 1995. Trunk strangulation and winter heating effects on fruit size, internal quality and maturation of 'Tosa Buntan' pummelo grown in a plastic house. *J. Hortic. Sci.* **70**, 65-74.

Figure 1. The accumulation of reducing and non-reducing sugars in 'Mihowase' Satsuma fruit from the physiological fruit drop period until maturity expressed as mg·g^{-1} dry mass (a) and mg·fruit^{-1} dry mass (b).

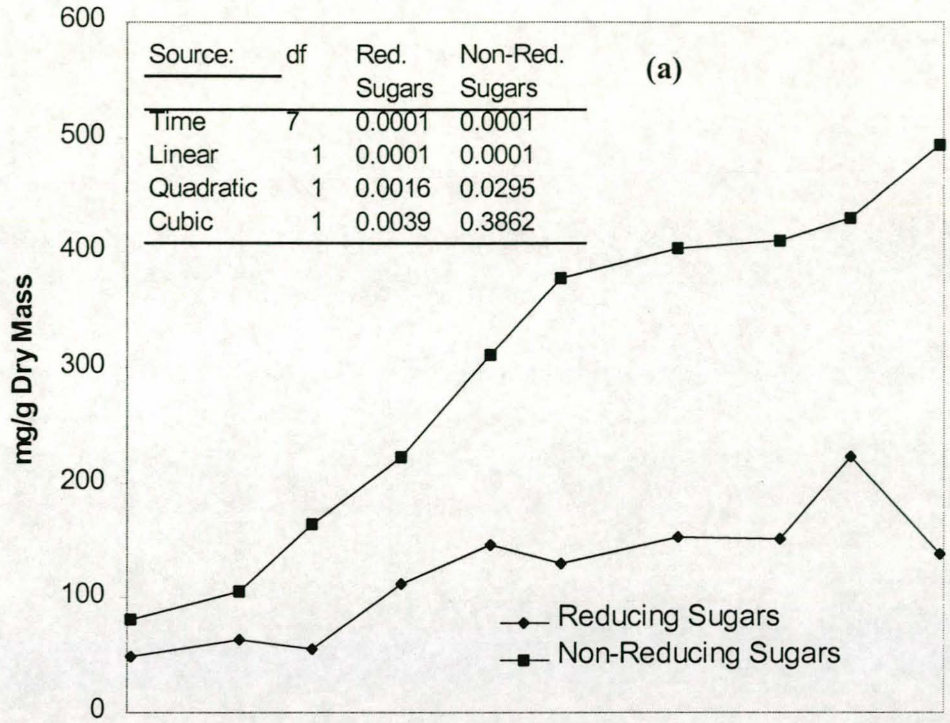


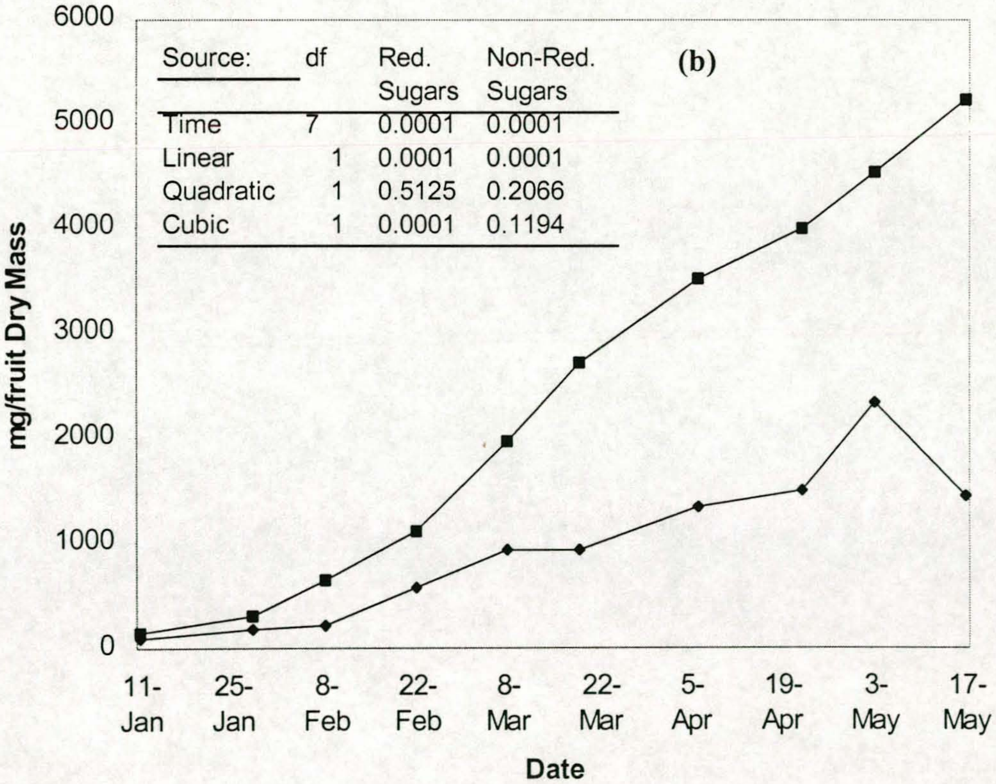
(a)
Source: df Red. Sugars Non-Red. Sugars
Time 7 0.0001 0.0001
Linear 1 0.0001 0.0001
Quadratic 1 0.1194 0.5133
Cubic 1 0.3591 0.7739
mg/g Dry Mass
0 50 100 150 200 250 300 350 400 450
Reducing Sugars
Non-Reducing Sugars



(b)
Source: df Red. Sugars Non-Red. Sugars
Time 7 0.0001 0.0001
Linear 1 0.0001 0.0001
Quadratic 1 0.0170 0.0094
Cubic 1 0.7271 0.5425
mg/fruit Dry Mass
0 500 1000 1500 2000 2500 3000
15-Dec 22-Dec 29-Dec 5-Jan 12-Jan 19-Jan 26-Jan 2-Feb 9-Feb 16-Feb 23-Feb 2-Mar 9-Mar 16-Mar
Date

Figure 2. The accumulation of reducing and non-reducing sugars in 'Nules' Clementine fruit from the physiological fruit drop period until maturity expressed as $mg \cdot g^{-1}$ dry mass (a) and $mg \cdot fruit^{-1}$ dry mass (b).


600
500
400
300
200
100
0
mg/g Dry Mass
Source: df Red. Sugars Non-Red. Sugars
Time 7 0.0001 0.0001
Linear 1 0.0001 0.0001
Quadratic 1 0.0016 0.0295
Cubic 1 0.0039 0.3862
(a)
Reducing Sugars
Non-Reducing Sugars


6000
5000
4000
3000
2000
1000
0
mg/fruit Dry Mass
Source: df Red. Sugars Non-Red. Sugars
Time 7 0.0001 0.0001
Linear 1 0.0001 0.0001
Quadratic 1 0.5125 0.2066
Cubic 1 0.0001 0.1194
(b)
11-Jan
25-Jan
8-Feb
22-Feb
8-Mar
22-Mar
5-Apr
19-Apr
3-May
17-May
Date

PAPER 5: TIMING AND TYPE OF GIRDLING ON THE HEALING ABILITY

Abstract

Tree response to girdling depends on the girdling date, and the girdling procedures or techniques, resulting in differential girdle widths. Girdling effects last only as long as the wound is unhealed. The time of girdling during the growing season also affects the healing ability. The effect of timing of girdling and type of girdling tool on the healing ability of the girdle was investigated in two trials: A) girdling with a Stanley carpet knife, monthly, for six consecutive months, starting on 21 September 1998, and B) girdling on 14 December 1998, with either the Stanley carpet knife or the Outspan girdling tool. The trials were carried out on 'Nules' Clementine trees on Troyer citrange rootstock in Stellenbosch, South Africa (34°S 19°E). In trial A the number of days until any healing occurred (lag-phase) decreased with the later girdling treatments (warmer summer period), but increased again with the last girdling treatment (8 February 1999). Highest and lowest gradients of healing were obtained with the first (21 September 1998) and last (8 February 1999) girdling treatments, respectively, while the other girdling times had intermediate gradients. The number of days from girdling to complete healing also decreased with the later treatments, except for the last treatment (8 February 1999). Therefore, slow healing and essentially at the same rate, took place when trees were girdled in September, October and November, and faster healing resulted when trees were girdled in December and January (the hottest period), followed by slower healing when girdled in February. In trial B the Outspan girdling tool resulted in girdles which took more time to heal than the Stanley carpet knife, since the Outspan tool causes more damage to the trunk. These results indicate that healing ability of a girdle is influenced by the time of girdling during a season and by the girdling tool or method used.

Introduction

Girdling is a very old horticultural practice, albeit with a history of erratic results, aimed at increasing fruit set and fruit size, better juice quality and the alleviation of alternate bearing, depending on the time of year it is done (Krezdorn, 1960). A girdled tree is one in which the phloem is completely severed either by a narrow incision (Cohen, 1981) or by the removal of a cylinder of bark (usually 2-3 mm wide) around the trunk (Noel, 1970; Monselise *et al.*, 1972; Cohen, 1981). Citrus tree response to girdling depends on girdling date, girdling procedures and techniques, i.e. the girdle width and the position, i.e. whether done on the trunk or branches (Peng & Rabe, 1996). Noel (1970) and Cohen (1984b) stated that the season of girdling will also affect the healing ability. Thus, trees girdled in the summer or spring heal faster, but trees girdled during the dormant phase will heal very slowly or not at all. This may be due to climatic differences during the season (Cohen, 1984b). Cohen (1977) stated that the girdles have to be rather wide to have the desired effects, but that wide girdles may cause long-term damage to the girdled branches or trees. The girdle must be around the whole circumference of the trunk or branch to be effective (Cohen, 1981). Hochberg *et al.* (1977) suggested that the effect of girdling can be enhanced by re-opening the scar a month later, because the effects of girdling last as long as the girdle remain open, i.e. as long as the callus has not bridged over the girdling wound (Cohen, 1981; 1984a, 1984b). Cohen (1984a, 1984b) also found that double girdling (repetition of narrow girdles at the same site three weeks later), had a greater effect than a single girdle, even if it is a wide one.

When a tree is girdled, the cut edge of the bark dries out and the most superficial cells die (Noel, 1970). The sieve tubes above the girdle degenerate (older sieve tubes first and younger ones later) and cease to transport materials (Schneider, 1954). Girdling also disrupts cambial continuity (Mosse & Labern, 1960; Noel, 1970). After girdling there is a formation of undifferentiated wound callus which increases the trunk diameter and the differentiation of vascular tissue from a new vascular cambium formed within the wound callus (Mosse & Labern, 1960; Noel, 1968a; 1970). Callus formation may be due to proliferation from the original phloem, xylem, or the vascular cambium depending on the type of plant and the species (Mosse & Labern, 1960; Noel, 1968b; 1970). In juvenile citrus trees callus proliferates from the xylem (Cohen, 1981). Callus formation at the girdling wound leads to discontinuity of the xylem vessels, because the callus does not differentiate into normal xylem vessels (Cohen, 1977; 1981). Excessive callus formation delays both bark and xylem healing (Cohen, 1977; 1981). In summary, regeneration, leading to girdle healing, occurs from secondary vascular cambia and phellogens, differentiating from callus tissue (Noel, 1968a).

The objectives of this trial were to determine how the timing of girdling will affect the healing ability, and how fast the tree will heal after girdling with different girdling tools.

Materials and Methods

Plant Material

Healthy, uniform 'Nules' Clementine trees on Troyer citrange rootstock in the same irrigation block were used for two separate trials (A and B). The orchard was planted in 1991 and is situated in the Stellenbosch area, South Africa (34°S 19°E). The soil in the orchard is a clay loam. Tree spacing is 4.5 m between rows and 1.0 m in row. The row-direction of the orchard is north-south.

Girdling procedures

Girdling was carried out in trial A by using a Stanley carpet knife. In trial B, an Outspan girdling tool was compared with the Stanley carpet knife. A single cut was made through the bark of the main trunk about 10 cm above the bud union in both trials. No strip of bark was removed.

Treatments

Girdling for trial A was carried out at six different times throughout the spring and summer period. Girdling was carried out monthly, starting on 21 September 1998 and ending on 8 February 1999. Trial B consisted of two treatments, i.e. comparing a Stanley carpet knife and an Outspan girdling tool. Both treatments were girdled on 14 December 1998.

Trial layout

Trial A consisted of a randomised complete block design with six treatments and ten single-tree replicates per treatment. Trial B consisted of a randomised complete block design with two treatments and ten single-tree replicates per treatment.

Measurements

In both trials each girdled tree was evaluated weekly after girdling until the girdle was completely healed. A piece of bark was removed at right angles to the girdle (different positions around the trunk at each time of evaluation) to determine if the two pieces of bark can still be separated. The healing stage was scored on a scale of 1 to 5, i.e. 1=two pieces of bark still falls apart when cut, 2=two pieces loosely bound (breaks when cut), 3=two pieces loosely bound, 4=two pieces bound, but breaks when pressure exerted on both ends, 5=two pieces completely bound and cannot be pulled apart.

The pieces of removed bark were put back on the wound with a pin and sealed with tree-seal.

Statistical analysis

Analyses of variance were performed using the GLM (General Linear Models) procedure in the SAS (Statistical Analysis System) computer program (SAS Inc., 1990). Three parameters were determined in the statistical analysis of both trials: (i) the 'lag phase', i.e. the number of days from girdling until any healing starts; (ii) the 'gradient', i.e. the gradient of healing from the onset of healing until the girdle is completely healed and (iii) the number of days from the girdling date until the girdle is completely healed.

Results

Trial A. There is a trend towards a decreasing lag-phase as the girdling dates were delayed, but the last girdling date (8 February 1999) had a longer lag-phase than the second last girdling date (11 January 1999) (Fig. 1 and Table 1). There was also a trend towards a decreasing gradient, i.e. slower healing, as the girdling dates were delayed. The number of days from girdling until complete healing decreased as the girdling dates were delayed, but increased towards the last girdling treatment. Therefore, slow healing takes place when girdled in September, October and November (approximately 48 days), faster healing when girdled in December and January (the hottest period), followed by slower healing when girdled in February.

[Figure 1 and Table 1]

Trial B. There were no significant differences in the lag-phase (P=0.2789) and in the gradients (P=0.5438) between girdling done with a Stanley or an Outspan girdling tool (Fig. 2 and Table 2). Visually, however, girdling with a Stanley carpet knife had a slightly shorter lag-phase and higher gradient (although not significant) than girdling with an Outspan girdling tool (Fig. 2). Therefore, the Outspan tool took significantly longer (number of days) to heal than the Stanley carpet knife (P=00012).

[Figure 2 and Table 2]

Discussion

Girdling at the start of the trial took long to heal, but the number of days to healing decreased with the later treatments (warmer summer period), but increased again with the last girdling treatment (cooler, late summer). One or two more girdling treatments carried out in March and April would have given a more complete trend for the healing. Judging from the trends it seems, however, that the number of days to healing would have increased with such later girdling treatments. According to Cohen (1984b) the girdle heals over much faster during the period of active growth. The results of this trial confirm these findings.

Girdling with a Stanley carpet knife healed much quicker than with the Outspan girdling tool. The Stanley knife also made a cleaner cut, with less damage to the trunk (pers. obs.). A possible reason for the delay in healing, when using an Outspan girdling tool, may be excessive callus formation, due to more damage caused by the girdle, which then prevents bark healing.

These results indicate that the time of the year when girdling is carried out will influence how fast the girdle heals. The speed of healing will in turn influence the method of girdling and/or width of the girdle to be used. In the spring and summer when citrus trees are growing actively, the girdle would heal over quite fast. To ensure the desired effect during this time of the year, it would thus be advised to increase the girdle-width or reopen the scar a few weeks after girdling. In this case the Outspan girdling tool or other methods resulting in a slight delay in healing would be preferred to the Stanley carpet knife.

References

COHEN, A., 1977. Girdling effects on tree performance. *Proc. Int. Soc. Citric.* **1**, 178-181.

COHEN, A., 1981. Recent developments in girdling of citrus trees. *Proc. Int. Soc. Citric.* **1**, 196-199.

COHEN, A., 1984a. Citrus fruit enlargement by means of summer girdling. *J. Hortic. Sci.* **59**, 119-125.

COHEN, A., 1984b. Effect of girdling date on fruit size of Marsh seedless grapefruit. *J. Hortic. Sci.* **59**, 567-573.

HOCHBERG, R., MONSELISE, S.P. & COSTO, J., 1977. Summer girdling and 2,4-D effects on grapefruit sizes. *HortScience* **12**, 228.

KREZDORN, A.H., 1960. The influence of girdling on the fruiting of Orlando tangelos and navel oranges. *Proc. Fla. State Hortic. Soc.* **73**, 49-52.

MONSELISE, S.P., GOREN, R. & WALLERSTEIN, I., 1972. Girdling effects on orange fruit set and young fruit abscission. *HortScience* **7**, 514-515.

MOSSE, B. & LABERN, M.V., 1960. The structure and development of vascular nodules in apple bud-unions. *Ann. Bot.* **24**, 500-507.

NOEL, A.R.A., 1968a. Callus formation and differentiation at an exposed cambial surface. *Ann. Bot.* **32**, 347-359.

NOEL, A.R.A., 1968b. The effects of girdling, with special reference to trees in South Central Africa. *Kirkia* **6**, 181-196.

NOEL, A.R.A., 1970. The girdled tree. *Bot. Rev.* **36**, 162-195.

PENG, Y.H. & RABE, E., 1996. Effect of summer trunk girdling on fruit quality, maturation, yield, fruit size and tree performance in 'Mihowase' satsumas. *J. Hortic. Sci.* **71**, 581-589.

SAS INSTITUTE INC., 1990. SAS/STAT User's Guide, Version 6. 4th ed. Vol.1 and 2, Cary, NC, USA.

SCHNEIDER, H., 1954. Effect of trunk girdling on phloem of trunk of sweet orange trees on sour orange rootstock. *Hilgardia* **22**, 593-601.

Table 1. The effect of the time of girdling on the healing ability of the girdle on 'Nules' Clementine.

		[w]LAG		[x]GRADIENT		[y]DAYS	
	Girdling date						
	21/09/98	29.4	a[z]	1.43	a	47.6	a
	19/10/98	20.3	bc	0.80	bc	49.0	a
	16/11/98	24.5	b	1.12	ab	47.6	a
	14/12/98	16.3	cd	1.06	b	41.0	b
	11/01/99	9.4	e	0.88	bc	35.0	c
	08/02/99	11.9	de	0.63	c	46.2	a
LSD		4.754		0.352		4.805	
SE		1.669		0.124		1.687	
Source:	df						
Treatment	5	0.0001		0.0007		0.0001	
Time linear	1	0.0001		0.0006		0.0003	
Time quadratic	1	0.3787		0.9168		0.0539	

[z]Means with the same letter are not significantly different at the 5% level (LSD)
[w]Lag phase (days) before the onset of any healing
[x]Gradient of healing (from onset of healing to completely healed)
[y]Days of healing from girdling date to completely healed

Table 2. The effect of the girdling method on the healing ability of the girdle on 'Nules' Clementine when girdled on 14 December 1998.

		wLAG	xGRADIENT	yDAYS
Treatment:				
	Stanley	14.7 a[z]	0.77 a	35.0 b
	Outspan	16.8 a	0.72 a	47.6 a
LSD		4.123	0.204	6.156
SE		1.289	0.0639	1.924
Source:	df			
Treatment	1	0.2789	0.5438	0.0012

[z]Means with the same letter are not significantly different at the 5% level (LSD)
[w]Lag phase (days) before the onset of any healing
[x]Gradient of healing (from onset of healing to completely healed)
[y]Days of healing from girdling date to completely healed

Figure 1. The effect of the timing of girdling on the healing ability of the girdle on 'Nules' Clementine. The girdling dates are provided below each line and the healing stage is explained in the text.

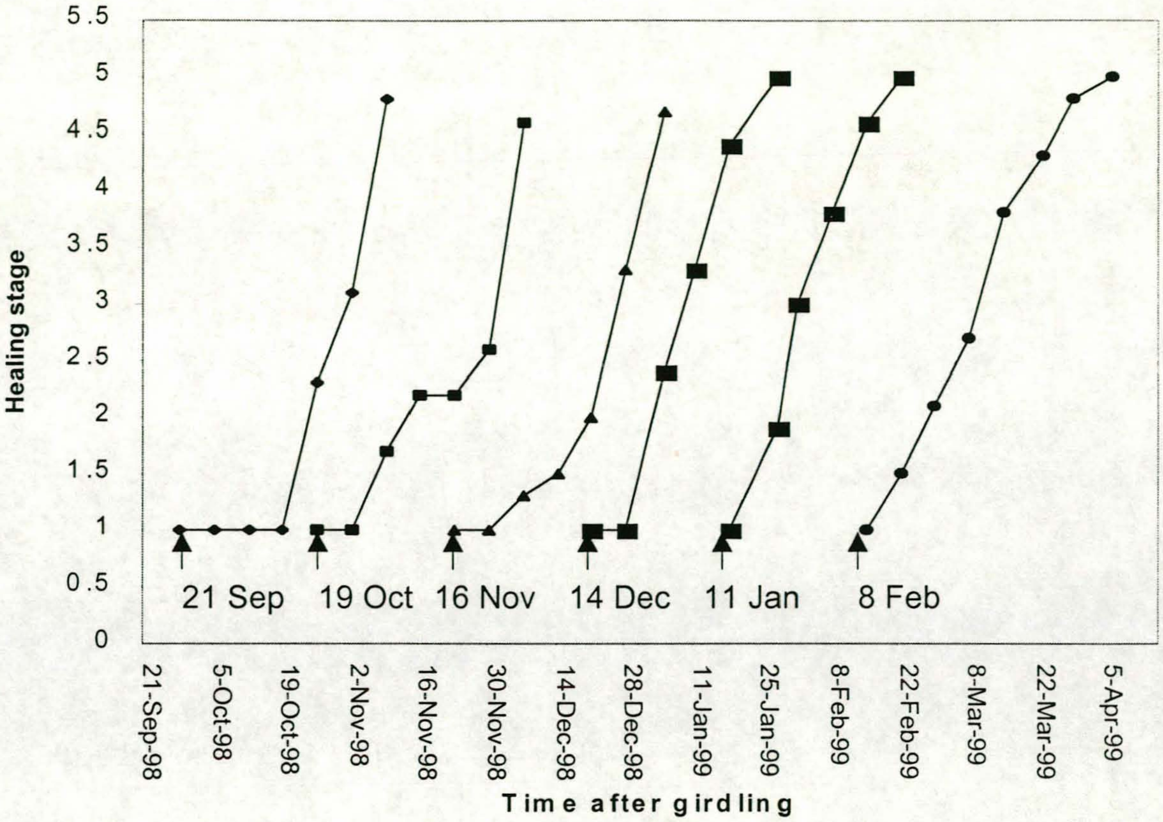
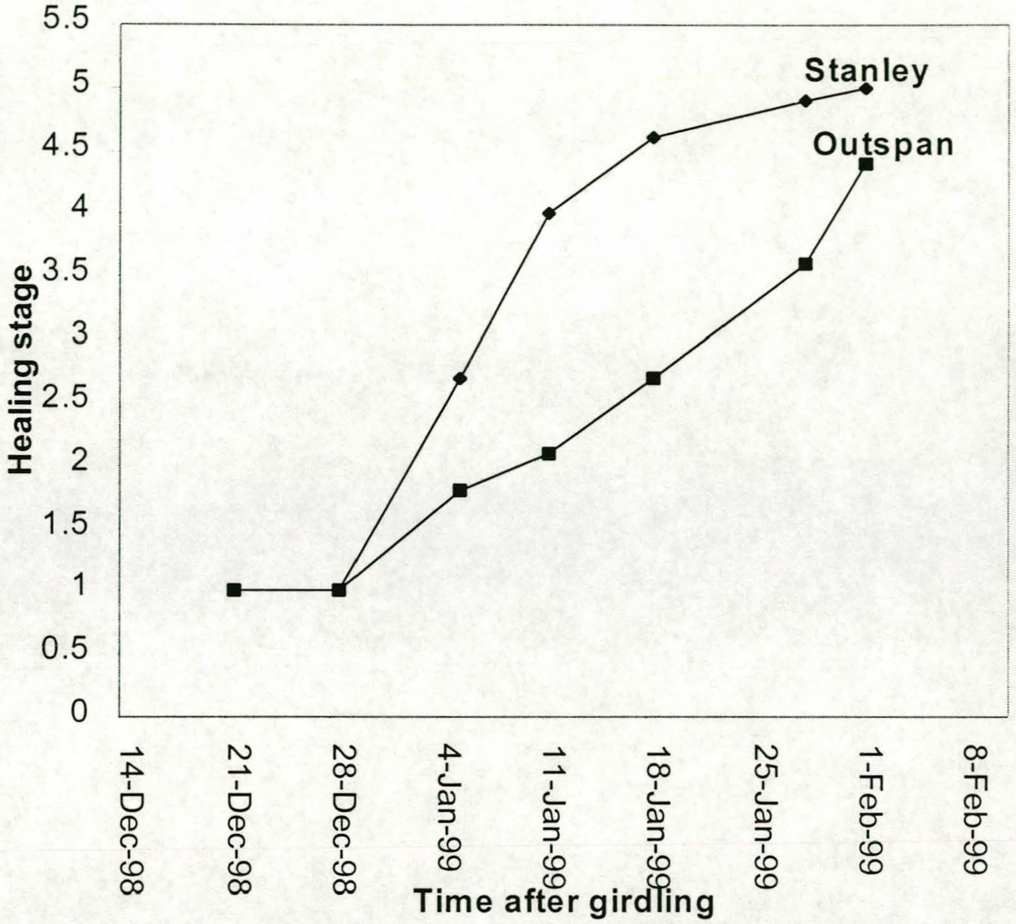

Healing stage
5.5
5
4.5
4
3.5
3
2.5
2
1.5
1
0.5
0
21 Sep
19 Oct
16 Nov
14 Dec
11 Jan
8 Feb
21-Sep-98
5-Oct-98
19-Oct-98
2-Nov-98
16-Nov-98
30-Nov-98
14-Dec-98
28-Dec-98
11-Jan-99
25-Jan-99
8-Feb-99
22-Feb-99
8-Mar-99
22-Mar-99
5-Apr-99
Time after girdling

Figure 2. Comparison of the healing ability of a girdle performed on 'Nules' Clementine using either the Outspan girdling tool or the Stanley carpet knife.


Stanley
Outspan
Healing stage
5.5
5
4.5
4
3.5
3
2.5
2
1.5
1
0.5
0
14-Dec-98
21-Dec-98
28-Dec-98
4-Jan-99
11-Jan-99
18-Jan-99
25-Jan-99
1-Feb-99
8-Feb-99
Time after girdling

7 OVERALL DISCUSSION AND CONCLUSION

Summer trunk girdling was conducted to improve internal fruit quality, especially the TSS. Summer trunk girdling on 'Temple' tangors and 'Delta' Valencias cannot be recommended as a practice to improve internal fruit quality, although later girdling treatments on 'Temple' gave the best results in 1999. 'Temple' and Valencia trees do not respond to girdling or heal over very fast. Thus, 'Temple' and Valencias may require a larger girdle-width or re-opening of the girdle a few weeks after girdling, to respond in the same way as was reported for Satsumas. Girdling on 'Marisol' Clementines improved internal fruit quality (TSS) in all the girdling trials, with the later treatments giving the best results. Therefore, further studies should be conducted, where girdling is carried out at a later stage and trials with increased girdle-width should also be conducted.

According to all the girdling trials, citrus trees are not very sensitive to girdling treatments. Clementines trees were girdled monthly, from September until February to investigate how fast the girdles would heal over. Girdles (when girdled in December) healed completely after approximately 40 days. The rate at which girdles in other cultivars heal over should also be investigated, since the time of the year when girdling is carried out and the specific cultivar, influences the time the girdle takes to heal over and will therefore influence the eventual result required.

Deficit irrigation was carried out to improve internal fruit quality, especially the TSS. Deficit irrigation on 'Marisol' Clementines improved internal fruit quality (TSS) in all the trials, when conducted from shortly after the physiological fruit drop period. Although girdling and deficit irrigation on its own increased the TSS, the combination of girdling and deficit irrigation enhanced the increase in TSS. Deficit irrigation on 'Delta' Valencias improved internal fruit quality in 1998, but not in 1999. The deficit was probably not extreme enough, especially in 1999 (86% of normal amount applied), because there were no major differences in tensiometer readings between the normal and deficit blocks. Due to the very hot and dry summer, deficit irrigation could not be carried out properly, because of fear for permanent damage to the trees. At this stage, our data do not support deficit irrigation or the combination of girdling and deficit irrigation on 'Delta' Valencias as a means to improve TSS, but further studies should be conducted on late-season cultivars, which are usually harvested after receiving winter rains, e.g. 'Temple'. Also, irrigation blocks with similar soil types should be used and more extreme deficit levels employed.

Fruit quality parameters differ in different positions in the tree. Top and outside bottom fruit had the best internal fruit quality and inside bottom fruit the worst, probably due to higher light intensities and higher temperatures of sun-exposed fruit. This was the reason why we conducted summer pruning; to improve the internal quality of fruit inside the canopy receiving low light levels and lower temperatures. This study provides information which can be used as a guide for spot-picking and early harvesting and in developing pruning strategies to improve the quality of inside canopy fruit.

Summer pruning was conducted to expose shaded fruit to direct sunlight. Summer pruning on 'Nules' Clementines improved internal fruit quality, but regrowth should be controlled after pruning. At this stage our data do not support summer pruning on 'Mihowase' Satsumas to improve internal fruit quality, possibly due to the already inherent light-friendly nature of a Satsuma tree. Further studies should be conducted on older Satsuma trees with larger canopies. Summer pruning on other mandarin types should also be conducted.

The rapid sugar accumulation after the physiological fruit drop period in Satsumas and Clementines corresponds with the period when we normally manipulate the trees to improve the internal fruit quality. Monitoring the sugar accumulation in 'Marisol' fruit would have given a better indication of whether the timing of the girdling treatments and the introduction of deficit irrigation coincides with the rapid sugar accumulation in the fruit. Measuring the TSS and TA at every sampling date would also provide a more complete picture of the trends in quality parameters when fruit are maturing. Further studies should be conducted on oranges, e.g. Valencias, to compare sugar levels in fruit from normal and deficit irrigation blocks throughout the fruit growth period until maturation.

Ridging improved internal fruit quality (TSS and TSS:TA ratio) of 'Bahianinha'

Navel fruit. Therefore, ridging can be used as a cultural practice in citrus to promote internal fruit quality, especially where cultivars of inherently low internal quality are produced or where other manipulations, i.e. deficit irrigation, girdling and pruning, do not have the desired effect. Further studies should also be conducted on other cultivars.