SEASONAL GROWTH PATTERNS AND WATER RELATIONS IN RESPONSE TO REDUCED IRRIGATION REGIMES IN MANGO (*Mangifera indica* L.)

By

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To my family that stood by me and encouraged me through my studies and friends that lent support and comfort through difficult times a special word of thanks

I thank God for giving me the opportunity to be able to study further and standing by me through the time I was doing research and writing my thesis.

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Abstract:

'Kent' mango (*Mangifera indica L.*) trees were subjected to four irrigation treatments, consisting of 100% of field capacity = control, 75 and 50% of control, respectively (all progressively reduced) and a regulated deficit irrigation treatment (RDI). Trees exposed to normal farm practices were also monitored. Since the soil contained 80 ± 1.48% coarse sand, 4 ± 4.86% silt and 9 ± 1.15% clay, associated with a high infiltration rate accounting for 289 ± 52 mm $h^{-1,}$ the experimental orchard was well suited for pulse irrigation. The frequent applications of irrigation water lead to savings between 40 – 50 % in the four-irrigation treatments in contrast to the farm control. Experimental treatments were selected to determine if a reduction in irrigation would affect vegetative and reproductive growth patterns. Vegetative growth such as trunk diameter and tree height were only affected in the progressively reduced treatments at the end of the 2000 season. No significant differences were found between the irrigation treatments in terms of fruit growth and yield indicating that there were no negative effects from the irrigation treatments. Physiological measurements consisted of stomatal conductance and photosynthesis with no significant differences between treatments except when stress was introduced in the RDI treatment.

1 General introduction.

Man has practised the use of irrigation to grow agricultural crops since biblical times. The methods used to irrigate have changed dramatically over the last few decades, with more emphasis being placed on water use efficiency and water conservation. The goal of modern agriculture is to use less water for irrigation without a decrease in fruit quality and yield.

South Africa has very few water resources. In recent years various factors have contributed to greater uncertainty in the environment (global change in climate) within which decisions need to be taken for agricultural water management (Backeberg and Odendaal, 1998). In the Blyde River valley where the irrigation trail was conducted, the current form of irrigation distribution (earthlined canals) has led to a loss of 60% water before it reached the farmer (Anonymous, 1999). Because of this immense loss and political environment, farmers and government had to re-examine cultural practices of the past (government policy has focused to distribute running water to all rural communities, due to insufficient infrastructure). Therefore government and farmers have committed themselves to build an underground pipeline to distribute water. This will lead to a higher percentage of water available not only for irrigation but also informal settlements (Backeberg and Odendaal 1998; Anonymous 1999). Thus, to utilize irrigation water efficiently farmers have to optimize irrigation management.

Varying soil conditions have a major influence on the suitability of soils for irrigation purposes. Soil with a high clay content usually has a lower infiltration rate, intensifying irrigation management not to over-irrigate, while allowing a higher degree of freedom in sandy soils. Soil depth and water-holding capacity contributes to the challenge of managing irrigation optimally. For the farmer the knowledge and suitability of soils for irrigation purposes is essential.

There are generally two approaches involved when managing irrigation. The first is progressively reduced irrigation, where the amount of irrigation water applied, is reduced through the whole growing season of the tree. This method, however, does

not take varying carbon demands by different tree organs throughout the season into consideration, leading in many cases to a decrease in tree performance (Boland et al., 2000). The method could nevertheless be useful in determining a crop coefficient, since soil moisture monitoring alone is not sufficient in determining tree water requirements.

A second method is known as regulated deficit irrigation (RDI), where irrigation is withheld during certain growing stages of the plant. Regulated deficit irrigation might represent a suitable method to optimize irrigation management. Water deficit can create a balance between vegetative growth and fruit growth by reducing vegetative growth in certain stages, such as flushes, and promoting fruit growth at the same time, since fruits represent the dominant sinks in the tree (Chalmers et al., 1984; Mitchell et al., 1989). It can also contribute to reducing pruning, overcoming leaching and improving manageability of high-density orchards. For the efficient use of this method it is essential to gain knowledge and to understand interactions between carbon and water demands of vegetative and reproductive growth patterns over the season. Both of these methods lead to a decrease in the amount of irrigation water applied, while not negatively affecting the tree in most cases (Chalmers et al., 1981; Mills et al., 1996).

The objective of this study was to optimize irrigation management by minimizing irrigation water applications and leaching of nutrients, to keep yield constant or to improve it, and to enhance the understanding of mango (*Mangifera indica* L.) fruit and tree growth for the specific climatic region it was essential to identify periods suited for the implementation of regulated deficit irrigation strategies.

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2 Properties and Seasonal Soil Water Content

Introduction

The production of agricultural crops is a very important contributor to the economy of South Africa. The production of high value crops such as fruits, has the greatest contribution. The performance of these crops is highly influenced by the amount of water they receive in certain growing stages. Therefore, irrigation management plays a vital role in stabilizing production and facilitating the growing of these crops. Despite many advantages, irrigation has taken its toll on the limited water resources of the country. Backeberg and Odendaal (1998) stated that 53.6% of the total water available was used in agriculture, with the Northern Province being the second highest consumer. In view of this problem improving water use efficiency of tree crops poses a major challenge.

The Lowveld of South Africa (Mpumalanga and Northern Province) is one of the best areas for the cultivation of sub-tropical fruit. This is of particular importance considering the fact that South Africa has a very low percentage of arable land and a low variable rainfall for the cultivation of these crops. The farm Mariepskop is situated on the base of the eastern escarpment (Drakensberg in the Northern Province). Unfavourable climatic, topographic conditions and parent material (granite) influenced soil formation in this area. These factors combined gave rise to a Glenrosa form (Lithic Ustochrept soil) that consists of two horizons, A and B. The A horizon (topsoil) is characterized by a shallow layer of well weathered material with a low organic matter content. The subsoil consists of a fairly deep, hard Lithocutanic B horizon. This means that more than 70% of the horizon consists of partly to well weathered rock. The other 30%of this soil profile forms typically tongues into the weathered rock, where plant roots grow into.

Important factors to consider when implementing an irrigation trial are the suitability of the soil for irrigation. The most substantial factors to take into account are soil depth, soil infiltration rate, and soil water retention. All these factors are predominately influenced by the soil particle size distribution within the orchard. Soil infiltration rate refers to the

potential of the soil to take up water (thus the downward flow of it). This is influenced by the depth and uniform distribution of the applied irrigation. In most cases the initial infiltration rate for most soils is as high as the emission rate of the irrigating system, but starts to diminish as the soil profile fills up and will eventually lead to surface runoff if the rate of soil water infiltration is less than the application rate (Baver et al., 1972). Water infiltration, however, does not just occur downwards but also sidewards. The strength of this sideward movement depends on the matric potential of the soil, where the matric potential is influenced by the cohesion forces of other water molecules and wetting surfaces (Baver et al., 1972).

Soil water retention refers to the amount of water and ion solution present in the soil profile that can be removed by drying the soil at a temperature of 110°C to a constant weight. The amount of water present depends on the size of pores between soil particles, with large pores usually emptying first when the soil starts to dry out (Koorevaar et al., 1983). Water present in the crystalline structure is often not taken into consideration when determining this factor since a considerable amount of energy is needed to extract it from this form (Baver et al., 1972). Relative values for these parameters are not available since soils differ over wide areas and under circumstances of formation.

The state of water in the soil can be described in two ways, in terms of quantity present and the energy status of the water. The quantity present is expressed either on gravimetric or volumetric basis (Rundell et al., 1991). The energy level of water is particularly useful for describing the dynamics of flow, the availability to plants and the driving forces causing water to flow in the soil (Warick, 1990). Soil water potential can be defined as the work (energy) necessary to transfer a quantity of water from a reference state to the point of interest, where the reference state is pure water. The most meaningful instruments used to estimate soil water potential (deficit) are tensiometers or the neutron probe. The tensiometer is a good indicator of water taken up by the plant, which indicate when uptake potential drops below the soil water potential exceeded in the root zone (Campbell and Mulla, 1990). A neutron probe is a more exact form of measurement with

the advantages of measuring at different depths in the soil thus giving a better representation of the true water content.

The specific use of various irrigation equipment, which is more beneficial to water conservation while applying an adequate amount of water, is a very controversial question with many advantages and disadvantages to current systems. At present the systems most widely used are sprinkler irrigation followed by flood and then micro (drip) irrigation. Micro irrigation has the highest efficiency level with a mean of 85% (Backeberg and Odendaal, 1998).

The objectives of this study was to determine the suitability of the soil for frequent irrigation, to reduce water and nutrient losses by evaluating two different methods of irrigation, progressively reduced and regulated deficit irrigation, to observe the effect of reduced irrigation on soil water availability, and to investigate the pattern of water movement in the soil profile.

2.2 Materials and Methods

The experiments were conducted on a commercial farm (Westfalia, Mariepskop) in the Hoedspruit vicinity during the 1999 and 2000 season. The different irrigation treatments were implemented within a one hectare mango (*Mangifera indica* L, cv. Kent) orchard planted in 1996. The 4-5 year old trees grown on Sabre rootstocks were planted at a density of 6 ×1.5m. Cultural practices such as pruning, pest management and fertilization were conducted according to commercial farm practices. Temperature had a yearly mean of 31°C maximum and 13°C minimum with an average recorded rainfall of 510 mm. The mango orchard is lying on a slight incline towards the mountain (southwest) The four irrigation treatments (four replicates per treatment) were randomly distributed in a block design in six rows within the orchard. Meteorological data for the duration of the study were obtained from the neighbouring farm, Bavaria, until the Campbell Scientific weather station located on the Mariepskop farm was in working condition.

2.2.1 Soil analysis

Physical and chemical properties of the orchard soil and the nutrient content in the leaves were analyzed by the Soil Science laboratories of the Department of Plant Production and Soil Science, University of Pretoria. Soil depth was measured in each replicate. Soil particle size distribution was also determined for eight locations randomized in the orchard at three different depths in the profile (30, 60 and 90 cm) using the hydrometer method as described by Day (1950). Chemical soil analysis included basic element concentration and pH level of the same samples collected for soil particle size analysis according to methods described by the soil testing advisory manual (Anonymous, 1990).

Soil infiltration rate was determined on six locations in the orchard. The retention rate was determined using the pressure plate method as described by Richards and Weaver (1944).

Leaf samples were collected in each treatment, to determine the nutritional status of the plant in the four replicates assigned across the orchard. Twenty-five fully mature leaves from the last flush were collected randomly, then oven-dried and ground to a fine powder. Samples were analysed according to laboratory methods for fertilizers and nutrient content (Scott et al., 1999)

2.2.2 Irrigation treatments

Trees were irrigated using a single drip irrigation system. The orchard was pulse irrigated three times a day, five days a week for the first season and three times a day, seven days a week, for the second season using 4ℓ h^{-1} drippers. This was compared to the traditional farm method where irrigation was applied at 8ℓ h^{-1} for a specific period once a day. In the first season (1999), drippers were placed between trees (75 cm from the tree). This was done to stimulate a bigger root zone for better water and nutrient absorption. During the second season (2000) drippers were moved and placed 30 cm from the stem of each tree,

because of the possibility of under-irrigation. Each tree had, therefore, two individual drippers instead of one. A farm control (Co-F) was also added to evaluate differences between the treatments and normal farm practices. For the farm control, 8ℓ h^{-1} drippers were placed between each tree (75 cm between adjacent trees).

Irrigation treatments consisted of:

-100% control	T0
-75% of the control (progressively reduced)	T1
-50% of the control (progressively reduced)	T2
-Regulated deficit irrigation	T3
-Farm control	Co-F

Water dispersion within the soil was also studied after irrigation for 15, 30 and 60 minutes. These were graphed to determine if the movement of water was sideways or downward.

To determine the amount of irrigation water to apply in the different treatments, water deficits were determined by taking neutron probe (model 503DR Hydroprobe, Neutron Depth Moisture Gage, Campbell Pacific Nuclear, California U.S.A) measurements on a weekly basis. Aluminium tubes were inserted in the soil profile in each replicate up to a depth of one meter. Tubes were placed 20 cm from the tree. The amount of irrigation water applied was based on neutron probe readings and an irrigation scheduling program (Soil Water Balance).

An evaluation was also done between the neutron probe and capacitance sensors (Automatic soil moisture data collector 3, Netafim, Israel) to determine the sensitivity of the sensors in response to irrigation fluctuations. One capacitance sensor was installed in each treatment at three depths 30, 60 and 90 cm. They were placed at the same distance from the tree and drippers as the neutron probe tubes. Sensitivity was evaluated on two

days, one in autumn (10 May 2000) and one in summer (10 January 2001), in hourly intervals.

The three dimensional distribution of irrigation water in the soil profile was determined by installing neutron probe tubes in the form of a cross in one of the replicates of the T0 treatment. Two tubes were placed on each side of the tree, approximately 50 cm apart from each other across the row, and another two within the row, 35 cm from each other (Fig. 2.1).

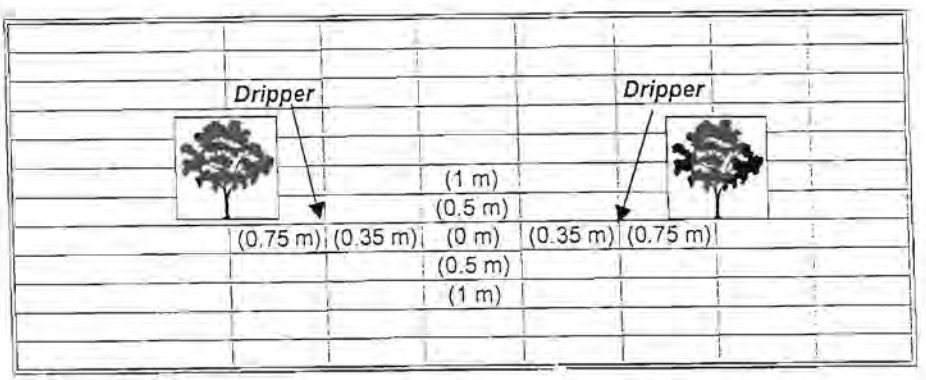


Figure 2.1. Layout of neutron probe cross in T0 treatment.

Measurements were taken once a week and seasonal patterns were determined.

Statistical analysis

Results were analysed by the department of Statistics, University of Pretoria. The program SAS (Statistical Analysis System) was used according to instructions from J. Grimbeck and M. van der Linde. The test, repeated measurements for water deficit was done at a level of 5% using one factor (see appendix).

2.3 Results and Discussion

The orchard where the experiment was conducted had differences in soil depth with the middle of the orchard being more shallow (70 -80 cm) and the sides averaging (90 -110 cm). Mean soil particle size showed the same trend for all the treatments averaging 80 ± 1.48% coarse sand content (Fig 2.2).

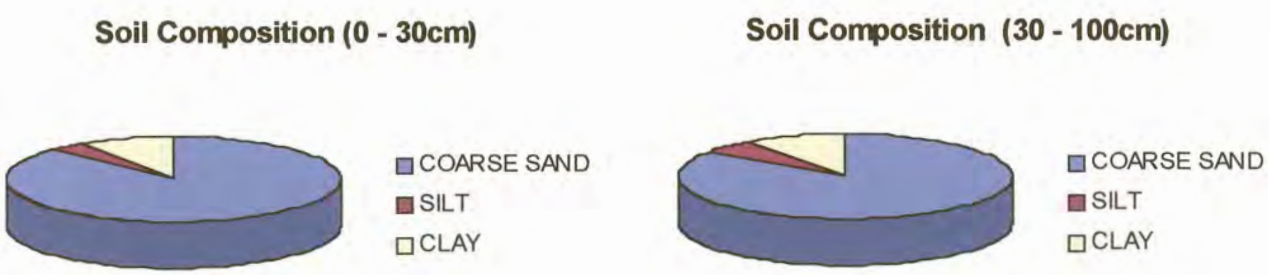


Figure 2.2. Soil particle size distribution, indicated as a mean average of the orchard at 0-30 cm and 30-100 cm

The sample for 30-60 cm was pooled with the 60-100 cm one since the specific soil family Glenrosa only has two horizons and little differences were found between the different depths. The mean soil silt and clay content were low for the specific orchard with a mean value of 4 ± 4.86% and 9 ± 1.15%, respectively. The soil type is a sandy-loam, with an average depth of 70-90 cm followed by a layer of semi weathered Saprolite.

Mean calculated water infiltration rate was quite high accounting for 289 ± 52 mm h^{-1} for all the treatments. The high rate of infiltration is a good indicator that no soil crust formation will take place because of the high sand content and low clay, conjointly with the high irrigation frequency that has a negative impact on crust formation (Hillel 1980). The chance of stagnant surface water or running surface water in the treatments is

extremely low. Soil analysis emphasised the suitability of the soil for frequent pulse irrigation.

Leaf (Tab. 2.1) and soil (Tab. 2.2) analyses indicated a severe deficiency in a certain element in the fertilization program. This deficiency could have had a negative impact on the tree performance and growth of the second season (for the different treatments, the deficiencies are currently being corrected).

Table 2.1.Norm values (Tomlinson and Smith, 1998) for foliar mineral content compared to measured values found in the experimental leaves during the 2000 season.

Element	Norm	Actual
N(%)	3	1.18
P(%)	0.09-0.11	0.19
K(%)	0.8-1	0.99
Ca(%)	2.0-2.8	2.45
Mg(%)	0.2-0.25	0.30
Zn(mg/kg)	20-100	48
Cu(mg/kg)	10-20	1300
Mn(mg/kg)	60-200	310
Fe(mg/kg)	70-100	78

Low nitrogen levels may be due to the high rainfall experienced in the beginning of the year that led to increased leaching of nutrients, especially nitrogen that is easily leached in comparison to the other elements that are more stable in the soil profile. There were also technical difficulties experienced in the beginning of the experiment concerning fertilization that could have attributed to this phenomenon. The copper concentration (Tab. 2.1) was extremely high in analogue to the norm values (Tomlinson and Smith, 1998). This was due to very frequent applications with copper-oxy-chloride to combat fungal diseases infecting the trees.

Soil nutritional concentrations (Tab. 2.2) were at desirable levels as indicated by Tomlinson and Smith (1998). Soil pH was in the range of 6.0 to 6.3 and all other macro elements were present in sufficient quantities.

Table 2. Norm values (Tomlinson and Smith, 1998) for soil mineral content compared to actual values found in the experimental blocks for the second season

Soil Parameter	**Norm**	**Actual**
pH(H_2O)	6.0-6.8	6-6.3
Ca:Mg	2.5-5	6.5
K(mg/kg)	60-100	100
P(mg/kg)	20-50	15

The wetting zone of a 4ℓ h^{-1} dripper in certain time intervals indicated that as time progressed the infiltration rate of the soil stayed almost constant (Fig. 2.3). Although water dispersal in this specific soil took place mainly downwards, there was a trend of sidewards movement. This sidewards movement emphasized the contribution of the small percentages of clay and silt holding the water to make this sidewards suction possible (Baver et al., 1972).

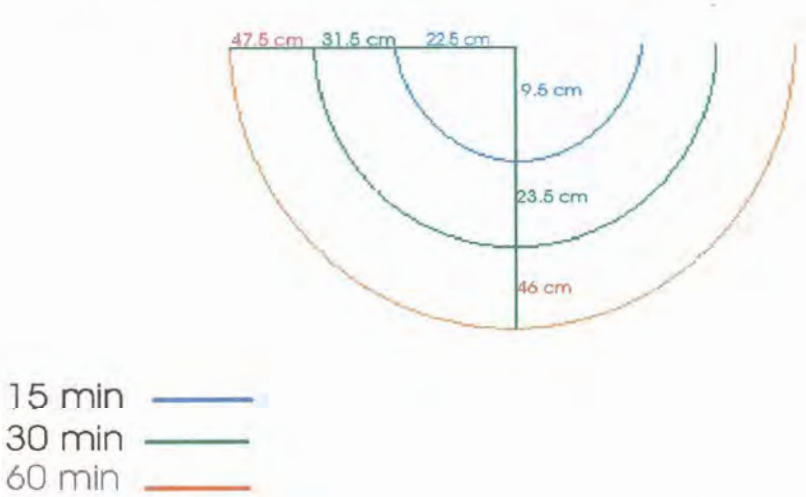
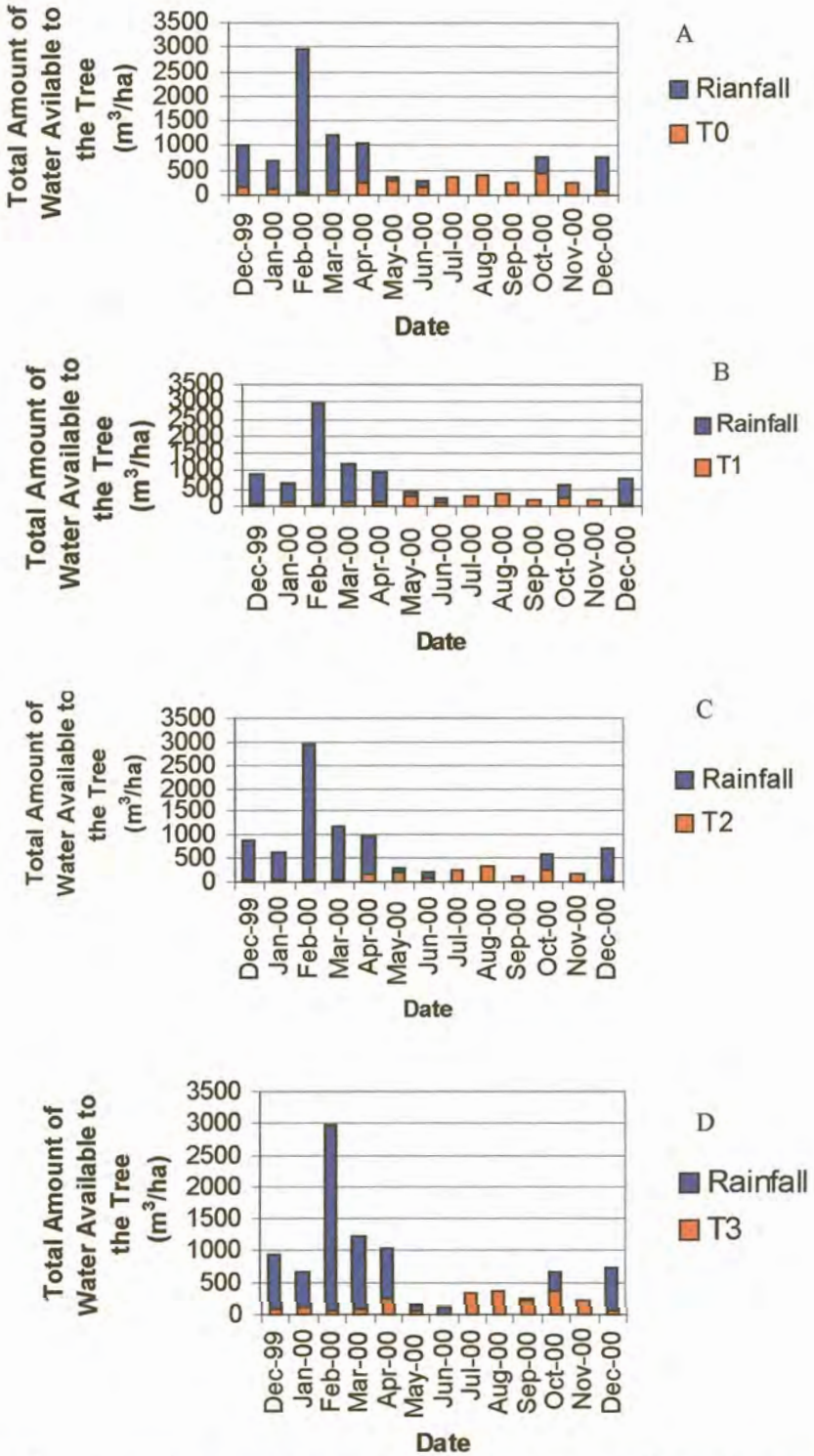


Figure 2.3. Water dispersal diagram over time for a 4ℓ h^{-1} dripper, indicating dispersal in the soil profile.

Total water application were calculated separately for all the treatments, although T0 and T3 received the same amount of irrigation for the time period December 99 - June 2000 (Fig. 2.4 A and D).

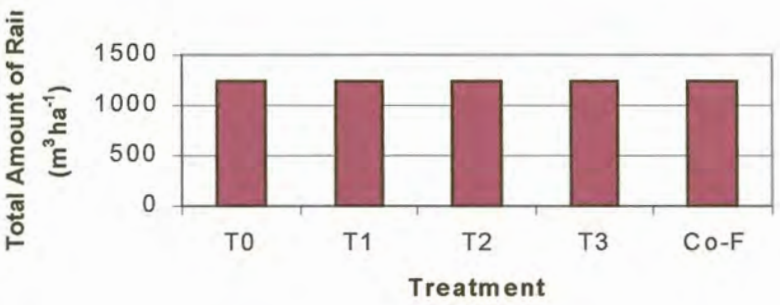


Fiure2.4. Total amount of irrigation and rain available to trees during December 1999 to December 2000.

The months February to March, normally associated with high temperatures, were subjected to a high frequency and quantity of rainfall leading to the drastic decrease in amount of water irrigated in all the treatments No irrigation took place during the rainy season (February and March) in weeks having rainfall higher than 20 mm. This procedure was implemented on the farm, where the farm was not irrigated during this time. However, during the second half of the 2000 season irrigation took place when necessary and also over weekends, even if it did rain. Thus the first part of the experiment was not highly influenced by the experimental treatments due to the influence of rain.

In comparison to normal farm practices (Co-F) 33% less water was applied in the control (T0) (Fig. 2.5). Water savings in T1 and T2 amounted to 46 and 56%, respectively in comparison to the amount applied in the farm control (Co-F). In comparison to the control (T0), T1 and T2 had only a 21 and 40% decrease. The lower decreases observed in T1 and T2 might be attributed to technical difficulties, such damaged irrigation pipes experienced during the first part of the experiment. Pipes were also flushed on a regular basis that led to a higher amount of water used.

A



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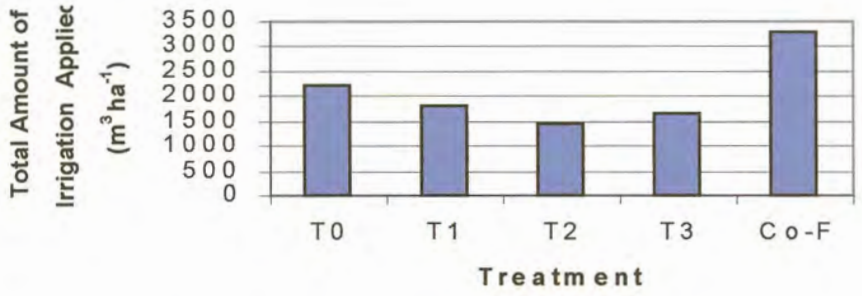

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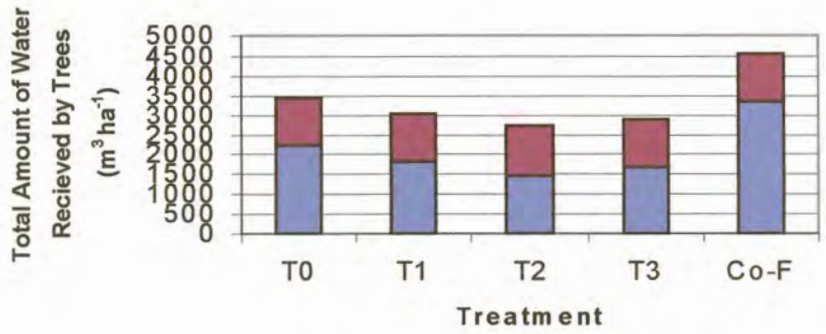

Figure 2.5.A. Total amount of rain received in m^3 from May 2000 up to December 2000

B.. Total amount of irrigation water applied in m^3 from May 2000 up to December 2000.

C. Total amount of water available in m^3 to trees from May 2000 up to December 2000.

Water savings in T3 amounted to 23 and 51% respectively, when compared to (T0) and *the farm control (Co) respectively. This high amount of water saving* was to be expected since T3 received almost no water for two months during the year, except during fertilization that lasted not longer than 10 min at a time. The total amount of water available to the trees (irrigation and rain) in the farm control, compares very well with

values experienced by farms in the vicinity (personal communication). Thus the goal to reduce water availability to the trees and to regulate it was successful during the later part of the season. Caspari et al. (1993, 1994) and Mostert et al. (1996), also found similar high relative values of water savings when applying RDI on apples and pulse irrigation on mangoes. Regulated deficit irrigation seems to be a viable option, if a producer wants to save costs (irrigation).

Comparison of the capacitance sensor and the neutron probe led to different observations between the autumn and summer experiment (Fig. 2.6 and Fig. 2.7). During the autumn the deficit at 60 cm, recorded by the capacitance sensor, was greater than at 30 cm (Fig. 2.6). This is in contrast to the neutron probe measurement for that particular time where the observation at 30 cm experienced the largest deficit. The neutron probe gave a good indication when irrigation took place as can be seen at 60 and 90 cm depth at 8:00, 11:00 and 14:00. The difference between measurements method, might be due to technical problems with the experimental set-up, since the soil profile exhibited a high infiltration rate, with water having a rapid downward movement (Fig.2.3), thus making an accurate hourly observation in especially the 30 cm section almost impossible.

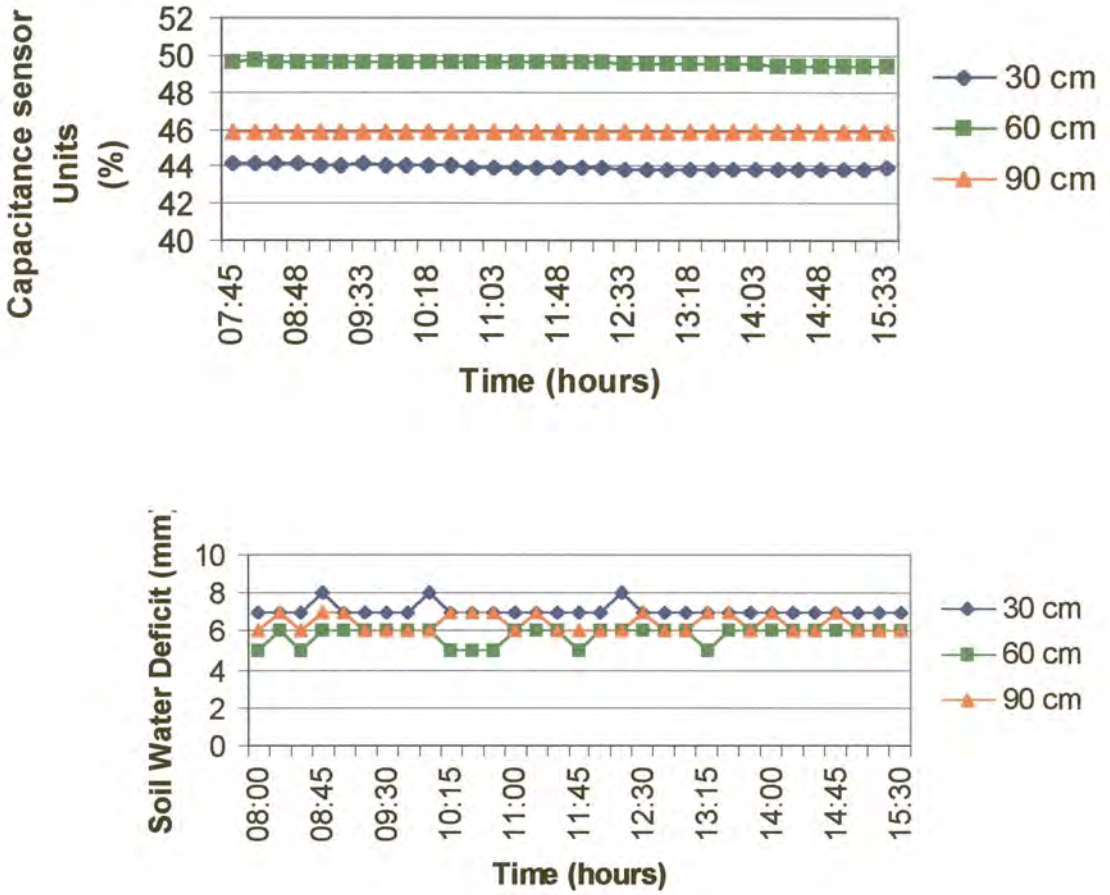

Figure 2.6. Comparison between capacitance sensor and neutron probe for 10 May 2000 (autumn)

During the summer (Fig 2.7) the capacitance sensor and neutron probe readings behaved in a similar manner as during autumn (Fig. 2.6). The neutron probe gave a slightly better indication at 11:00 when irrigation took place than the capacitance sensors. However responses to irrigation were not consistent at the different irrigation times in the three depths. This behaviour can not be explained, because both equipment's measurements were done in the same replicate in the same type of soil with the same rate of infiltration.

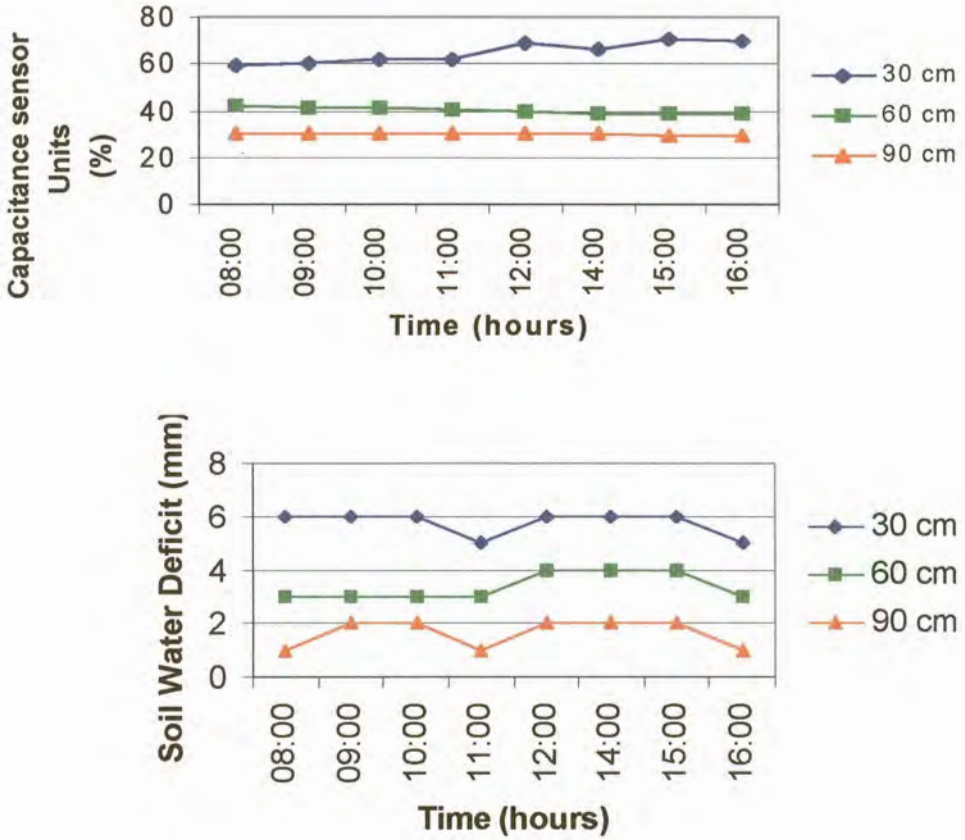

Figure 2.7. Comparison between capacitance sensor and neutron probe for 10 January 2001 (summer)

The lower sensitivity of the capacitance sensor in contrast to the neutron probe readings might be attributed to the long time intervals (60 minutes) when soil moisture was recorded in association with the high infiltration rate of soil. However, data taken over the season indicated that the capacitance sensors gave better results if the interval between measurements was much smaller (for example five to ten minutes), showing definite decreases in deficit when irrigation took place (data not shown). More testing of the equipment is necessary to verify these findings and to determine a correlation factor to relate neutron probe readings with those of the capacitance sensors.

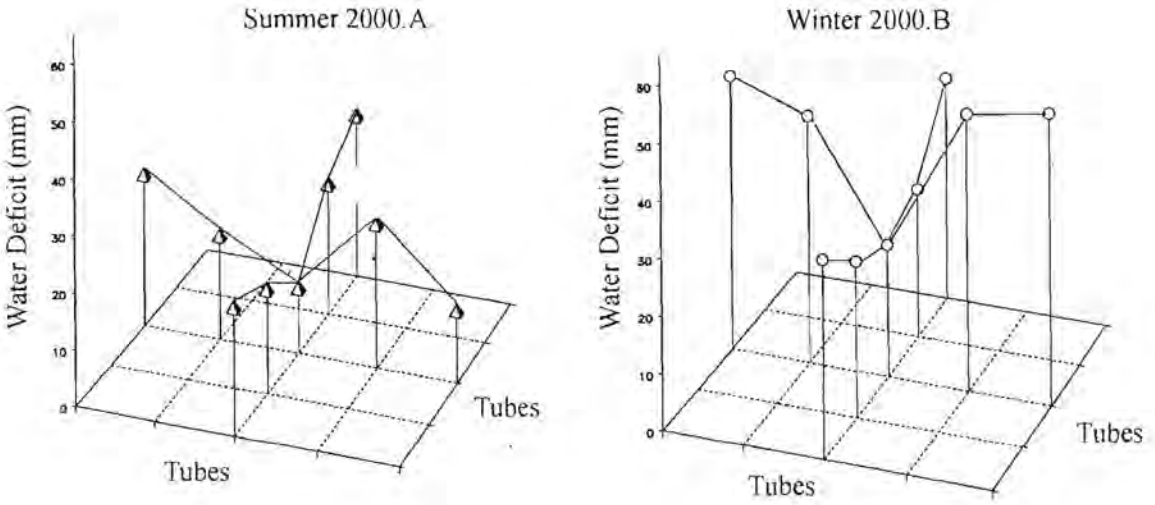

Figure 2.8 Water distrubution in the soil profile for the summer and winter season 2000 (each point represents the mean of 16 dates).

The neutron probe cross in the field showed large differences within the soil profile where irrigation took place, with an increase in deficits as the tubes moved further away from the dripper, towards the tree, and major increases in deficits as the tubes moved into the inter row spacing (Fig. 2.8). There were also large seasonal differences between readings, with the highest deficits averaging in the winter (Fig. 2.8 B). The summer of 2000 (Fig. 2.8 A) showed a much lower deficit than the summer of 2001 (data not shown). This might be due to the high rainfall experienced during the summer of 2000 in contrast to the low rainfall in summer 2001, while the effect of pulse irrigation also started to dry out the soil profile slowly restricting moisture close to the dripper. Roots that grow into the row are dependent on rainwater for a source of irrigation and thus only sporadic growth in this section of the root system will take place when rainfall is at a higher frequency. Most roots in this section were thick with few root hairs, leading to the assumption that trees might not have been dependent to a large extent on this part of the soil profile for water, since there is no consistent moisture present to sustain the root hairs (Salisbury and Ross, 1991).

2.4 Conclusion

Pulse irrigation in the particular orchard seemed to be suitable, because of soil properties such as a high sand content averaging 80% coarse sand and high infiltration rate. Because of the frequent irrigation and extremely low clay and silt content, more frequent fertilizer application in contrast to current farm procedure (once a month) might be necessary.

Water application varied widely among the irrigation treatments, the control (T0) was however still lower than normal farm procedure. The soil water balance cross installed in the orchard represented a good indicator of stress in other parts of the soil profile and shows the dispersal rate and pattern of water in the soil profiles. Weekly measurements taken in the cross can be used as a reference when experiencing problems in physiological measurements as well as to see the effect of rain on refilling the soil profile.

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3 Growth Responses to Progressively Reduced and Regulated Deficit Irrigation

3.1Introduction

The irrigation of agricultural crops makes it possible for many countries to grow crops continuously throughout the year where previously it was not possible. In South Africa, the erratic rainfall pattern makes water a scarce commodity, which needs to be managed with great caution not to exhaust it. The knowledge of time of application and withholding of irrigation water is of vital importance to the farmer, as it could have a negative effect on growth and yield of crops.

The annual vegetative and reproductive development of the mango tree takes place at definite phenological stages. These stages give the producer a clear phenological calendar of occurrences, such as, flower initiation, differentiation, flowering (anthesis), fruit set, fruit development, harvest, shoot and root flushes (Davie and Janse van Vuuren, 1998). This information can be useful in the planning of management procedures like spraying, fertilization, and irrigation.

Vegetative growth of mango and other tropical trees is not continuous but occurs as intermittent, short lasting flushes of terminal buds, before returning to a quiescent state (Singh, 1978). Modules produced during a flush may consist of a branch with up to 10-12 new leaves (Whiley et al., 1989). The extension growth of mango shoots terminates with the formation of a determined inflorescence. This type of growth gives rise to a Scarrone architectural tree model, where tree growth is determined by the terminal meristem that produces an indeterminate trunk bearing tiers of sympodial lateral branches (Schaffer et al., 1994). Three types of shoots can be produced: vegetative, reproductive and mixed shoots. Depending on the cultivar, shoots can produce flushes up to four times a year (Davenport and Nunez-Elisea, 1997). Initiation of flushes is usually influenced by pruning, irrigation, fertilization and temperature (Reece et al., 1949).

The period between floral initiation and anthesis can be as little as four weeks under tropical conditions. This period, however, is much more variable under subtropical conditions (Schaffer et al., 1994). This rapid transition demonstrates the capacity of the tree to take advantage of favourable environmental conditions, such as temperature and water relations (Singh, 1977; Pongsomboon, 1991). Trees may produce a few to thousands of inflorescences depending upon the genetic potential and climatic conditions. Both male and female (perfect) flowers are borne on the same on tree and inflorescence. The ratio between these is highly dependent on cultural practices and climatic conditions (Mukherjee, 1997). Most studies indicated that the distal half of the panicle usually has a higher percentage of perfect flowers and that most fruit set occurs on this part of the inflorescence (Singh, 1954; Majumder and Mukherjee, 1961). Singh (1965, 1966) indicated that there was a marked decrease in the amount of perfect flowers as temperatures decreased during bud break. The number of perfect flowers per panicle varies from year to year, depending on the location of the panicle on the tree and the cultivar (Singh, 1978; Young et al., 1981).

Water deficit can lead to physiological stress in a plant and can be a natural effect or one that is managed by man. With irrigation management two forms of stress can be introduced, progressively reduced irrigation and regulated deficit irrigation (RDI). With management of irrigation water use, efficiency can be increased depending on soil conditions. If irrigation water is applied in smaller amounts at a higher frequency during the day, less water will be wasted by drainage with this method especially in sandy soils. Most plants are able to adapt to drought situations, while with time the severity of the water stress becomes less on the plant (Pongsomboon, 1991). To achieve high yields of a particular crop under deficit irrigation, a good understanding of the vegetative and reproductive crop responses under varying degrees of available soil water is essential.

Most studies about the effects of irrigation on vegetative and reproductive growth have been done on temperate fruit crops. Reduced irrigation leads to a decrease in trunk cross sectional area in most fruit tree crops (Ginestar and Castel, 1996; Mills et al., 1996; Boland et al., 2000). In apples Ianca (1985) illustrated the sensitivity of trunk growth as a

better parameter for water stress than fruit growth. The time of application of water stress is also very important (Mills et al., 1996). In apples, the later stress was applied in the season the less trunk growth was reduced in comparison with normal irrigated trees. Boland et al. (2000) detected that the size of the root volume and soil volume also had an influence on trunk growth in peaches, while Ginestar et al. (1996) indicated that there appeared to be an exponential relationship between water stress and trunk growth in citrus.

Tree height as a water stress indicator is not a well-known parameter. In most studies it was found that the effect of water stress on shoot extension and diameter increases correlated well with tree height. Most authors perceived a decrease in shoot extension rate when reduced irrigation was initiated (Mitchell et al., 1989; Proebsting et al., 1989; Johnson et al., 1992; Boland et al., 1993; Caspari et al., 1993; Girona et al., 1993). However, Atkinson et al. (1998) indicated that shoot extension in apples was not negatively affected by water stress but that the number of shoots developing increased. In comparison to studies from other authors the magnitude of decrease was, however, very small. Mitchell et al. (1986) showed that pear trees still kept some of their potential for shoot extension even after water stress began and that the decrease in growth only started when the parchedness of the soil profile started to influence root growth. The same pattern was observed by Steinberg, (1990) in peaches where water stress led to a decrease in the root:stem diameter ratio that was due to the roots being a stronger sink. Mitchell et al. (1989) suggested that reduced irrigation lead to a decrease in shoot growth while improving fruit growth for the specific period and that reduced irrigation is a good management tool for high density orchards to control vegetative growth.

Different organs on the same plant are known to have different sensitivities to deficit irrigation, with fruit growth being generally less sensitive to water deficit than vegetative growth according to Higgs and Jones, (1991). However Berman and DeJong (1996) found that fruit fresh weight was very sensitive to water deficit, while fruit dry weight was only reduced at very light crop loads. It has been hypothesized that under deficit irrigation fruits can adjust, osmotically thus enabling them to retain fruit turgor and grow

actively (Mills et al., 1996). In most cases reduced irrigation had no negative effect on fruit growth and yield (Johnson et al., 1992; Torrecillas et al., 1993; Kilili et al., 1996; Naor et al., 1999), and in some cases even led to an improvement in quality and yield in apples (Kilili et al., 1996). The time of application of stress is of great importance with almost no effect observed when pear trees were stressed during the fruit expansion phase (stage 3) (Mitchell et al., 1989; Caspari et al., 1993). Ginestar et al. (1996) and Kilili et al. (1996) found that deficit irrigation early in the season and during stage 2 of fruit growth led to a decrease in fruit weight in apples and citrus and return bloom the next year, but had no effect during stage 3. Torrecillas et al. (1993) noted that reduced irrigation during flowering on citrus led to a lower fruit set, but after full irrigation was resumed no effect on fruit growth was noted between the different treatments. This effect was also observed by Boland et al. (1993) in peaches which, attributed it to the low initial fruit set that occurred due to the thinning effect of reduced irrigation. The most striking effect of water stress on fruit growth was the increased potential of fruit growth recovery after full irrigation was resumed (Mitchell et al., 1986). In some tree crops, it even alleviated the effect of biannual bearing decreasing it satisfactory, and had no negative effect on the yield in the next on-year (Mitchell et al., 1986).

The objective of this investigation was to determine the effect of progressively reduced and regulated deficit irrigation on mango tree growth and crop production and to identify periods during the year to initiate water stress that will reduce vegetative growth, while not affecting fruit growth.

3.2 Material and Methods

For this experiment the same orchard with the same experimental trees and irrigation treatments were used as described in Chapter 2.2.

3.2.1 Vegetative evaluation

Trunk diameter – Measurements started at the end of November 1999 and were undertaken first in bimonthly but later in monthly intervals to provide a more distinct pattern of growth over the different seasons. Diameters of all the experimental trees were measured using a digimatic caliper (Mitutoyo, Japan). Measurements were taken 10 cm above the scions parallel and perpendicular to the tree row and mean trunk cross sectional area (TCA) was determined.

Tree height – Height increase monitoring was started in the middle of March 2000 in bimonthly intervals. Increases were measured using an abney level, at a distance of 4m from the tree. Mean tree height was calculated using the equation:

$$H=(\text{Tan}(\alpha)*4\text{ m})+\text{height of person}$$

Shoot growth – Stem extension rate (SER) was only measured during November and December 2000. Only one set of measurements was taken, as mango trees do not flush simultaneously throughout the year among and within treatments hampering correlation between treatments and dates. Sixteen trees per treatment were evaluated with four shoots on each tree when possible. (Stem length was measured using a digimatic calliper).

3.2.2 Fruit evaluation

Fruit diameter – During the first season, monitoring of fruit diameter was started 70 days after flowering when fruits had reach about the size of a golf ball. The measurements started late, since mango is known for the high percentage of infertile fruits that drop between 40-50 days after flowering. Measurements were carried out in biweekly intervals up to harvest at the end of January 2000. Fruit growth was determined by measuring two diameters with a digimatic caliper (axial and perpindicular to the axis). Sixty fruits (5 fruits per tree × 3 trees × 4 replicates) were tagged in each treatment. Fruit on trees were also thinned down to a certain fruit number to eliminate the effect of crop load on

plant water relations and assimilate partitioning. During the second season a different approach was taken since the fruit growth curves of the previous season (1999) indicated that measurements started too late. In the 2000/2001 season, two trees per replicate of each treatment were selected that had six shoots and at least three previous flushes. All the fruits on those flushes were tagged and fruit diameter was measured in weekly intervals starting 52 days after flowering until harvest.

Estimating fruit dry weight – During the 2000/2001 season, 20 fruits from a separate set of trees were randomly collected on a weekly basis. Following measurements of fruit diameter, the fruits were oven-dried at 75-100^{0}C and their dry weight then measured. Dry weight of tagged fruits was estimated using the regression analysis between fruit diameter and dry weight of the destructive fruit samples of 20 fruits

Yield and export determination – The 2000 season fruits were harvested at the end of January and their fresh weight was determined and afterwards they were oven-dried. During the 2001 season, harvest was during the middle of February and fruits were treated in the same manner as the previous year. The harvesting method followed normal farm procedures. The exportability of fruit was determined according to fruit fresh weight standards used in the local industry. These values were supplied by a local packhouse (Bavaria Packers Hoedspruit).

Statistical analysis

The logistic regression and the repeated measurement test in the SAS program at 5% significant was used for statistical analyses. Analyses were performed on most vegetative and reproductive parameters using one factor, irrigation. All treatments were compared for a specific date, for the specific parameter.

3 3 Results and Discussion

3.3.1 Vegetative evaluation

Irrigation treatments did not seem to have a negative effect on mean trunk cross sectional area (TCA) in the first season (February 2000), but in the second season (July 2000 - January 2001) trunk growth was reduced in all irrigation treatments in contrast to the farm control (Fig. 3.1). Trunk increases stayed at a constant rate for all the treatments, with the rate only affected when irrigation stress was applied as showed by Strabbioli (1992) in peaches. T0, T3 and the farm control (Co-F) showed the highest accumulation of TCA over the season only T3 was affected during the last part of the experiment (January 2001). T1 and T2 exhibited almost the same TCA as T0 and T3 during the beginning of the experiment but their accumulation of TCA decrease as the progressively reduced irrigation continued.

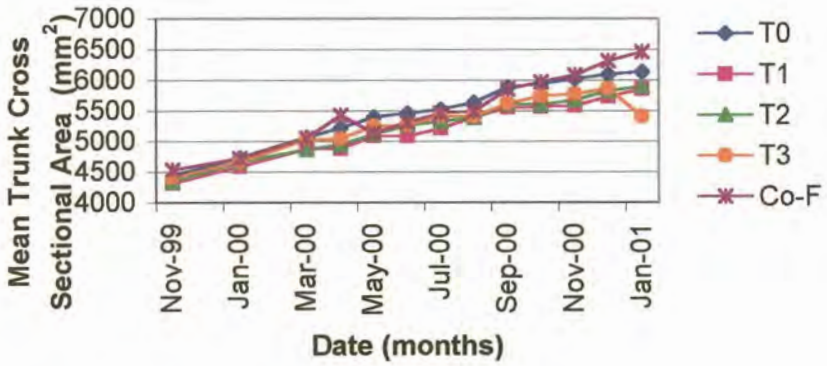

Figure 3.1. Mean trunk cross sectional area from November 1999 to January 2001 (each point represents the mean ± SD of 24 trunks).

Only the trunk growth in T3 was negatively affected during the measurement period from December 2000 to January 2001. This may be due to the stress applied in December 2000. Strabbioli (1992) observed decreasing TCA in response to water deficit in peaches. Accumulation of TCA in T1 and T2 also started to decline from September 2000 indicating the reducing effect that continuous progressively reduced irrigation appeared

to have on the trees in a manner similar as also described by Garnier et al. (1986) and Behboudian et al. (1998) in peaches and apples, respectively. Higher temperatures together with water stress may have also contributed to the higher sensitivity of T1 and T2 to water deficit (Klepper et al., 1971). Marler et al. (1989) reported a decrease in trunk growth for severely stressed citrus trees in the first season whereas a decrease in growth for the moderately stressed trees was only observed in the second season.

Trunk relative growth rate (Fig. 3.2) stayed at the same ratio for all the treatments with a decline in growth rate in all the treatments only during the winter months (May 2000 to July 2000), following a pattern similar as shown by Mills et al. (1996) in apples. This decrease was more severe in the farm control (Co-F) than in T3, although both received no water during May 2000. Only T3 was stressed during December 2000 showing a significant decrease in comparison to the other treatments

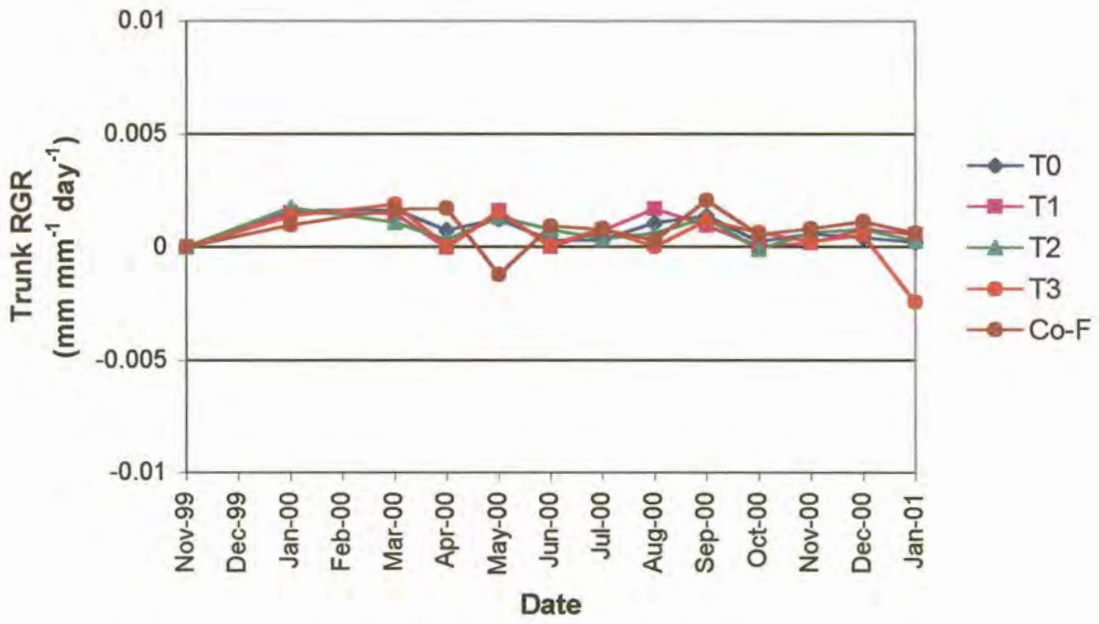

Figure 3.2 Trunk relative growth rate measured from November 1999 to January 2001 (each point represents the mean ± SD of 24 trunks).

Iancu (1985) stated that trunk growth in apples were even more reduced when no active growth takes place late in the season highlighting the emphases on our experimental farm control during June 2000 when no irrigation was applied. However, trees recovered to an acceptable norm after normal irrigation practices were resumed in July as was also found by Boland et al. (1993) and Girona et al. (1993) in peaches (Fig 3.2). This recovery effect may be due to the build up potential of the trees to rapidly take up water once irrigation is resumed as in the case with stressed fruit (Kozlowski, 1968; Mitchell et al., 1986). Our results may indicate the suitability of progressively reduced irrigation as a method to effectively manage tree size since trunk cross sectional area is linearly related to the aboveground weight and size of the tree as indicated by Westwood et al. (1970) and Mitchell et al. (1989).

Tree height showed no significant differences between treatments, with all the trees having the same pattern of growth (Fig 3.3). In all treatments there was a decline in tree height growth during the winter months June 2000 to August 2000. This could be due to a decrease in temperature that led to a slower growth rate.

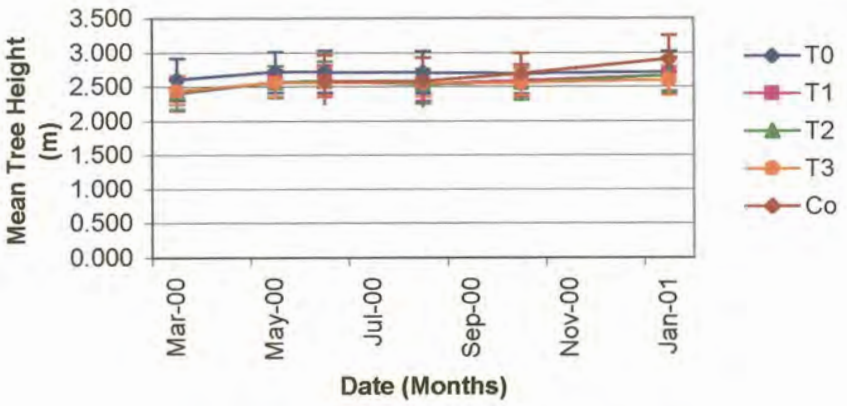

Figure 3.3. Mean tree height from March 2000 to January 2001 (each point represents the mean ± SD of 24 trees).

Tree height relative growth rates (Fig 3.4) for the different treatments were not significantly affected during the first section of the experiment up to 10 August 2000. Growth rates started to increase at a slower rate after the winter (August 2000). Cooler temperatures during the winter months led to a decrease in growth rates in all the treatments except for the farm control (Co-F) (Fig 3.4). In contrast to T0, T3 and Co-F, growth rates were slower observed in T1 and T2 possibly, coinciding with water stress effects on the trees as shown by Chalmers et al. (1981) in peaches. However, T0 trees that were irrigated up to field capacity every time, also experienced a decline in the growth rate during this time (August 2000 to January 2001). This might have been related to the lower amount of water irrigated (chapter 2.3.2) in contrast to the farm control (Co-F).

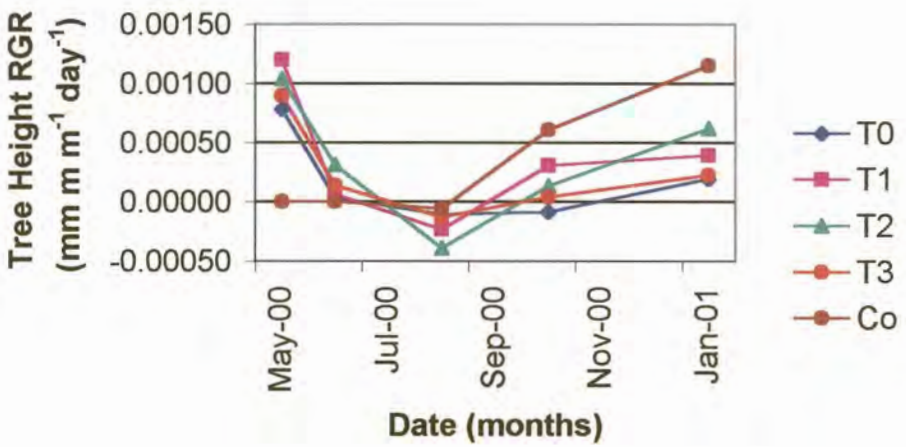

Figure 3.4. Tree height relative growth rate measured from 16 March 2000 (130 Julian days) until 10 January 2001 (10 Julian days) (each point represents the mean ± SD of 24 trees).

Shoot relative growth rate appeared not to have been significantly affected by the different irrigation treatments during the flush in November\December 2000 (Fig 3.5). Growth rate started to diminish after two weeks of shoot emergence for all the treatments in a manner similar as described by Davenport and Núñez-Elisea (1997) for mango during high temperatures. During the third week (8-14 December 2000) there was a slight increase in growth rate in all treatments, this was probably due to high rainfalls experienced during this week.

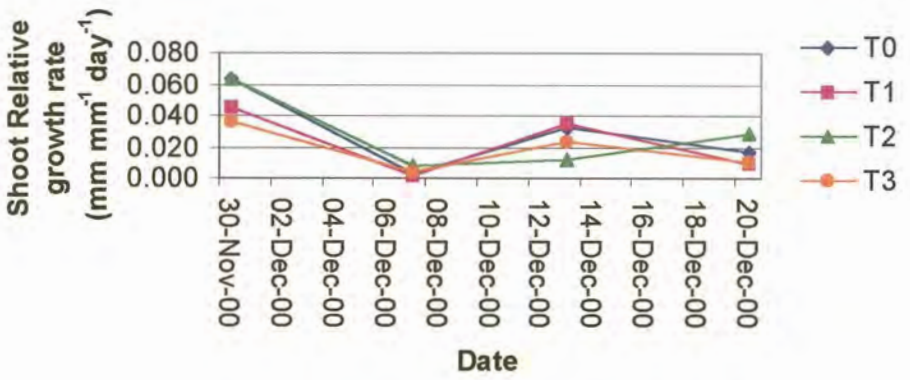

Figure 3.5. Shoot relative growth rate from 22 November 2000 to 20 December 2000. (each point represents mean ± SD of 32 shoots)

Ginestar and Castel, (1996) indicated the sensitivity of shoot growth in Citrus clementines during the end of stage two and beginning of stage three of the sigmoid fruit growth curve when shoot extension was measured in the treatments. Treatment T3 did not differ significantly from the other treatments in contrast to results by Boland et al. (1993) in regulated deficit experiments on peach trees. Steinberg et al. (1990) also indicated a decrease in stem elongation in progressively reduced irrigation treatments in peaches, in contrast to our findings in T1 and T2 that were already subjected to a second season of progressively reduced irrigation treatment. These results were not unexpected since no significant difference in photosynthesis were measured between treatments, indicating that there appeared to be no difference in the amount of assimilates available between treatments.

2.3.2 Fruit evaluation

Fruit Drop

A high percentage of fruit drop took place during the first few weeks when diameter measurements started (Fig 3.6). The highest fruit drop took place in T0 (79%) with T3 (69%) the least affected of the treatments. This is consistent with findings by Núñez-Elisea and Davenport, (1983) they suggested that most inflorescence lose all of the originally fruitlets set, this pattern of abscission is greatest during the first weeks following anthesis.

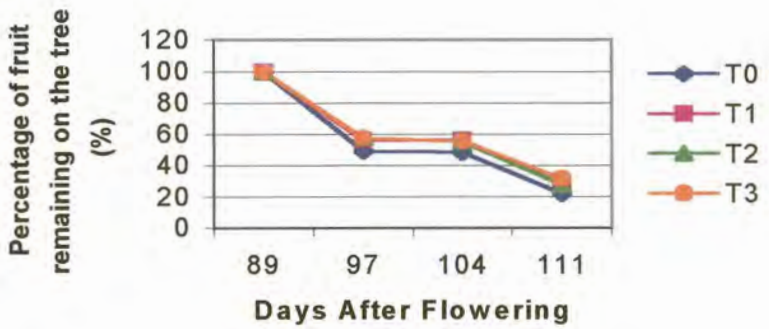

Figure 3.6 Mean percentage of fruit number remaining on the experimental trees after four weeks of fruit diameter measurements (89 DAF = 18 October 2000)

The low fruit set and high fruit drop could have been associated to the earlier flowering (2 weeks) of trees in the experiment treatments in comparison to the farm control. The low temperatures during the time of emergence could also have contributed to a lower percentage of perfect flowers, inevitably leading to a high fruit drop as found by Singh et al. (1966). Davenport and Núñez-Elisea, (1997) showed that there is a tendency to retain fruit on the distal portion of the inflorescence panicles, while abscission of flowers and fruitlets was random. Only 1% of the 13% flowers setting fruit will reach maturity (Prakash and Ram, 1984). After the initial high fruits drop in our experiment and

selection of more fruit to measure the percentage fruit number remaining on the tree stayed constant until harvest

Fruit growth

Fruit diameter increases showed the same pattern during the 1999/2000 (Fig 3.7) and 2000/2001 (Fig 3.8) seasons and no significant differences among the treatments were observed complementing the work of Jerie et al. (1989) in pears under RDI. Since fruit diameter measurements gave an indication of a double sigmoidal fruit growth pattern in mango, two periods for the implementation of the RDI treatment for the following season were identified: Six weeks before flowering and at the beginning of stage 3 of the double sigmoid growth curve.

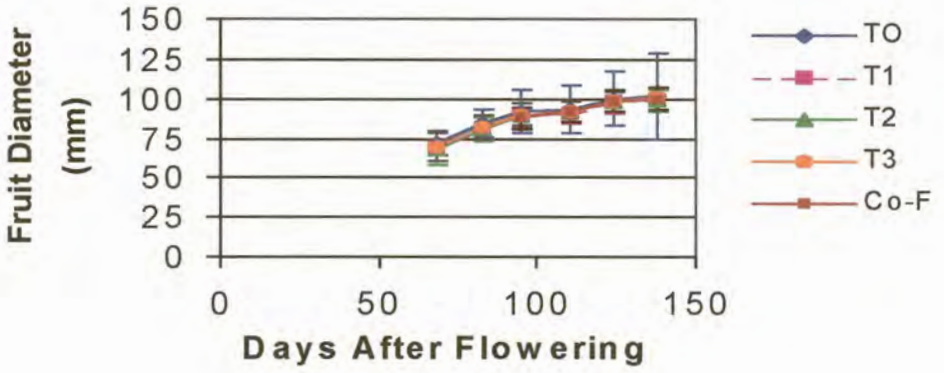

Figure 3.7. Seasonal pattern of fruit diameter for the different irrigation treatments in 1999/2000 (each data point represents the mean ± SD of 60 fruit samples).

No significant differences were observed between the different treatments during the 2000/2001 season (Fig 3.8). There was no high frequency of rainfall as was the problem in the previous year. All the treatments had the same seasonal growth pattern, even though RDI was implemented for three weeks (20 December 2000 to 10 January 2001) during the third growing phase in T3. Caspari et al. (1994) also found no effect of RDI on fruit growth in pears, although he implemented the RDI treatment before the rapid fruit growth phase. Irving and Drost, (1987) and Behboudian et al. (1994) came to the same

conclusion when implementing RDI late in the season in apple and peaches, respectively. Huang et al. (2000) found contradictory results where deficit irrigation during growth phase 3 led to a decrease in fruit growth rate of citrus fruit. However, the growth rate recovered quickly after re-watering possibly because of the genetic fruit growth potential. Since fruits are strong sinks that attract water more efficiently than other tree organs (Forshey and Elfving, 1989; Mills et al., 1996), fruit growth might not have been influenced by the reduced irrigation treatments. A lower crop load in the progressively reduced irrigation treatments (T1 and T2 compared to T0) might explain why there was no fruit growth reduction. Pavel and DeJong, (1993) showed that a higher crop load on the tree led to a smaller growth rate in peach.

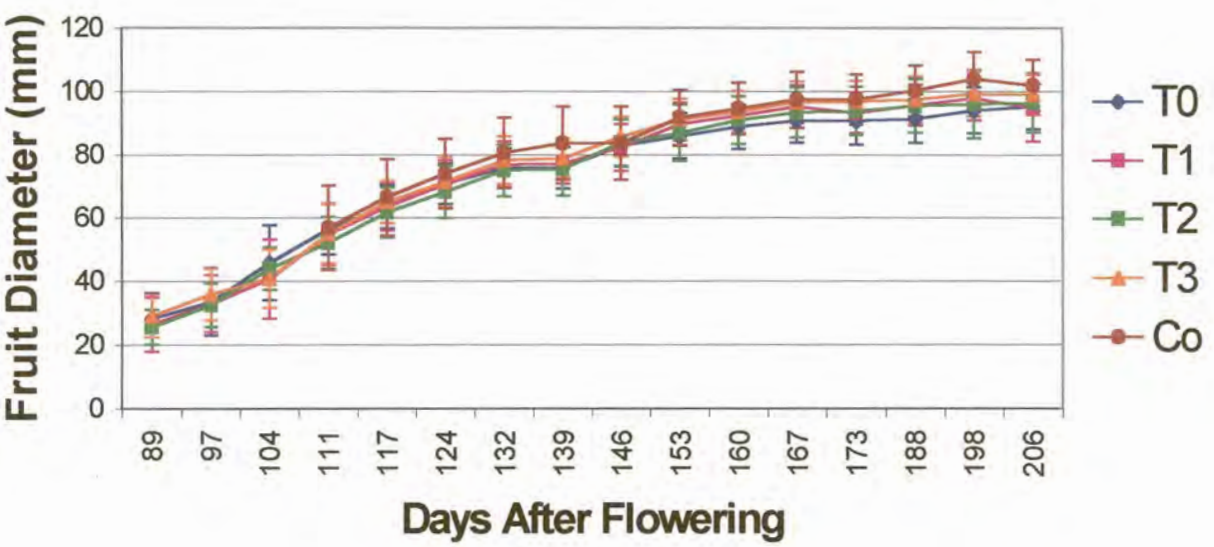

Figure 3.8. Seasonal pattern of fruit diameter for the different irrigation treatments in 2000/2001. 18 October 2000 to 12 February 2001 (89 DAF to 206 DAF each data point represents the mean ± SD of 55 fruit samples).

Seasonal fruit dry weight accumulation exhibited a double-sigmoidal growth curve (Fig.3.9) that is typical for deciduous stone fruits, such as apricot (Lilleland, 1930), and plum (Lilleland, 1933). No significant differences in fruit dry matter were observed

between the various irrigation treatments although the farm control followed by T3 exhibited the highest dry weight accumulation towards harvest. In contrast to the experimental control T0, reduced irrigation treatments tended to increase fruit dry weight content towards harvest. A similar response to progressively reduced irrigation treatments was also found by Domingo et al. (1996) in citrus.

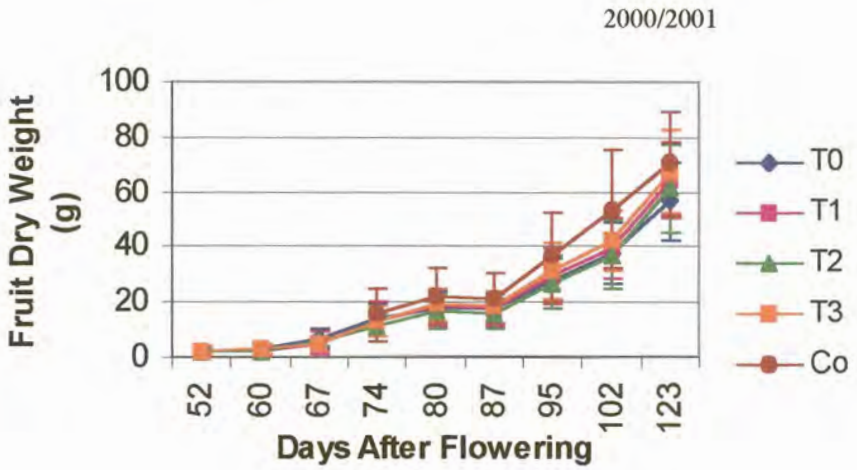

Figure 3.9 Mean fruit dry weight accumulation during the 2000/2001 season (each data point represents the mean ± SD of 55 fruit samples).

Regulated deficit irrigation practices did not have a negative effect on T3 in the 2000/2001 season (Fig 3.9). Dry weight accumulation of T3 and the farm control displayed the highest accumulation towards harvest in contrast to the other treatments.

All the treatments had similar relative growth rates (RGRs), indicating that dry matter accumulation was not negatively affected by the different irrigation practices (Fig. 3.10). Seasonal patterns of fruit growth exhibited primarily phase 2 and phase 3 of the RGR curve. Pavel and DeJong (1993,1995) found rapid increases of sucrose accumulation during the levelling of the fruit growth curve (phase 2) in peaches and apples. Diffrences in RGR between the farm control and the other irrigation treatments were minor,

although the farm control received substantially more irrigation water than the other treatment (chapter 2.3).

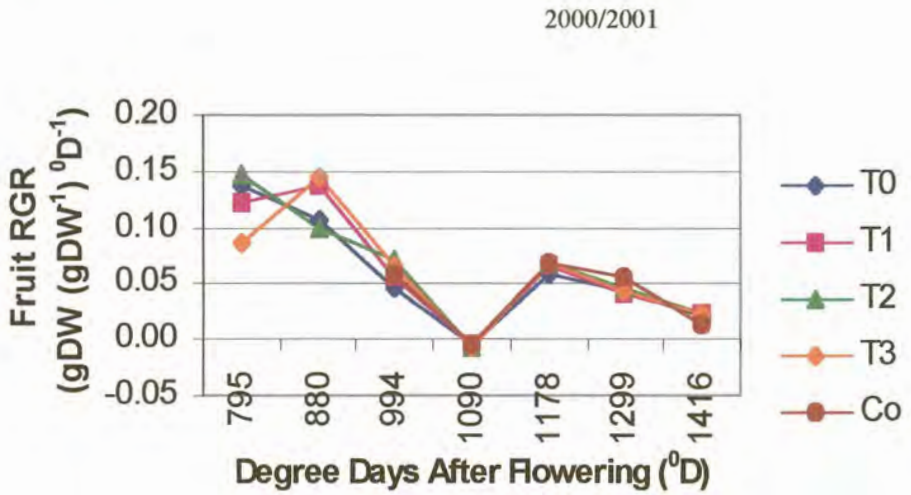

Figure 3.10. Estimated fruit relative growth rate for 2000/2001 season (Each point represents the mean of 55 fruit samples for the specific sampling date)

Domingo et al., (1996) suggested that this pattern is a useful tool to determine the onset of the rapid expanding phase and that it could consequently be used as tool to schedule RDI more efficiently. T3 had the same growth rate even though RDI was practised for three weeks in December 2000.

Fruit yield

Reduced irrigation practices had no significant effect on yield during the 1999/2000 season. In most cases fruit yield was increased in comparison to the farm control (Fig 3.11A) supporting results in peaches of (Boland et al., 1993; Domingo et al., 1996). The larger amount of irrigation water applied to the farm control in contrast to our irrigation treatments did not have an effect on mean final fresh weight. The irrigation treatments might also have had a more effective usage of water applied than the farm control since they were pulsed and the farm control irrigated for a few hours per irrigation cycle thus leading to a higher leaching of water and nutrients out of the soil profile.

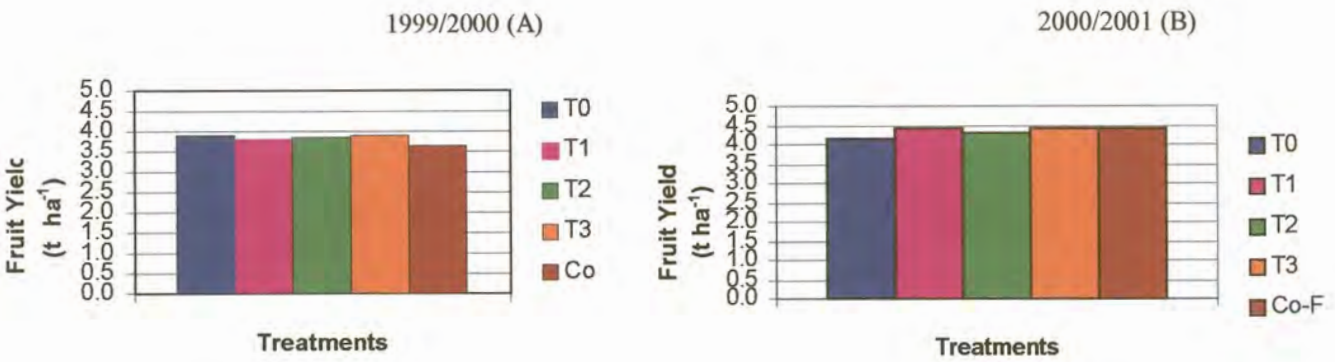

Figure 3.11. Fruit yield for the different irrigation treatments at harvest for the 1999/2000 (A) season (each bar represents the mean of 60 fruit samples extrapolated to a hectare basis) and 2000/2001 (B) season (each bar represents the mean of 55 fruit samples extrapolated to a hectare basis).

The 2000/2001 season had a higher yield per hectare than the previous season Fig 3.11(B) since the trees were one year older. All the treatments except for T0 had the same yield indicating that the reduced irrigation did not show negative effects on fruit yield during the two years following the irrigation of the experiment. The low yield in T0 might be associated with shallower soil depths in two of the replicates in contrast to the other treatments T1 and T2.

During the 1999/2000 season, more than 80% of the fruits of all the treatments and farm control, were suitable for export (Fig. 3.12 A). Most of the fruit that did not fall into the export category were too large. The average count size distribution was 7-9 for all the different treatments. An explanation for the too large fruits in the 1999/2000 season could be because trees were thinned down to five fruits per tree, thus eliminating the competition effect between fruits of trees with a higher crop loads. Mcfadyen et al. (1996) observed a similar response in peaches when a high crop load led to a higher water deficit in the plant and in return to a decline in fruit size due to larger fruit shrinkage in the night in contrast to control trees.

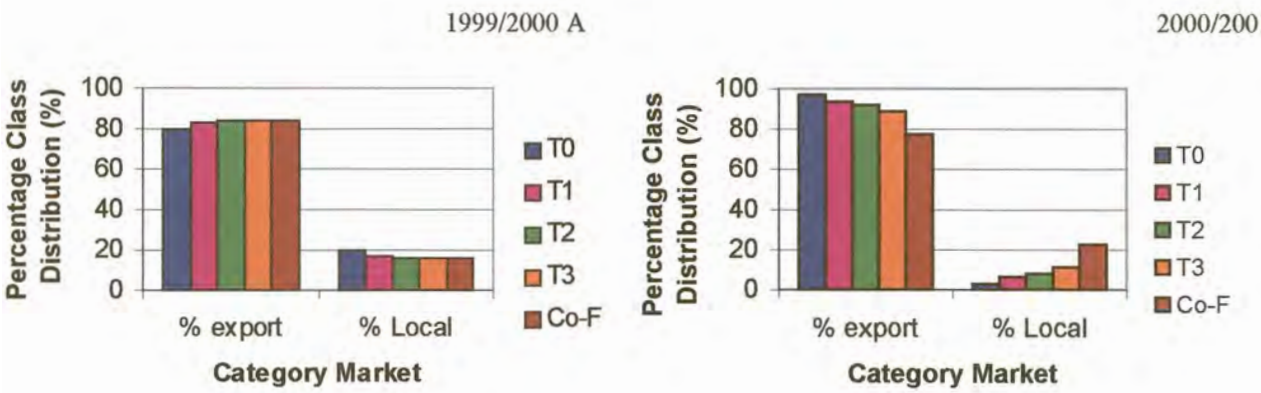

Figure 3.12. Percentage fruit size distribution for the different irrigation treatments at harvest 1999/2000 (A) season (each treatment represent the sixty fruit at harvest) and 2000/2001 (B) season (each treatment represent the fifty five fruit at harvest)

The amount of fruit falling in to export categories were larger in the 2000/2001 season in comparison to the previous year 1999/2000 season, with most of the fruit falling into the6-8 categories. The smaller fruit size compared to the previous year was due to the trees not being thinned down that lead to a decrease in fruit size. Because of the smaller fruit size 90% of harvested fruit were suitable for export in all treatments.

2.4 Conclusion

Vegetative growth parameters were slightly affected (tree height) in some parameters monitored, while reproductive growth parameters appear not to have been negatively affected by the progressively reduced and regulated deficit irrigation. Trunk cross sectional area growth followed the same pattern over both seasons for all the treatments, except when RDI stress was applied in T3 and the farm control (Co-F), did the rate of growth decline. Trees however quickly recovered upon re-watering. Tree height and shoot growth was not negatively affected with a constant growth over both seasons. Tree

height declined during the colder parts of the year as expected with low temperatures. Shoot extension rate also decreased after a high initial growth rate, in concordance with environmental conditions.

Fruit growth exhibited the same growth pattern during both growing seasons. No significant differences were found among the different treatments in fruit diameter in the 2000 and 2001 season. Even nitrogen deficiencies (Chapter 2) did not have an effect on fruit growth rate. Fruit growth followed a typical double sigmoidal growth pattern depicting three-growth stages. Estimated fruit dry weight accumulation did not display any significant differences among the treatments. Eighty percent of fruit harvested in 1999/2000 in the treatments were suitable for export with most fruits not falling into this category because they were too large. The 2000/2001 season had an average increase of 10% to ninety percent exportable.

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4. Physiological Responses to Progressively Reduced Irrigation and Regulated Deficit Irrigation

4.1 Introduction

One of the most limiting environmental factors for crop production is the lack of water. In South Africa the water supply is limited and the addition of water through irrigation during the summer months ensures successful production of crops in general and mango in particular. Successful crop production is, however, not only influenced by environmental factors but also by the genetic composition of the cultivar. Actual yield, tree growth and development are mediated by several endogenous factors, including previous fruit load, pre-and postharvest vegetative growth, flowering maturity of terminal shoots, nutritional status and carbon to nitrogen ratios (Schaffer et al., 1994). These plant characteristics are both directly and indirectly affected by environmental factors such as light, temperature, vapour pressure deficit and water availability and will be affected more severely with dramatic changes in environmental factors, leading to a decline in tree performance. Nonetheless, mediated stress or the release of stress caused by normal seasonal changes, provide conditions that result in the progression of crop cycles due to phenological changes in the plant (Whiley and Schaffer, 1997). Understanding the impact of the environment on tree physiology and growth, and the particular adaptive strategies developed through selection and evolution, can provide a framework to manage the crop to maximize the genetic yield potential (Schaffer et al., 1994).

The productivity of a crop is dependent on the amount of carbon fixed by the process of photosynthesis during the season and the partitioning of these carbohydrates to various plant organs. The effect of environmental stress experienced by the plant can be determined by photosynthesis. In the majority of studies using fruit trees, the method employed to determine photosynthetic efficiency involves the measurement of CO_2 uptake by the leaf (Whiley and Schaffer, 1997). The rate of photosynthesis of a crop is greatly influenced by photon flux density, temperature, change in vapour pressure deficit (Syvertsen, 1996) and will decline if water stress is experienced (Flore et al., 1985). This

is because water stress affects stomatal aperture and chloroplasts function (Beadle et al., 1985). Measuring the rate of photosynthesis as an indicator of water stress should not be done alone, but in conjunction with measurements of stomatal conductance as water stress leads to a closure of stomata that directly influences the rate of photosynthesis. In almonds, the manipulation of irrigation to cause water stress led to a decrease in both stomatal conductance and photosynthesis (Girona et al., 1993). Stomatal closure occurred before photosynthetic rates declined when irrigation is reduced and may therefore be a more sensitive parameter to measure than photosynthesis (Girona et al., 1993). This is however crop dependent, because the opposite was found in Hazelnuts (Girona et al., 1994).

During water stress most plants experience stress in the form of reduced vegetative growth, notably affecting leaf size, without significantly influencing photosynthesis of the plant (Hsiao, 1993). However, as the stress intensifies photosynthesis per unit leaf area will begin to decline (Boyer, 1970). This will only be noticed in the beginning of the stress period during the hottest part of the day (midday), but as the stress continues this becomes more apparent during the earlier parts of the day and the longer time it takes to recover during the afternoon. With photosynthesis restricted to fewer and fewer hours, carbon accumulation declines; affecting vegetative and fruit growth more negatively. The amount of carbon accumulation during water stress is closely correlated with stomatal conductance (g_s).

The restriction of CO_2 uptake caused by the increased amount of closed stomata, cannot be the only cause for reduction in photosynthesis. The metabolic capacity for photosynthesis of cells in the affected leaves is also reduced, thereby reducing the rate of photosynthesis (Hsiao, 1993). This means that when the plant is re-watered it takes longer to adjust to the optimum condition and at the same time the damaging effect of water stress on the plant cells might be overcome.

Caspari et al. (1994) showed with pears that although water stress early in the season had no significant effect on g_s between the controlled and stressed trees, the difference in g_s

became more distinct as time progressed. Trees exposed for a significant time to stress took more than two weeks to recover after full irrigation had been resumed indicating a lasting affect of stress on the plant (Behboudian et al., 1994). A similar pattern was found in lychee (Stern et al., 1998) where low irrigation frequency was associated with low g_s. In peaches, Marsal and Girona, (1997) highlighted the sensitivity of different phenological stages of the tree to deficit irrigation. Williams and Matthews, (1990) noted that in grape vines g_s also declined as stress intensified and that in most cases vine leaves did not recover during the night as sufficiently as the non-stressed ones did. In peaches, Girona et al. (1993) showed that g_s and photosynthesis were affected negatively by water stress. The effect on photosynthesis was, however, not as great as on g_s indicating that the leaves of peach trees are better adapted to overcoming stress. This is only possible when trees are exposed to a gradual stress instead of abrupt stress.

In some cases, trees exposed to a deficit irrigation situation use water more efficiently than non-stressed ones. Girona et al. (1993) found that although stomata closed rapidly in peaches when stress is experienced, the effect on photosynthesis was not as great in comparison to the control. This might have been due to environmental factors, but trees could also adapt to the stress situation if they were exposed to a gradual stress for a continuous period (Harrison et al., 1989).

The effect that water deficit can have on the ability of fruit trees to photosynthesize and transpire has not received as much attention in the past as other environmental factors such as the effect of temperature and photon flux density. Most authors in this field (water stress) concentrated on temperate fruit crops with little attention being given to subtropical fruit trees. The objective of this research was to study effects of progressively reduced and deficit irrigation treatments on photosynthesis and stomatal conductance of the mango during the season.

4.2 Material and Methods

The same experimental setup and site was used as described in chapter 2.2

4.2.1 Measurement of Seasonal Changes in Stomatal conductance (g_s) and Photosynthesis (Pn)

Seasonal changes in g_s among treatments were started during the middle of June 2000. Measurements were recorded using a porometer (LICOR-1600, Licor Inc., NE, USA). Records were taken on cloud-less days at midday at all measurement periods in monthly intervals, except for days when weather did not permit or when trees were flushing vigorously and no unshaded leaves of the same age as previously for measurements could be found on the tree. Three trees in three replicates were selected in each treatment, and four leaves measured on each tree (total 36 leaves per treatment).

Measurement of Pn was initiated during the beginning of July 2000 and was also evaluated on a monthly basis using an Infrared Gas Analyzer (Ciras, PP-System, U.K.). Measurements were taken on sunny days and on fully exposed leaves. No measurements were taken in months with high activity in vegetative growth due to the lack of mature and fully exposed leaves. Three trees for three replicates of each treatment were measured, using three leaves in each tree (total 27 leaves per treatment). Pn was measured three times a day at 8:00, 11:00 and 14:00 to create a diurnal curve. Measurements during the late afternoon were not possible because of a shading effect by the windbreaks adjacent to the block.

During two periods, a month before flowering and in the third growing stage of fruit growth, irrigation water was withheld in T3 for about 4 weeks. The first period (a month before flowering) is well known in mango cultivation, especially in countries where the minimum temperature is not low enough to synchronize flower initiation (Singh 1977, Bernier et al., 1981). Irrigation was withheld from 19 May 2000 until 19 June 2000 and g_s was measured after 21 days of stress. Trees were re-irrigated after the farm manager started re-irrigating the farm control trees. The second period irrigation of RDI was from 16 December 2000 until 15 January 2001. During the first week of stress midday g_s was measured on three trees per treatment using three leaves on each tree. During the same

time water deficits were recorded for each treatment taking continuous capacitance sensor measurements as described in chapter 1.2.3. Stomatal conductance measurements were discontinued after one week because of high rainfall (see chapter 1). However, the stress treatment was continued until neutron probe measurements indicated that the soil profile started to dry from the bottom.

Statistical analysis

According to the procedure described in chapter 3.2 statistical analyses were calculated by the department of statistics University of Pretoria. Data were tested for one factor, irrigation, for specific dates and treatments.

4.3 Results and Discussion

4.3.1 Seasonal changes in Stomatal conductance and Photosynthesis.

Maximum temperatures remained relatively constant during the growing season of 2000 (Fig.4.1). Minimum temperature fluctuations during the season were, however, much more apparent, especially during the winter (Jun-Jul) and the summer (Oct-Dec).

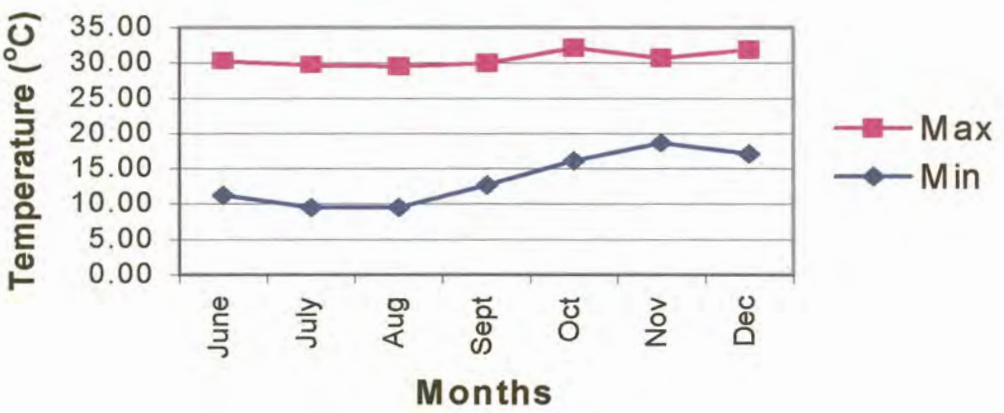

Figure 4.1. Average monthly maximum and minimum air temperatures experienced during the 2000 season.

The optimum growing temperature range for mango is 24 to 30°C. Photosynthesis drastically decreased as temperature started to decline reaching the lowest threshold of 15/10°C (Pongsomboon, 1991). Taylor and Rowley, (1971) reported that temperatures below 10°C inhibited photosynthesis and other metabolic process in leaves. This may suggest that air temperatures required below this threshold for shoot growth (Whiley et al., 1989) are also a limiting factor for physiological processes such as gas exchange (Whiley et al., 1997).

Photosynthetically active radiation (PAR) differed significantly between summer (October 2000) and winter (July 2000). (Fig. 4.2)

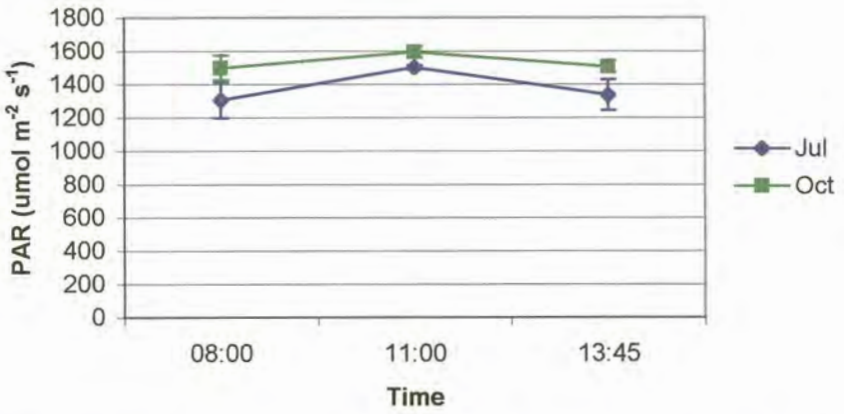

Figure 4.2 Diurnal time course for photosynthetically active radiation between summer (October) and winter (July) in the 2000 growing season (each point represent the mean of 27 leaves)

The mean PAR value for winter accounted for about 1300 µmol m^{-2} s^{-1} this being much higher than reported by Schaffer and Gaye, (1989) for Florida. They established that the leaf light saturation point of container grown Turpentine mango trees in the winter was about 350 to 400 µmol m^{-2} s^{-1}. Summer values were also high, averaging around 1650 µmol m^{-2} s^{-1} during midday. Whiley et al., (1993) calculated a leaf light saturation point for mature Tommy Atkins trees under field condition in the winter of 630 µmol m^{-2} s^{-1} and 1200 µmol m^{-2} s^{-1} in the summer. These values are, however, cultivar dependent. The PAR values recorded for both seasons appeared to be sufficient for trees to

photosynthesize, because mango trees (Kensington) with induced water stress only photosynthesized at two thirds of their potential (Whiley and Schaffer, 1997).

Photosynthetic rates measured over the winter season showed no differences between treatments for the 2000 season (Fig. 4.3). Significant differences were, however, recorded during the summer among the treatments and T2 (Fig. 4.3). Mean photosynthesis rates were also much lower in the summer for all the treatments compared to in the winter. During the winter trees recovered faster during the afternoon than in the summer, when the midday depression continued much later into the afternoon.

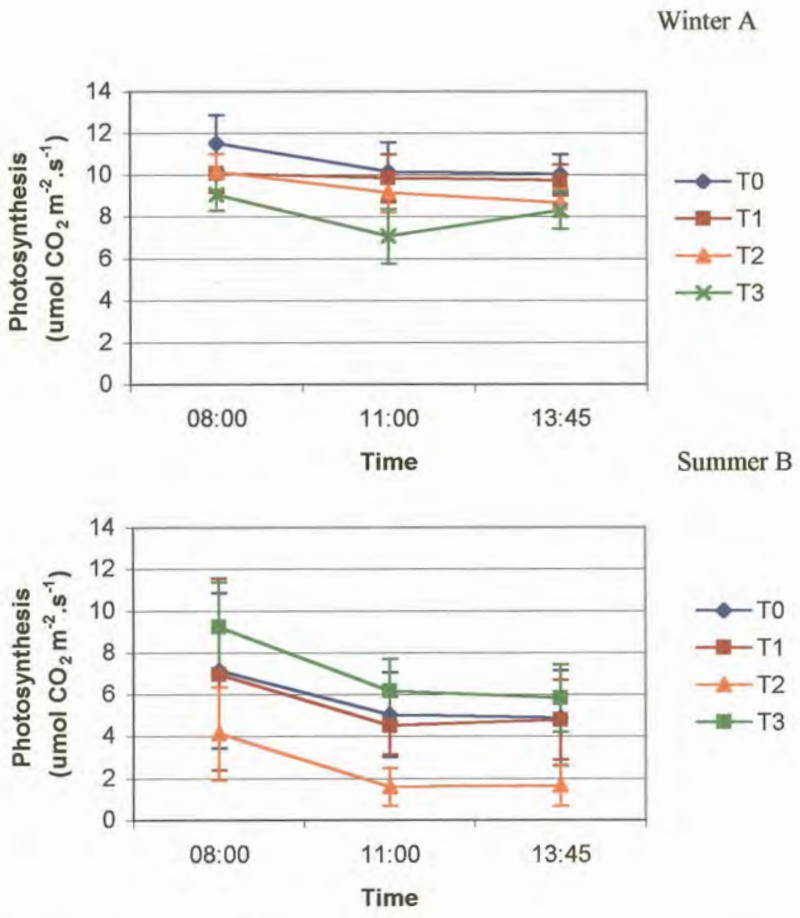

Figure 4.3. Diurnal pattern of leaf photosynthesis of the different irrigation treatments in winter (July 2000 A) and summer (October 2000 B) (each point represent the mean of 27 leaves).

Values for both seasons corresponded well with results from Whiley et al., (1993) who found averages of 10μmol CO_2 m^{-2} s^{-1} for the winter and 14μmol CO_2 m^{-2} s^{-1} for the summer in mango. The difference in photosynthesis in winter between T3 and the other treatments may have been due to stress that was induced in T3 a month prior to these experiments that had a lagging influence on photosynthesis although it was full irrigated after one month of water stress. Similar responses have also been reported by Goldhamer et al. (1999) and Behboudian et al. (1994), who suggested that the soil profile in field grown trees took a longer time to refill after resuming fully irrigation, leaving a large deficit for two weeks after full irrigation. During the summer, photosynthesis differed significantly between T2 and the other treatments. This might be due to the effect of leaf age and the phenological stage that some of the branches were in, or the effect the treatment had on the tree. Mango trees are evergreen and can have leaves ranging from a few months old to a few years old (Whiley et al., 1993; Schaffer et al., 1994) with different photosynthetic abilities.

Midday photosynthesis for the period July to October (Fig. 4.4) showed the same pattern as the seasonal changes (Fig. 4.3) between treatments. Significant differences between treatments started to appear in September. T0 and T2 were more affected than the other treatments during September 2000 and October 2000.

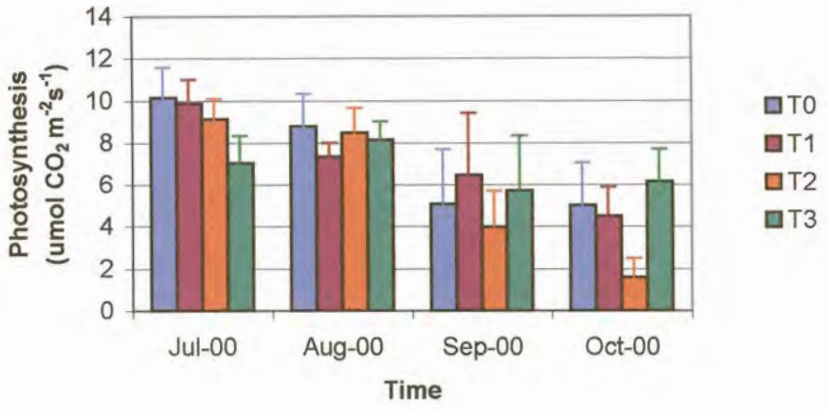

Figure 4. Seasonal changes among treatments in midday photosynthesis from July to October for the 2000 season (each point represent the mean of 27 leaves).

The considerable decrease in photosynthesis from September in T2 might be due to the declining effect of shoot growth and leaf size area canopy due to prolonged water stress it was exposed to. This compare well with results from Williams and Matthews, 1990; Salisbury and Ross, 1991 and Caspari et al., 1994. This decrease could have affected the amount of chloroplasts present in the leaf or the ability to photosynthesize optimally, even under optimal conditions (Leegood and Walker, 1985; Salisbury and Ross 1991).

Stomatal conductance varied greatly over the season between treatments, highlighting the fact that g_s is an important indicator of water stress. Significant differences existed in July between T3 (RDI treatment) and the other treatments (Fig. 4.5). This indicated the effect of the stress T3 trees were exposed to during this period. Variability during the season among T0, T1 and T2 was not as great, although a steady decline in g_s was observed in all treatments

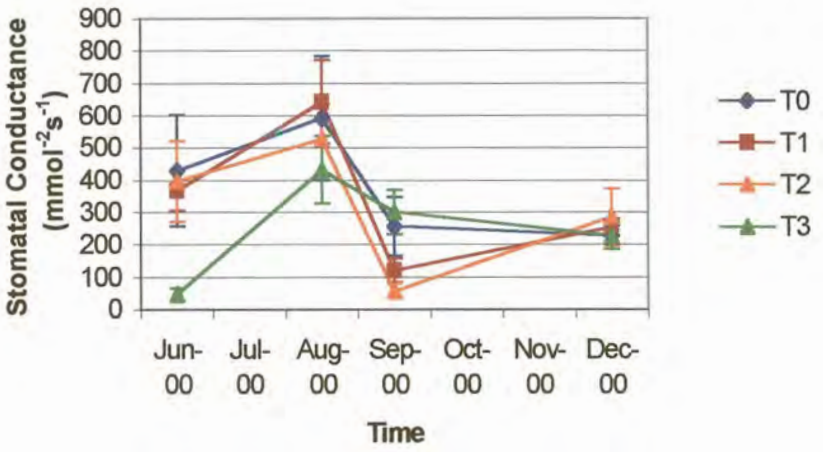

Figure 4.5. Seasonal variability in stomatal conductance between treatments from June to December for the 2000 season (Each point represent the mean of 27 leaves).

Stomatal conductance rates during June and August compared favourably with those found by Pongsomboon et al. (1992) at a midday temperature of 30°C and g_s of 750 mmol m^{-2} s^{-1}. The decrease in g_s later in the season might be explained by the higher temperatures experienced during September and December and low relative humidity of 28% and 32%, respectively, in comparison to the earlier months. Pongsomboon et al. (1992) suggested that g_s is much higher under more favourable relative humidity conditions.

Prolonged exposure to stress may give plants the ability to adapt to stress and overcome problems with low soil water availability, while still opening their stomata, as was found in T1 for August. Jones, (1985) found that trees had the ability to adapt to water stress by lowering the potential gradient between the soil and leaves, thereby having the ability to open their stomata. The low value recorded for T2 during September may be due to the effect of leaf age as described by Syvertsen, (1996), where leaves of different age in the tree canopy gave variable results in g_s. It is apparent that great caution must be taken (as with photosynthesis measurements) to lessen the effect of variability in the tree when selecting leaves to measure g_s.

4.3.2 Physiological response of trees exposed to regulated deficit irrigation (RDI).

At midday, stress markedly influenced the T3 treatment in comparison with the other treatments during the stress period in June (Fig. 4.6). Values differed significantly with a mean low of 46 mmol m^{-2} s^{-1} measured during midday for T3, the other treatments exhibited the same range as those described by Pongsomboon et al. (1992).

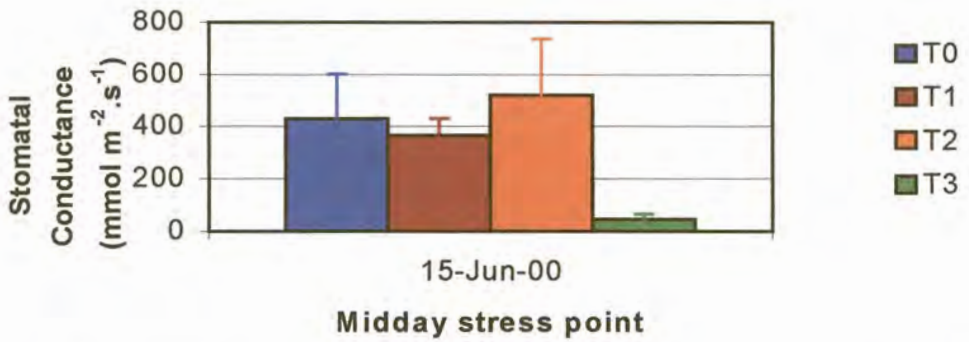

Figure 4.6. Differences in stomatal conductance differences between treatments for the stress period 23 May 2000 until 22 June 2000 (measurement date 15 June 2000, each point represents the mean of 18 leaves of 9 trees).

Low g_s rates observed in T3 in comparison with the other treatments seemed not to be unusual for RDI as has been reported by Girona et al. (1993) in hazelnuts and by Marsal et al. (1997) in peaches. Low stomatal conductance rates of trees exposed to water shortage seems to be a much more sensitive indicator of water stress than photosynthesis (Marsal et al., 1997).

The second stress period (during stage 3 of fruit growth) had a negative effect on the amount of water available for uptake by the trees for the stressed T3 treatment and the non-stressed treatment T0 (Fig. 4.7). Readings from the capacitance sensors indicated a sharper decline at 30 cm for the T3 treatment than for T0 treatment. The T0 and T3 treatments had both a decline at depths of 60 and 90 cm in the root zone area. The T3

treatment had, however, a sharper decline from the second day of stress (17 December 2000) in the 30 cm root zone area.

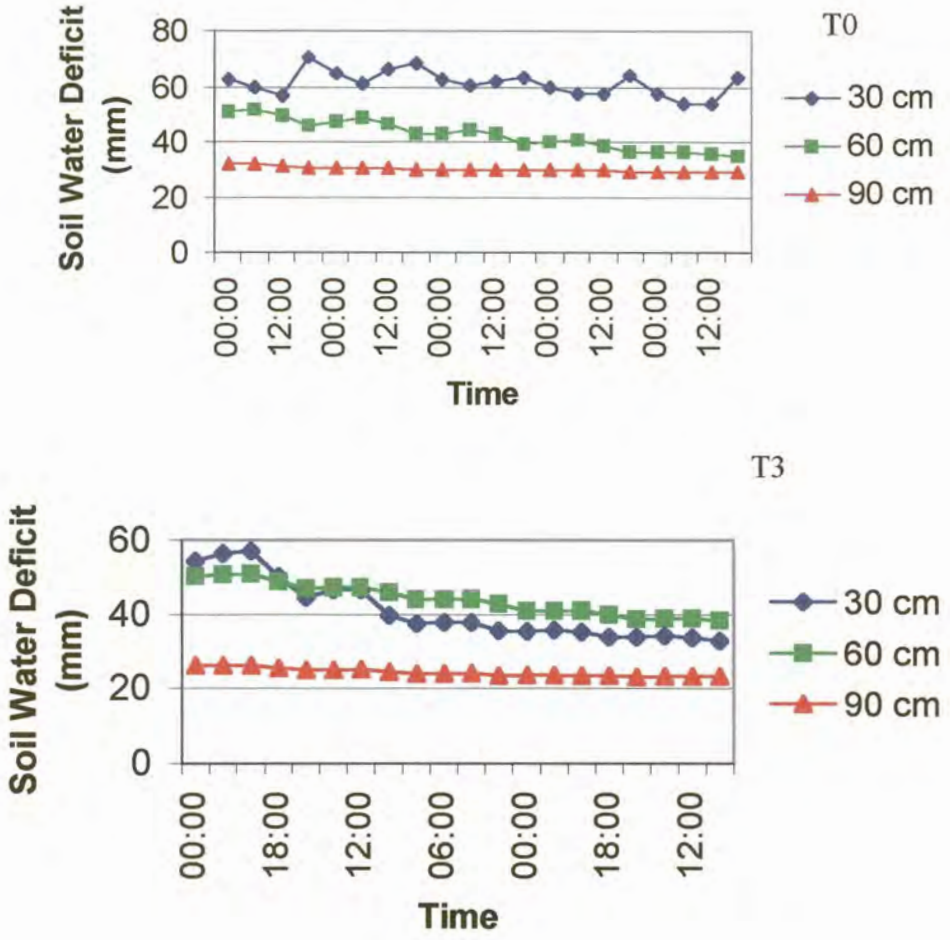

Figure 4.7. Differences recorded in soil available water (relative values) with capacitance sensors between treatments T0 and (16 to 21 December 2000).

The dramatic decline in the 30 cm root zone area of treatment T3 may be due to the high temperatures experienced in this specific week (mean 37°C) and the low water holding capacity of the soil (see chapter 2). The relatively low values recorded for the 60 and 90 cm in the T3 treatment in contrast with T0 could be attributed to the shallow soil for T3 that was only 90 cm deep in contrast to T0 that was 110 cm deep which was then followed by a layer of weathering saprolite in both treatments.

The stress period in summer did not have such a dramatic effect on g_s, although the effect of the stress was evident in soil moisture readings. Stomatal conductance recorded for T0 and T3 were, however, lower than those described for mango by Pongsomboon et al. (1992). There were no significant differences between the two treatments for the specific stress period in contrast to the first stress period.

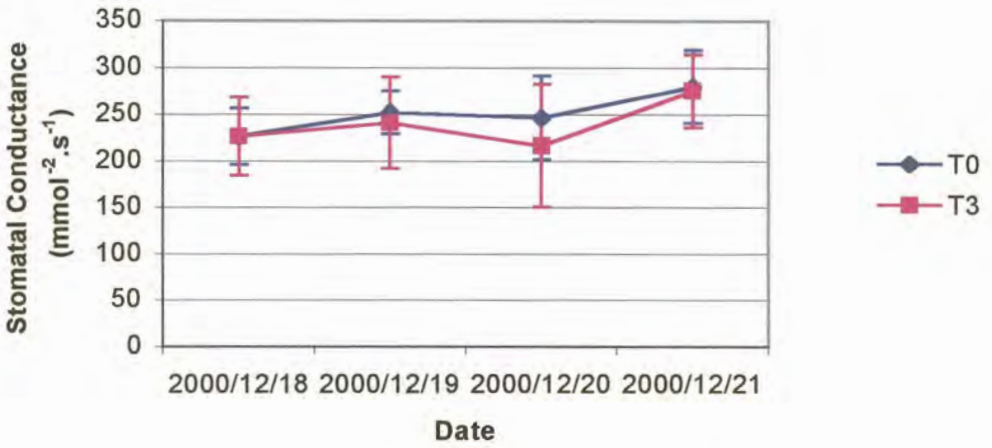

Figure 4.8. Stomatal conductance differences recorded between treatments T0 and T3 16 to 21 December 2000 (each point represent the mean of 18 leaves of 9 trees).

No evidence could be found to support the results for the specific stress period initiated in T3. Most authors had findings contrary to our results with differences between stress and non-stress peach trees due to low or no-rainfall during the time of there experiment (Girona et al., 1993; Marsal et al., 1997; Stern et al., 1998). Summer rainfall and effects of root growth into the surrounding rows (Schaffer et al., 1994) from where trees extract water might have led to only a moderate stress in summer in our RDI treatments. This growth could have been caused by high rainfall during the previous year (see chapter 2) that led to a low irrigation frequency and subsequent root growth into the rows. The reason why trees did not behave in the same pattern during the winter might possibly be due to the low availability of soil moisture during this time in the whole orchard. The higher g_s recorded during the last day was probably due to the higher relative humidity as well as the effect of clouds that led to a lower irridiance. Similar results were found by Schaffer et al. (1994).

Leaf water potential is probably the most sensitive indicator of water stress experienced in the plant (Girona et al., 1993; Marsal et al., 1997). Measurement of this physiological parameter was, however, not possible in mango as was done by Larson et al., (1989), Pongsomboon et al.,(1992) and Davenport and Núñez-Elisea, (1997) in mango. The main reasons for not including leaf water potential measurements in this project was, because there was no clear visible difference between latex and water that was excreted from the leaf when it is placed in the pressure chamber. Secondly water potential measurements may be not such a sensitive indicator in the beginning of a stressing period (Goldhamer et al., 1999). It is possible that the use of this instrument in mango research is more subjective than in other temperate crops.

4.4 Conclusion

Progressively reduced irrigation does not seem to negatively affect stomatal conductance or photosynthesis during the growing season. Most of the differences between treatments could be attributed more to environmental changes over seasons than any physiological changes taking place in the plant. Regulated deficit irrigation on the other hand had a definite effect on stomatal conductance during the first stressing period when water availability in the soil was very low. When the second period of stress was initiated the effect of stress was cancelled by rain and root growth, to an extent that there was no difference in stomatal conductance between treatments.

4.5 References

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5. Summary

Mango trees generally did not seem to be affected negatively by the different irrigation treatments they were subjected to. A high water infiltration rate indicated the suitability of the soil for pulse irrigation, with the soil profile having a high sand content and low silt and clay percentage. Total irrigation applied to the full-irrigated treatment was considerably lower than the farm control. Nutritional deficiencies experienced during the second season did not affect tree parameters negatively in comparison to the farm control. Growth parameters were not significantly affected during the first season, with most decreases in growth rate due to non-water environmental factors. Fruit growth and total yield were improved during the second season, indicating that physiological parameters were not negatively influenced between treatments. Stomatal conductance and photosynthesis gave the same pattern for all treatments with significant changes only during seasonal changes. Severe water stress led to a decrease in the rate of the physiological parameters.

6 Appendix

Table 1 Analysis of repeated measurements (one factor, completely randomized) of water deficit for 14 months from December 1999 to January 2001.

Source of variation	df	SS	MS	F	
Source	55	21968.99	399.43	4.27	
Error	132	12357.23	93.61		
Total	187	34326.22			
Irrigation	3	671.39	223.79	2.39	ns
Months	13	19925.67	1532.74	16.37	ns
Irrigation * Months	39	1319.42	33.83	0.36	ns

Least Squares Means for Treatment effect

	T0	T1	T2	T3	
T0	.	0.0593	0.8556	0.0952	ns
T1	0.0593	.	0.0390	0.8249	ns
T2	0.8556	0.0390	.	0.0647	ns
T3	0.0952	0.8429	0.0647	.	ns

Table2 Analysis of repeated measurements (one factor, completely randomized) of trunk growth for 13 months from December 1999 to January 2001.

Source of variation		df	SS	MS	F	
Month	November					
Source		3	30.77	10.25	0.33	
Error		108	3378.11	31.27		
Total		111	3408.89			
Irrigation		3	30.77	10.25	0.33	ns
Month	January					
Source		3	18.95	6.13	0.19	
Error		108	3586.26	33.26		
Total		111	3605.21			
Irrigation		3	18.95	6.13	0.19	ns
Month	March					
Source		3	78.74	26.24	0.71	
Error		108	3965.60	36.71		
Total		111	4044.34			
Irrigation		3	78.74	26.24	0.71	ns
Month	April					
Source		3	148.25	49.41	1.25	
Error		108	42.72.54	39.56		
Total		111	4420.79			
Irrigation		3	148.25	49.41	1.25	ns
Month	May					
Source		3	136.39	45.46	1.08	
Error		108	4539.67	42.03		
Total		111	4676.06			
Irrigation		3	136.39	45.46	1.08	ns
Month	June					
Source		3	129.55	43.18	1.06	
Error		108	4403.30	40.77		
Total		111	4532.86			
Irrigation		3	129.55	43.18	1.06	ns

Month	July					
Source		3	103.03	34.34	0.79	
Error		108	4673.59	43.27		
Total		111	4776.62			
Irrigation		3	103.03	34.34	0.79	ns
Month	August					
Source		3	87.05	29.01	0.74	
Error		108	4249.89	39.35		
Total		111	4336.95			
Irrigation		3	87.05	29.01	0.74	ns
Month	September					
Source		3	125.99	41.99	0.88	
Error		108	5154.33	47.72		
Total		111	5280.33			
Irrigation		3	125.99	41.99	0.88	ns
Month	October					
Source		3	171.65	57.21	1.17	
Error		108	5266.79	48.76		
Total		111	5438.45			
Irrigation		3	171.65	57.21	1.17	ns
Month	November					
Source		3	183.81	61.27	1.20	
Error		108	5519.92	51.11		
Total		111	5703.74			
Irrigation		3	183.81	61.27	1.20	ns
Month	December					
Source		3	128.96	42.98	0.81	
Error		108	5706.65	52.83		
Total		111	5835.62			
Irrigation		3	128.96	42.98	0.81	ns
Month	January					
Source		3	1198.12	399.37	0.40	
Error		108	106502.42	986.13		
Total		111	107700.54			
Irrigation		3	1198.12	399.37	0.40	ns

Table 3 Analysis of repeated measurements (one factor, completely randomized) of tree height for 6 months measured from March 2000 to January 2001.

Source of variation		df	SS	MS	F	
Month	16/03/2000					
Source		3	0.84	0.28	4.56	
Error		124	7.62	0.06		
Total		127	8.46			
Irrigation		3	0.84	0.28	4.56	*
Month	09/05/2000					
Source		3	0.59	0.19	3.26	
Error		124	7.49	0.06		
Total		127	8.08			
Irrigation		3	0.59	0.19	3.26	*
Month	16/06/2000					
Source		3	0.50	0.16	2.53	
Error		124	8.30	0.06		
Total		127	8.81			
Irrigation		3	0.50	0.16	2.53	*
Month	10/08/2000					
Source		3	0.64	0.21	3.75	
Error		124	7.15	0.05		
Total		127	7.79			
Irrigation		3	0.64	0.21	3.75	*
Month	16/10/2000					
Source		3	0.36	0.12	2.10	
Error		124	7.09	0.05		
Total		127	7.45			
Irrigation		3	0.36	0.12	2.10	*
Month	10/01/2001					
Source		3	0.23	0.07	1.13	
Error		124	8.46	0.06		
Total		127	8.69			
Irrigation		3	0.23	0.07	1.13	ns

Table 4 Analysis of repeated measurements (one factor, completely randomized) of shoot growth for 5 weeks measured from November 2000 to December 2000.

Source of variation		df	SS	MS	F	
Date	22/11/2000					
Source		3	200583.163	66861.054	0.15	
Error		21	9233070.144	439670.007		
Total		24	9433653.307			
Irrigation		3	200583.1631	66861.0544	0.15	ns
Date	30/11/2000					
Source		3	38250842.1	12750280.7	0.86	
Error		21	312545891.7	14883137.7		
Total		24	350796733.8			
Irrigation		3	38250842.13	12750280.71	0.86	ns
Date	07/12/2000					
Source		3	13622663.3	4540887.8	0.97	
Error		21	98787025.1	4704144.1		
Total		24	112409688.4			
Irrigation		3	13622663.25	4540887.75	0.97	ns
Date	13/12/2000					
Source		3	29259241.5	9753080.5	0.62	
Error		21	333024968.0	15858331.8		
Total		24	362284209.5			
Irrigation		3	29259241.53	9753080.51	0.62	ns
Date	20/12/2000					
Source		3	1407905.43	469301.81	0.40	
Error		21	24393350.47	1161588.12		
Total		24	25801255.90			
Irrigation		3	1407905.432	469301.811	0.40	ns

Table 5 Analysis of repeated measurements (one factor, completely randomized) of fruit growth for 11 weeks measured from November 1999 to January 2000.

Source of variation		df	SS	MS	F	
Date	11/11/1999					
Source		3	64.083076	21.361025	0.63	
Error		44	1498.567848	34.058360		
Total		47	1562.650924			
Irrigation		3	64.08307623	21.36102541	0.63	ns
Date	25/11/1999					
Source		3	68.750957	22.916986	1.01	
Error		44	1000.203412	22.731896		
Total		47	1068.954368			
Irrigation		3	68.75095659	22.91698553	1.01	ns
Date	08/12/1999					
Source		3	63.4767855	21.1589285	1.17	
Error		44	795.4768936	18.0790203		
Total		47	858.9536791			
Irrigation		3	63.4767855	21.1589285	1.17	ns
Date	23/12/1999					
Source		3	203.255213	67.751738	1.49	
Error		44	1999.895633	45.452173		
Total		47	2203.150846			
Irrigation		3	203.255213	67.751738	1.49	ns
Date	06/01/2000					
Source		3	34.8434077	11.6144692	0.94	
Error		44	542.2425433	12.3236942		
Total		47	577.0859510			
Irrigation		3	34.8434077	11.6144692	0.94	ns
Date	20/01/2000					
Source		3	54.5656963	18.1885654	1.22	
Error		44	657.0127960	14.9321090		
Total		47	711.5784924			
Irrigation		3	54.5656963	18.1885654	1.22	ns

Table 6 Analysis of repeated measurements (one factor, completely randomized) of stomatal conductance, measured from August 2000 to December 2000 for specific dates.

Source of variation		df	SS	MS	F	
Month	08/08/2000					
Source		3	49737.66	16579.22	0.78	
Error		6	127502.02	21250.33		
Total		9	177239.69			
Irrigation		3	49737.66	16579.22	0.78	ns
Month	14/09/2000					
Source		3	47266.94	15755.64	1.56	
Error		6	60747.79	10124.63		
Total		9	108014.74			
Irrigation		3	47266.94	15755.64	1.56	ns
Month	18/12/2000					
Source		3	47575.08	15858.36	0.81	
Error		6	117777.33	19629.55		
Total		9	165352.41			
Irrigation		3	47575.08	15858.36	0.81	ns

Table 7 Analysis of repeated measurements (one factor, completely randomized) of stomatal conductance, measured from 18 December 2000 to 21 December 2000.

Month	18/12/2000					
Source		1	0.02	0.02	0.00	
Error		16	21579.06	1348.69		
Total		17	21579.08			
Irrigation		1	0.02	0.02	0.00	ns
Month	19/12/2000					
Source		1	585.58	585.58	0.40	
Error		16	23226.41	1451.65		
Total		17	23812.00			
Irrigation		1	585.58	585.58	0.40	ns
Month	20/12/2000					
Source		1	4120.30	4120.30	1.31	
Error		16	50229.30	3139.33		
Total		17	54349.61			
Irrigation		1	4120.30	4120.30	1.31	ns
Month	21/12/2000					
Source		1	98.00	98.00	0.06	
Error		16	224136.49	1508.53		
Total		17	24234.49			
Irrigation		1	98.00	98.00	0.06	ns