DEFICIT IRRIGATION STUDIES TO IMPROVE IRRIGATION SCHEDULING IN DECIDUOUS FRUIT ORCHARDS

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DEFICIT IRRIGATION STUDIES TO IMPROVE IRRIGATION SCHEDULING IN DECIDUOUS FRUIT ORCHARDS

by

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Final Report to the Water Research Commission on the Project:
"The evaluation of a model for water use in deciduous fruit orchards and scheduling of irrigation with the aid of meteorological data".

Head of Department & Project leader: P.J.E. Louw

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TABLE OF CONTENTS

EXECUTIVE SUMMARY

1.1 *Introduction and scope of study*

Economically viable fruit production in the Western Cape region of South Africa is only possible under irrigation. However, the increasing competition of industry and urbanisation for water currently allocated to agriculture necessitates a more efficient utilisation of water by the agricultural sector. Expected increases in water tariffs and predicted water shortages will also hamper the further development of irrigable land. Improved irrigation scheduling is therefore imperative to ensure optimal utilisation of water.

Besides the increasing demand by industry and urbanisation for water currently allocated to agriculture, periods of drought occur from time to time in the Republic of South Africa. Water stress experienced by fruit trees during periods of severe water deficit can be a limiting factor in fruit production. Quality of the crop is, because of its export nature, an important consideration and cannot be compromised. Strategic management of water on the deciduous fruit farm is therefore of utmost importance under drought conditions, applying the water when and where it would render the best economical benefit. Knowledge of tree response to water deficits is, however, necessary to compile a set of decision making rules concerning irrigation management under limited water supply.

Furthermore, the current trend towards high-density plantings necessitates different managerial practices to ensure the control of vegetative growth. Optimum tree growth and optimum water utilisation can be obtained by regulated deficit irrigation (RDI), a practice whereby plant water deficits are manipulated by applying less water through irrigation than the trees would have used under normal conditions. The reason why RDI is effective relates to the growth pattern of shoots and fruit. For certain deciduous fruit species and cultivars, the shoots grow rapidly during the early season and their growth slows down as rapid fruit growth begins. Water stress during this period will reduce the growth of shoots without markedly affecting fruit growth.

The RDI approach has the potential to enhance effective water use by producers. For example, the amount of water allocated to producers in the Breede River Valley during the 1998/99 season was in the order of 7 450 m^3 ha^{-1}, whereas the estimated water requirement for peaches at Robertson Experiment Farm was 7 853 m^3 ha^{-1}. A water deficit of 400 m^3 ha^{-1} was expected for the season. However, application of RDI from October to December could result in an estimated water saving of 1 680 m^3 ha^{-1}. This would mean that a saving of 23% on the water allocation could be achieved.

Information on water use by trees under varying RDI management systems, and comparison thereof to water use under conventional irrigation, would help to understand plant response under limited water supply. It could also assist in the formulation of RDI strategies. Research on the response of fruit trees to RDI during different phenological growth stages was therefore undertaken in order to optimise the application of this technique under Western Cape conditions.

1.2 Objectives

The objective of the study was to supply guidelines for irrigation scheduling of deciduous fruit trees.

In the context of this study, to supply information on the effect of water deficits on tree response to improve existing guidelines and thus aid in irrigation management decision-making during periods of limited irrigation water or alternative management practices through:

- Determining the effect of regulated water deficiencies during different phenological growth stages on shoot-, fruit- and tree growth of peach and apple trees.
- Quantifying the effect of regulated water deficiencies on the production and quality of peaches and apples.
- Determining the water consumption of these trees under regulated water deficiencies.

1.3 Structure and summary of the report

The report of the project "Evaluation of a model for water use in deciduous fruit orchards and scheduling of irrigation with the aid of meteorological data" resulted in publication of two reports. This report covered improvement of guidelines for irrigation scheduling of deciduous fruit trees. Evaluation of a model for water use in deciduous fruit orchards is discussed in a separate report, namely "*Selection and calibration of a model for irrigation scheduling of deciduous fruit orchards*".

The motivation for the research on the deficit irrigation studies is outlined in the Introduction (Section 1), followed by a literature review (Section 2) that covers the effect of reduced irrigation on tree response. The studies on deficit irrigation on stone fruit (peaches) and pome fruit (apples) are presented in sections 3 and 4. Results for peaches are presented for trees with a normal (3.1) and a high (3.2) crop load, respectively.

Results and conclusions

Deficit irrigation of peach trees

The effects of regulated deficit irrigation on the production and fruit quality of peaches were investigated. A field trial was carried out in a twelve-year-old Neethling peach orchard at Robertson Experiment Farm. Treatments consisted of five different soil water depletion levels applied during five different growth stages. Irrigation was applied at the five soil water depletion levels of which T1 was regarded as relatively wet (irrigation was applied when the average soil matric potential reached *ca.* –50 kPa). T2 was regarded as normal (irrigation applied at *ca.* –100 kPa) and three different deficit irrigation regimes T3, T4 and T5, were irrigated at soil matric potentials of *ca.* –200, –400 and –800 kPa, respectively. The five growth stages were Stage 1 (cell growth), Stage 2 (slow fruit growth), Stage 3 (rapid fruit growth), Stage 4 (ripening) and Stage 5 (post-harvest).

Fruit was thinned as such to allow a low crop load in the first and a high crop load in the second season. The soil water content was monitored and irrigation was scheduled by means of a neutron water meter. Vegetative and fruit growth, fruit mass and production were measured. Fruit were examined for bruises and firmness.

Fruit size, fruit mass, fruit quality, as well as production, were not sensitive to water deficits during the different growth stages with a normal crop load. However, a tendency to reduced shoot growth with decreasing soil matric potentials was observed during the slow fruit growth, rapid fruit growth as well as the ripening stages. The application of deficit irrigation during the slow fruit growth or post-harvest stages can save substantial amounts of water with a normal crop load, provided that normal irrigation is applied during the other growth stages.

A combination of water deficits during the ripening stage and high crop load resulted in smaller fruit and lower production. Fruit size, fruit mass, fruit quality, as well as production, were not sensitive to water deficits during the cell growth, slow fruit growth or post-harvest growth stages, provided that normal irrigation is applied in the other growth stages. Irrespective of crop load, soil matric potentials down to –200 kPa can be allowed during any one of the growth stages without seriously affecting the final fruit size, fruit mass, fruit quality or production. However, this soil water deficit may then only be allowed in one of the growth stages and normal irrigation must be applied during the other four stages.

Although deficit irrigation reduced seasonal water consumption, it could not be recommended as a water saving strategy for trees with a heavy crop load, due to its negative effects on fruit quality and production.

Deficit irrigation of apple trees

The study on deficit irrigation of apples was terminated before objectives were reached. A lack of expected plant reaction was ascribed to unsuccessful induction of treatments. This was due to a combination of cool weather, large variation in soil water holding capacity, variation in tree size and unquantifiable water seepage from higher ground influencing the soil water balance. These problems were identified too late to redo the study on another plot and the remainder of the funds had been applied to other aspects of the project. Selected data are presented to illustrate the extent of the problems encountered.

1.4 Recommendations for further research

A study similar in design to the present deficit irrigation approach for apple, provided it is performed on a suitable site, could be considered, since the objectives were not realised and guidelines for irrigation scheduling of apples could not be improved. Irrigation scheduling guidelines could improve water management by producers and it will be possible to apply limited water resources more effectively if definite deficit irrigation strategies are available.

Deficit irrigation studies for the emerging olive tree industry are also needed, because many of the plantings are located in low rainfall areas, some prone to salinity. International research has shown that water stress can influence production and quality of both fruit and oil.

1.5 Capacity building

Ms Beukes obtained an MSc degree in Botany at the University of Stellenbosch through completion of the thesis titled "The effect of regulated deficit irrigation on the production and fruit quality of peaches." Valuable experience in research methodology and reporting was gained from the project and will be used in the PhD study of Ms. Volschenk with the title "The effect of saline irrigation on selected soil properties and the plant physiology, vegetative and reproductive growth of apricot trees". Capacity building amongst farmers was achieved by means of an information day, lectures at a short course, presentations at symposiums and publications.

ACKNOWLEDGEMENTS

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THE EVALUATION OF A MODEL FOR WATER USE IN DECIDUOUS FRUIT ORCHARDS AND SCHEDULING OF IRRIGATION WITH THE AID OF METEOROLOGICAL DATA

The Steering Committee responsible for this project, consist of the following persons:

Dr Backeberg	:	Water Research Commission (Chairperson 1998 to 2000)
Dr S. Mkhize	:	Water Research Commission (Chairperson 2001 to 2003)
Prof J.G. Annandale	:	University of Pretoria
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Mr E.C. Molteno	:	Deciduous Fruit Producers Trust
Mr R. Müller	:	Deciduous Fruit Producers Trust
Dr P. Myburgh	:	Agricultural Research Council
Prof S. Walker	:	University of the Free State

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Individuals:
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LIST OF TABLES

LIST OF FIGURES

CHAPTER 1

INTRODUCTION

1.1 Background

Economically viable fruit production in the Western Cape region of South Africa is only possible under irrigation. However, the increasing competition of industry and urbanisation for water currently allocated to agriculture (Liebenberg & Uys, 1995) necessitates a more efficient utilisation of water by the agricultural sector. Expected increases in water tariffs and predicted water shortages will also hamper the further development of irrigable land. Improved irrigation scheduling is therefore imperative to ensure optimal utilisation of water.

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Furthermore, the current trend towards high-density plantings necessitates different managerial practices to ensure the control of vegetative growth. Optimum tree growth and optimum water utilisation can be obtained by regulated deficit irrigation (RDI), a practice whereby plant water deficits are manipulated by applying less water through irrigation than the trees would have used under normal conditions (Mitchell, Jerie & Chalmers, 1984). The reason why RDI is effective relates to the growth pattern of shoots and fruit. For certain deciduous fruit species and cultivars, the shoots grow rapidly during the early season and their growth slows down as rapid fruit growth begins. Water stress during this period will reduce the growth of shoots without markedly affecting fruit growth (Goodwin 2000).

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CHAPTER 2

LITERATURE REVIEW

Limited water supplies or the practice of alternative irrigation management strategies in orchards could cause water deficits in fruit trees. Water stress can intentionally be induced by withholding irrigation or by applying less water than plants use, a method called regulated deficit irrigation (RDI, Mitchell *et al.*, 1984). To effectively apply RDI as a tactical tool to reduce vegetative growth and thus pruning costs, or to manipulate fruit quality, knowledge of plant response to water stress is important. Fereres and Goldhamer (1990) reviewed irrigation of deciduous fruit and nut trees, including effects of reduced irrigation on growth, development, yields and fruit quality. Kotzé (1991) discussed factors that should be considered when formulating an irrigation strategy during a year of critical water shortage, including the amount of irrigation water available, orchard composition, cultivar composition, sensitive development stages, the irrigation history of orchards, water holding capacity of soils and adjustment of cultivation practices. The literature review in this report focuses on selected aspects of the effects of water deficits on deciduous fruit trees. The emphasis will be on studies where peach, apple and pear trees were subjected to deficit irrigation.

The effect of water deficits on vegetative growth

Chalmers, Mitchell and Van Heek (1981) found that a decrease in the rate of water application during spring had a strong effect on the vegetative growth of peaches. They also concluded that irrigation could be developed into a powerful tool to manipulate plant growth for greater fruit-fullness and less vegetative growth. However, increased yields with reduced irrigation can only be obtained when the tree has excess vegetative growth that can be suppressed in favour of fruit growth. They also suggested that appropriate irrigation strategies must be determined in accordance with the natural vigour of the crop, the age of the trees, the soil type, the fruit growth as well as the crop load.

Ten years of research at Tatura (Victoria, Australia) on peach trees showed that the application of RDI practices from the beginning of the growing season, can significantly limit vegetative growth, increase fruit yields and reduce the tendency to biennial bearing (Decroix, 1992). Experiments performed on peaches (cv. Carnival) in Tunisia indicated that a restriction of water supply decreased shoot elongation and branch thickening by up to 35% and 12%, respectively (Ghrab *et al.* 1998). Girona *et al.* (1993) indicated that RDI caused only an 8% reduction in trunk growth relative to a well-watered control in peach trees (cv. Cal Red). However, they found no clear visible indications of decreased shoot growth with the RDI trees compared to well-watered controls. This was probably a consequence of the relatively long time needed to achieve moderate water stress in the RDI treatments on a deep soil.

Research on peach trees (cv. Golden Queen) by Mitchell and Chalmers (1982) in Australia indicated that by withholding as much as 0,875 of the irrigation requirements of the tree (determined from Class A pan evaporation) during periods of little growth, or during the period of declining growth rate of the fruit, vegetative growth can be reduced by 75% without reducing fruit yield. In a lysimeter trial at the Tatura Centre (Victoria, Australia), Boland *et al.* (1993) reported a reduction in shoot extension, leaf area index, pruning weights and trunk cross-sectional area with RDI treatments in peaches.

Li *et al.* (1989) reported that restricted water supply instantaneously inhibited shoot elongation and shoot diameter increase in peach trees. They also found that neither after-effect nor favourable action of water stress were evident during the post-stress period. Their results also indicated that water deficit had no effect on leaf area. Based on the intensity of the growth inhibition by water deficiency, they classified the sensitivity of organs to water stress in the following order of severity: shoot diameter increase > shoot elongation growth > fruit growth > expansion of leaf area. They concluded that it is possible to control the vigour of peach trees without reducing fruit size and yield, and without affecting fruit quality, by applying deficit irrigation during the first rapid fruit growth and pith hardening phases. According to Chalmers, Mitchell and Jerie (1985) summer and winter pruning of peach trees can also be reduced and simplified. Summer shoot growth was decreased by 75% by applying RDI. Winter pruning would therefore become simpler, lighter and less expensive.

Water stress decreased the leaf area (smaller leaves/ premature leaf fall) and caused premature setting of terminal buds of apple trees (Ebel, 1991). Shoot growth of 1-year-old apple trees was reduced by approximately 7% and 32% and leaf area 7% and 36% where 60% and 80% of the available soil water, respectively, was depleted compared to a 40% depletion level (Reuther *et al.*, 1981). Furrow irrigation intervals of 14 and 21 days on a sandy loam soil decreased shoot growth of third leaf pear trees by ±40% and ±60%, respectively, compared to where a 7 day irrigation interval was applied. It is expected that the effect of water stress on vegetative growth would be augmented in young trees with limited root systems compared to older trees that have deeper, more extensive root systems.

According to Reuther *et al.* (1981 and references therein), bearing orchard trees produce most new shoot growth when irrigated frequently at soil matric potentials of –15 kPa to –40 kPa in the top 300 to 600 mm of the soil, slightly less when irrigated at -60 kPa to –80 kPa and much less when irrigated at –200 kPa to -500 kPa. Lötter, Beukes and Weber (1985), in a study where Granny Smith apple trees were irrigated at four levels of total available soil water applied during each of four phenological phases, reported a significant decrease in apple shoot extension growth when average soil matric potential was –60 kPa compared to –20 kPa applied during the shoot growth phase.

Although data from pot experiments are not directly applicable to orchard conditions, it is considered informative regarding plant response to water deficits. Van der Maas (1995, 1996), in a controlled pot study on shoot and fruit growth of young apple trees (cv. Elstar/ M.9), compared the effect of soil matric potentials of –45 and –101 kPa during the shoot growth period followed by –7 kPa in the period thereafter to a soil matric potential of –7 kPa applied throughout the season. The growth of shoots at the –45 kPa treatment was reduced to ±47% of that of the –7 kPa treatment, while fruit growth was reduced by 11% in comparison with –7 kPa throughout the season. No re-growth of shoots was recorded after increasing the water application. The –101 kPa treatment reduced shoot growth by ±74% and fruit weight by 34% of that at –7 kPa, while 10% of the shoots showed regrowth. The positive effects of the –45 kPa deficit level during the shoot elongation stage were confirmed by another experiment where the soil matric potential was maintained at a level of –45 kPa during three weeks near the end of the shoot growth period. This decreased shoot growth by 32% with no significant effect on fruit growth or fruit quality.

In addition to shoot elongation, shoot initiation is another critical aspect of vegetative growth that can influence tree productivity (Fereres & Goldhamer, 1990). According to Peretz, Proebsting and Evans (1986), the limited wetting of the root volume of Delicious apple trees by daily trickle irrigation (100% of Class-A pan evaporation), induced water deficits that reduced shoot length, but increased the number of shoots. The total length per tree was similar to that of sprinkler irrigated trees that received 90% of Class-A pan evaporation. Regulated deficit irrigation combined with trickle irrigation reduced the number and length of vigorous shoots when compared to furrow-irrigated control trees (Ebel, Proebsting & Evans, 1995). The authors also reported that crop load did not affect shoot length, but they obtained an inverse relationship between the number of vigorous shoots and crop load. Rawash *et al.* (2000), in contrast, found that although reduced irrigation of Anna apple trees on MM106 rootstock decreased the shoot length, it increased the number of shoots per tree.

Shoot and trunk thickening of apple trees are also considered sensitive to water deficits (Assaf, Levin & Bravdo, 1975; Landsberg & Jones, 1981 and references therein; Rawash *et al.*, 2000). Deficit irrigation reduced the trunk cross sectional area of Redspur Delicious/ MM 106 and Golden Delicious/ M26 over a period of three years (Peretz *et al.*, 1986). According to Lötter *et al.* (1985), trunk growth decreased signigficantly when the total available soil water level was decreased from 85% (soil matric potential *ca.* –20 kPa) to 25% (soil matric potential *ca.* –1200 kPa) during the period from the end of shoot extension until harvest before irrigation was applied. Trees received irrigation during the rest of the season whenever the total available soil water level was decreased to 65% (soil matric potential *ca.* –60 kPa).

In a study conducted near Prosser, Washington State (U.S.A.), Ebel *et al.* (1995) reported that RDI favoured reproductive growth over vegetative growth by suppressing vegetative growth in apple trees. Drought stress early in the cell elongation phase of fruit growth reduced vegetative growth and improved yield efficiency without reducing fruit size at harvest. It is important to note that the fruit growth stages most favourable for applying growth retarding water deficits are different for stone and pome fruit. For peaches, pit hardening (Chalmers *et al.*, 1981; Li *et al.*, 1989; Mitchell & Chalmers, 1982) and for apple and pear fruit, early in the cell elongation stage (Irving & Drost, 1987; Mitchell *et al.*, 1984, 1986), is considered the most appropriate development stage to induce water stress for restraining vegetative growth without detrimental effects on fruit growth (Ebel, 1991).

The effect of water deficits on fruit growth

According to Zahner (1968), the stage of fruit enlargement in relation to soil moisture and irrigation practices has been studied for many decades, for example in *Citrus* (Bartholomew, 1926), *Pyrus* (Lewis, Work & Aldrich, 1935), *Malus* (Boynton, 1937) and *Prunus* (Hendrickson & Veihmeyer, 1950). Zahner (1968) also concluded that the rate of fruit enlargement is strongly reduced following the rapid depletion of soil water and that the final fruit size and quality are strongly regulated by the amount of water available during fruit enlargement. Gospodinova (1997) found that water deficit under the 50% evapotranspiration RDI treatment, applied during the second fruit development stage of peach trees, can lead to a slightly negative effect on fruit quality. Regulated deficit irrigation sometimes suppresses fruit growth. However, there is some evidence of an enhanced fruit growth rate for peach trees when full irrigation is restored following the deficit period (Mitchell & Chalmers, 1982; Li *et al.* 1989).

According to Chalmers *et al.* (1981), less severe water-withholding treatments during the dry weight stage of peach fruit growth increased fruit yield by as much as 36% when compared to the fully irrigated treatments, while reducing vegetative growth. Chalmers, Olson and Jones (1983) state that reduced irrigation treatments suppressed fruit growth only slightly and then only when water was withheld from the trees during dry weight stage 2 (slow fruit growth) and stage 3 (rapid fruit growth and fruit ripening). They also found that, when all treatments received an equal and full allocation of water during dry weight stage 3, fruit on trees that had previously received a restricted allocation of water, grew substantially faster, resulting in larger fruit at harvest.

According to Goodwin (2000), fruit growth is rapid during the ripening stage and water stress must be avoided during this stage as the tree needs ample water to maintain fruit growth. This viewpoint is similar to that of Parker and Marini (1994), as they state that drought during the ripening stage will reduce fruit size and quality most seriously. Kotzé (1991) also reported that the most rapid increase in fruit size, especially in the case of stone fruit, took place during the ripening stage i.e. the last two to three weeks before harvest. Apart from the fact that cell growth is decreased by water stress, water and nutrients can also be extracted from the fruit. It is therefore clear that the ripening stage of development is extremely critical and water stress will not only adversely affect fruit size and therefore yield, but also fruit quality.

According to Li *et al.* (1989, and references therein), the growth rate of peach fruit under conditions of severe water stress was not at all affected during the first stage of rapid fruit growth, although a very low leaf water potential and stomatal closure were observed. They also found that fruit expansion was significantly limited by water deficits during the final stage of rapid fruit growth. This suggests that cell enlargement appears more sensitive to water stress than cell division (Hsiao 1973). Li *et al.* (1989) also reported that a period of water stress imposed on peach trees during stage 1 (first stage of rapid fruit growth) and stage 2 (fruit pith hardening) favoured fruit growth after alleviating water stress in the trees. Mitchell and Chalmers (1982) also observed this effect on fruit growth during the post-stress period. Since the rate of cell enlargement is dependent on the cell's expandability and turgidity status (Hsiao 1973), and the cell turgidity status in those water-stressed fruits is the same as in the non-stressed fruit during the post-stress period, it is possible that cell expandability would be increased. This effect may be due to the violent changes of water status in the cells, from a good turgidity status to a significant water deficit, or inversely during the period of water stress or at the time of water stress removal (Li *et al.* 1989).

Peach fruit growth during the day was less and fruit shrinkage was greater with a heavy crop load than with a light crop load (McFadyen, Hutton & Barlow, 1996). This appeared to be correlated with lower fruit water potential and turgor potential in trees with a heavy crop load. They concluded that increased crop loads increased fruit water deficits, which reduced fruit growth. The reduction in fruit size commonly associated with increased crop load may be due, at least in part, to the effect of crop load on fruit water relations.

The fruit enlargement process in apple trees is sensitive, even to mild water deficits (Landsberg & Jones, 1981). In a Golden Delicious apple orchard in Spain, low levels of irrigation resulted in a higher frequency of small fruits (Bonany, Camps & Blanke, 1998). Ebel (1991) concluded from a study on late season drought stress applied only during the cell enlongation phase of apple fruit growth, that fruit weight at harvest was linearly related to drought strain within the plant. Fruit growth declined slightly, but was not strongly reduced until the volumetric soil water content of a 1.1 m deep silt loam soil was reduced below 12%. This value corresponds to ±20% of total available water or a soil matric potential of –300 kPa.

Normal pear fruit growth rates continued as long as the available water depletion in the 900 mm deep clay soils in Medford, Oregon did not exceed 30% (Lewis, Work & Aldrich, 1935). A 20% reduction in fruit growth rate occurred at 60% available water depletion. Research by Assaf *et al.* (1975) on the effect of different irrigation regimes on apple fruit growth rates on a clay soil in Israel, showed that the weekly increase in fruit volume was almost halved when irrigation was applied at 70% available water depletion instead of at 20 to 30% available water depletion. Reuther *et al.* (1981) adapted published work of Kumashiro and Tateishi (1966), which showed that the average weight of apple fruit reduced to 94%, 85% and 79% of that of the control, irrigated at a soil matric potential of –10 to –20 kPa, when trees were irrigated at a soil matric potential –20 to –30 kPa, –50 to –60 kPa and –400 to –500 kPa, respectively. They concluded that most studies show that bigger fruits are obtained from trees irrigated when the top 600 to 900 mm of soil reaches soil matric potentials between –40 and –100 kPa than from trees where soil is allowed to dry to –200 to –1000 kPa. They also stated that trees receiving less irrigation water than the ET requirement always have smaller fruit sizes than trees receiving full irrigation. However, in a study comparing trickle to furrow irrigation, apple fruit growth was reduced when daily trickle irrigation replaced 100% of Class-A pan evaporation (Peretz *et al*, 1986), while a continuously trickle irrigated treatment did not show any decrease in fruit size.

Furthermore, there is some evidence of compensative fruit growth for apple and pear trees, as for peaches, when full irrigation is restored following the deficit period (Ebel, 1991; Ebel *et al.*, 1995; Mitchell *et al.* 1984, 1986). Fruit growth rate of apple trees subjected to water deficits early in the cell elongation phase of fruit growth by withholding irrigation until a soil matric potential of –300 kPa was reached, for example, was reduced to 50% of those receiving adequate irrigation, but reduction in fruit volume up to 15% and 20% was recovered after irrigation was restored by trickle and microsprinkler irrigation, respectively (Ebel, 1991). The amount of recoverable fruit size depended on the volume of soil rewetted after irrigation was restored and it was concluded that deficits should be alleviated at least 3 weeks before harvest to ensure that fruit regain their size.

Crop load may alter the effect of water deficits on apple fruit growth. According to Ebel (1991), the amount of compensative apple fruit growth depends on the level of plant water deficits after irrigation is restored and crop load. Fruit growth rate was higher on lightly cropped trees compared to trees with a normal crop load and the trees could have tolerated a more severe drought stress to achieve the maximum recoverable reduction in fruit volume.

The effect of water deficits on production

Production is a function of fruit size as well as the number of fruit on trees. Research on peaches (cv. Carnival) in Tunis, Tunisia, indicated that a 30% irrigation restriction reduced crop yield and fruit load by 10% to 25% and 5% to 23%, respectively, compared to the well-watered control (Ghrab *et al.* 1998). Boland *et al.* (1993) found that the yield of RDI trees (*Prunus persica* L. Batsch) irrigated weekly was reduced compared to that of the non-limiting irrigation treatments. In a trial on Bartlett (Williams' Bon Chretien) pears, the average yields over 5 years were increased by 20% and irrigation volume was reduced by 29% (Decroix, 1992).

According to Peretz *et al.* (1986), higher yields, less vegetative growth and higher yield efficiencies of Delicious apple trees were associated with trickle irrigation operated at a deficit level. It is suggested that trickle irrigation was causing a shift from vegetative growth to fruit growth. Results showed that the shift toward fruitfulness did not reduce fruit size. Rawash *et al.* (2000) found, in a study during two successive seasons, that reducing daily irrigation amounts of young Anna apple trees (rootstock MM 106) by a factor of 0.6 and 0.4 of Class-A pan evaporation, reduced yields on average by 7% and 37%, respectively compared to reduction by a factor of 0.8 of Class-A pan evaporation. The differences in production could solely be attributed to smaller fruit since the drier treaments had significantly higher fruit numbers.

Fruitfulness increased as vegetative vigour in deciduous trees was reduced by RDI (Jerie, Van den Ende & Dann, 1989). Flowering, fruit set, fruit number at harvest and in most cases total yield, were all increased by applying RDI to peach and pear trees (Mitchell *et al.* 1984; Mitchell *et al.* 1986; Mitchell *et al.* 1989). However, fruit set of apple trees was considerably reduced by water stress and less fruit per cluster were retained in droughted trees (Powell, 1974). Landsberg and Jones (1981) reviewed the effects of water deficits on development of apple trees in detail and concluded that bud morphogenesis is more likely to develop to the point where floral primordia are produced if trees are not subjected to significant water deficits. Assaf, Bravdo and Levin (1974) and Assaf *et al.* (1975) furthermore showed that fruit drop of apple trees under irrigation in Israel was inversely related to the amount of water applied.

In a detailed study of young apple trees (cv. Elstar/ M.9), Van der Maas (1996) concluded that soil matric potential treatments of –45 kPa and –101 kPa applied during shoot growth stage decreased the number of flower buds on 1-year-old wood by 63% and 79%, respectively, and almost doubled the number of flower buds on older wood compared to the –7 kPa treatment throughout the season. It was estimated that the –45 kPa treatment would retain the most flower buds after pruning.

The effect of water deficits on photosynthesis, stomatal conductance and leaf/ stem water potential

The physiological control of water status in temperate fruit crops have been reviewed by Jones, Lakso and Syvertsen (1985) and the influence of water status on stomatal conductance and photosynthesis by

Flore and Lakso (1989). Flore (1994) more recently reviewed the consequences of drought on vegetative and reproductive growth and physiological processes in *Prunus* with emphasis placed on sensitivity and how water can be managed to improve yield.

Andersen and Brodbeck (1988) found that shoot and leaf expansion were more sensitive to water deficits than photosynthesis or stomatal conductance. Stomatal conductance of peach trees was not affected until leaf water potentials lower than –2000 kPa were reached and photosynthesis was not affected adversely until these levels of stress were reached (Flore, Moon & Lakso, 1985). According to Flore (1994), it seems thus that under field conditions, stomatal conductance and photosynthesis of peach trees are not affected until severe stress conditions are imposed. Ferreira *et al.* (1996) in research on well-irrigated and droughted peach trees in orchards in Portugal, found that a change in tree behaviour occurred at a threshold pre-dawn leaf water potential value of –450 kPa. This value corresponded to a 50% reduction in stomatal conductance measured ±1 hour after noon, a 35% reduction of daily transpiration and a daily relative trunk shrinkage twice that of well-irrigated trees at 10% of available water in the main root zone of up to 1 m. According to Proebsting and Middleton (1980), peach trees exposed to extreme water stress under Washington State conditions (no irrigation and receiving only 86 mm of rainfall during the growing season), died after leaf water potentials were reduced below –3000 kPa during mid- to late summer.

Girona *et al.* (1993) stated that the leaf water potential of peach trees (cv. Cal Red) under RDI appeared to be less affected by plant water deficits than the stomatal conductance of the same trees during the second growth stage. Leaves of trees subjected to deficit irrigation were therefore photosynthetically more water-use efficient during the latter part of the stress period than those of the non-stressed trees. Boland *et al.* (1993) indicated that adaptation of peach trees to water stress during RDI was associated with stomatal closure and reduced leaf area.

Leaf water potential has generally been used to relate drought stress to the water status of deciduous fruit trees. According to Lakso (1994), typical leaf water potential values expected for exposed apple tree leaves in orchards under sunny conditions, moderate evaporative conditions and adequate soil moisture are –1500 kPa to –2000 kPa. Leaf water potential depends on the soil water potential, the resistance of the plant-soil system to flow of water and the rate of transpiration from the leaves. In apple trees, in contrast to many annuals where control of leaf water potential is primarily a function of soil water potential, there is a strong control of leaf water potential by transpiration and any factor that affects it. Such factors would include vapour pressure deficit, radiation, wind, and stomatal opening (Lakso, 1994).

However, Ebel, Proebsting and Evans (2001) and Garnier and Berger (1985) concluded that stem water potential measurements had less leaf to leaf variation compared to that of leaf water potential. According to Ebel *et al.* (2001) the minimum stem water potential, reached during midday, characterizes the maximum diurnal plant water deficits and incorporates the effects of the atmospheric demand as well as soil water on the tree. Fruit growth rate of apples declined below a stem water potential of –1500 kPa when the soil matric potential was about –300 kPa. Measurement of stem water potential could therefore be used to determine when fruit growth limiting drought strain is reached within the plant (Ebel, 1991).

According to the author apple trees were very drought tolerant and stomata of trees closed below a stem water potential of –1500 kPa. Photosynthesis may be reduced by water stress through stomatal closure or damage to the photosynthetic apparatus. Massaci and Jones (1990) showed that with rapid water stress development, only stomatal conductance was reduced, while with long-term stress both stomatal and non-stomatal limitations affected photosynthesis of apple trees. High crop load with high water status can induce the same effect as drought stress on photosynthesis and stomatal conductance of apple trees (Lakso, 1994) and thus affect fruit size and production.

Interactions between internal plant water status, stomatal conductance and vapour pressure deficit make it difficult to characterize adequately the negative effects of water deficits without integrating such interactions over time (Syvertsen,1985). Ebel *et al.* (2001) calculated a crop water deficit index (CWDI) with the aid of stem water potential data and a significant statistical relationship was found between CWDI and apple fruit weight at harvest. However, they concluded that models developed to predict fruit weight at harvest during a drought might have to be made for specific cultivar/rootstock combinations.

The effect of water deficits on fruit quality

Drought can affect fruit maturity and quality at harvest. Fruit quality refers to fruit size, colour, firmness and flavour as well as physiological disorders before or after storage. Gospodinova (1997) found that water deficit under the 50% evapotranspiration RDI treatment, applied during the second fruit growth stage, provided a slightly negative effect on the quality of the fruit. Water stress applied during the first two growth stages did not significantly affect peach fruit storage capacity (Li *et al.* 1989). Researchers, from the Ecophysiological and Horticultural Research Unit, Paris, studied fruit growth and the accumulation of sugars and acids (Anon 2000). They found that peach fruit size is a vital characteristic in determining quality. Almost 50% of the dry mass of the fruit consist of sucrose, which accumulates in the fruit particularly during the ripening stage. The carbon supply of the fruit, which is mainly composed of sugars, depends on the flow of water for transport. It follows that a peach poorly supplied with water, will also have a poor supply of sugar and nutrients, which will be detrimental to fruit quality.

Li *et al.* (1989) reported that smaller fruit, higher levels of total soluble solids and longer storage capacity after harvest were characteristic of fruit from peach trees subjected to water stress in the fruit ripening stage. Cell enlargement and subsequent fruit growth of peaches is dependent on water availability during the ripening stage (Parker & Marini 1994). Sugars resulting from photosynthesis accumulated in the fruit during the final few weeks before harvest. Drought stress during this stage resulted in small, poorly-coloured and poor-tasting fruit, which matured up to 10 days later than normal. Johnson, Handley and DeJong (1992), under California conditions, found that post-harvest water deficits of early maturing peach trees increased the occurrence of double fruit. This phenomenon could be countered by a well-timed irrigation before carpel differentiation.

Zahner (1968) and Ryall and Aldrich (1944) reported that well-watered pear trees produced fruits smoother in texture, higher in sugar content and lower in acids than the fruits on trees growing under normal summer soil water deficits. Pears in storage maintained green color and firmness best when given limited water late in the season (Ryall & Reimer, 1940 in Reuther *et al.*, 1981). The same authors found that firmness of pear fruit decreased with increasing frequency of irrigation.

Several researchers evaluated the effect of water deficit on apple fruit quality (Guelfat-Reich *et al.*, 1974; Mills *et al.*, 1994; Mills, Behboudian & Clothier, 1996; Peretz *et al.*, 1986, Proebsting, Drake & Evans, 1984; Rawash *et al.*, 2000) and it was earlier thoroughly reviewed by Landsberg and Jones (1981). According to Ebel (1991 and references therein), mild water deficits that slightly reduced fruit growth advanced physiological maturity of apple fruit and increased soluble solids. Effects of drought stress on starch, titratable acidity, firmness and colour of apples was inconsistent (Ebel, 1991) and varied between studies (Assaf et al., 1975; Ebel *et al.*, 1993; Guelfat-Reich *et al.*, 1974; Mills *et al.*, 1994, 1996; Proebsting *et al*, 1984; Rawash *et al.*, 2000) and it was earlier thoroughly reviewed by Landsberg and Jones (1981). However, the more recent studies of Mills *et al.* (1994) and Rawash et al. (2000) both found positive effects of water stress on red skin pigmentation of fruit.

According to Ebel *et al.* (1993), smaller apples were obtained at harvest with a RDI-treatment compared to well-watered treatments. Lötter *et al.* (1985) also reported that Granny Smith apple size distribution was markedly affected by the different total available water treatment levels (85%, 65%, 45% & 25%) applied during four different phenological phases (first 40 to 50 days after full bloom, 40 to 50 days after full bloom until end of shoot extension growth, end of shoot extension growth until harvest and post-harvest) per season. An increased percentage small fruit resulted especially where a 25% instead of 85% total available water level was induced during the period from the end of shoot extension growth until harvest. Lötter *et al.* (1985), although treatment effects was not as obvious when induced during the period from 40 to 50 days from full bloom until the end of shoot extension growth, recommended that a total available water level of 85% should be favoured by producers during the main fruit development period, i.e. from 40 to 50 days from full bloom until harvest. A physiological disorder such as watercore, however, was found to increase with a higher total available water level, in contrast to sunburn, that showed a strong increase with a lower total available water level. An increased incidence of bitter pit was found during all phases when the total available water level was raised.

Water consumption

According to Girona *et al.* (1993 and references therein) RDI treatments on a peach (cv. Cal Red) orchard, resulted in a 40% saving in irrigation water. These savings were achieved with only minor effects on fruit size and production. Decroix (1992) concluded that the RDI system of irrigation scheduling can save considerable amounts of water without reducing yields with the additional benefit of reducing labour requirements for pruning. The results of Boland *et al.* (1993) showed that peach trees irrigated under frequent RDI with non-saline water were highly productive and efficient in the use of water throughout the season. According to Mitchell & Chalmers (1982), all reduced irrigation treatments saved considerable water. A replacement of 12,5% E_{ps} (evaporation over the planting square) to mid January followed by 100% replacement to harvest required 6 000 m^3 ha^{-1} compared to 9 000 m^3 ha^{-1} for 100% replacement during the season. They concluded that irrigation methods based on this approach prove to be highly suitable for growing fruit in areas with limited water supplies.

According to Chalmers *et al.* (1985) plants respond to RDI in a highly predictable and quantifiable manner. Shoot and secondary growth were suppressed in direct proportion to the water deficit. Fruit growth was also stimulated in a predictable way. The most severe water deficit applied was a withdrawal of 87,5% of the normal water requirement, applied over 66% of the growing season. This reduced total water consumption by 33% and vegetative growth by 75% without reducing fruit size or production.

In a 5-year experiment in the Hula valley, Israel, the effect of six irrigation treatments on apple trees was compared. The best yield and largest fruit sizes were obtained when irrigation was applied from 10^{th} June to 10^{th} August whenever the 0-600 cm soil layer reached 40% available water, and during the rest of the season when it reached wilting point. During these two periods the water content of the 600-1200 cm layer was kept above 80% and 60%, respectively (Assaf *et al.*, 1975). In comparison to commercial practice in the area that applied irrigation when 50% of the 0-1200 mm profile soil water was available, ±16% less water was used with a ±38% increase in commercial fruit yield. Rawash *et al.* (2000) found a higher estimated water use efficiency for Anna apple trees under Egypt conditions when 0.6 or 0.4 of Class-A pan evaporation was daily replaced by trickle irrigation compared to 0.8 of Class-A pan evaporation. However, the latter treatment resulted, despite significantly lower fruit numbers, in significantly larger fruit, higher yield and the best total net profit.

Beukes and Weber (1982) found in the winter rainfall region of South Africa, during the peak growing period of Granny Smith apple trees, that the actual evapotranspiration of plots receiving irrigation at a 25% total available water level decreased to approximately a third of that measured at plots irrigated at an 85% total available water level. They evaluated growth and fruit quality parameters and recommended for commercial production that, to control excessive growth and/or save water when irrigation water supply is limited, the optimum sequence of total available water levels (%) for the season was 25/45/85/25 applied during four phenological phases, namely the first 40 to 50 days after full bloom, 40 to 50 days after full bloom until end of shoot extension growth, end of shoot extension growth until harvest and post-harvest. This combination yielded actual evapotranspiration of 1099 mm and would need 39% less irrigation water compared to maintenance of a seasonal 85% total available water level. However, if control of vegetative growth is not desired, a sequence of total available water levels of 25/85/85/25 was suggested, that could still save ±17% irrigation water compared to a wet regime throughout the season.

Summary

Vegetative growth of apple and peach trees appear to be more sensitive to water deficits than fruit growth. An opportunity is hereby created to withhold irrigation or use RDI to inhibit vegetative growth without reducing production. This could result in reduced pruning costs and decreased water consumption. The extent and timing of water stress, however, is critical, and care should be exercised to ensure fruit quality of the current season as well as the development of the crop of the following season is not adversely affected. Different irrigation strategies will be applicable to deep and shallow soils as well as young and full-bearing trees and crop load effects should be taken into account. Vegetative and reproductive growth patterns may differ for different fruit crops and / or cultivars and should also be considered when a deficit irrigation approach for the season is taken. A prerequisite for control of tree growth and thus successful implementation of deficit irrigation or RDI, is that trees do not have access to supplementary sources of water, besides rain or irrigation, during deficit periods.

CHAPTER 3

DEFICIT IRRIGATION OF PEACH TREES

3.1 BACKGROUND

There is little quantitative information available on the cropping response of fruit trees to water stress during different phenological stages. Chalmers, Mitchell and Jerie (1984) reported that final fruit size, number of fruit or production of peaches and pears were not affected by reduced water supply during the early stages of fruit growth until the end of shoot growth. The effects of water deficits during the rapid fruit growth stage on the final fruit size of apples have been reported as being of little importance (Irving & Drost, 1987). However, Lötter *et al.* (1985) reported that water deficits during the rapid fruit growth stage of apples had a negative effect on the final fruit size.

In this project, experiments were carried out in order to study the behaviour of peach trees under conditions of water deficits during the different phenological growth stages.

3.2 THE EFFECT OF DEFICIT IRRIGATION ON THE PRODUCTION AND FRUIT QUALITY OF PEACHES WITH A NORMAL CROP LOAD

3.2.1 Material and methods

Experimental design: The experiment was carried out during the 1998/99-season at Robertson in the Western Cape Province, Republic of South Africa, an area especially suited for the production of peaches (Figure 1). However, as the average annual rainfall at Robertson only amounts to 277,5 mm during the growth season, additional irrigation is required. The field trial was established on the Experiment Farm of Infruitec-Nietvoorbij (an Institute of the Agricultural Research Council), located at 33° 50' S, 19° 54' E and 156 m above sea level. An automatic weather station, situated approximately 500 m from the orchard, recorded daily precipitation (mm), hourly maximum and minimum temperature (°C), total daily solar radiation (MJ m^{-2}), average daily wind speed (m s^{-1}) at a height of 2 m and relative humidity (%). Daily evaporation from an American Class-A pan was also recorded.

The orchard was established in June 1987 in a North-South oriented hedgerow planting pattern and the trees were trained as a closed vase. Tree spacing was 5 m x 3 m with four trees (*Prunus persica (L.)* Batsch) cultivar 'Neethling' on seedling rootstock, per treatment plot. Two guard trees bordered each plot.

Figure 1. Map of the Republic of South Africa illustrating the locality where the peach deficit irrigation trial was carried out.

Treatments consisted of five different soil water regimes applied during the following five growth stages:

Stage 1 - Cell division, enlargement and growth (*ca.* 40 days)
Stage 2 - Slow fruit growth (*ca.* 5 weeks)
Stage 3 - Rapid fruit growth (*ca.* 5 weeks)
Stage 4 - Ripening (*ca.* 7- 8 weeks)
Stage 5 – Post-harvest (*ca.* 12 weeks)

Irrigation was to be applied at the following five soil water depletion levels:

T1 - Relatively wet (Irrigation was applied when the average soil matric potential for the soil profile of 600 mm reached *ca.* –50 kPa)
T2 - Normal (Irrigation was applied when the average soil matric potential for the soil profile of 600 mm reached *ca.* –100 kPa)
T3 - Deficit (Irrigation was applied when the average soil matric potential for the soil profile of 600 mm reached *ca.* –200 kPa)
T4 - Deficit (Irrigation was applied when the average soil matric potential for the soil profile of 600 mm reached *ca.* –400 kPa)
T5 – Deficit (Irrigation was applied when the average soil matric potential for the soil profile of 600 mm reached *ca.* –800 kPa)
Irrigation treatments T3, T4 and T5 were regarded as deficit irrigation. These treatments were applied during only one of the growth stages each while the T2 treatment was applied for the remainder of the season. This resulted in twenty-five treatment combinations (Table 1). Each treatment was replicated three times. However, due to the influence of the prevailing weather conditions, the soil matric potentials targeted for treatments could not always be reached and the soil matric potentials measured at the end of each specific stage were used in analyses. The average soil matric potentials reached per stage for the 1998/99 and 1999/2000 seasons are listed per treatment alongside the targeted soil matric potentials in Table 1.

Crop load: Fruit were thinned by hand at the end of the first growth stage to an average of 380 fruit per tree.

Soil preparation and soil analysis: Soil preparation was done before planting to a depth of 600 mm and plastic sheeting was installed between plant rows up to a depth of 1200 mm in order to avoid any lateral movement of water between plots. Soil samples were taken on experimental plots at depths of 0-300 mm, 300-600 mm and 600-900 mm. The disturbed soil samples were analysed for water-holding capacities as well as particle size distribution (De Kock, undated). Percentage water by volume was determined at soil matric potentials of –10, –50, –100, –200, –400, –800 and –1500 kPa to obtain soil water retention curves in accordance to the method of De Kock *et al.* (1977). The soil water retention curves for each experimental plot (See Appendix A for an example) were transformed to obtain a Log-Log equation for estimation of soil matric potential from volumetric soil water content. Although the soil properties varied throughout the orchard, it could be regarded as a sandy loam.

Table 1. Targeted and actual soil matric potentials in the regulated deficit irrigation field trial with Neethling peaches for the 1998/99 and 1999/2000 seasons at the Robertson Experiment Farm.

Treat-ment no.	Soil matric potential (-kPa)														
	Stage 1 (Cell growth)			Stage 2 (Slow fruit growth)			Stage 3 (Rapid fruit growth)			Stage 4 (Ripening)			Stage 5 (Post harvest)		
	A^z	B^y	C^x	A^z	B^y	C^x	A^z	B^y	C^x	A^z	B^y	C^x	A^z	B^y	C^x
A1	**50**	**49**	**53**	100	100	100	100	100	100	100	100	100	100	100	100
A2	**100**	**47**	**103**	100	100	100	100	100	100	100	100	100	100	100	100
A3	**200**	**61**	**148**	100	100	100	100	100	100	100	100	100	100	100	100
A4	**400**	**61**	**195**	100	100	100	100	100	100	100	100	100	100	100	100
A5	**800**	**65**	**85**	100	100	100	100	100	100	100	100	100	100	100	100
A6	100	100	100	**50**	**43**	**59**	100	100	100	100	100	100	100	100	100
A7	100	100	100	**100**	**101**	**187**	100	100	100	100	100	100	100	100	100
A8	100	100	100	**200**	**185**	**221**	100	100	100	100	100	100	100	100	100
A9	100	100	100	**400**	**320**	**560**	100	100	100	100	100	100	100	100	100
A10	100	100	100	**800**	**594**	**979**	100	100	100	100	100	100	100	100	100
A11	100	100	100	100	100	100	**50**	**28**	**56**	100	100	100	100	100	100
A12	100	100	100	100	100	100	**100**	**29**	**110**	100	100	100	100	100	100
A13	100	100	100	100	100	100	**200**	**206**	**257**	100	100	100	100	100	100
A14	100	100	100	100	100	100	**400**	**304**	**406**	100	100	100	100	100	100
A15	100	100	100	100	100	100	**800**	**474**	**696**	100	100	100	100	100	100
A16	100	100	100	100	100	100	100	100	100	**50**	**55**	**77**	100	100	100
A17	100	100	100	100	100	100	100	100	100	**100**	**75**	**154**	100	100	100
A18	100	100	100	100	100	100	100	100	100	**200**	**145**	**304**	100	100	100
A19	100	100	100	100	100	100	100	100	100	**400**	**256**	**386**	100	100	100
A20	100	100	100	100	100	100	100	100	100	**800**	**384**	**694**	100	100	100
A21	100	100	100	100	100	100	100	100	100	100	100	100	**50**	**61**	**60**
A22	100	100	100	100	100	100	100	100	100	100	100	100	**100**	**139**	**130**
A23	100	100	100	100	100	100	100	100	100	100	100	100	**200**	**194**	**296**
A24	100	100	100	100	100	100	100	100	100	100	100	100	**400**	**364**	**382**
A25	100	100	100	100	100	100	100	100	100	100	100	100	**800**	**480**	**554**

A^z = Targeted soil matric potential.

B^y = Soil matric potential reached during the 1998/99 season.

C^x = Soil matric potentials reached during the 1999/2000 season.

Water application: The irrigation system consisted of MicroJet (blue-base) micro-emitters, spaced 5 m X 2,5 m, with a delivery rate of 32 L h^{-1}, which wetted a strip of 3,0 m in the plant row. Water meters (Kent) recorded the total amount of water applied per treatment.

Monitoring of soil water content: Neutron water meter access tubes were installed 1000 mm from the tree trunk in the plant row in each experimental plot. The neutron water meter (Campbell Pacific Nuclear, California, USA) was calibrated in different soil types according to Karsten, Deist and De Waal (1975). Different calibration curves were obtained for depths shallower than 300 mm (Karsten & Van der Vyver 1979). The clay and silt contents for each measuring depth of each experimental plot were calculated from the particle size analyses. These values were entered into a custom-made computer program (J.H.M. Karsten, an associate researcher at ARC Infruitec-Nietvoorbij) in order to calculate different calibration curves for each measuring depth of each experimental plot (Karsten *et al.* 1975). The volumetric soil water content was determined before and after each irrigation with the aid of the neutron water meter at depths of 200, 300 and 600 mm.

Irrigation scheduling: The neutron water meter measured volumetric soil water content was converted to soil matric potential by means of the different soil water retention curve equations. The soil water retention curve for the 300 mm depth was used to estimate the soil matric potential for the 200 mm depth. The volumetric soil water content at the 200, 300 and 600 mm depths was representative of the 0-200 mm, 200-400 mm and 400-600 mm depths of the soil profile, respectively. The average of the soil matric potentials for the three depths was used as the soil matric potential of the soil profile. Irrigation was applied when the required soil matric potentials were reached.

Growth measurements: Forty-eight fruit per treatment combination (four fruit per tree, four trees per plot, three replicate blocks) were labelled and fruit diameter was measured at fortnightly intervals with the aid of electronic callipers (Mitutoyo Corporation, Japan). Twenty-four shoots per treatment (two shoots per tree) were labelled and shoot growth was measured with standard measuring tapes. The percentage shoot growth was determined as follows:

$$\%SG = (SL_b - SL_a)/SL_a * 100 \qquad (1)$$

where %SG is percentage shoot growth, SL_b is shoot length at end of growth stage and Sl_a is shoot length at start of growth stage.

Fruit and shoot growth measurements commenced after the fruit was thinned at the start of Stage 2 at the beginning of October and continued until harvest. Tree stem circumferences were measured with standard measuring tapes at the start of the growing season and at the end of each growth stage. Tree volumes (V) were estimated by measuring the height (h) and the mean diameter (2r) of each tree's canopy with standard measuring tapes. Assuming that the shape of the trees was conical, the following formula was used to calculate tree volume:

$$V = 1{,}047r^2h \qquad (2)$$

The effect of soil matric potentials on stem, shoot and fruit growth as well as tree volume were evaluated for the different growth stages.

Harvest procedure: Fruit were selectively harvested at the standard degree of ripeness. This necessitated four harvests at weekly intervals. During each harvest, the total mass of fruit from each experimental plot was determined separately. Simultaneously, fifty fruit from each experimental plot were randomly sampled and measured in order to obtain the average fruit mass of each experimental plot at each harvest. The weighted average fruit mass, according to the total mass of fruit per experimental plot at each harvest, was calculated to obtain the average fruit mass at harvest.

Fruit quality measurements: A sample of 45 fruit per treatment was collected at harvest and bruised according to the method of Robitaille & Janick (1973). Bruise volumes were determined after a period of 14 days of cold storage at 4°C using the equation of Pictian & Sun as referred to by Topping & Luton (1986). The firmness of 45 fruit per treatment was determined one day after harvest according to the method of Bramlage (1986) and Truter (undated), with a dial-type penetrometer (Facchini, Alfonsine, Italy), mounted on a modified drill stand. The plunger had a diameter of 11 mm. Skin was removed on two opposite sides of a fruit and two readings were taken on each fruit. The juice of individual fruit was analysed for sugar content with a calibrated refractometer using the method of Bramlage (1986). Fruit and leaf samples of each treatment were analysed for chemical composition according to standard laboratory techniques (AOAC, 1995).

Water consumption: Water consumption of the trees during each growth stage was determined by means of a water balance equation:

$$ET = SWC_b + P + I - SWC_e - R - D \qquad (3)$$

Where ET is water consumption during the growth stage (mm), SWC_b is water content of the soil profile at the start of the growth stage (mm), SWC_e is water content of the soil profile at the end of the growth stage (mm), P = rainfall during the growth stage (mm), I is irrigation applied during the growth stage (mm), R is runoff (mm) and D is drainage (mm).

Precipitation was assumed to be 100% effective, while runoff and drainage was considered negligible (set equal to zero in calculation of the water balance). The total water consumption of a specific treatment was considered as the water consumption during the stage when the irrigation treatment was applied plus the water consumption for the specific treatment during the rest of the season when normal irrigation was applied. Before each irrigation the soil water content of the specific treatment was measured with the neutron water meter and the amount of water to be applied in order to reach field capacity, was calculated. In order to ensure that drainage during irrigation can be considered as zero, only 80% of the calculated amount of water was consequently applied.

Data processing: A SAS (Version 6.12) software package for the analyses of variance and Student T-Test for significance of differences was used. Statistical analysis of the water consumption data could not be done as a mutual valve and water meter was connected to the irrigation pipes of the three replicates per treatment. An analysis of covariance was done to compare fruit growth measurements for the different treatment combinations.

3.2.2 *Results and discussion*

Shoot growth: The relationship between the percentage shoot growth as measured during the slow fruit growth, rapid fruit growth and ripening stages and the soil matric potential reached during the corresponding stages, is presented in Figures 2 to 4 respectively. In all three stages significant trends towards decreasing shoot growth with decreasing soil matric potential were obtained. The results correspond with results reported by Michell & Chalmers (1982) where similar trends were observed during the slow fruit growth stage.

The significance of the present results is that by manipulating irrigation applications during these periods excessive vegetative growth can be controlled. It is thus possible to eliminate adverse competition of vegetative growth to the advantage of fruit development. However, it is of importance to note that the different deficit irrigations were applied during only one of the different growth stages.

Stem growth and tree volume: No significant differences in increase of trunk circumferences or in tree volume were obtained between the different treatment combinations (data not shown).

Fruit growth: The effects of the different irrigation treatments during the five different growth stages are illustrated in Figures 5 to 9, respectively. No fruit growth measurements were done during the cell growth stage (Stage 1) as the fruit was only thinned at the end of this growth stage. However, the fruit growth for this treatment, as measured from the beginning of the slow fruit growth stage (Stage 2) until harvest, is presented in Figure 5. Due to the prevailing relatively moderate climatic conditions during the early spring, no significant divergent soil matric potentials were reached during this growth stage. The irrigation targets of –50 kPa and –100 kPa were reached for treatments T1 and T2. However, the maximum soil matric potentials reached for T3, T4 and T5, were also in the order of –100 kPa instead of the targeted –200 kPa, –400 kPa and –800 kPa respectively. As can thus be expected, the irrigation treatments applied during this stage had no significant effect on the fruit size at harvest time.

Irrigation treatments applied during the slow fruit growth stage (Stage 2) resulted in significant differences in fruit size at the end of this stage. The application of normal irrigation during the two succeeding growth stages eliminated this effect at harvest (Figure 6). Significant differences in fruit size for the different irrigation treatments applied during the rapid fruit growth stage (Stage 3) were obtained at the end of this stage (Figure 7). However, application of normal irrigation during the following ripening stage was not able to eliminate this effect and significant differences were still obtained at harvest. As the different irrigation treatments applied during the ripening stage (Stage 4) prevailed until harvest time, the largest difference between fruit growth for the different irrigation treatments presented in Figure 8, were expected. Obviously, no fruit growth measurements were possible during the post harvest stage of the present season. Results presented in Figure 9 were obtained from the fruit growth measured for the period from the cell growth stage until harvest. The different irrigation treatments were applied during the

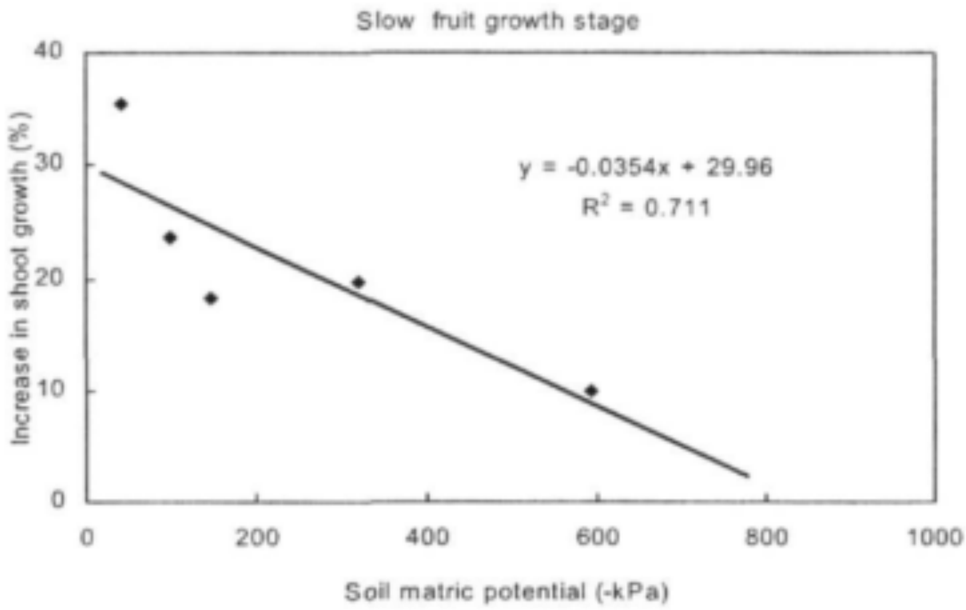


Figure 2. Relationship between percentage increase in shoot growth and soil matric potential as obtained during the slow fruit growth stage (Stage 2) of Neethling peaches during the 1998/1999-season at Robertson Experiment Farm.

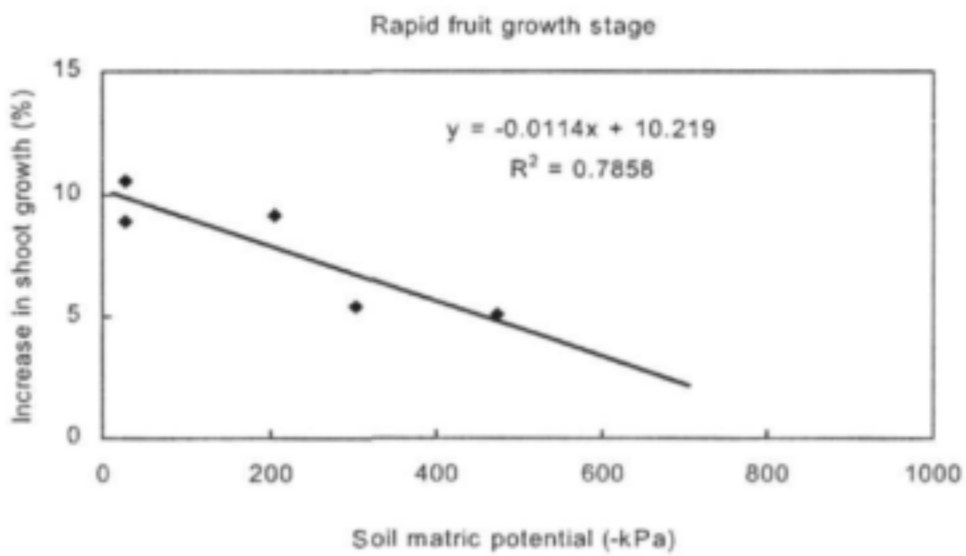


Figure 3. Relationship between percentage increase in shoot growth and soil matric potential as obtained during the rapid fruit growth stage (Stage 3) of Neethling peaches during the 1998/1999-season at Robertson Experiment Farm.

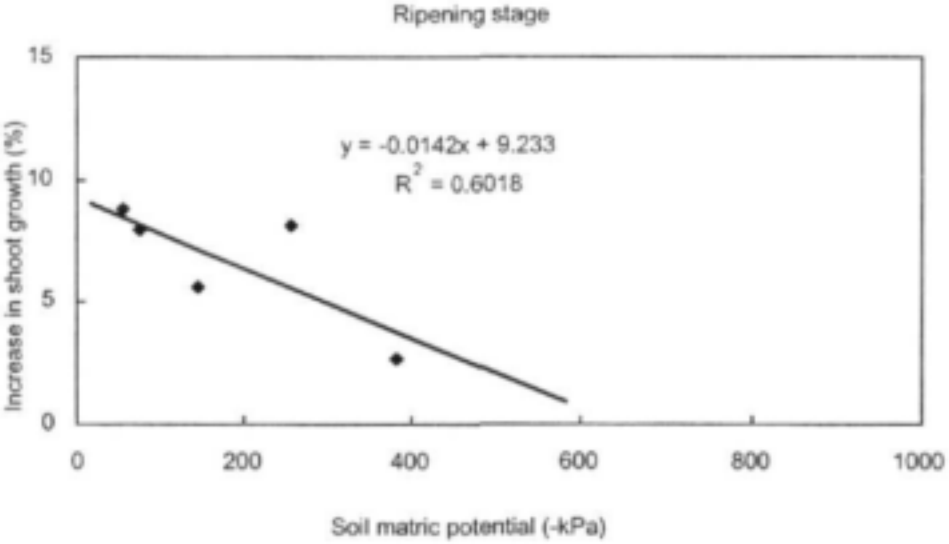


Figure 4. Relationship between percentage increase in shoot growth and soil matric potential as obtained during the fruit ripening stage (Stage 4) of Neethling peaches during the 1998/1999-season at Robertson Experiment Farm.

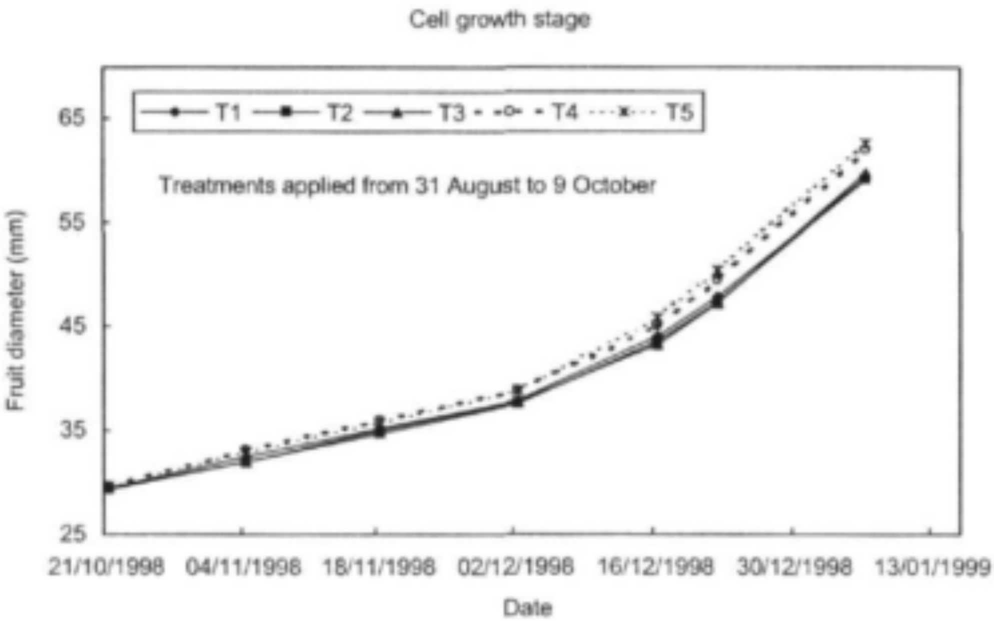


Figure 5. Effect of water deficits during cell growth (Stage 1) on fruit diameter of Neethling peaches as measured during the 1998/1999-season at Robertson Experiment Farm. Treatments T3, T4 and T5 were not successfully induced (Refer to material and methods for explanation of treatments).

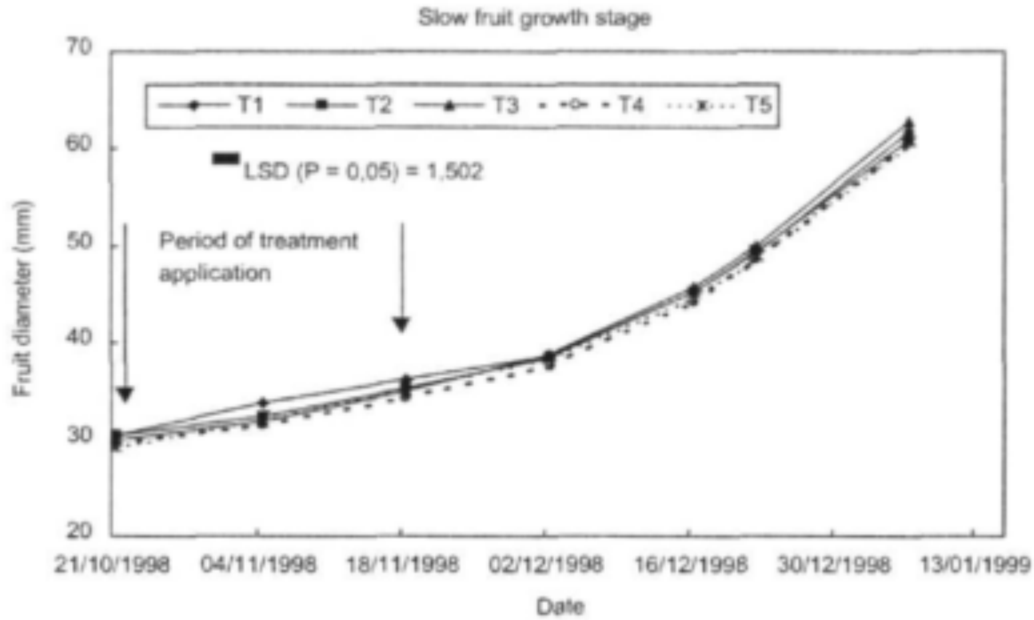


Figure 6. Effect of water deficits during slow fruit growth (Stage 2) on fruit diameter of Neethling peaches as measured during the 1998/1999-season at Robertson Experiment Farm (Refer to material and methods for explanation of treatments).

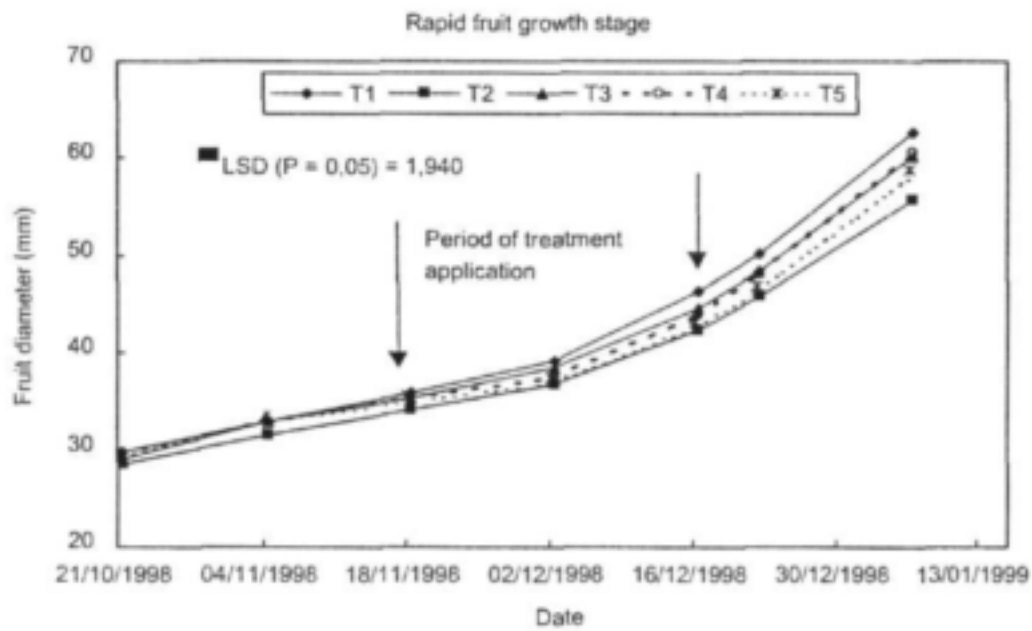


Figure 7. Effect of water deficits during rapid fruit growth (Stage 3) on fruit diameter of Neethling peaches as measured during the 1998/1999-season at Robertson Experiment Farm (Refer to material and methods for explanation of treatments).

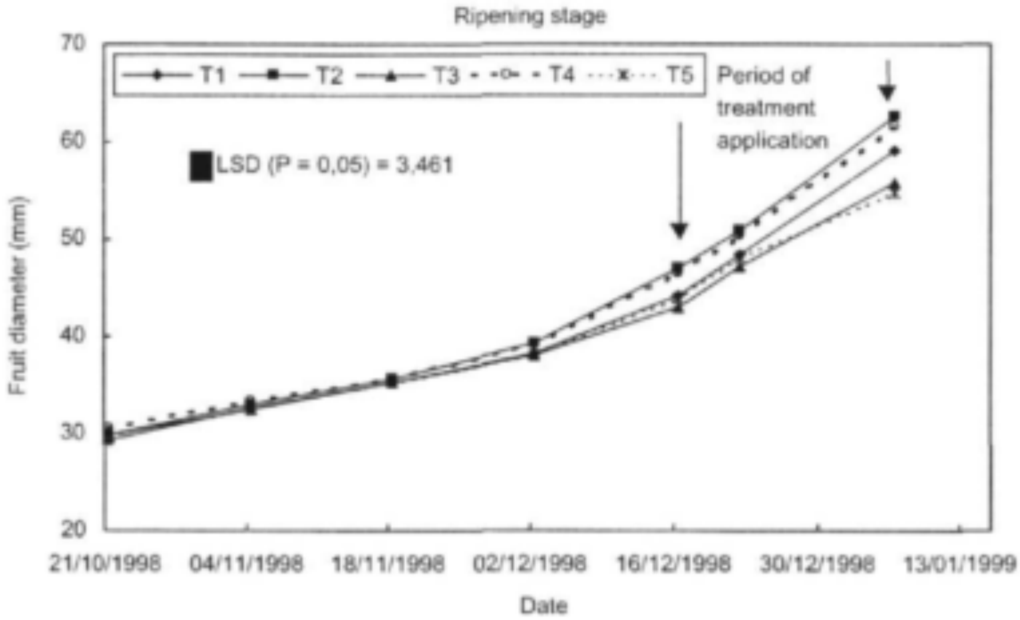


Figure 8. Effect of water deficits during fruit ripening stage (Stage 4) on fruit diameter of Neethling peaches as measured during the 1998/1999-season at Robertson Experiment Farm (Refer to material and methods for explanation of treatments).

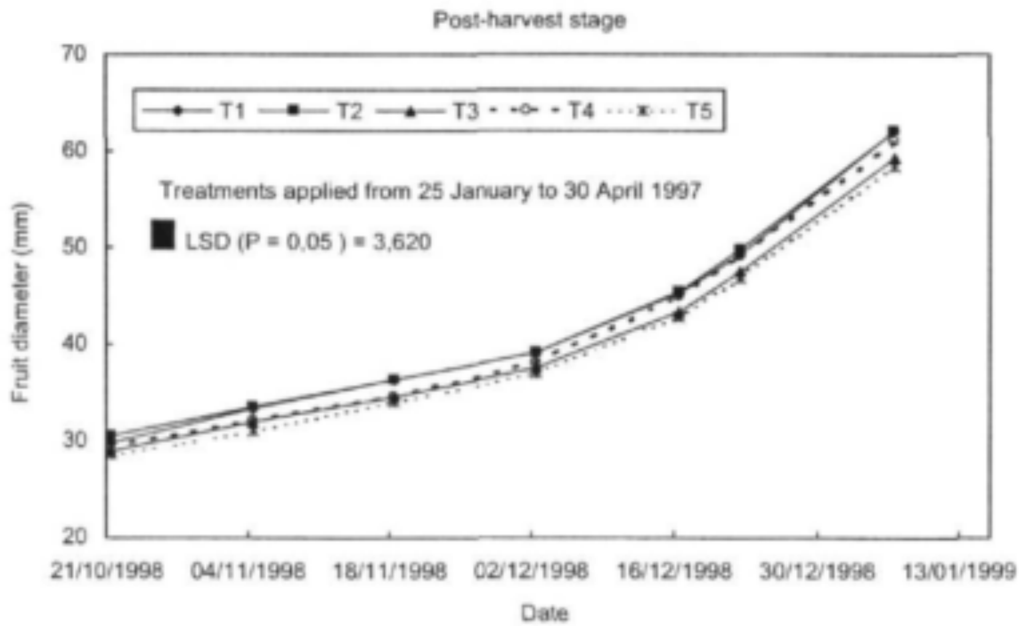


Figure 9. Effect of water deficits during post-harvest stage (Stage 5) of the previous season on fruit diameter of Neethling peaches as measured during the 1998/1999-season at Robertson Experiment Farm (Refer to material and methods for explanation of treatments).

post-harvest stage of the previous season. No effect of irrigation treatments was observed for this treatment combination.

It is important to note that the differences in fruit growth generated by the different irrigation treatments during the rapid fruit growth stage were not eliminated by normal irrigation applied in the following ripening stage. This implies that fruit size can adversely be affected by water deficits during both the rapid fruit growth and ripening stages.

Final fruit size: The final fruit size was significantly affected by the application of water deficit treatments during the rapid fruit growth and ripening stages (Figure 10). The unexpected small fruit size obtained with the T2 treatment in the rapid fruit growth stage was possibly due to smaller fruit randomly selected at the start of the season (Figure 7). The larger than expected fruit size obtained with the T4 treatment during the ripening stage can be ascribed to larger randomly selected fruit at the start of the growing season and rapid fruit growth from the beginning of December (Figure 8).

The relationship between final fruit diameter and soil matric potential (Figure 11) is probably of no importance as no significant differences in soil water potentials were obtained during the cell growth stage. For the remaining stages certain trends were observed, but poor relationships were obtained between final fruit diameter and soil matric potential for all growth stages (Figures 11 to 15). These results indicate that final fruit size was apparently not very sensitive to water deficits during the different growth stages.

Final fruit mass: Significant reduction in final fruit mass was obtained with a soil matric potential exceeding –400 kPa during the ripening stage (Figure 16) resulting in the smallest fruit of all the treatment combinations. The effects of soil matric potential on final fruit mass at harvest for the different growth stages are presented in Figures 17 to 21.

No significant reductions in final fruit mass were caused by water deficits during the different growth stages, except for a significant relationship between final fruit mass and soil matric potential during the ripening stage where a tendency of decreasing fruit diameter with decreasing soil matric potentials was observed (Figure 20). This corresponds with the findings of Li *et al.* (1989, and references therein). They reported that fruit expansion was significantly limited by water deficits during the ripening stage. A mean fruit mass (141,4 g), which is well within the norms of the Canning Industry, was obtained.

Production: No significant differences in production were caused by water deficits during the different growth stages (Figure 22). The relationships between production and soil matric potentials obtained for the different growth stages are illustrated in Figures 23 to 27.

A good relationship between production and soil matric potential was obtained during the rapid fruit growth stage where deficit irrigation treatments resulted in higher productions (Figure 25). This corresponds with the results obtained by Mitchell *et al.* (1984, 1986 & 1989). No relationships between production and soil matric potential were obtained for the other growth stages. Production was not

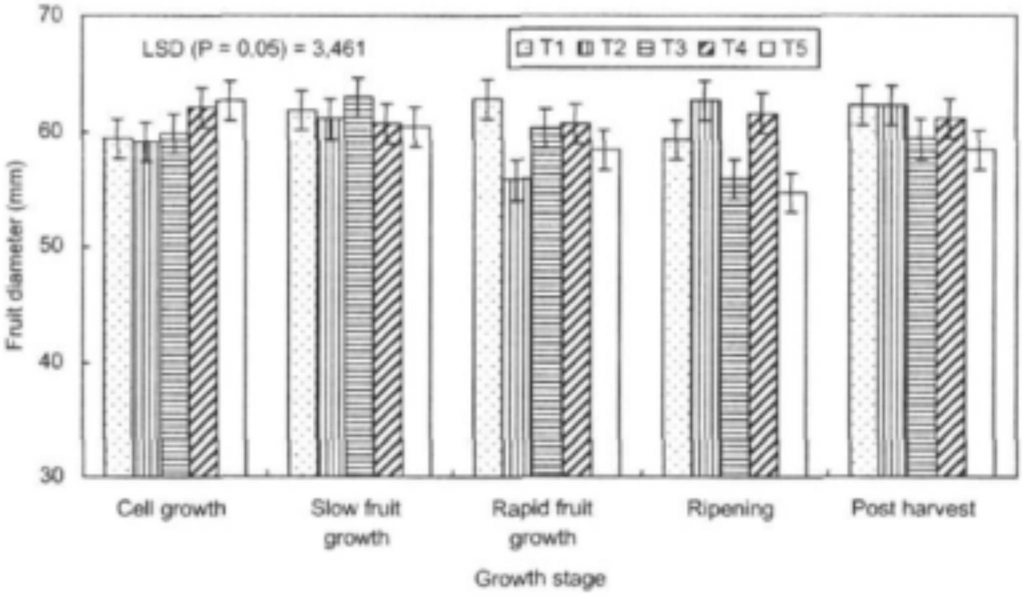


Figure 10. Effect of water deficits during the different growth stages on final fruit diameter of Neethling peaches as measured during the 1998/1999-season at Robertson Experiment Farm (Refer to material and methods for explanation of treatments).

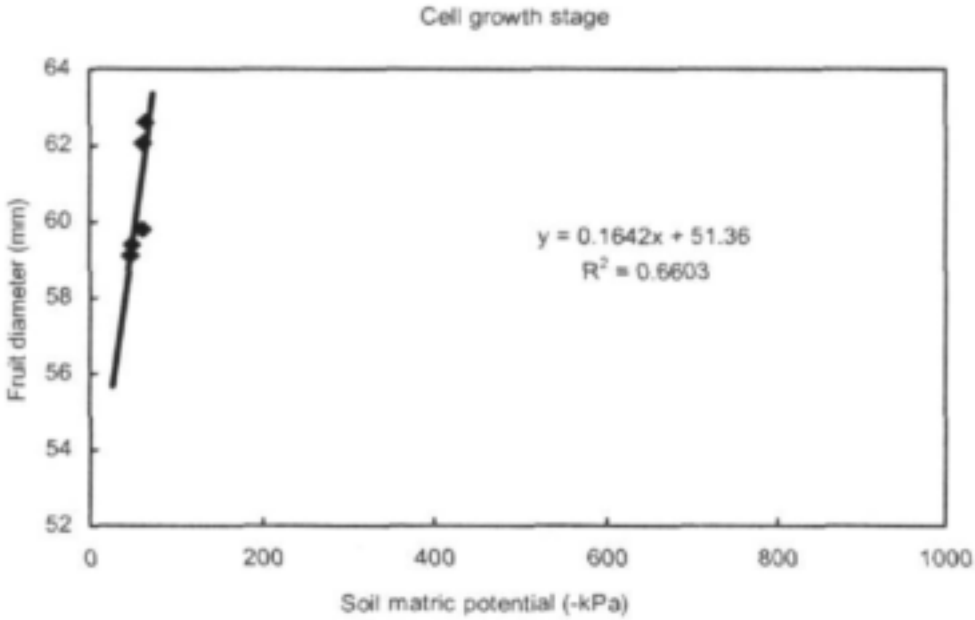


Figure 11. Relationship between final fruit diameter and soil matric potential as obtained for deficit irrigation during the cell growth stage (Stage 1) of Neethling peaches during the 1998/1999-season at Robertson Experiment Farm.

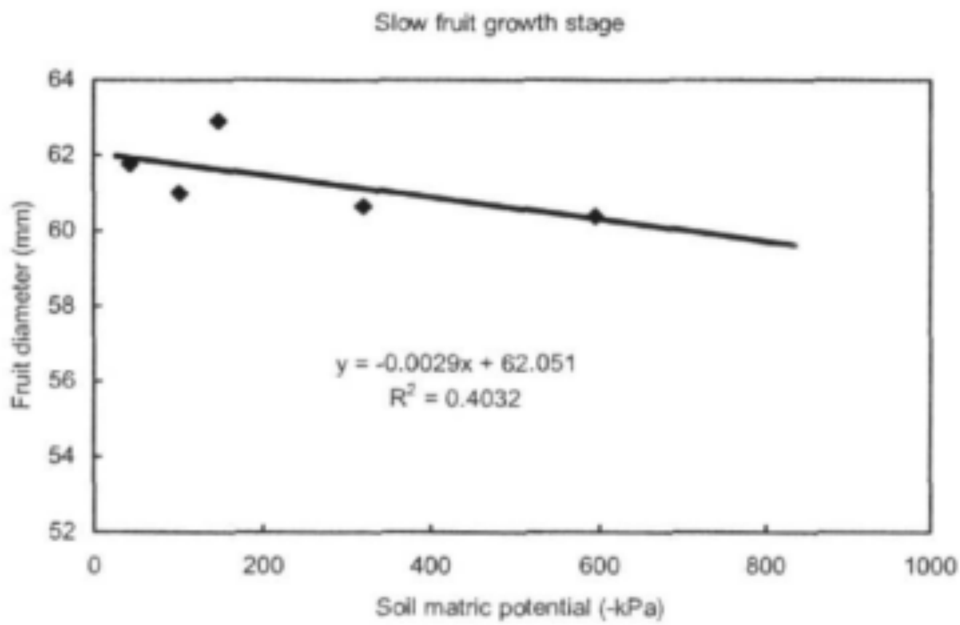


Figure 12. Relationship between final fruit diameter and soil matric potential as obtained for deficit irrigation during the slow fruit growth stage (Stage 2) of Neethling peaches during the 1998/1999-season at Robertson Experiment Farm.

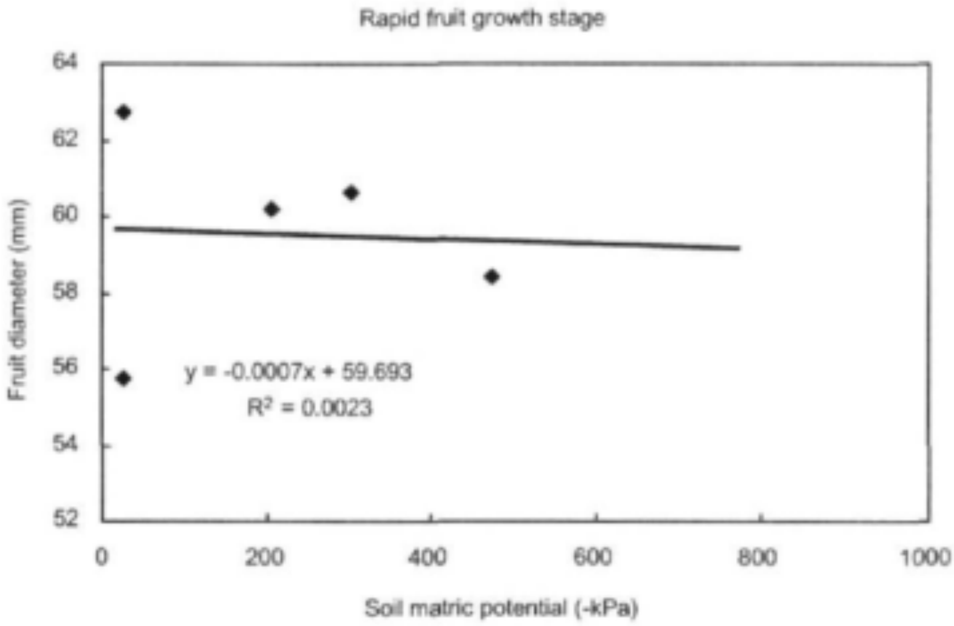


Figure 13. Relationship between final fruit diameter and soil matric potential as obtained for deficit irrigation during the rapid fruit growth stage (Stage 3) of Neethling peaches during the 1998/1999-season at Robertson Experiment Farm.

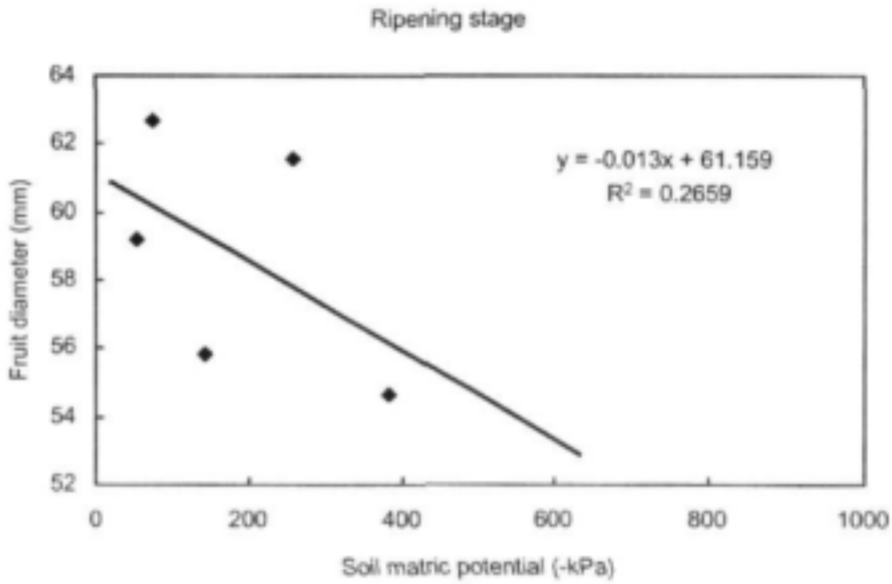


Figure 14. Relationship between final fruit diameter and soil matric potential as obtained for deficit irrigation during the ripening stage (stage 4) of Neethling peaches during the 1998/1999-season at Robertson Experiment Farm.

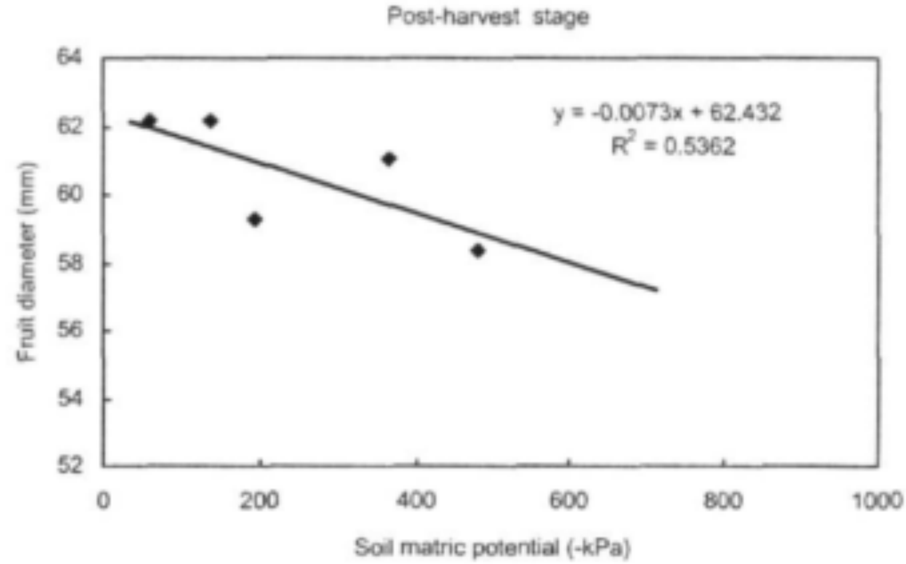


Figure 15. Relationship between final fruit diameter and soil matric potential as obtained for the post-harvest stage (Stage 5) of Neethling peaches during the 1998/1999-season at Robertson Experiment Farm.

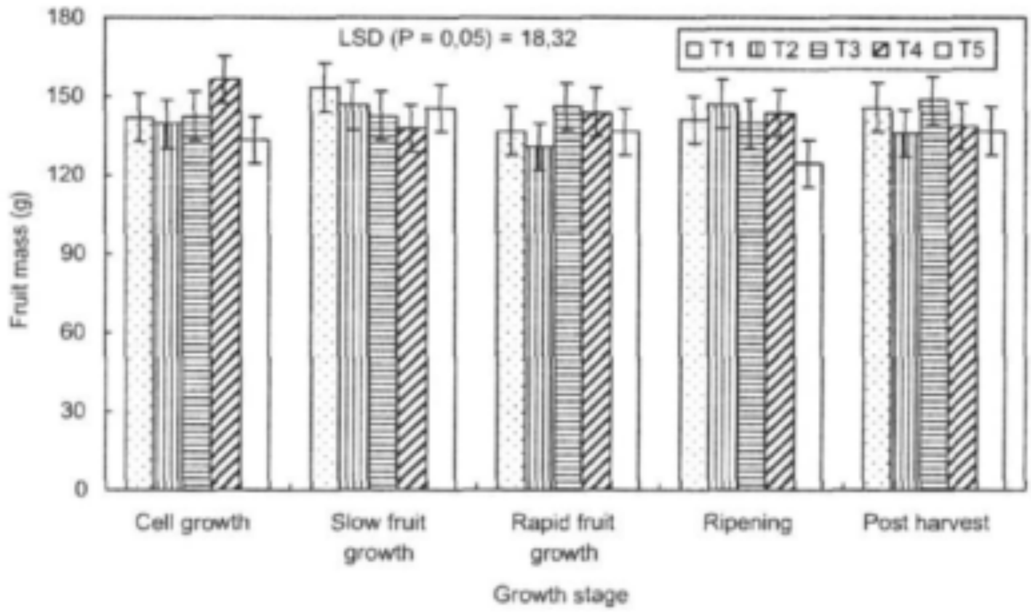


Figure 16. Effect of water deficits during the different growth stages on the final fruit mass of Neethling peaches as obtained during the 1998/1999-season at Robertson Experiment Farm (Refer to material and methods for explanation of treatments).

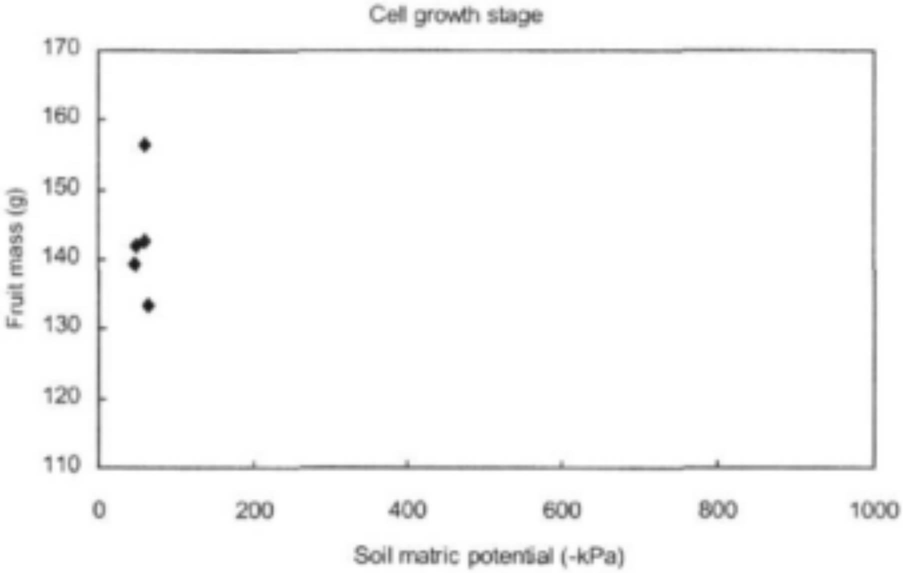


Figure 17. Relationship between final fruit mass and soil matric potential as obtained for deficit irrigation during the cell growth stage (Stage 1) of Neethling peaches during the 1998/1999-season at Robertson Experiment Farm.

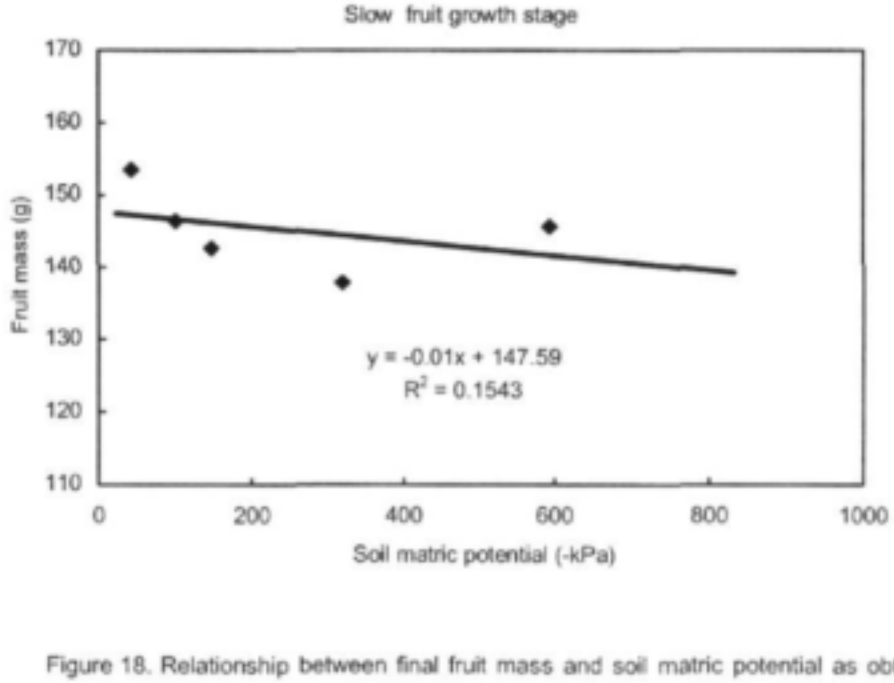


Figure 18. Relationship between final fruit mass and soil matric potential as obtained for deficit irrigation during the slow fruit growth stage (Stage 2) of Neethling peaches during the 1998/1999-season at Robertson Experiment Farm.

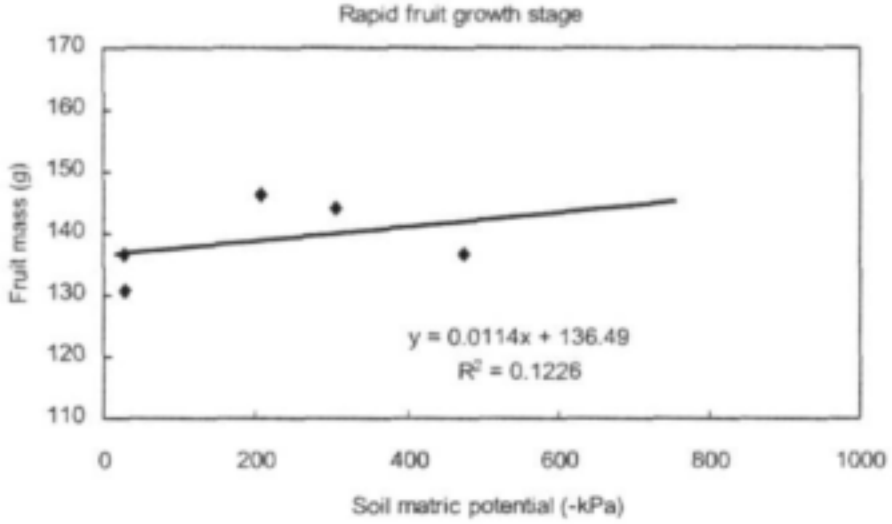


Figure 19. Relationship between final fruit mass and soil matric potential as obtained for deficit irrigation during the rapid fruit growth stage (Stage 3) of Neethling peaches during the 1998/1999-season at Robertson Experiment Farm.

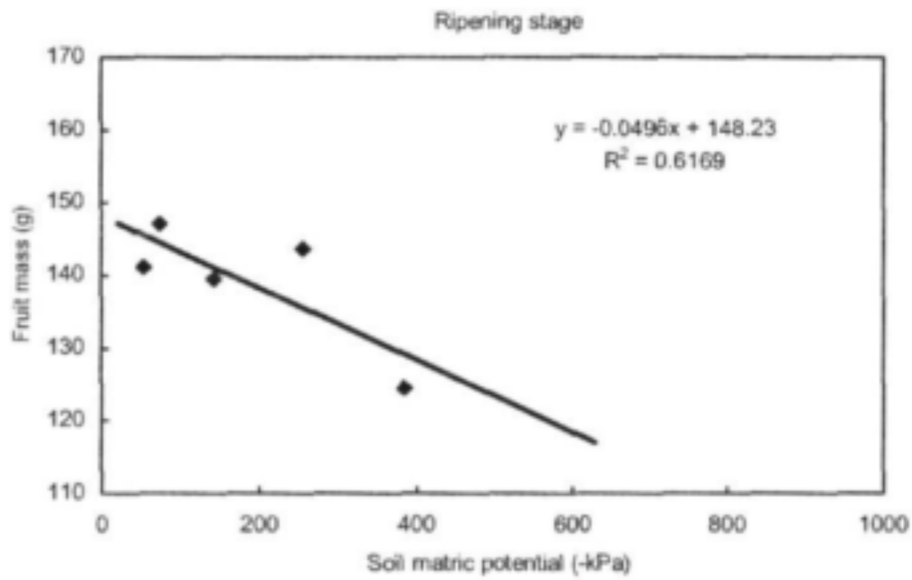


Figure 20. Relationship between final fruit mass and soil matric potential as obtained for deficit irrigation during the fruit ripening stage (Stage 4) of Neethling peaches during the 1998/1999-season at Robertson Experiment Farm.

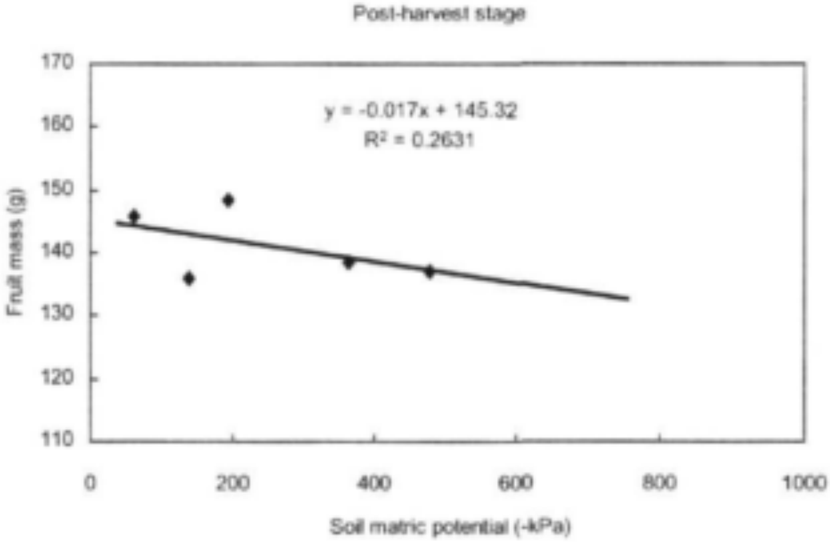


Figure 21. Relationship between final fruit mass and soil matric potential as obtained for deficit irrigation during the post-harvest stage (Stage 5) of Neethling peaches during the 1998/1999-season at Robertson Experiment Farm.

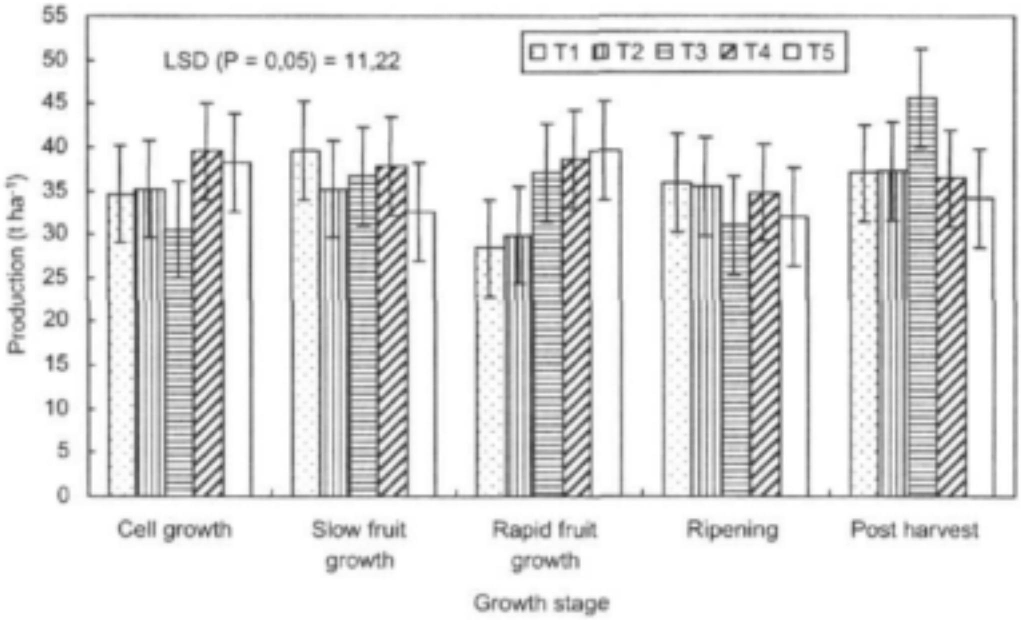


Figure 22. Effect of water deficits during the different growth stages on the production of Neethling peaches as obtained during the 1998/1999-season at Robertson Experiment Farm (Refer to material and methods for explanation of treatments).

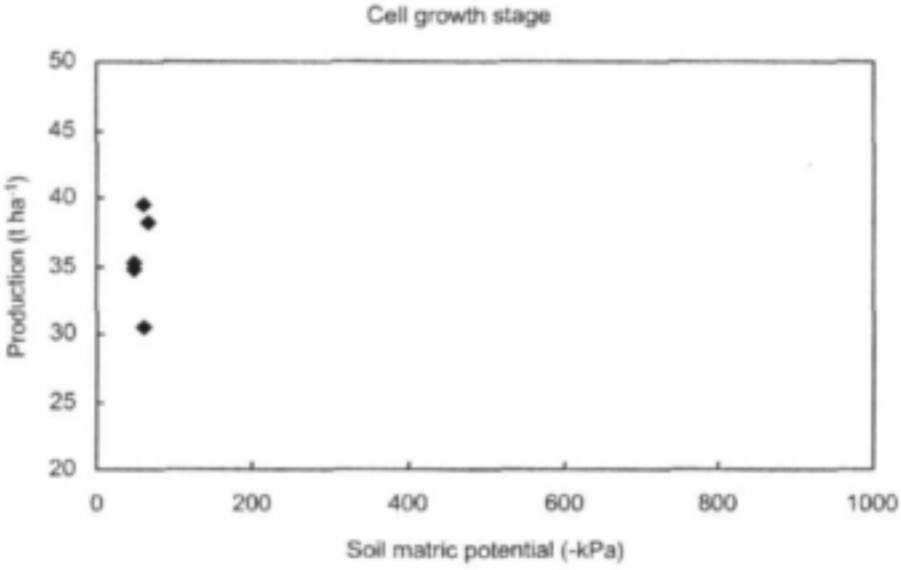


Figure 23. Relationship between production and soil matric potential as obtained for deficit irrigation during the cell growth stage (Stage 1) of Neethling peaches during the 1998/1999-season at Robertson Experiment Farm.

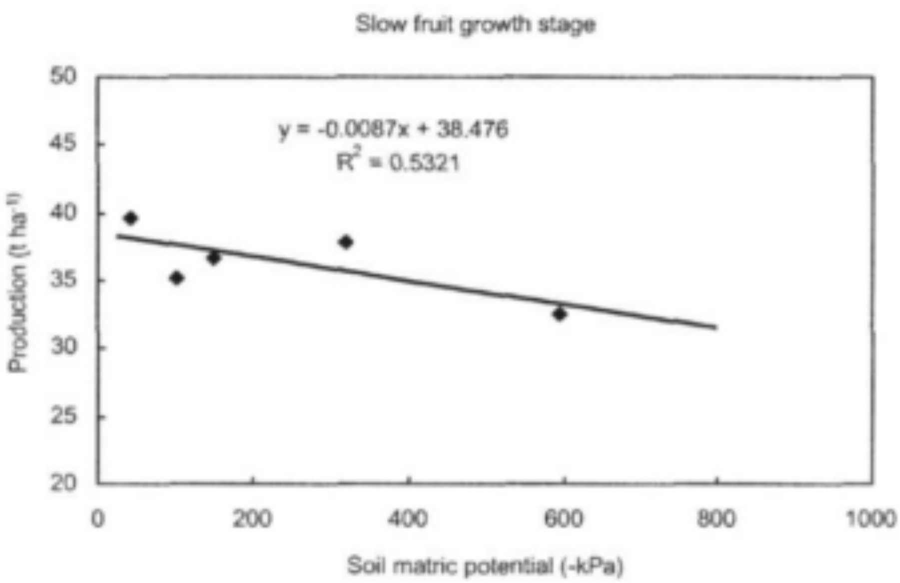


Figure 24. Relationship between production and soil matric potential as obtained deficit irrigation during for the slow fruit stage (Stage 2) of Neethling peaches during the 1998/1999-season at Robertson Experiment Farm.

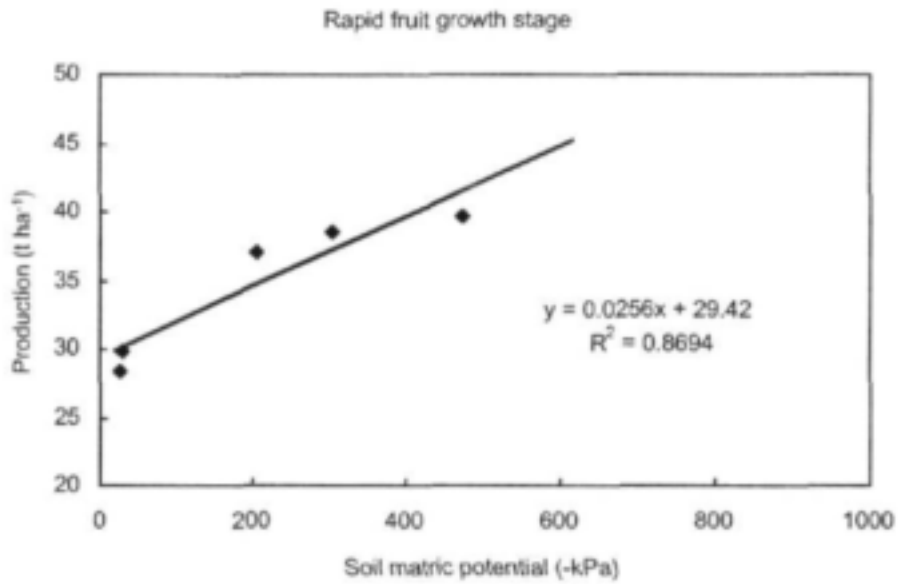


Figure 25. Relationship between production and soil matric potential as obtained for deficit irrigation during the rapid fruit stage (Stage 3) of Neethling peaches during the 1998/1999-season at Robertson Experiment Farm.

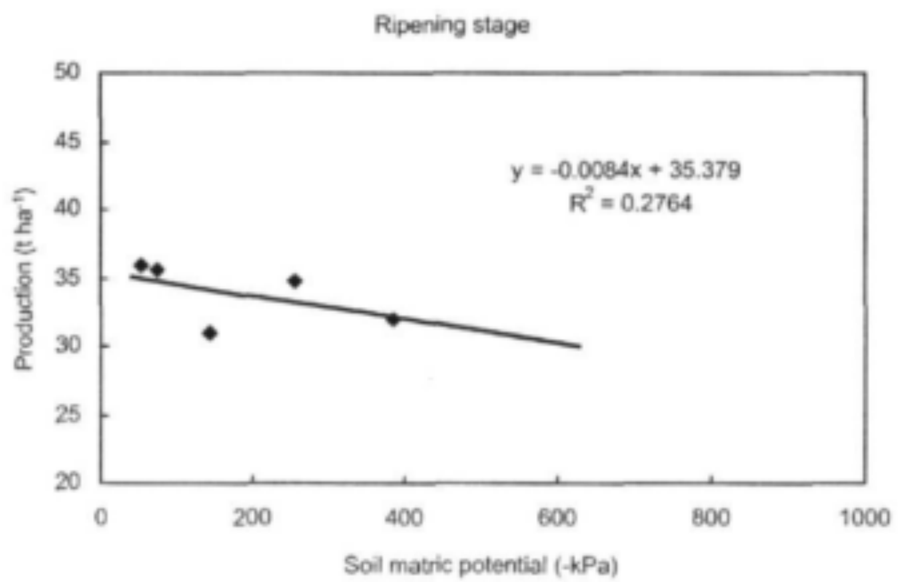


Figure 26. Relationship between production and soil matric potential as obtained for deficit irrigation during the fruit ripening stage (Stage 4) of Neethling peaches during the 1998/1999-season at Robertson Experiment Farm.

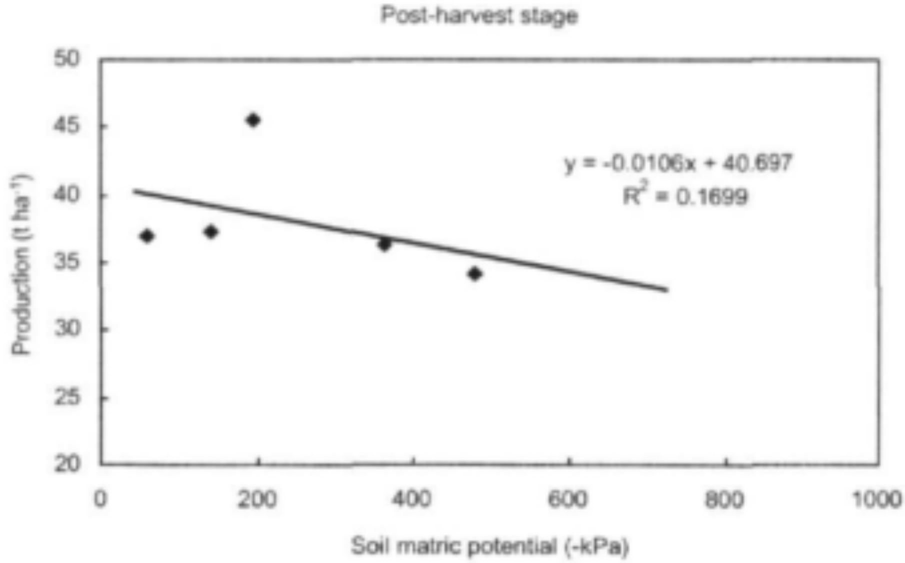


Figure 27. Relationship between production and soil matric potential as obtained for deficit irrigation during the post-harvest stage (Stage 5) of Neethling peaches during the 1998/1999-season at Robertson Experiment Farm.

directly related to the measured final fruit diameter or final fruit mass (Figures 28 & 29).

Fruit quality: Results obtained from the investigation on the bruisability of the fruit indicated that water deficits, applied during the different growth stages, had no significant effect on the percentage of fruit that developed bruises (Figures 30 to 34). Although no significant relationships between bruisability of fruit and soil matric potential were obtained for all the different growth stages, a tendency was observed that bruisability decreased with decreasing soil matric potentials during the rapid fruit growth and ripening stages (Figures 32 to 33).

Water deficits did not affect the firmness of the fruit as no significant relationships between fruit firmness and soil matric potential were obtained for the different growth stages (Figures 35 to 39). This corresponds with results reported for apples by Ebel *et al.* (1993). In contrast to the results reported by Ebel *et al.*(1993), no significant differences were obtained with the different treatment combinations with regard to percentage moisture or total soluble acid in the fruit (data not shown).

Water consumption: Results presented in Figure 40 illustrate the total water consumption for the different treatment combinations. The amount of water consumed during the slow fruit growth, rapid fruit growth, ripening and post-harvest stages decreased with deceasing soil matric potential. Applying deficit irrigation during the slow fruit growth and post-harvest stages can save substantial amounts of water. These results correspond to those reported by Decroix (1992) and Girona *et al.* (1993).

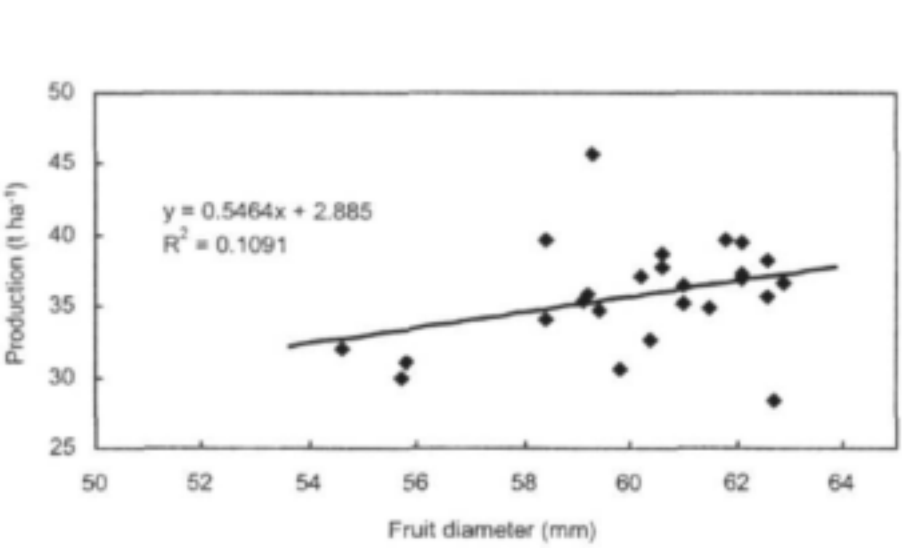


Figure 28. Relationship between production and final fruit diameter of Neethling peaches as obtained during the 1998/1999-season at Robertson Experiment Farm.

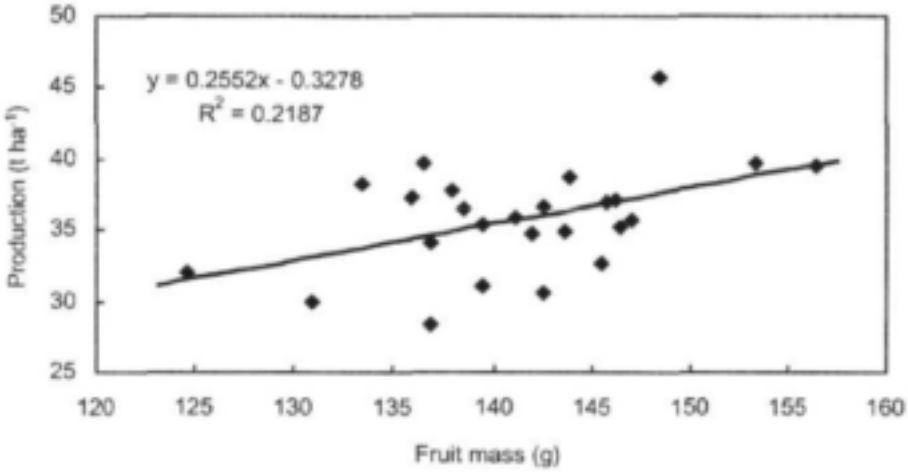


Figure 29. Relationship between production and final fruit mass of Neethling peaches as obtained during the 1998/1999-season at Robertson Experiment Farm.

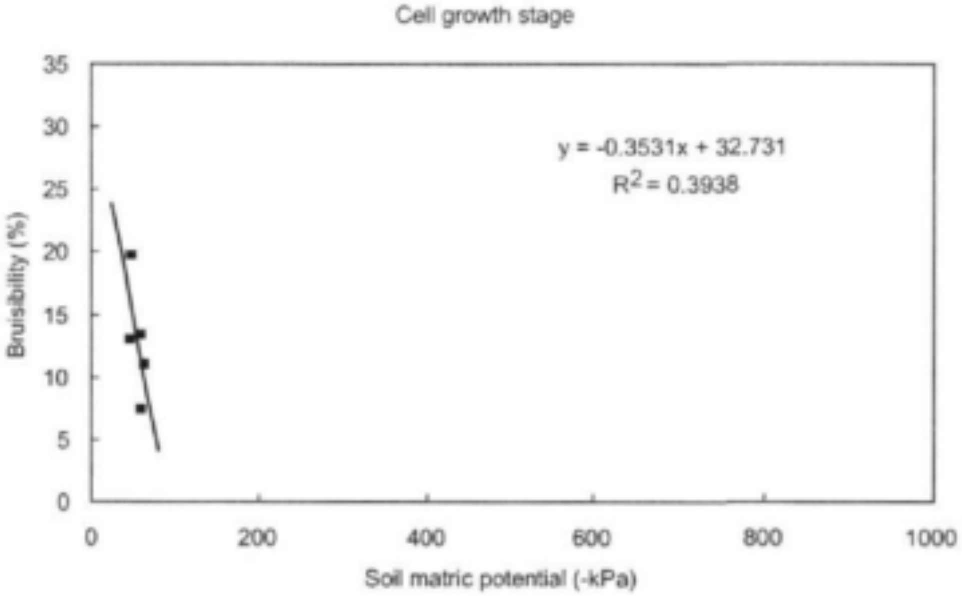


Figure 30. Relationship between the bruisibility of the fruit and soil matric potential as obtained for deficit irrigation during the cell growth stage (Stage 1) of Neethling peaches during the 1998/1999-season at Robertson Experiment Farm.

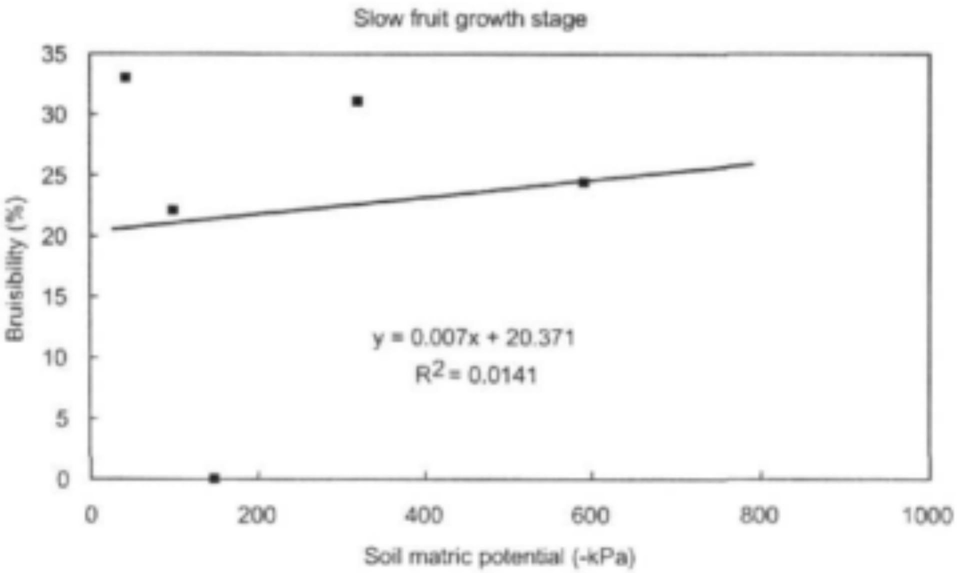


Figure 31. Relationship between the bruisibility of the fruit and soil matric potential as obtained for deficit irrigation during the slow fruit growth stage (Stage 2) of Neethling peaches during the 1998/1999-season at Robertson Experiment Farm.

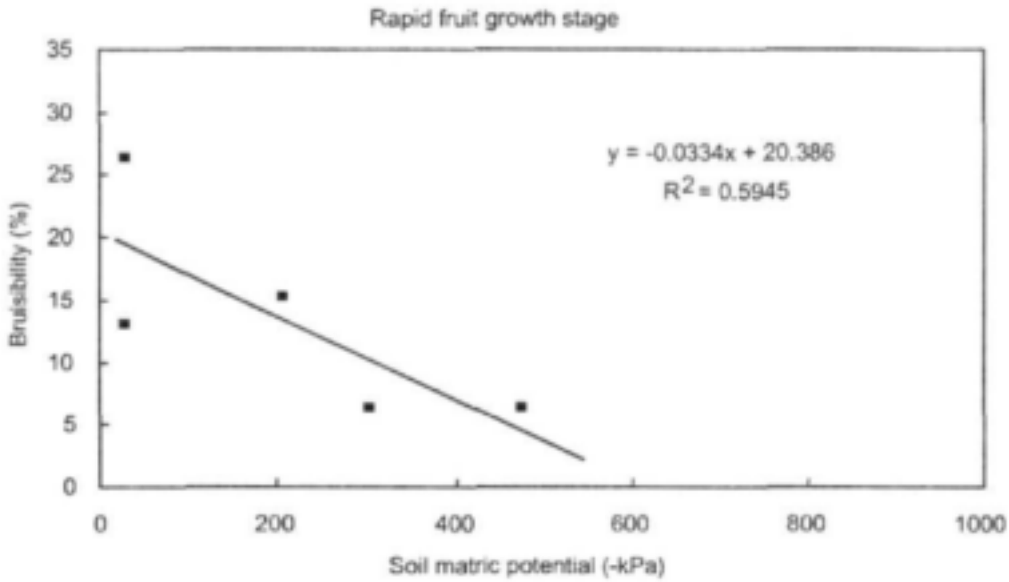


Figure 32. Relationship between the bruisibility of the fruit and soil matric potential as obtained for deficit irrigation during the rapid fruit growth stage (Stage 3) of Neethling peaches during the 1998/1999-season at Robertson Experiment Farm.

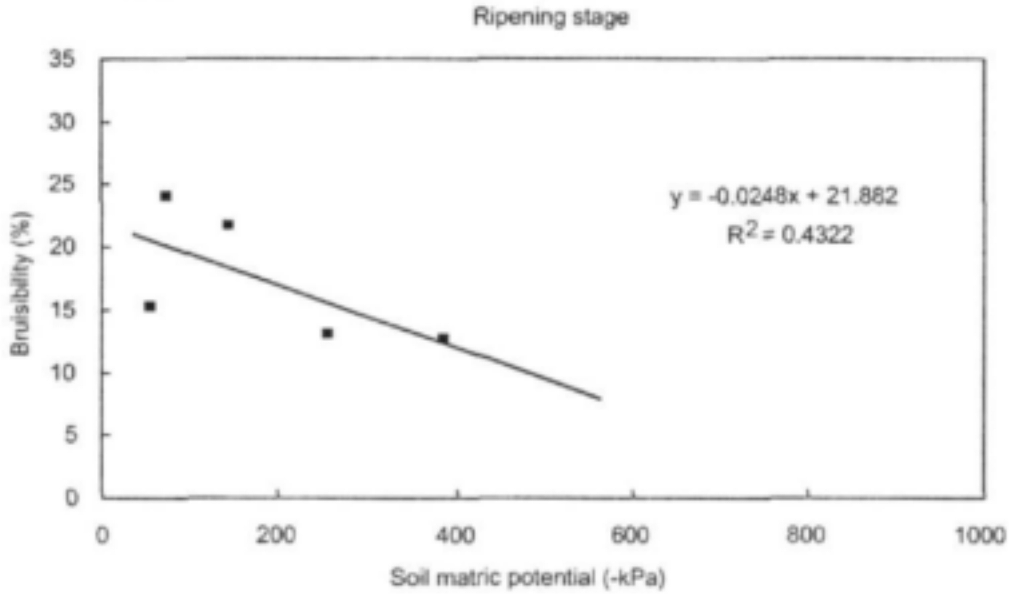


Figure 33. Relationship between the bruisibility of the fruit and soil matric potential as obtained for deficit irrigation during the fruit ripening stage (Stage 4) of Neethling peaches during the 1998/1999-season at Robertson Experiment Farm.

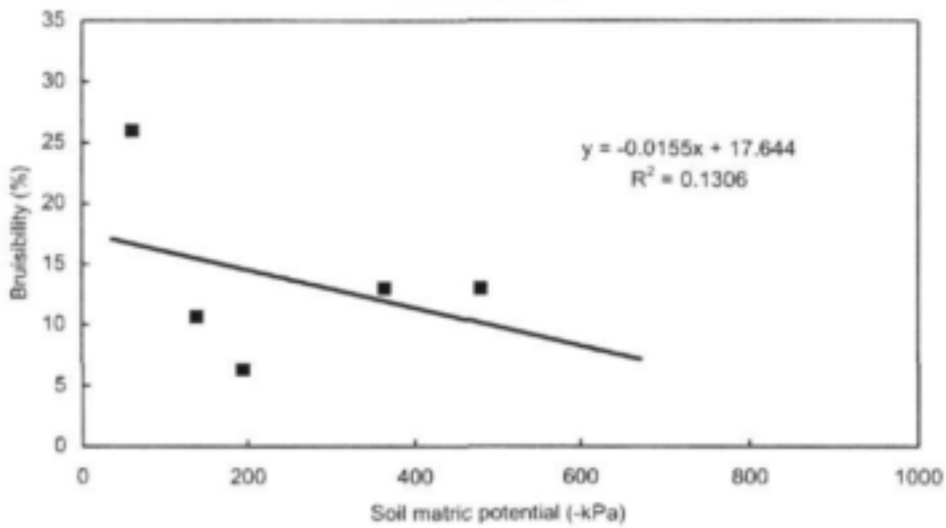


Figure 34. Relationship between the bruisibility of the fruit and soil matric potential as obtained for deficit irrigation during the post-harvest stage (Stage 5) of Neethling peaches during the 1998/1999-season at Robertson Experiment Farm.

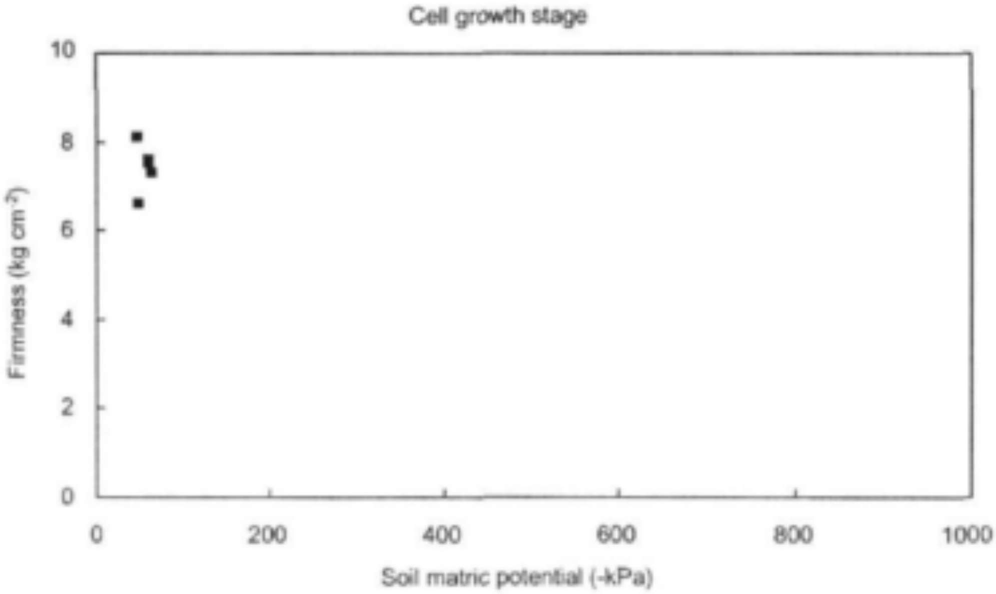


Figure 35. Relationship between the firmness of the fruit and soil matric potential as obtained for deficit irrigation during the cell growth stage (Stage 1) of Neethling peaches during the 1998/1999-season at Robertson Experiment Farm.

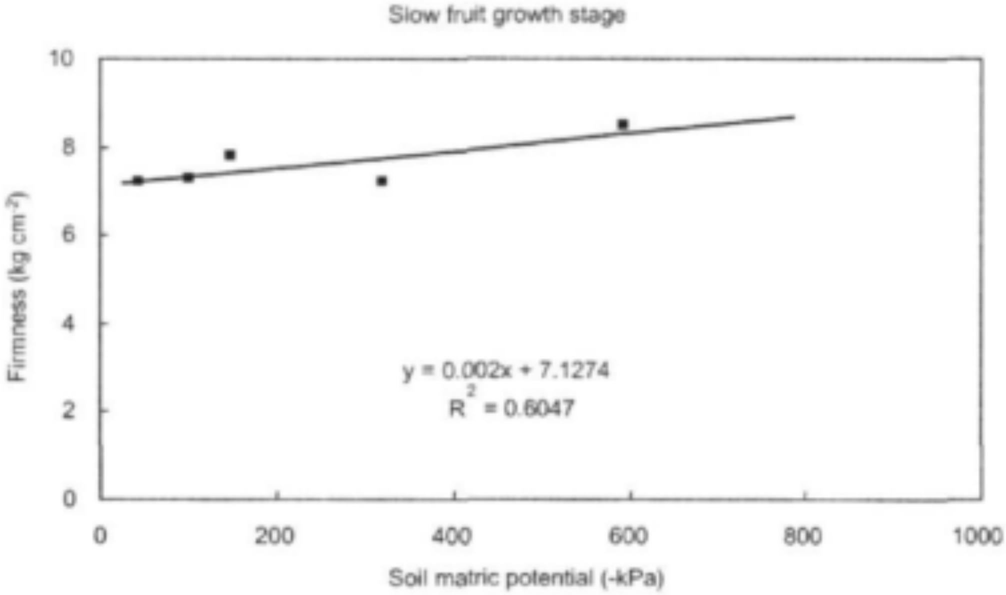


Figure 36. Relationship between the firmness of the fruit and soil matric potential as obtained for deficit irrigation during the slow fruit growth stage (Stage 2) of Neethling peaches during the 1998/1999-season at Robertson Experiment Farm.

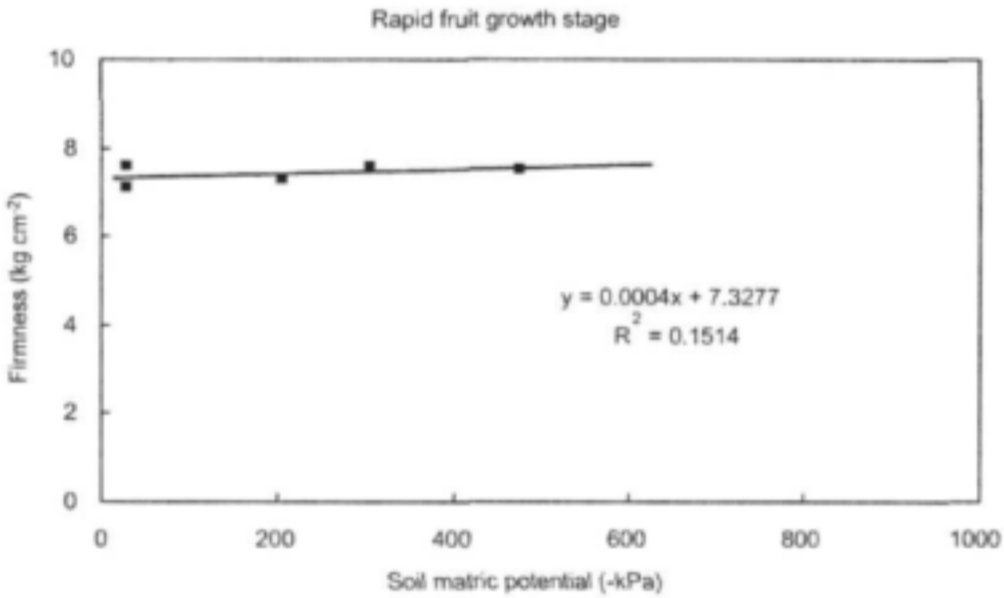


Figure 37. Relationship between the firmness of the fruit and soil matric potential as obtained for deficit irrigation during the rapid fruit growth stage (Stage 3) of Neethling peaches during the 1998/1999-season at Robertson Experiment Farm.

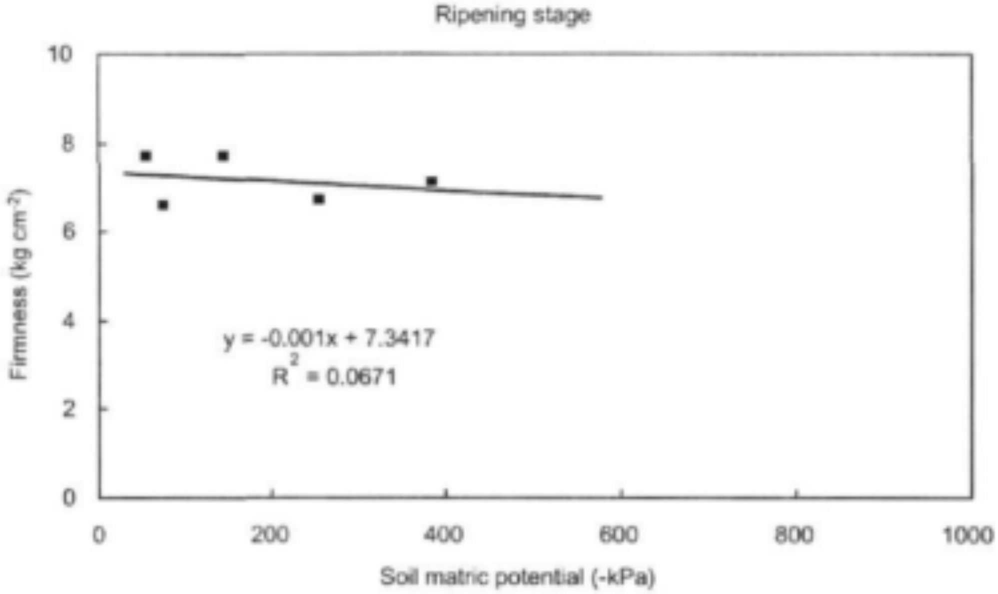


Figure 38. Relationship between the firmness of the fruit and soil matric potential as obtained for deficit irrigation during the fruit ripening stage (Stage 4) of Neethling peaches during the 1998/1999-season at Robertson Experiment Farm.

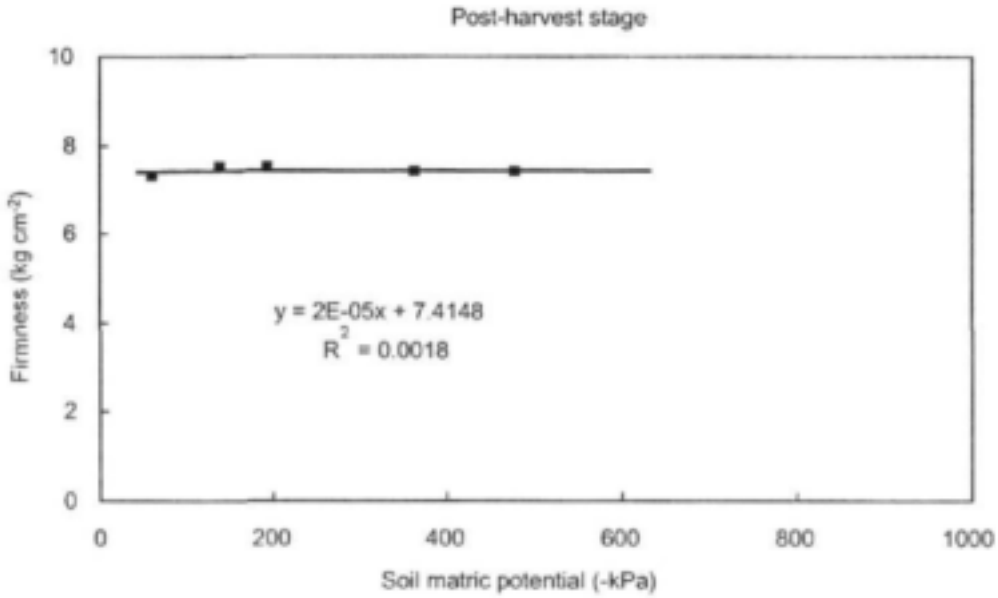


Figure 39. Relationship between the firmness of the fruit and soil matric potential as obtained during deficit irrigation for the post-harvest stage (Stage 5) of Neethling peaches during the 1998/1999-season at Robertson Experiment Farm.

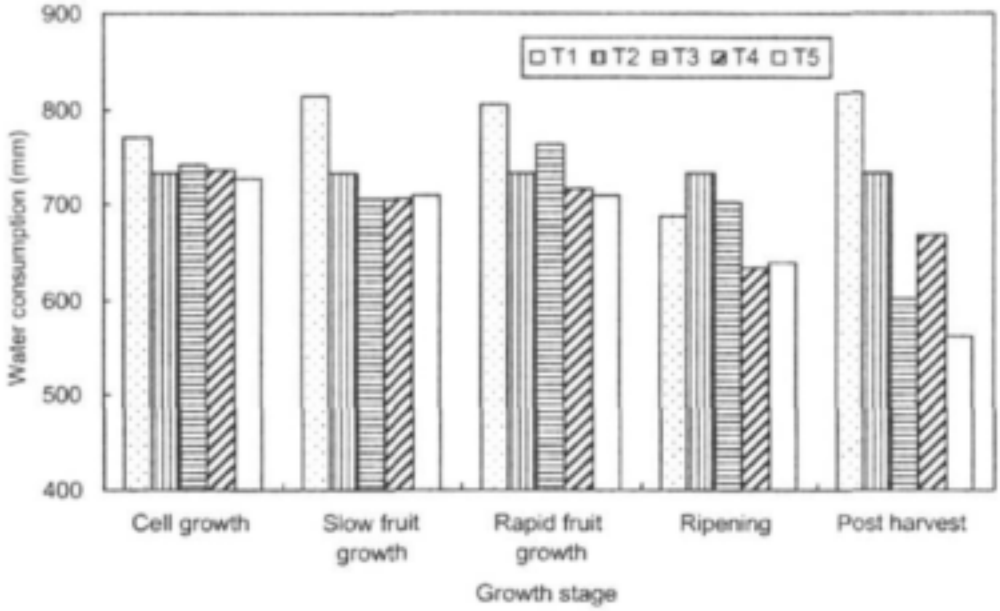


Figure 40. The effect of water deficits during the different growth stages on the total water consumption of Neethling peaches during the 1998/1999-season as measured in the wetted strip at Robertson Experiment Farm.

3.3 THE EFFECT OF DEFICIT IRRIGATION ON THE PRODUCTION AND FRUIT QUALITY OF PEACHES WITH A HIGH CROP LOAD

3.3.1 *Material and methods*

The trial was continued in the following season (1999/2000) in the same orchard. The procedures followed were identical to the 1998/1999 trial with the only exception that a 50% higher crop load was allowed in the second trial. The average crop load in the second trial was 572 fruit per tree compared to 380 fruit per tree for the first trial. Fruit growth measurements were done once a week but vegetative growth was not measured.

3.3.2 *Results and discussion*

Meteorological conditions: A comparison between relevant meteorological conditions experienced during the respective growing seasons of the two trials is presented in Table 2. Similar meteorological conditions prevailed during the 1998/1999 and the 1999/2000-seasons. No major differences in average daily maximum temperature, average daily wind speed or relative humidity were experienced during the two different seasons. However, the total rainfall during the 1998/1999-season was much higher than the total rainfall for the 1999/2000-season. The average Penman-Monteith reference evapotranspiration (ETo) was somewhat higher for the 1998/1999-season compared to the present season.

Stem growth and tree volume: No significant differences in increase of trunk circumferences or in tree volume occurred between the different treatment combinations (data not shown).

Fruit growth: The effects of the five different irrigation treatments on fruit growth during the different phenological growth stages are illustrated in Figures 41 to 45, respectively. As in the first experiment, no fruit growth measurements were done during the cell growth stage, as this stage proceeded thinning. In addition, the targeted soil matric potentials could also not be reached. However, the irrigation treatments that were applied during this stage had an effect on the fruit growth as measured throughout the rest of the season (Figure 41).

Significant differences in fruit diameter were obtained by the different irrigation treatments applied during the slow fruit growth stage (Figure 42). At the end of this stage, the fruit of the T1 treatment was the largest and differed statistically from the fruit of the T5 treatment. However, as in the first experiment, these differences were eliminated at harvest by applying normal irrigation during the consecutive rapid fruit growth and ripening stages. This suggests that fruit growth can recover from the negative effects of deficit irrigation applied earlier in the growing season. These results correspond with those reported by Li *et al.* (1989) and Mitchell *et al.* (1982, 1984 & 1986).

Table 2. Relevant meteorological conditions that prevailed during the two trials at Robertson Experiment Farm.

Month	Average daily maximum temperature (°C)			Average daily wind speed ($m\ s^{-1}$)			Total rainfall (mm)			Average daily Penman-Monteith ETo[1] (mm)			Relative daily humidity (%)		
	1998/ 1999	1999/ 2000	Long term	1998/ 1999	1999/ 2000	Long term	1998/ 1999	1999/ 2000	Long term	1998/ 1999	1999/ 2000	Long term	1998/ 1999	1999/ 2000	Long term
Feb.	31.8	30.7	30.8	2.3	2.4	1.5	2.6	17.4	11.1	5.9	5.6	4.6	70.2	77.8	63.5
Mar.	28.5	30.8	30.3	2.2	2.1	1.4	18.4	0.8	15.7	4.7	3.9	3.3	71.6	89.6	64.9
Apr.	27.1	26.5	28.6	2.0	2.0	1.3	35.4	0.4	15.8	3.5	1.7	2.2	73.4	93.9	66.0
Sep.	22.7	22.2	19.5	2.5	2.6	1.6	13.6	0.2	37.1	4.0	3.5	3.3	66.5	71.4	67.9
Oct.	26.3	26.9	21.9	2.6	2.5	1.7	0.2	2.4	18.8	5.9	4.3	4.1	63.7	73.1	65.9
Nov.	26.9	28.6	24.5	2.5	2.9	1.6	44.8	0	23.1	5.9	7.2	5.0	67.6	60.5	64.6
Dec.	29.5	33.2	27.2	2.6	2.3	1.7	54.8	23.6	18	6.7	6.8	5.6	67.8	63.2	63.2
Jan.	32.0	31.4	29.4	2.4	2.4	1.7	5.2	10.0	15.1	6.8	6.1	5.5	71.3	65.1	63.4
Average	28.1	28.8	27.5	2.4	2.4	1.6			----	5.4	4.9	4.2	69.0	74.3	64.5
Total	----	----	----	----	----	----	175.0	54.8	154.7	----	----	----	----	----	----

1 Reference evapotranspiration

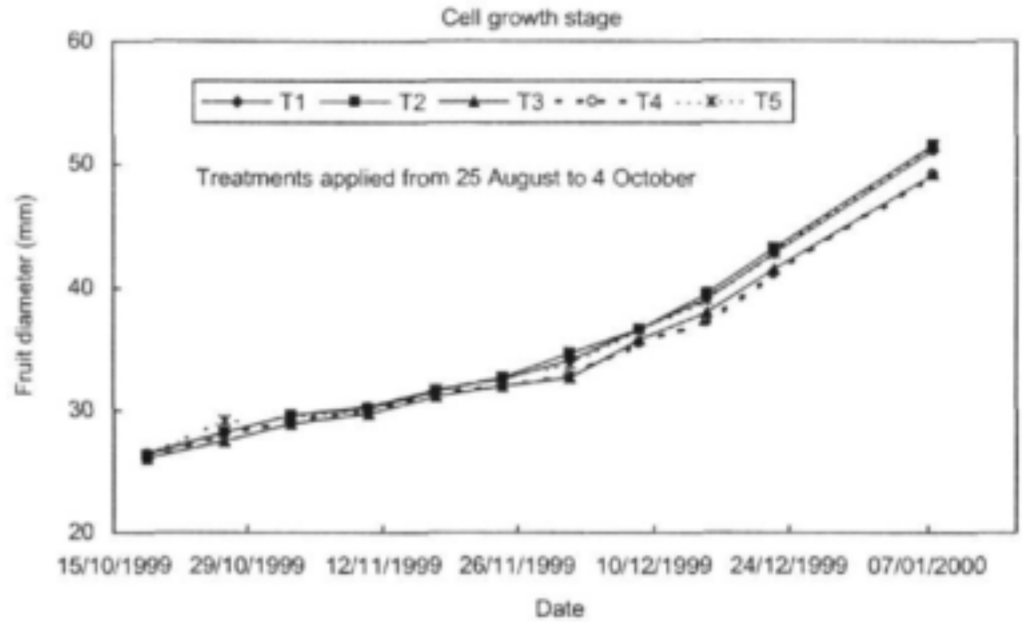


Figure 41. Effect of water deficits during cell growth (Stage 1) on fruit diameter of Neethling peaches as measured during the 1999/2000-season at Robertson Experiment Farm. Treatments T3, T4 and T5 were not successfully induced (Refer to 3.2.1 for explanation of treatments).

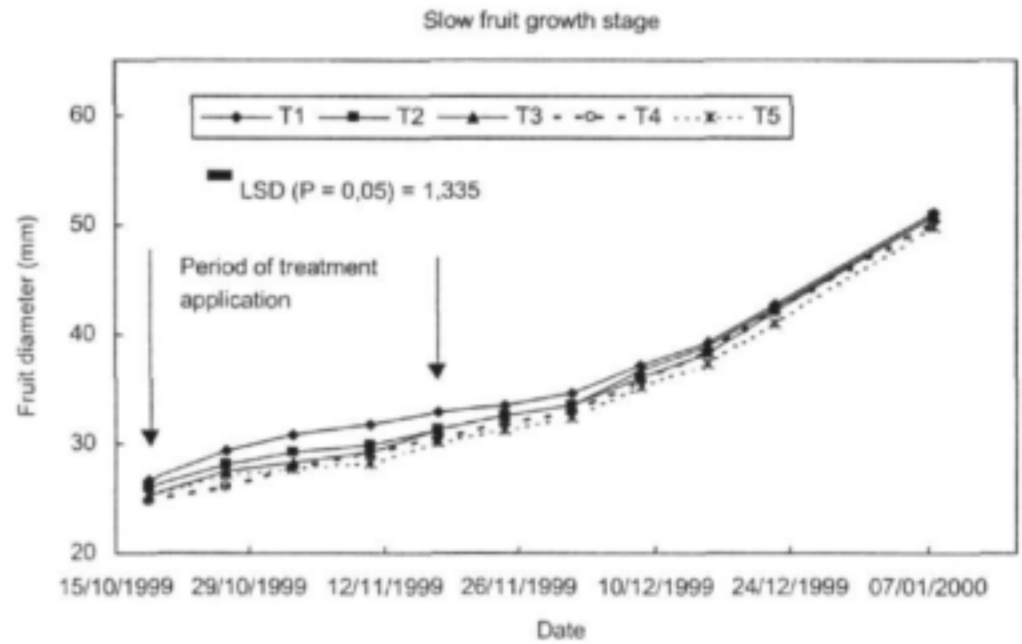


Figure 42. Effect of water deficits during slow fruit growth (Stage 2) on fruit diameter of Neethling peaches as measured during the 1999/2000-season at Robertson Experiment Farm (Refer to 3.2.1 for explanation of treatments).

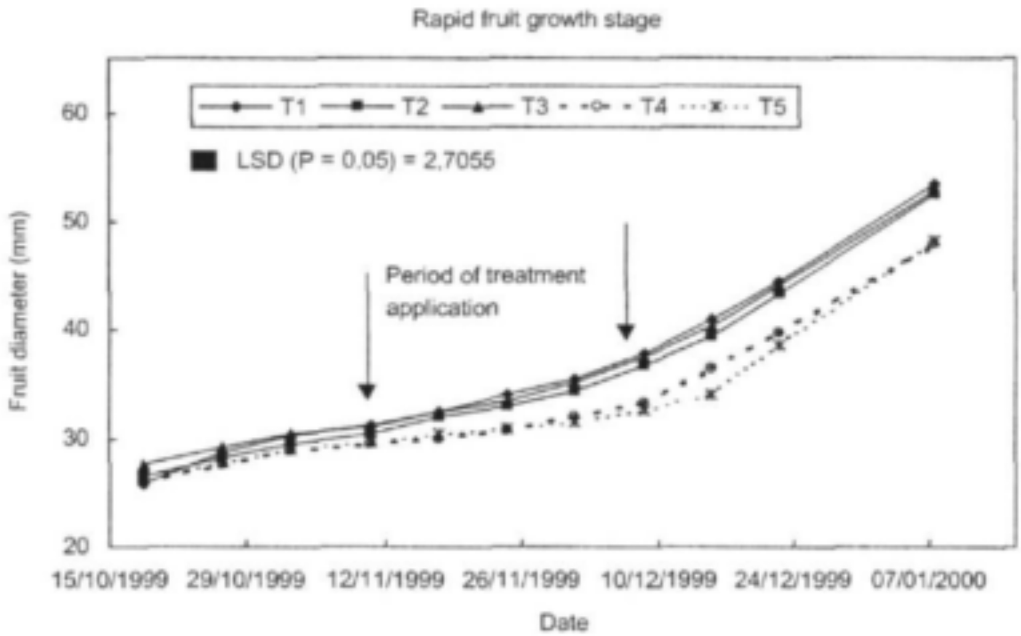


Figure 43. Effect of water deficits during rapid fruit growth (Stage 3) on fruit diameter of Neethling peaches as measured during the 1999/2000-season at Robertson Experiment Farm (Refer to 3.2.1 for explanation of treatments).

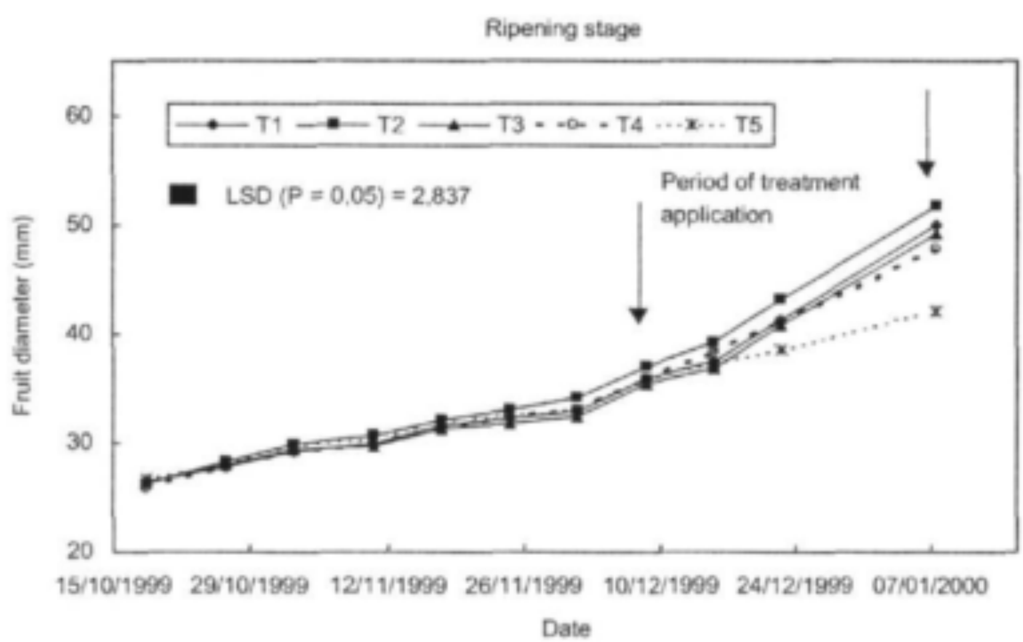


Figure 44. Effect of water deficits during ripening (Stage 4) on fruit diameter of Neethling peaches as measured during the 1999/2000-season at Robertson Experiment Farm (Refer to 3.2.1 for explanation of treatments).

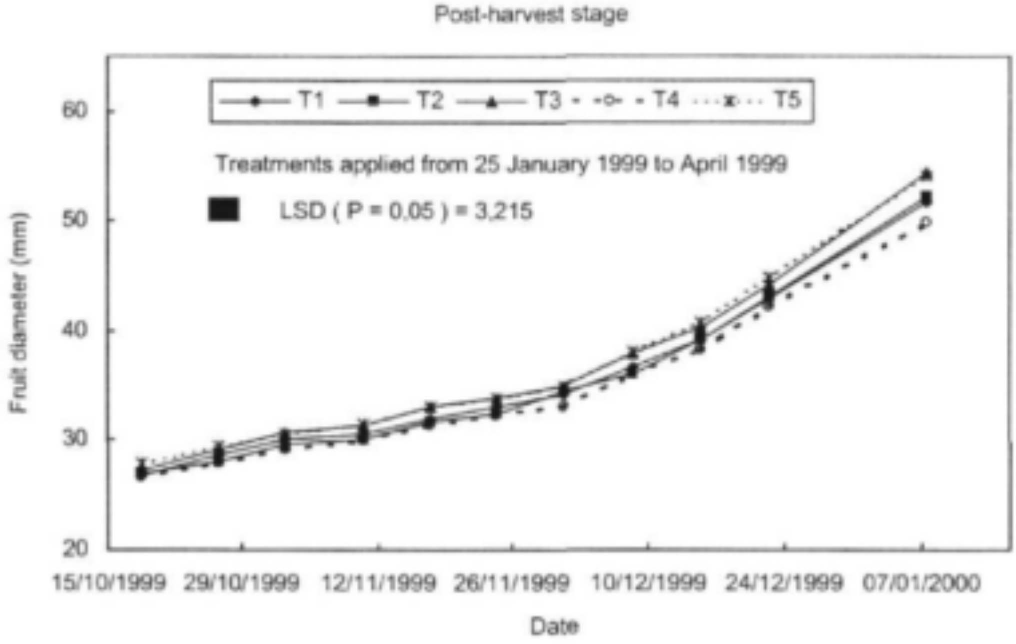


Figure 45. Effect of water deficits during post-harvest (Stage 5) of the previous season on fruit diameter of Neethling peaches as measured during the 1999/2000-season at Robertson Experiment Farm (Refer to 3.2.1 for explanation of treatments).

Irrigation treatments applied during the rapid fruit growth stage again induced differences in fruit growth during this period (Figure 43). The largest fruit size was obtained with the T1 treatment, followed by the T2, T3, T4 and T5 treatments. However, consistent with results obtained in the previous season, the differences were not eliminated by the application of normal irrigation during the following ripening stage and the treatment sequence remained the same. The treatment sequence during this stage was T1, T3, T2, T4 and T5.

Water deficits applied during the ripening stage significantly affected fruit growth (Figure 44). It is thus important not to apply any severe water deficits during this stage since this is the final and most important fruit growth stage. Water deficits during this stage might have inhibited the conversion of acids and starch to sugars. These results correspond to those reported by Anon (2000). The irrigation treatments applied during the post-harvest stage of the 1998/1999-season had a significant effect on fruit growth during the 1999/2000-season (Figure 45).

Final fruit size: The final fruit size was significantly affected by irrigation treatments applied during the rapid fruit growth, ripening and post-harvest stages (Figure 46). Smaller fruit were obtained with the deficit irrigation treatments during the rapid fruit growth, as well as the ripening stages, while no definite trend was observed during the post-harvest stage. The final fruit size correlated to soil matric potentials reached in the five different phenological stages, are presented in Figures 47 to 51, respectively.

It was not possible to reach lower (more negative) soil matric potentials during the cell growth stage due to the relatively mild climatic conditions experienced during this stage (Figure 47). However, compared to the previous experiment, the soil matric potentials actually reached during this stage were significantly lower and a good relationship between final fruit size and soil matric potential was obtained. Similar results were obtained for the slow fruit growth, rapid fruit growth and ripening stages, where good relationships were obtained between final fruit size and soil matric potentials (Figures 48 to 50). Although significant differences in fruit size during the post-harvest stage were obtained (Figure 46), no significant relationship between fruit size and soil matric potential was observed (Figure 51).

Results obtained during the 1999/2000-season mostly contradicted results obtained during the 1998/1999-season, where no significant relationships between fruit size and soil matric potentials were reached. This can be ascribed to the higher crop load during the 1999/2000-season. It can be assumed that fruit trees with a higher than normal crop load will be more sensitive to water deficits than trees with a normal crop load. In addition, due to lower rainfall during the 1999/2000-season, it was possible to reach much lower (more negative) soil matric potentials compared to the 1998/1999-season. This also contributed to the better relationships obtained between fruit size and soil matric potentials.

The present results revealed that fruit size was sensitive to water deficits during all the pre-harvest stages. These results are similar to those reported by Li *et al.* (1989, and references therein). In general, soil matric potentials of up to –200 kPa could be applied during any one of the growth stages without seriously affecting the final fruit size. However, normal irrigation should be applied in the other growth stages.

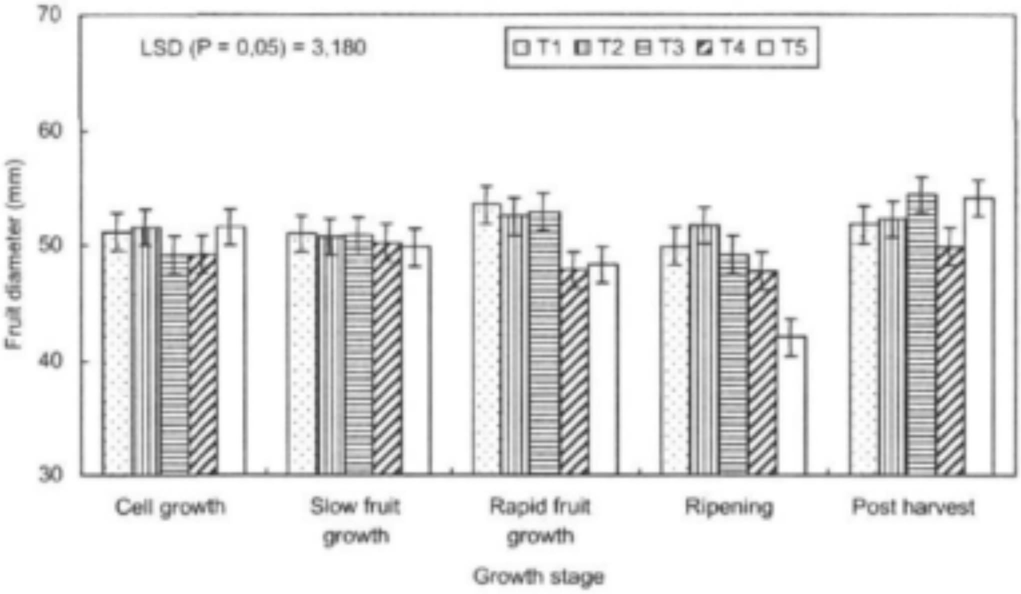


Figure 46. Effect of water deficits during the different growth stages on final fruit diameter of Neethling peaches as measured during the 1999/2000-season at Robertson Experiment Farm (Refer to 3.2.1 for explanation of treatments).

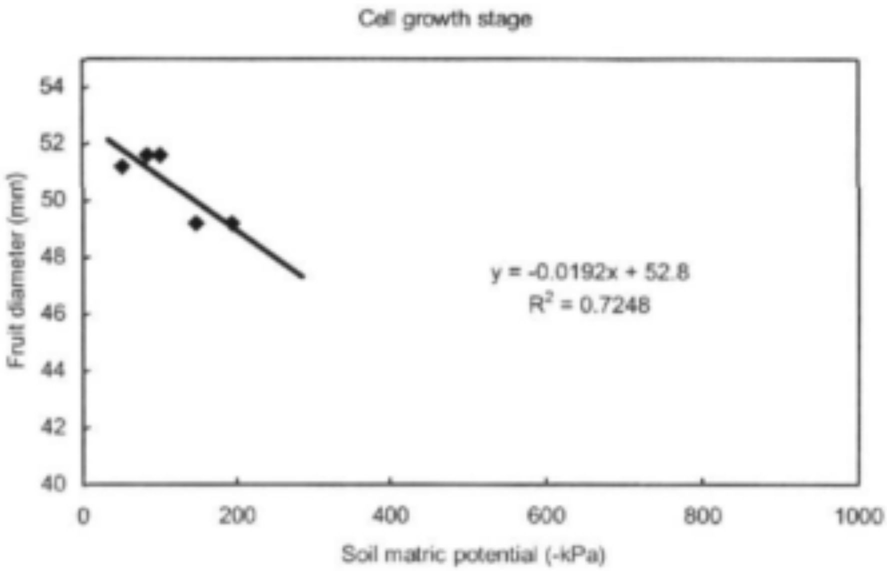


Figure 47. Relationship between final fruit diameter and soil matric potential as obtained for deficit irrigation during the cell growth stage (Stage 1) of Neethling peaches during the 1999/2000-season at Robertson Experiment Farm.

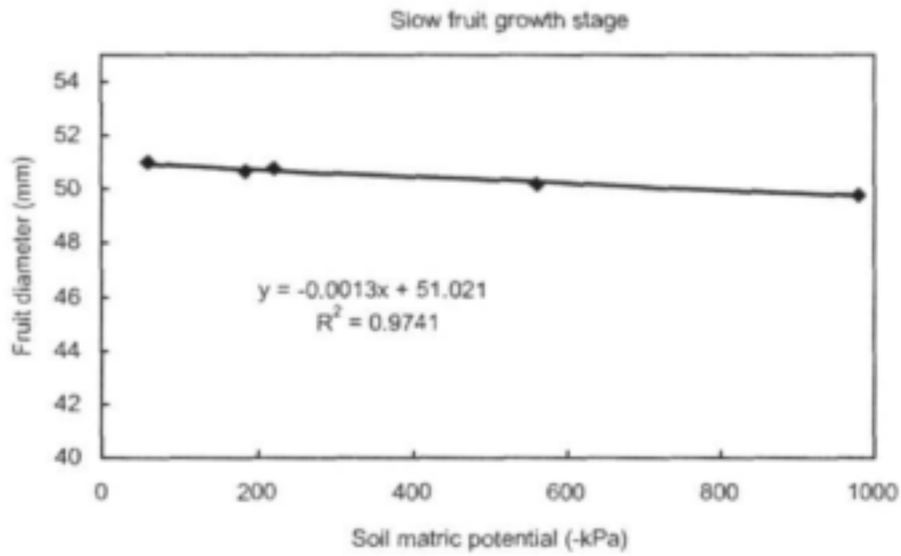


Figure 48. Relationship between final fruit diameter and soil matric potential as obtained for deficit irrigation during the slow fruit growth stage (Stage 2) of Neethling peaches during the 1999/2000-season at Robertson Experiment Farm.

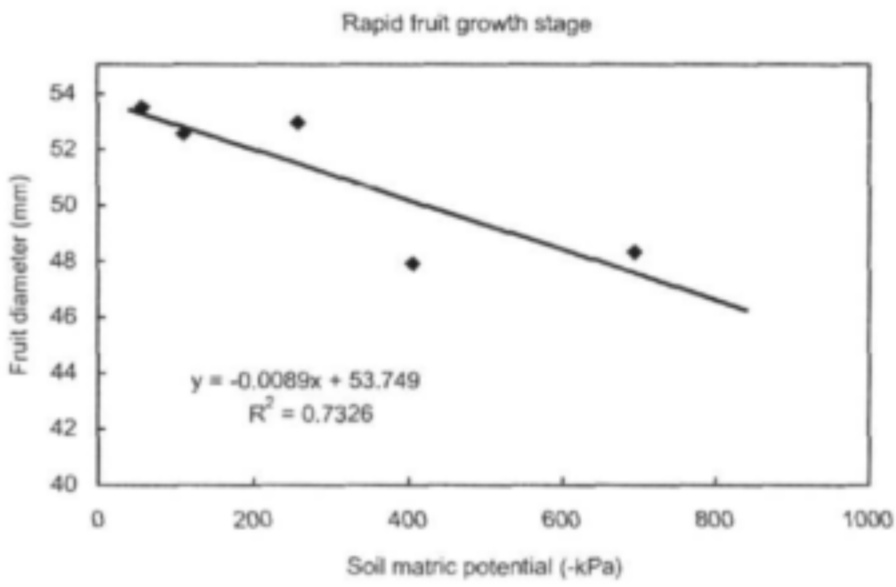


Figure 49. Relationship between final fruit diameter and soil matric potential as obtained for deficit irrigation during the rapid fruit growth stage (Stage 3) of Neethling peaches during the 1999/2000-season at Robertson Experiment Farm.

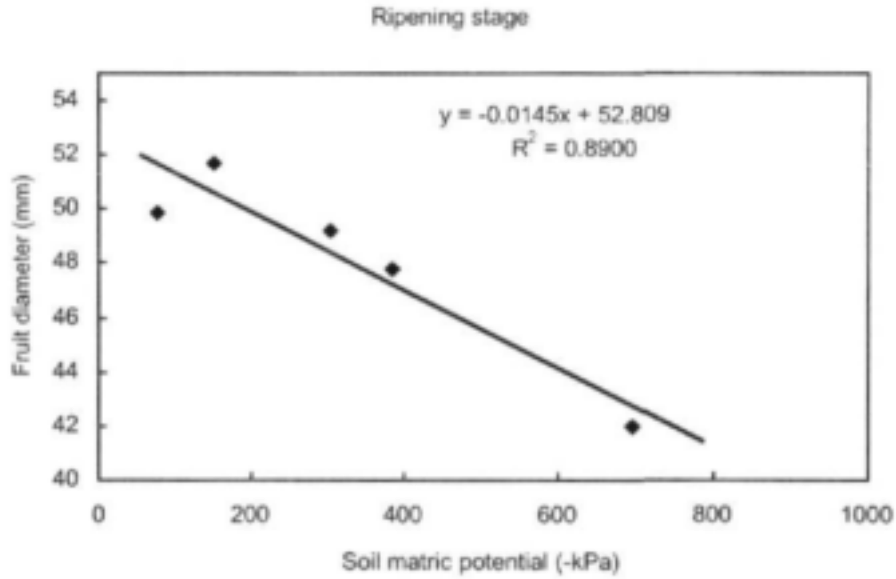


Figure 50. Relationship between final fruit diameter and soil matric potential as obtained for deficit irrigation during the fruit ripening stage (Stage 4) of Neethling peaches during the 1999/2000-season at Robertson Experiment Farm.

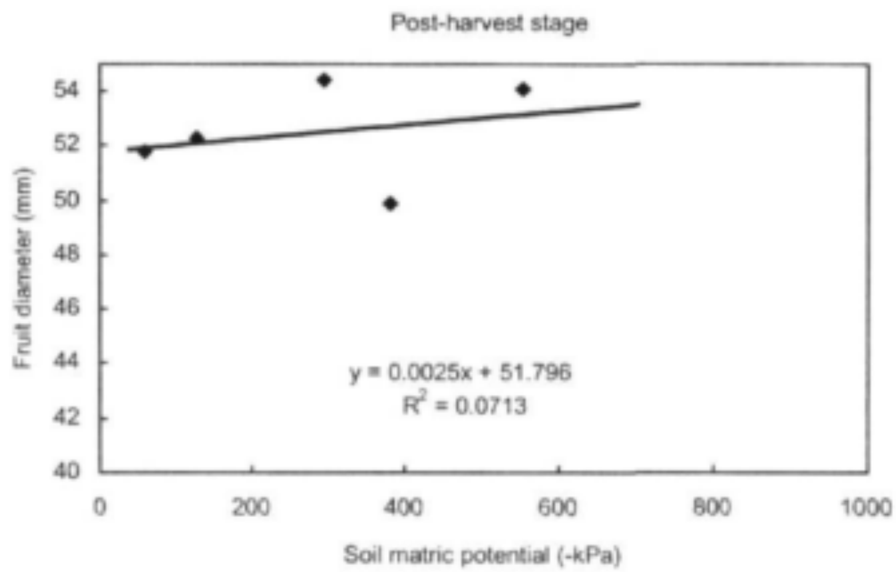


Figure 51. Relationship between final fruit diameter and soil matric potential as obtained for deficit irrigation during the post-harvest stage (Stage 5) of the previous season of Neethling peaches during the 1999/2000-season at Robertson Experiment Farm.

Fruit mass: The most significant reduction in final fruit mass was caused by water deficits during the ripening stage (Figure 52). The relationships between final fruit mass and soil matric potential for the different phenological growth stages are presented in Figures 53 to 57. No significant relationships between fruit mass and soil matric potentials were reached during the different growth stages, except during the ripening stage (Figure 56). This corresponds to results obtained during the 1998/1999-season (Figure 20) and is reflected in Figure 52.

Water deficits should therefore definitely be avoided during the ripening stage. This suggests that water deficits limited accumulation of solids in fruit. This viewpoint supports the results of Parker and Marini (1994). Present results indicated that, soil matric potentials of up to –200 kPa can be applied during any one of the growth stages without serious negative effects on final fruit mass. Smaller fruit were obtained with all the treatment combinations during the 1999/2000-season (Figure 52) in comparison to the 1998/1999-season (Figure 16). This can be ascribed to the higher crop load during the 1999/2000-season.

Production: The production obtained for the different treatment combinations is presented in Figure 58, while the relationships between production and soil matric potentials for the respective growth stages are shown in Figures 59 to 63. A significant negative effect on production was induced by water deficits during the ripening stage (Figure 58). This effect was confirmed in Figure 62, where a good relationship between production and soil matric potential was obtained.

Relationships between production and final fruit diameter as well as between production and final fruit mass are illustrated in Figures 64 and 65, respectively. The same tendencies as in the 1998/1999-season (Figures 28 and 29), were observed. In contrast to the latter, a very good relationship between production and final fruit mass was observed during the 1999/2000 season. This was to be expected as similar tendencies are observed when the effect of water deficits during individual growth stages on final fruit mass (Figures 53 to 57) and production (Figures 59 to 63), respectively, are compared. The decrease in production induced by water deficits during the ripening stage (Figure 62) corresponds to results reported by Ghrab (1998), while a similar tendency was observed during the 1998/1999-season (Figure 26). The present results suggested that soil matric potentials of up to –200 kPa could be allowed during any one of the stages without the risk of seriously reducing production.

Fruit quality: The different deficit irrigation treatments had no significant effect on the amount of fruit bruised, total soluble solids or the firmness of the fruit (data not shown). These results correspond with those obtained during the 1998/99-season.

Water consumption: The water consumption recorded for the different treatment combinations during the 1999/2000-season is presented in Figure 66. Water consumption is largely dependent on the meteorological conditions experienced during the trial, such as evaporation and amount and timing of rainfall. For instance, a relatively small amount of rain on a dry top layer of soil will have little or no effect on the replenishment of water. Tree volume and crop load can also have a significant effect on water consumption.

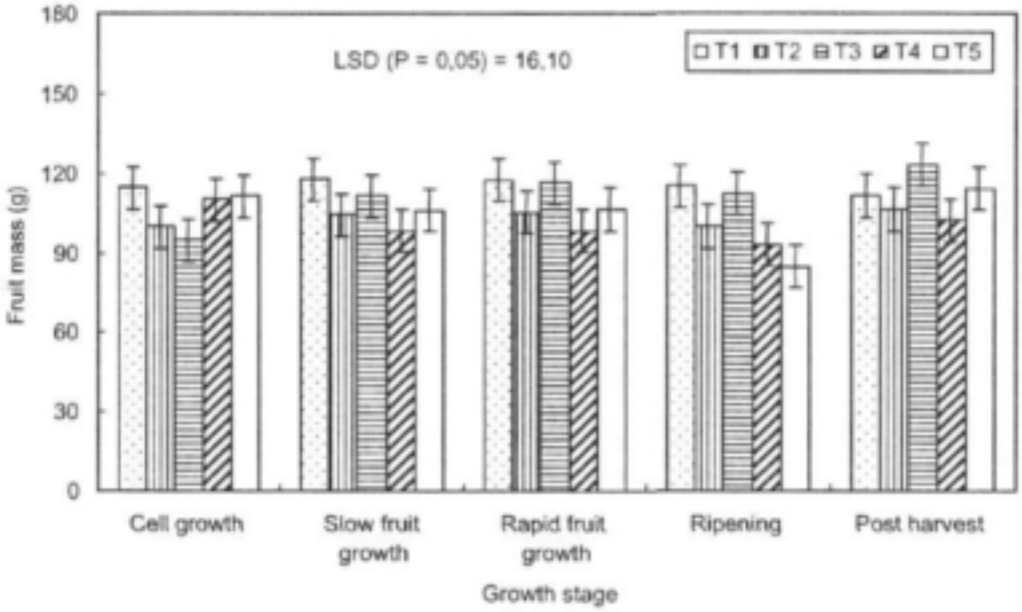


Figure 52. Effect of water deficits during the different growth stages on the final fruit mass of Neethling peaches as obtained during the 1999/2000-season at Robertson Experiment Farm (Refer to 3.2.1 for explanation of treatments).

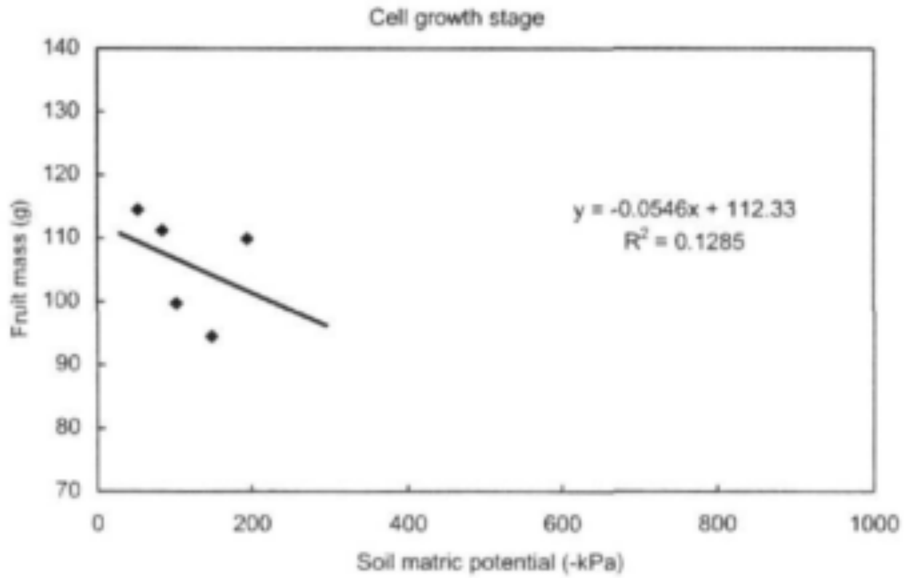


Figure 53. Relationship between final fruit mass and soil matric potential as obtained for deficit irrigation during the cell growth stage (Stage 1) of Neethling peaches during the 1999/2000-season at Robertson Experiment Farm.

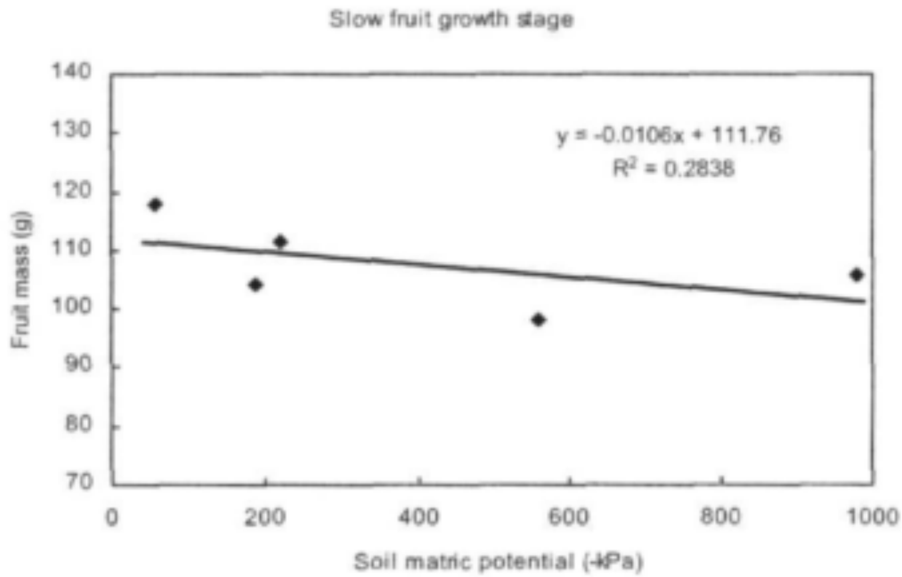


Figure 54. Relationship between final fruit mass and soil matric potential as obtained for deficit irrigation during the slow fruit growth stage (Stage 2) of Neethling peaches during the 1999/2000-season at Robertson Experiment Farm.

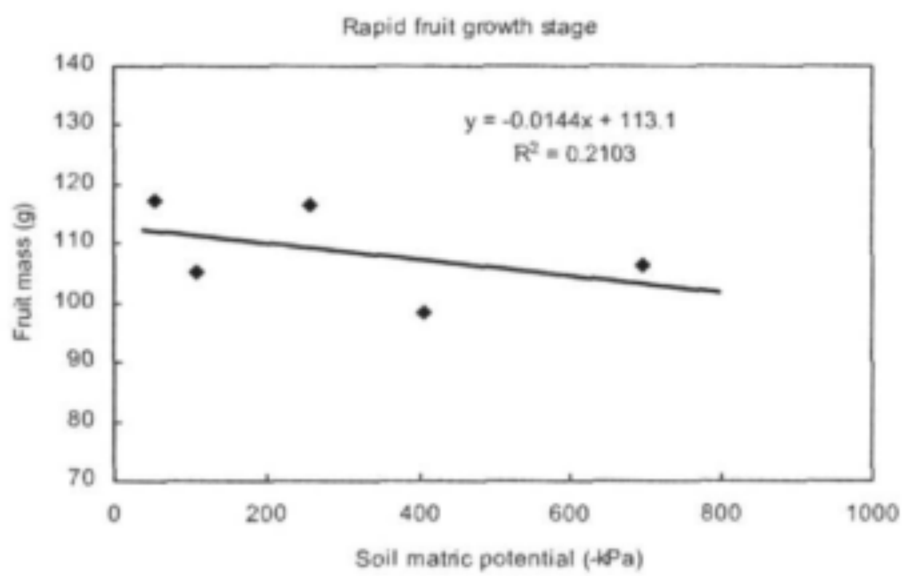


Figure 55. Relationship between final fruit mass and soil matric potential as obtained for deficit irrigation during the rapid fruit growth stage (Stage 3) of Neethling peaches during the 1999/2000-season at Robertson Experiment Farm.

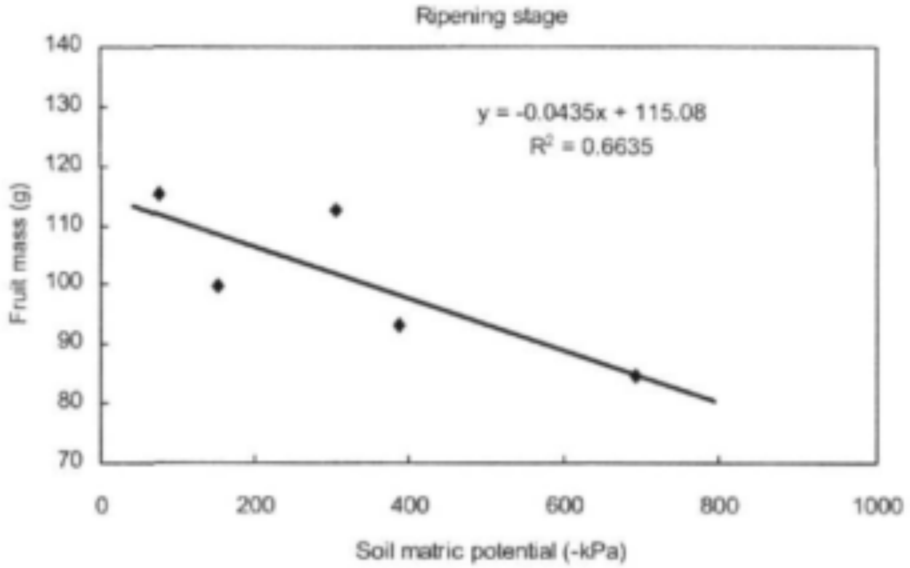


Figure 56. Relationship between final fruit mass and soil matric potential as obtained for deficit irrigation during the fruit ripening stage (Stage 4) of Neethling peaches during the 1999/2000-season at Robertson Experiment Farm.

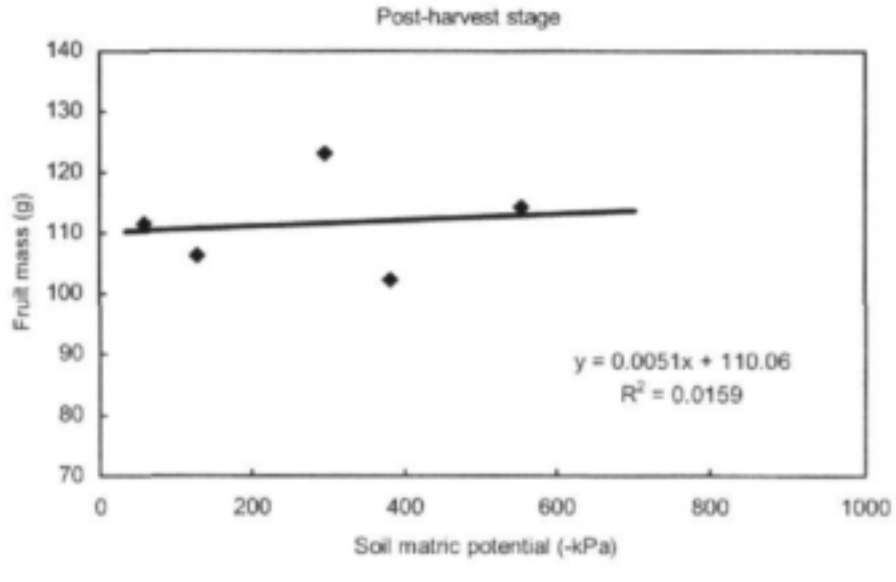


Figure 57. Relationship between final fruit mass and soil matric potential as obtained for deficit irrigation during the post-harvest stage (Stage 5) of Neethling peaches during the 1999/2000-season at Robertson Experiment Farm.

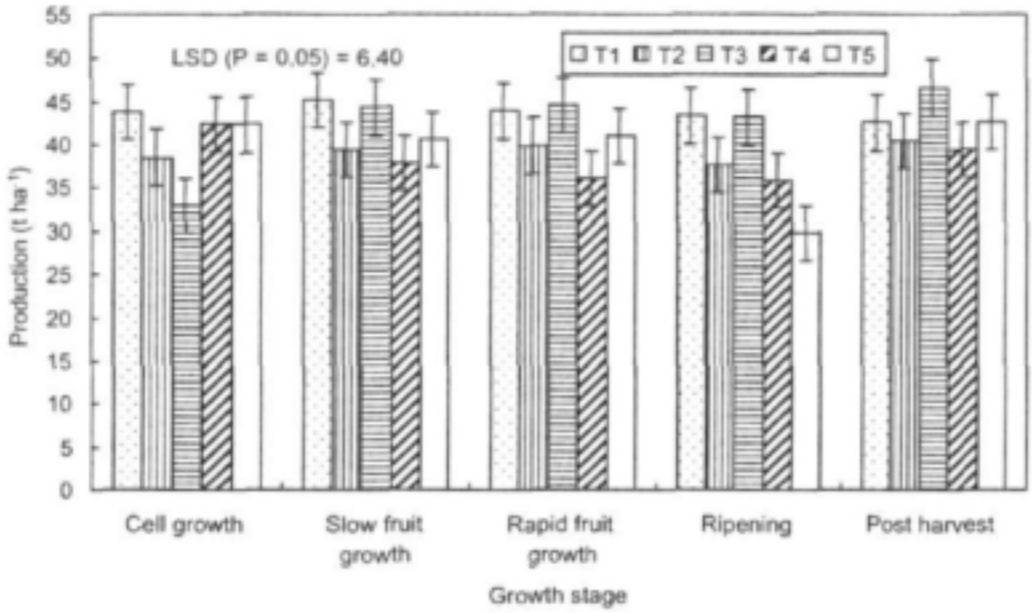


Figure 58. Effect of water deficits during the different growth stages on the production of Neethling peaches as obtained during the 1999/2000-season at Robertson Experiment Farm (Refer to 3.2.1 for explanation of treatments).

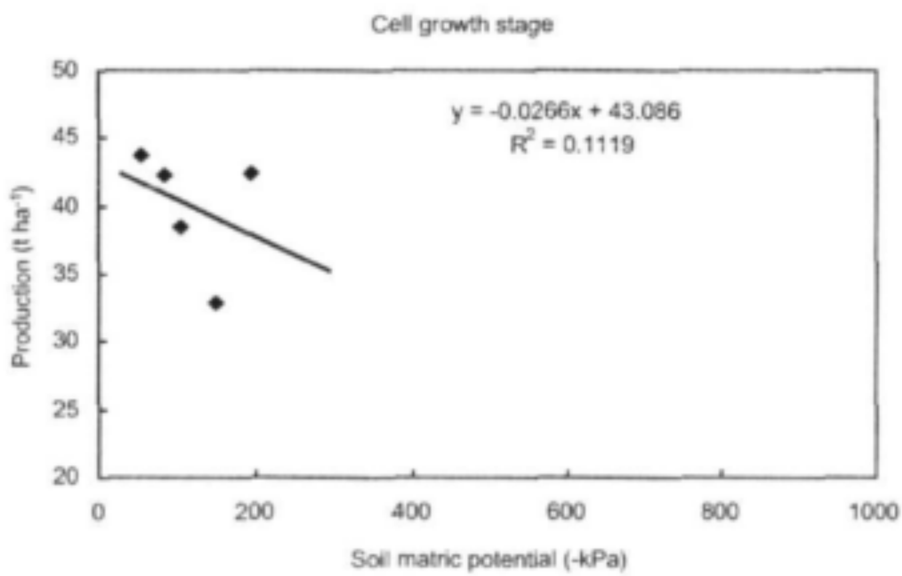


Figure 59. Relationship between production and soil matric potential as obtained for deficit irrigation during the cell growth stage (Stage 1) of Neethling peaches during the 999/2000-season at Robertson Experiment Farm.

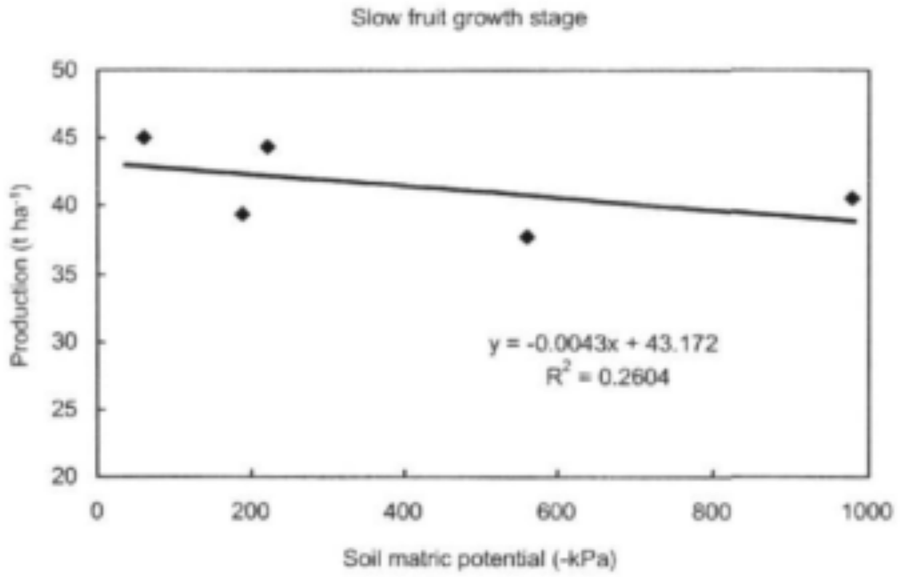


Figure 60. Relationship between production and soil matric potential as obtained for deficit irrigation during the slow fruit growth stage (Stage 2) of Neethling peaches during the 1999/2000-season at Robertson Experiment Farm.

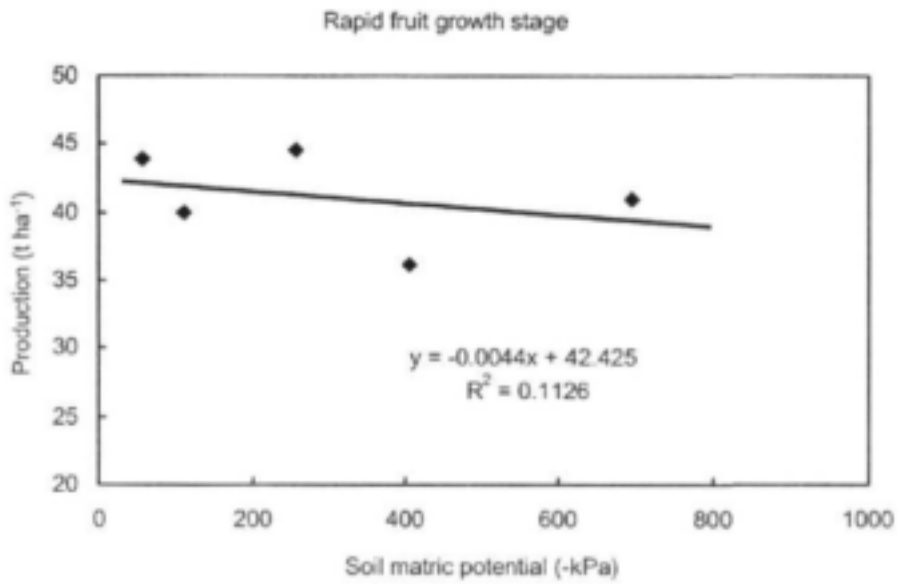


Figure 61. Relationship between production and soil matric potential as obtained for deficit irrigation during the rapid fruit growth stage (Stage 3) of Neethling peaches during the 1999/2000-season at Robertson Experiment Farm.

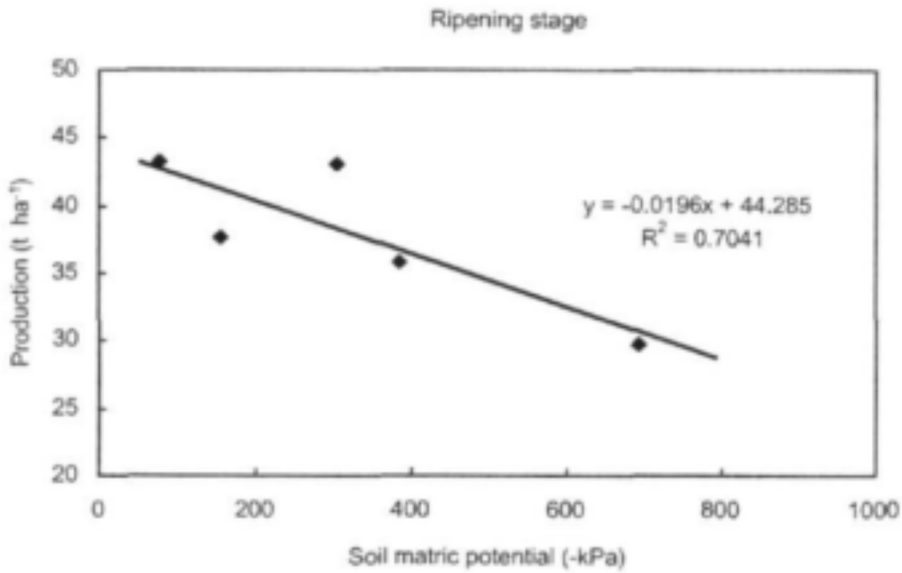


Figure 62. Relationship between production and soil matric potential as obtained for deficit irrigation during the fruit ripening stage (Stage 4) of Neethling peaches during the 1999/2000-season at Robertson Experiment Farm.

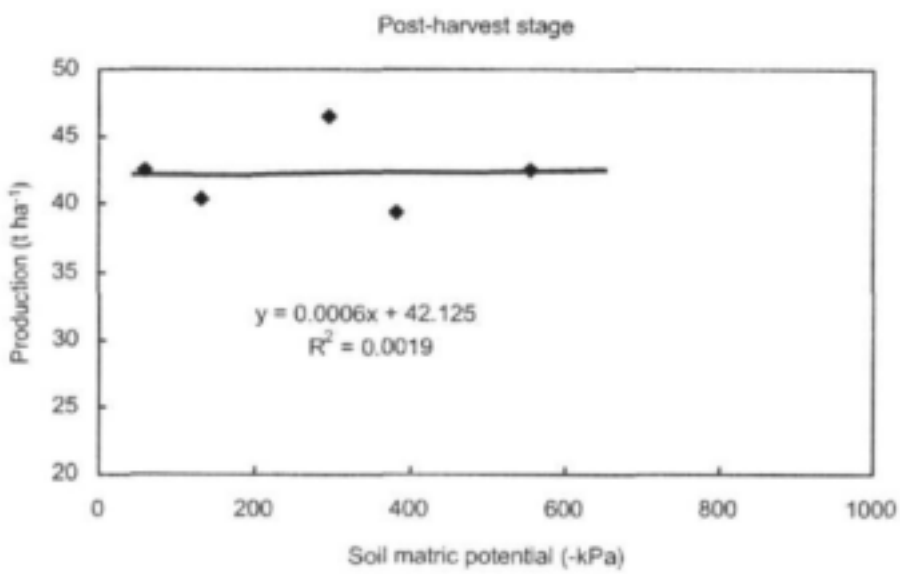


Figure 63. Relationship between production and soil matric potential as obtained for deficit irrigation during the post-harvest stage (Stage 5) of Neethling peaches during the 1999/2000-season at Robertson Experiment Farm.

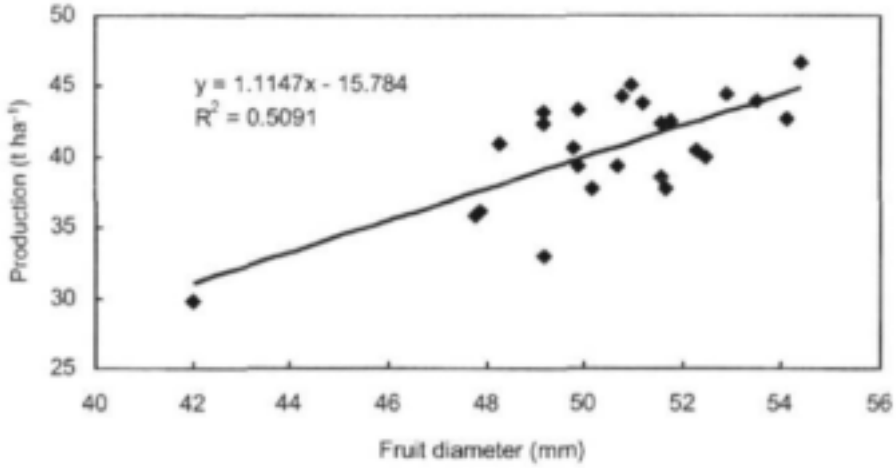


Figure 64. Relationship between production and final fruit diameter of Neethling peaches as obtained during the 1999/2000-season at Robertson Experiment Farm.

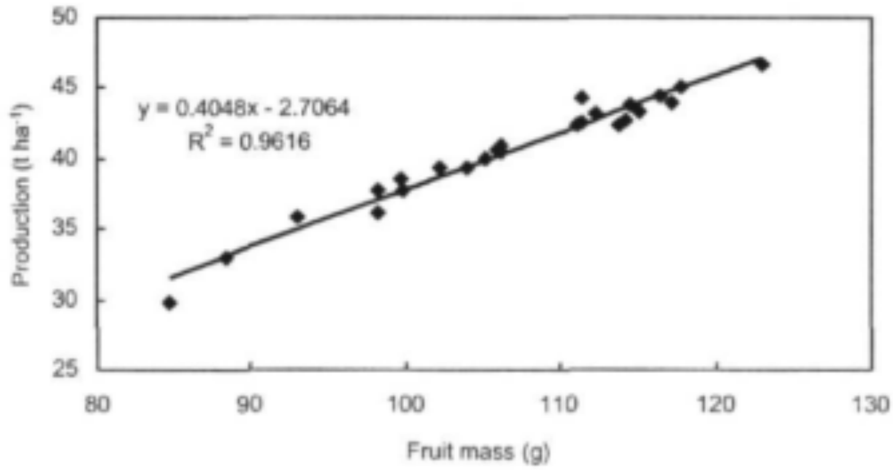


Figure 65. Relationship between production and final fruit mass of Neethling peaches as obtained during the 1999/2000-season at Robertson Experiment Farm.

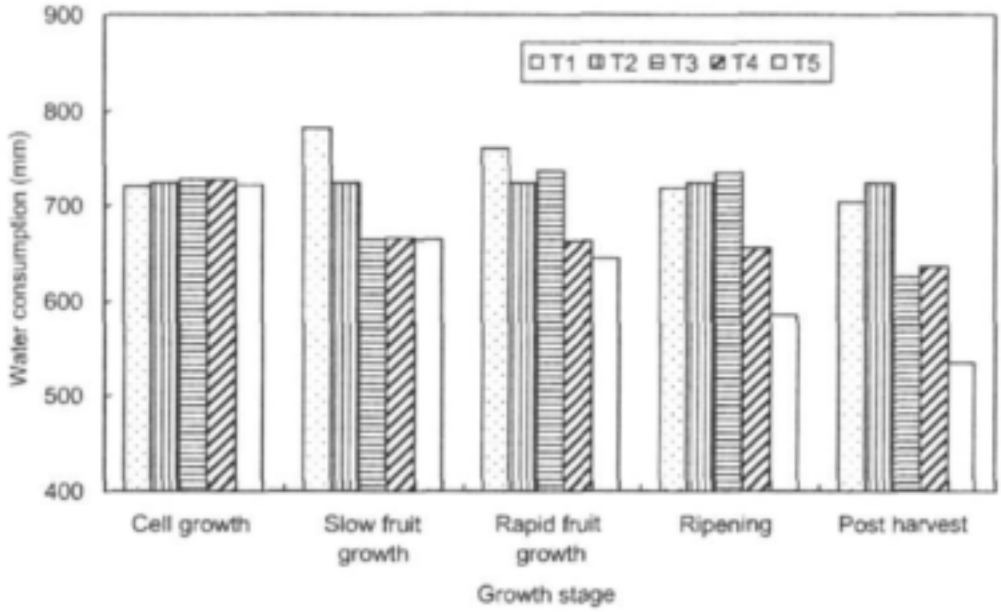


Figure 66. Total water consumption of Neethling peaches during the 1999/2000-season as affected by water deficits during the different growth stages as measured in the wetted strip at Robertson Experiment Farm.

The water consumption during the 1999/2000-season was on average lower than the water consumption during the 1998/1999-season (Figure 40). This corresponds to the slightly lower ETo of the 1999/2000-season as indicated in Table 2.

During both seasons, no considerable differences in water consumption were obtained during the cell growth stage. This can be related to sparse foliage and mild meteorological conditions experienced during the beginning of the season. For instance, during the rapid fruit growth stage of both seasons, an unexpected but considerably higher water consumption was obtained with treatment T3 (*ca.* –200 kPa), compared to the normal T2 treatment (*ca.* –100 kPa). This can be ascribed to tree size. The average tree volumes and stem circumferences as measured after harvest in the 1998/1999-season were, respectively, 15,4 m^3 and 439 mm for the T3 treatment compared to 10,2 m^3 and 393 mm for treatment T2. In the second season the respective average stem circumferences were 463 mm and 414 mm.

In general, apart from the cell growth stage, deficit irrigation treatments tended to reduce seasonal water consumption. By applying the water deficit T3 treatment (*ca.* –200 kPa) instead of the normal T2 (ca. –100 kPa) treatment during the post-harvest stage, an average water saving of 1150 m^3 ha^{-1} per season can be realized without any adverse effects on production.

3.4 CONCLUSIONS AND RECOMMENDATIONS

No major differences in the meteorological conditions, recorded during the 1998/1999-season or 1999/2000 growing season, were experienced. However, the total rainfall recorded during the first season was much higher than during the second season, while the average Penman-Monteith ETo for the first season exceeded that of the second season.

The higher, and in some respects untimely rainfall, as well as the lower crop load probably prevented targeted soil matric potentials of all treatments to be reached during the first season. Lower soil matric potentials were reached during the second season and the effect of water deficits was thus more readily observable in trees. Deficit irrigation tended to reduce seasonal water consumption.

The effect of water deficit applied during the different phenological stages of peaches on tree response and the implications thereof for irrigation management is summarized as follows:

Cell growth stage

The mild climatic conditions experienced during this stage had the effect that no significant water deficits were reached. No significant effect of irrigation treatments on fruit size or production was obtained and shoot growth was still in an initial stage. The water requirement during this stage is about 35 mm, of which at least 50% is provided by rainfall during a normal year. This stage is of little importance in terms of water saving aspects.

Slow fruit growth stage

By the application of water deficits during the slow fruit growth stage, it was possible to limit excessive vegetative growth. The deficit irrigation treatments had a significant negative effect on fruit growth at the end of this stage. However, this effect was eliminated at harvest time by application of normal irrigation treatments during the successive rapid fruit growth and ripening stages. No negative effect of irrigation treatments was observed on production. This stage can thus be considered as a suitable period for applying deficit irrigation with the aim of saving water and to limit excessive vegetative growth.

Rapid fruit growth stage

As with the slow fruit growth stage, it was possible to limit vegetative growth by applying deficit irrigation. The application of deficit irrigation during this stage had a negative effect on fruit growth at the end of this stage. However, this negative effect was not eliminated by the application of normal irrigation during the succeeding ripening stage. Although production was not significantly affected by irrigation treatments, severe water deficits are not recommendable during this stage.

Ripening stage

The application of water deficits during this stage had a negative effect on fruit size as the smallest fruit were obtained, although vegetative growth was limited. Production was also decreased by water deficits during this stage. The application of water deficits during this stage is not recommended and normal irrigations should therefore be applied.

Post-harvest stage

No effects of deficit irrigation applied during the post-harvest stage of the previous season were transferred to the succeeding season. Substantial savings of irrigation water can be obtained by applying deficit irrigation during this stage without affecting fruit size or production in the following season.

The different deficit irrigation treatments, applied in any one of the growth stages, had no significant effect on the amount of fruit bruised, total soluble solids or the firmness of the fruit. It is furthermore important to note that the different deficit irrigation treatments were applied during only one of the five different growth stages with normal irrigation treatments in the remaining four growth stages.

CHAPTER 4

DEFICIT IRRIGATION OF APPLES

4.1 BACKGROUND

Economically viable apple production in the Western Cape, South Africa, is only possible under irrigation and export markets demand quality fruit. Soils in the major apple production regions are coarse textured gravelly and shallow, which places extreme demands on irrigation management. Guidelines for water use under conditions of high atmospheric demand are not available and most producers are unsure of correct irrigation practices, especially under conditions of limited water supply. Furthermore, the current trend towards high density plantings necessitates the use of management practices which will ensure control of vegetative growth.

Regulated deficit irrigation could be used to control tree growth as well as optimize water use (Chalmers *et al.*, 1985). Research in this regard had been done for apple (Assaf et al., 1974; Beukes & Weber, 1982; Peretz *et al.*, 1986; Ebel, 1991). However, it was mainly conducted on relatively deep soils and studies need to be conducted on shallower or lighter soils to determine the drought tolerance of trees droughted earlier in the season. In this study, experiments were carried out in order to evaluate the response of apple trees to water deficits applied during the different phenological growth stages on soils typical of one of the main apple production regions.

4.2 MATERIALS AND METHODS

Due to major changes in the definition of irrigation treatments during the two years of this project the following detailed description of materials and methods is included.

The trial was conducted in Elgin, an area situated in one of the main apple growing regions in the Western Cape, South Africa (Figure 67). An irrigation trial was established on the experiment farm of an Agricultural Research Council institute, Infruitec-Nietvoorbij, located at 19' S, 19°34' E and 305 m above sea level. An automatic weather station, approximately 800 m from the orchard, recorded daily precipitation (mm), hourly maximum and minimum temperature (°C), hourly wet bulb temperature, total daily solar radiation (MJ m^{-2}) and average daily wind speed at 2 m height (m s^{-1}).

The orchard was established in June 1985 in an East-West oriented hedgerow with forty irrigation treatment plots replicated in three blocks. Tree spacing was 4.5 m x 2.5 m with 4 apple trees (*Malus domestica*) of the cultivar Golden Delicious (scion) on Merton 793 rootstock per treatment plot. Each plot started and ended with a cultivar Granny Smith tree that served as pollinator and border tree. Granny Smith border trees also bordered the orchard.

Figure 67. Map of the Republic of South Africa illustrating the locality where the apple deficit irrigation trial was carried out.

Soil properties varied throughout the orchard, but could be regarded as loamy to clayey loam soils having a large proportion of coarse material (approximately 57%) with a clayey layer in the subsoil of some plots. The stone percentage was determined as follows:

$$\%Stone = (M_t - M)/M_t * 100 \qquad (4)$$

where M_t is mass of the total soil sample and M is the mass of soil passed through a 2 mm sieve.

Soil preparation had been done to a 600 mm depth during establishment of the trees and plastic sheeting was inserted in the middle of the work row to a depth of approximately 1500 mm to prevent lateral flow between treatment plots. Due to variability of soils, water holding capacity and particle size distribution of all treatment plots was determined in the laboratory.

The irrigation system consisted of micro-sprinklers with 4.5 m x 2.5 m spacing and a 32 L h^{-1}-delivery rate, which wetted a 3.0 m strip in the tree row. To reduce problems with clogging, green Eintal microsprayers with a 31.2 L h^{-1} delivery rate, which wetted a strip of 2.8 m in the tree row, were installed during winter 1998. Water content was monitored using a neutron water meter . Irrigation was applied to restore soil water content to field capacity to a depth of 600 mm. Water meters were used to measure irrigated volumes.

Deficit irrigation: Sixty plots from the original experimental layout were selected for deficit irrigation during 1997/98. There were five irrigation treatments where soil water depletion to –50 kPa, –100 kPa, –200 kPa, –400 kPa and –800 kPa were imposed during four phenological phases and were replicated in three blocks. The –50 kPa treatment level was applied as a control for each treatment in phenological phases during which the five treatment levels were not induced. The phenological phases were defined as bud break, full bloom to 40 days from full bloom (vegetative growth phase or phase 1); 40 days from full bloom to four weeks before harvest (fruit growth phase or phase 2); ripening to harvest (phase 3) and post harvest (phase 4). Treatment combinations are presented in Table 3. Irrigation of all treatments was done according to neutron water meter measurements.

Several problems with induction of treatments during 1997/98 resulted in re-evaluation of the treatments. New treatments were imposed during the 1998/99 season and only block 2 and 3 were used as replicates. The amount of soil water to be depleted for a normal irrigation treatment (–75 kPa) was estimated from an averaged soil water retention curve (data from blocks 2 and 3). The soil water content of disturbed soil samples from each plot was determined at –10 kPa, –75 kPa and –500 kPa in the laboratory. Particle size distribution was determined and a realistic estimation of the coarse component done. This provided data for a soil water retention curve for each plot and allowed more accurate estimation of soil matric potential.

A hundred percent irrigation efficiency was assumed to prevent over-irrigation. Since climatic conditions did not allow water deficits during phase 1, the four phenological phases were reduced to three (Table 4). Treatments were redefined with regard to a normal irrigation treatment and included fifteen combinations of the different treatment levels (Table 4).

Volumetric soil water content was monitored using a neutron water meter before and after irrigation. Three neutron water meter access tubes were used per monitoring site. Two tubes were located in line with the tree in the tree row 500 mm and 1000 mm from the tree trunk on the west side. The third one was installed at 45° from the tree line at 1000 mm from the tree trunk at the north side. Hence, soil water content was measured only in the wetted area.

Plant measurements: Water stress was monitored by measurement of leaf photosynthesis (A_l), stomatal conductance (STC_l) and/or stem water potential or predawn leaf water potential ($Pd_{\psi l}$). Initially, midday stem water potential was used during 1997/98 as a measure of water stress due to its significant correlation to predawn water potential found by other researchers (Ebel, 1991; Garnier & Berger, 1985). Before selected irrigation events $Pd_{\psi l}$ was measured between 02h30 and 05h00 from the beginning of the season (October) to harvest (February) on three leaves per tree on nonbearing extension shoots. Stem water potential was measured on three enclosed leaves between 10h30 and 14h00 in full sun conditions. Leaf photosynthesis and STC_l measurements were done, weather permitting, whenever significant differences between treatments were expected. Measurements were done on five leaves per tree on nonbearing extension shoots from 10h30 until 14h00 in full sun conditions unless specified otherwise.

Shoot length was measured during 1997/98 at the end of phenological phases 1 and 2, but during the 1998/99 season at least fortnightly from end October to the beginning of January. A final measurement was made before harvest on ten extension shoots per tree on all four trees per plot. Stem circumference was measured at the beginning of the season and at the end of each phenological phase as defined for each season.

Bloom and fruit set were evaluated during 1997/98 by selecting five short and five long shoots per tree (all four trees per plot) before full bloom. During 1998/99 no stress was induced before full bloom and fruit set and therefore no evaluation was done.

Fruit diameter was determined weekly or fortnightly during phenological phases 2 and 3 for treatments T1 to T10 and T15 (10 fruit per tree, 4 trees per block). Maturity indices were determined at harvest. Total mass and number of fruit per tree were recorded at harvest and fruit graded to determine size distribution. Gross farm income was determined according to estimated income per carton for 1997/98 (personal communication, H. Campbell). Physiological disorders and maturity were evaluated after cold storage for three months at -0.5 °C, and 7 days at 20°C.

Soil profile studies: Due to lack of plant reaction to treatments, soil profiles were studied at the end of the 1998/99 season to establish if an external source of water did not contribute to the water consumption of the trees. Three profile pits were made – one above each replicate block - in the area between the experimental orchard and the orchards located above. Two profile pits were also made in blocks 2 and 3 to qualify root distribution to determine whether soil water extraction had occurred outside the wetted strip.

Table 3. Irrigation treatments for regulated deficit irrigation of Golden Delicious apple during the 1997/98 season at Elgin Experiment Farm.

Treatment number	Soil water matric potential (-kPa)			
	Phase 1 (Vegetative growth)	Phase 2 (Fruit growth)	Phase 3 (Ripening)	Phase 4 (Post-harvest)
T1	**50**	50	50	50
T2	**100**	50	50	50
T3	**200**	50	50	50
T4	**400**	50	50	50
T5	**800**	50	50	50
T6	50	**50**	50	50
T7	50	**100**	50	50
T8	50	**200**	50	50
T9	50	**400**	50	50
T10	50	**800**	50	50
T11	50	50	**50**	50
T12	50	50	**100**	50
T13	50	50	**200**	50
T14	50	50	**400**	50
T15	50	50	**800**	50
T16	50	50	50	**50**
T17	50	50	50	**100**
T18	50	50	50	**200**
T19	50	50	50	**400**
T20	50	50	50	**800**

Table 4. Redefined irrigation treatments for regulated deficit irrigation of Golden Delicious apple trees during the 1998/99 season at Elgin Experiment Farm.

Treatment number	Phase 1 (Vegetative growth)	Phase 2 (Fruit growth and ripening)	Phase 3 (Post harvest)
T1	N[1]	N	N
T2	N/2[2]	N/2	N/2
T3	N/4[3]	N/4	N/4
T4	N/2	N	N
T5	N/4	N	N
T6	N	N/2	N
T7	N	N/4	N
T8	2N[4]	N	N
T9	N/4	N/2	N
T10	N/2	N/4	N
T11	N	N	0
T12	N	N/2	0
T13	N	N/4	0
T14	N/2	N/4	0
T15	0[5]	0	0

1 N: Irrigate when soil water is depleted to the -75 kPa level.
2 N/2: Irrigate with each second irrigation of N.
3 N/4: Irrigate with each fourth irrigation of N or stress.
4 2N: Irrigate when half of the normal depletion is completed.
5 0: No irrigation.

4.3 RESULTS AND DISCUSSION

Deficit irrigation: The length of the phenological phases of Golden Delicious apple trees during which the irrigation treatments were imposed during the 1997/98 and 1998/99 seasons at Elgin experiment farm is summarised in Table 5. Although treatment plots were selected for uniformity to enable irrigation according to average water deficits, there were still large differences in irrigation requirements between replicates. Additional irrigation was supplied to plots with higher requirements by starting water application earlier. The number of irrigations applied during the 1997/98 and 1998/99 seasons, respectively, are presented in Tables 6 and 7. This excludes the irrigation applied to refill the profile to field capacity at the start of the first and end of all phenological phases. Due to abnormal climatic conditions, dry treatments could not be induced during the first phase. Although rainfall for October was less than the long term average, it was approximately 3.5 and 2.4 times the long-term average for November during the 1997/98 and 1998/99 seasons, respectively (Table 8). Rainfall for December was also higher than average during both seasons (52% and 70%, respectively). Approximately 42% and 82% of the monthly total precipitation occurred during the first phenological phases.

During the 1997/98 season problems were also encountered with inducing dry treatments during the second and third phenological phases. Precipitation during phenological phase 2 was approximately 45% higher than the long term average. Despite very low rainfall and high ETo, phenological phase 3 was too short for induction of dry treatments (Table 5). This problem was successfully solved during 1998/99 by redefinition of the phenological phases. All phase 4 treatments were successfully induced during 1997/98. During the 1998/99 season, however, the N/4 treatment level could not be induced during the post-harvest phase.

Total amounts of water applied during the 1997/98 season did not differ markedly between treatments (Table 9). The high totals for treatments 4 and 12 were ascribed to over-irrigation at the end of phenological phase 2 (±400 m^3 ha^{-1}) and 3 (±600 m^3 ha^{-1}), respectively, due to faulty electric valves. The measured amounts of water applied to the different treatments during the 1998/99 season (Table 10) show large differences and, despite the contribution of rainfall, one would expect significant stress to be induced at least at stress treatment trees during the second phenological phase and those that received no irrigation during the season. The differences in the total amount of water applied between the two seasons can mainly be attributed to a change from using an 80% to a 100% irrigation efficiency in calculation of irrigation volumes; application of different irrigation treatment level combinations; the timing and contribution of large rainfall events and the use of −75 kPa as replacement for −50 kPa as refill reference point for the normal irrigation events and its subsequent effect on irrigation interval.

Plant reaction

Plant water stress: To attain the objectives of the project with regard to the effect of stress on tree performance, it was necessary to establish if the proposed water stress was actually induced in trees. Hence, physiological paramaters were used as a means to monitor tree reaction to water stress.

Table 5. Length of phenological phases of Golden Delicious apple trees during the 1997/98 and 1998/99 seasons at Elgin Experiment Farm. Date of bud break was assumed as the 1st October of each season.

Season	Length of phenological phase (days)				
	Phase 1	Phase 2	Phase 3	Phase 4	Total
1997/98	57	62	29	64	213
1998/99[1]	76	84*	51	-	212

1 During 1998/99 phase 2 included both fruit growth and ripening while phase 3 represented the post harvest period.

Table 6. Rainfall and number of irrigation events per treatment level received during four phenological phases as recorded during the 1997/98 season at Elgin Experiment Farm.

Phenological phase	Period Start – End	Days	Rain (mm)	Number of scheduled irrigation events per irrigation treatment level				
				-50kPa	-100kPa	-200kPa	-400kPa	-800kPa
1	01/10/97 - 26/11/97	57	194.4	2	1	0	0	0
2	27/11/97 - 27/01/98	62	114.8	4	2	1	0	0
3	28/01/98 - 25/02/99	29	4.4	2	1	0	0	0
4	26/02/98 - 30/04/98	64	117.1	3	2	2	1	1

Table 7. Rainfall and number of irrigation events per treatment level received during three phenological phases as recorded during the 1998/99 season at Elgin Experiment Farm.

Phenological phase	Period Start – End	Days	Rain (mm)	Number of scheduled irrigation events per irrigation treatment level				
				2N	N	N/2	N/4	0
1	01/10/98 - 15/12/98	76	185.1	7	1	0	0	0
2	16/12/98 - 09/03/99	84	45.3	-	9	4	1	0
3	10/03/99 - 30/04/99	51	81.2	-	3	1	0	0

Table 8. Relevant meteorological conditions that prevailed during the1997/98 and 1998/1999 season at Elgin Experiment Farm.

Month	Average daily maximum temperature (°C)			Average daily wind speed ($m\ s^{-1}$)			Total rainfall (mm)			Average daily Penman-Monteith ETo[1] (mm)			Relative daily humidity (%)		
	1997/ 1998	1998/ 1999	Long term	1997/ 1998	1998/ 1999	Long term	1997/ 1998	1998/ 1999	Long term	1997/ 1998	1998/ 1999	Long term	1997/ 1998	1998/ 1999	Long term
Oct.	24.1	22.0	20.3	1.9	2.0	1.7	48.2	19.0	72.4	3.9	4.0	3.4	79.9	83.6	70.0
Nov.	22.4	21.9	22.6	2.3	1.7	1.6	143.6	100.3	41.6	4.5	3.7	4.1	78.3	87.1	68.7
Dec.	25.5	25.4	24.3	2.2	1.8	1.6	65.2	80.2	43.0	5.2	4.7	4.5	79.4	84.2	68.7
Jan.	25.8	27.6	25.6	1.8	1.7	1.5	49.6	18.5	34.3	4.7	5.0	4.6	83.2	85.4	68.6
Feb.	28.4	27.3	25.9	1.8	1.7	1.4	4.4	2.0	34.4	4.1	4.3	4.1	87.2	84.6	69.2
Mar.	25.1	27.0	24.9	1.7	1.5	1.3	23.7	17.4	49.1	3.1	3.4	3.2	88.1	82.1	69.4
Apr.	24.0	23.6	22.2	1.8	1.7	1.2	91.2	81.8	70.3	2.7	1.9	2.2	86.9	78.2	71.1
Average	25.0	25.0	23.7	1.9	1.7	1.5	----	----	----	4.0	3.9	3.7	83.3	83.6	69.4
Total	----	----	----	----	----	----	425.9	319.2	345.1	----	----	----	----	----	----

1 Reference evapotranspiration

Table 9. Amount of irrigation water applied by different irrigation treatments to Golden Delicious apple trees during four different phenological phases and for the 1997/98 season at Elgin Experiment Farm.

Treatment number[1]	Irrigation water applied to the full surface ($m^3 ha^{-1}$)				
	Phase 1	Phase 2	Phase 3	Phase 4	Total
T1	910	1750	1000	1750	5410
T2	370	1930	990	1720	5010
T3	0	1670	1000	1740	4420
T4	0	2230	1080	1870	5180
T5	0	1800	1020	1780	4600
T6	860	2120	970	1680	5630
T7	880	1040	1040	1820	4780
T8	950	1090	1040	2010	5090
T9	900	480	1010	1730	4120
T10	950	500	1020	1810	4280
T11	950	1750	1010	1790	5500
T12	890	1840	1530	1860	6110
T13	920	1850	640	1710	5120
T14	970	1940	680	1760	5360
T15	890	1860	810	1700	5250
T16	1190	1760	1010	1790	5750
T17	890	1760	970	980	4600
T18	860	1780	1000	1220	4860
T19	1000	2000	1030	1180	5200
T20	910	1890	1020	250	4070

1 Refer to Table 3 for explanation of treatments.

Table 10. Amount of irrigation water applied by different irrigation treatments to Golden Delicious apple trees during three different phenological phases and the whole 1998/99 season at Elgin Experiment Farm.

Treatment number[1]	Irrigation water applied to the full surface ($m^3 ha^{-1}$)			
	Phase 1	Phase 2	Phase 3	Total
T1	288	2455	677	3420
T2	0	1388	272	1660
T3	0	673	0	673
T4	0	2141	600	2741
T5	0	2246	580	2826
T6	249	1481	669	2399
T7	260	617	648	1525
T8	1898[2]	2434	600	4932
T9	0	1581	673	2254
T10	0	800	794	1594
T11	366	2372	0	2738
T12	245	1698	0	1943
T13	320	796	0	1116
T14	0	747	0	747
T15	0	0	0	0

1 Refer to Table 4 for explanation of treatments.

2 Overirrigated due to system error (1222 $m^3 ha^{-1}$).

Due to three outliers, midday stem water potential rendered a poor correlation (R^2 = 0.36) to predawn leaf water potential during phenological phase 2 of season 1997/98. Consequently, it was decided to proceed with predawn measurements in the third phenological phase despite the practical problems. During the 2nd and 3rd phenological phases, respectively, water stress was quantified by calculating a stress day index and evaluating its effect on different tree parameters. This was done by fitting a mathematical function to plant water potential versus day of season and integrating the area under the functions. This data showed that irrigation treatments were definitely not succesfully replicated (Tables 11 & 12). This was confirmed by results of stomatal conductance measurements (data not shown).

After redefinition of treatments for the 1998/99 season, the treatment which received stress throughout the season (T3) was the only treatment where predawn leaf water potential reached significantly lower values than the normal irrigation regime (Table 13). In order to induce significant stress during the second phenological phase, the drying period of the N/4 treatment level was extended to N/6 (irrigate with each sixth irrigation of N). However, the T7 and T10 treatments as well as the T15 treatment still showed no significant water stress. Photosynthesis and stomatal conductance measurements confirmed this lack of significant stress (data not shown).

The following three contradictions in plant reaction led to the theory that trees obtained water from a source other than rain or irrigation:

1) The lack of stress at the treatment which received no irrigation during the season (T15).
2) Only one of the stress treatments showed significant stress after five normal irrigation events were withheld (T3).
3) An increase in fruit growth rate of the stress treatment (T3) during a period (14/01 to 21/01) in which neither rain or irrigation occurred (See Figure 71).

Vegetative growth: Stem growth did not differ significantly between treatments during the selected phenological phases or the total of the growth period monitored for both seasons (data not shown). Negative growth values during phase 4 of the 1997/98 season proved that measurement errors due to irregularities in the bark of the stems can interfere with treatment induced differences. The use of stem growth as an indicator of water stress is probably more applicable to young trees where large increments in stem growth still occur.

No significant differences in cumulative shoot growth were found between treatments during the 1997/98 (data not shown) and 1998/99 (Figures 68A & 69A) seasons. Even a second statistical analysis of 1998/99 data with crop density as covariant, to eliminate the effect of crop load on vegetative growth, showed no significant differences. Shoot growth rate of treatments T1 to T10 and T15 (Table 4), however, was significantly different, but only between 07/01/99 and 04/03/99 (Table 14). This coincides with the first period where water stress could actually be induced.

Shoot growth rate showed that the stress treatments (T3) tended to stop growth at an earlier stage than the normal (T1) and wet (T8) irrigation regimes (Figure 69B) which caused the tendency towards lower cumulative shoot growth (Figure 69A). All treatments where stress was induced at some stage during the

Table 11. Stress days[1] accumulated by Golden Delicious apple trees at different irrigation treatment levels in replicate blocks during the 2nd phenological phase of the 1997/98 season.

Treatment level (-kPa)	Stress days ($-kPa \times 10^{-3}$ days)			
	Block 1	Block 2	Block 3	Mean
50	52.7	54.4	57.7	54.9
20	65.1	66.5	79.8	70.5
200	67.4	83.9	80.9	77.4
400[2]	62.6	53.0	67.5	61.0
800[2]	60.9	71.3	78.6	70.3

1 Based on stem water potential.

2 Irrigation treatment not induced.

Table 12. Stress days[1] accumulated by Golden Delicious apple trees at different irrigation treatment levels in different replicate blocks during the 3rd phenological phase of the 1997/98 season.

Treatment level (-kPa)	Stress days ($-kPa \times 10^{-3}$ days)			
	Block 1	Block 2	Block 3	Mean
50	5.7	6.6	6.6	6.3
100	5.7	14.1	6.3	8.7
200	5.5	5.1	6.4	5.7
400[2]	5.0	4.4	7.4	5.6
800[2]	5.7	5.8	5.9	5.8

1 Based on predawn leaf water potential.

2 Irrigation treatment not induced.

Table 13. The effect of irrigation treatment level on predawn leaf water potential of Golden Delicious apple trees at selected dates during phase 2 as well as the seasonal mean till harvest of the 1998/99 season.

Treatment number[1]	Predawn leaf water potential (-kPa)					
	Phase 2					Seasonal mean till harvest
	5 January	15 January	22 January	9 February	24 February	
T1	388	405	462	360	343	368
T2	307	467	560	418	315	377
T3	521	523	642	453	518	439
T4	367	348	423	318	308	336
T5	317	317	440	293	324	318
T6	355	437	543	407	312	376
T7	427	373	487	378	415	372
T8	410	332	448	252	300	311
T9	348	353	452	358	307	351
T10	367	312	440	325	340	334
T15	327	290	430	370	367	332
LSD ($P \leq 0.05$)	83	122	107	83	63	54

1 Refer to Table 4 for explanation of treatments.

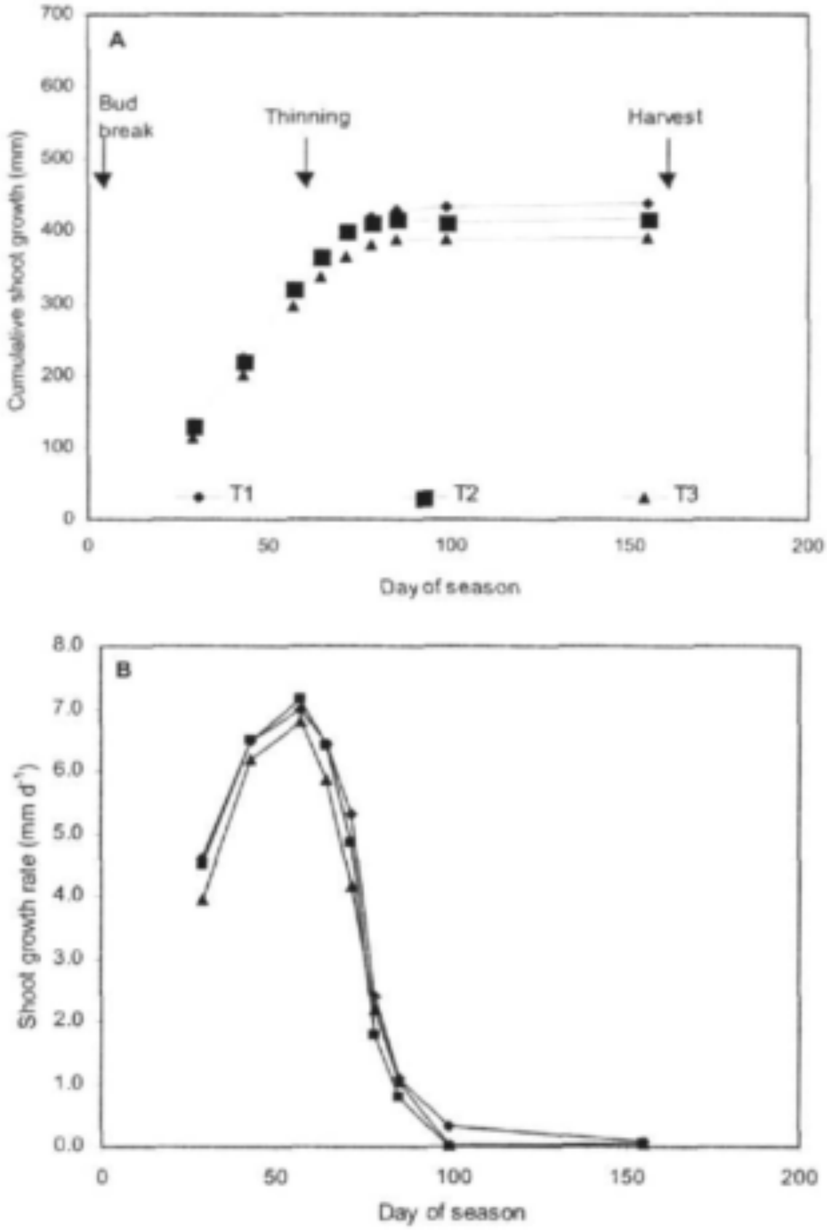


Figure 68. Effect of irrigation treatment on Golden Delicious apple cumulative shoot growth (A) and shoot growth rate (B) of selected irrigation treatments during the 1998/99 season. The season started on the 1st of October.

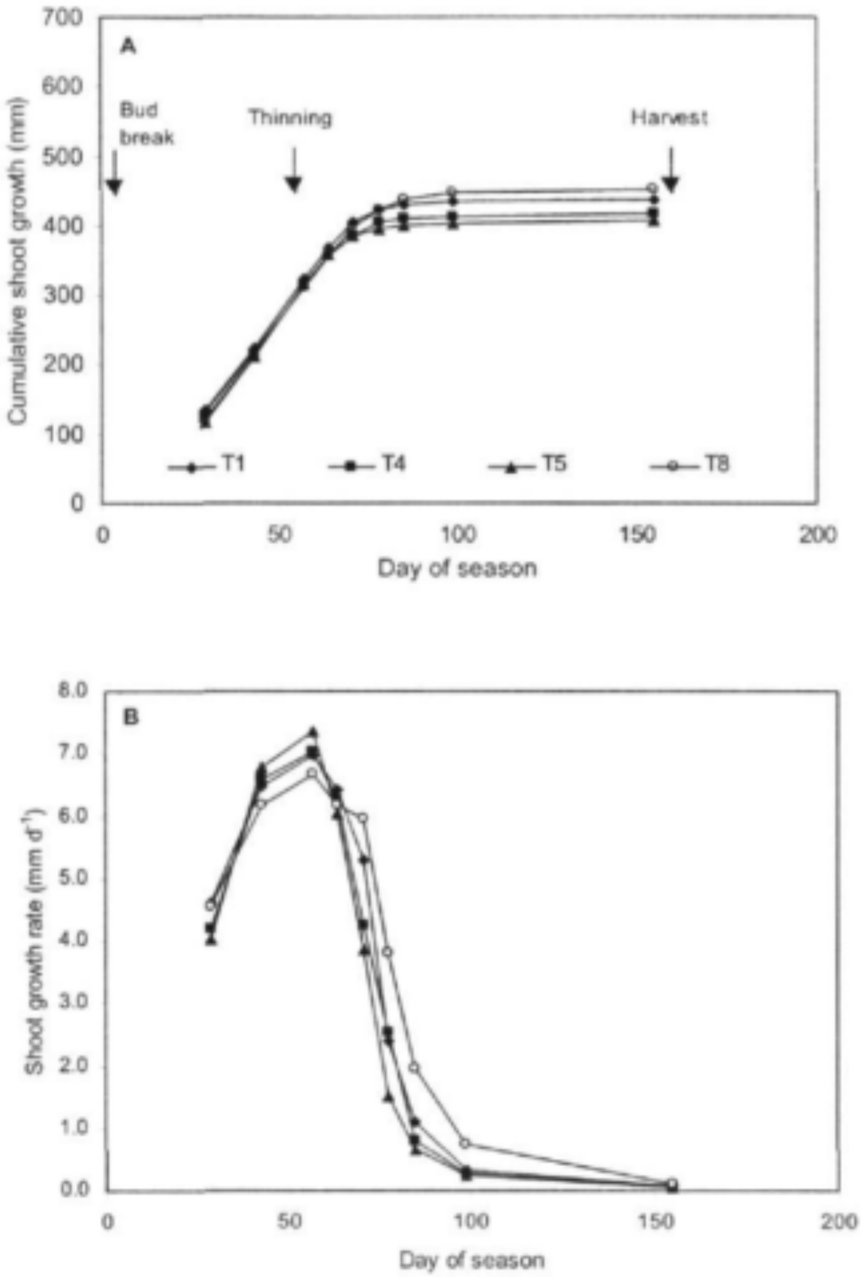


Figure 69. Effect of irrigation treatment on Golden Delicious apple cumulative shoot growth (A) and shoot growth rate (B) of selected irrigation treatments during the 1998/99 season. The season started on the 1st of October.

Table 14. The effect of selected regulated deficit irrigation treatments on shoot growth rate of Golden Delicious apple trees during day of season 99 to 155 (07/01/99 to 04/03/99) of the 1998/99 season.

Treatment number[1]	Irrigation level combination	Shoot growth rate (mm day^{-1})
T1	N-N-N	0.07^{b}
T2	N/2-N/2-N/2	0.06^{b}
T3	N/4-N/4-N/4	0.05^{bc}
T4	N/2-N-N	0.08^{ab}
T5	N/4-N-N	0.06^{b}
T6	N-N/2-N	0.08^{ab}
T7	N-N/4-N	0.05^{bc}
T8	2N-N-N	0.11^{a}
T9	N/4-N/2-N	0.07^{b}
T10	N/2-N/4-N	0.03^{c}
T15	0-0-0	0.06^{b}
LSD ($p \leq 0.05$)		0.031

1 Refer to Table 4 for explanation of treatments.

season was significantly lower than the T8 treatment (Table 14). The stress treatment was, however, not completely induced in all phenological phases (Table 7). Furthermore, not all treatments that received the same treatment level at a certain phase reacted in the same way in that specific phase. These differences could be due to varying levels of stress induced by differences in soil matric potential resulting from differences in soil texture between replicates.

Bloom and fruit set: No significant water stress could be induced before full bloom (± 18-26 October) or the period of fruit set in each of the two seasons. This rendered the objective to evaluate these aspects of fruit development to water stress obsolete.

Fruit quality: Only firmness, seed colour and starch content differed significantly at harvest during the 1997/98 season (Table 15). Differences could, however, not be attributed to irrigation treatment. During 1998/99 only seed colour and total dissolved solids were significantly different (Table 16). These parameters tended to be higher at treatments that received the stress (N/4) treatment during phenological phase 2.

Fruit diameter and final fruit size was not significantly different between treatments during the 1997/98 season (data not shown). During the 1998/99 season data were corrected for crop density effects and severe stress was induced at some treatments in the period before harvest. Wetter treatment combinations tended to have larger fruit diameters during the 2nd phenological phase in comparison with a stress treatment that was definitely induced (Figure 70). Although treatments did not differ significantly, the differences in fruit size can still affect count per carton and gross farm income. The T8 treatment produced fruit size of count 88, which could cause an increase of between approximately 13% to 17% in price per carton.

Fruit growth rate (corrected for crop density) showed significant differences between treatments (Figures 71 to 74). Fruit growth rate of stress treatments declined as soil water was depleted, but increased after rain occurred in the previous or same measurement period. The effect of stress on fruit growth was countered by significantly enhanced growth of the stress treatment fruit after rain or irrigation events. This could explain why final fruit diameters between treatments did not differ significantly.

Production: There were no significant differences ($P \leq 0.05$) with regard to cropping density (number of fruit per cm stem circumference), yield effectivity (kg fruit per cm stem circumference), fruit mass and gross farm income in both seasons (data not shown). Percentage exportable fruit during 1997/98 was also not significantly different. In 1998/99 trends showed fruit mass and gross farm income tended to decline with lower seasonal predawn leaf water potential (Figure 75A&B).

Water consumption: Average water consumption during the second phenological phase of the 1997/98 season tended to decrease with increasing stress days, with the exception of one data point (Figure 76). Water consumption occurred to a depth of 900 mm despite the fact that the irrigation was only applied to a 600 mm soil depth. Water balance calculations for estimation of water consumption were discarded

Table 15. Effect of irrigation treatment on maturity of Golden Delicious apple fruit at harvest during the 1997/98 season.

Treatment number[1]	Firmness (kg)	Fruit color	Seed color	TDS[2] (%)	Acid (%)	Starch (%)
T1	7.9	2.7	4.9	12.1	0.48	7.3
T2	7.9	2.7	5.2	12.7	0.46	13.3
T3	8.0	2.7	5.1	13.6	0.50	8.3
T4	7.7	2.6	4.9	13.0	0.48	11.7
T5	7.9	2.7	5.1	11.9	0.47	9.7
T6	7.9	2.8	5.0	12.5	0.47	9.3
T7	8.1	2.7	5.4	12.8	0.46	6.0
T8	8.1	2.8	5.0	12.4	0.47	4.7
T9	7.9	2.8	4.9	12.6	0.47	7.0
T10	8.4	2.7	5.6	13.3	0.46	4.3
T11	8.0	2.7	5.1	12.3	0.46	10.0
T12	8.1	2.6	4.9	13.1	0.48	10.3
T13	8.0	2.6	4.7	13.4	0.48	13.3
T14	8.1	2.6	4.9	12.8	0.47	12.0
T15	8.2	2.6	5.0	12.7	0.48	13.3
T16	8.1	2.6	5.2	13.0	0.47	11.0
T17	7.7	2.5	4.6	12.0	0.47	10.0
T18	8.0	2.7	5.0	12.8	0.48	12.0
T19	7.9	2.7	4.9	12.9	0.51	10.3
T20	8.1	2.7	5.4	12.8	0.52	9.3
LSD ($p \leq 0.05$)	0.32	†	0.4	†	†	4.9

1 Refer to Table 3 for explanation of treatments.

2 Total dissolved solids.

† No significant difference

Table 16. Effect of irrigation level combination on maturity of Golden Delicious apple fruit at harvest during the 1998/99 season.

Treatment number[1]	Firmness (kg)	Fruit color	Seed color	TDS[2] (%)	Acid (%)	Starch (%)
T1	7.2	2.5	5.0	12.9	0.46	5.0
T2	7.5	2.6	5.5	14.1	0.48	4.0
T3	7.6	2.5	5.8	14.7	0.49	4.0
T4	7.4	2.4	5.1	13.4	0.50	5.5
T5	7.3	2.4	4.8	13.2	0.50	6.5
T6	7.4	2.3	5.2	13.7	0.46	4.0
T7	7.5	2.4	5.4	13.6	0.48	4.0
T8	7.5	2.5	5.0	13.2	0.51	6.5
T9	7.4	2.5	5.2	13.6	0.48	4.0
T10	7.5	2.6	5.2	13.9	0.52	2.5
T11	7.5	2.5	4.8	13.4	0.50	2.0
T12	7.4	2.6	5.1	13.5	0.50	5.0
T13	7.5	2.6	5.6	14.3	0.50	4.5
T14	7.2	2.6	5.5	13.7	0.48	4.5
T15	7.5	2.5	5.6	13.7	0.50	4.0
LSD ($p \leq 0.05$)	†	†	0.3	0.8	†	†

1 Refer to Table 4 for explanation of treatments.

2 Total dissolved solids.

† No significant difference

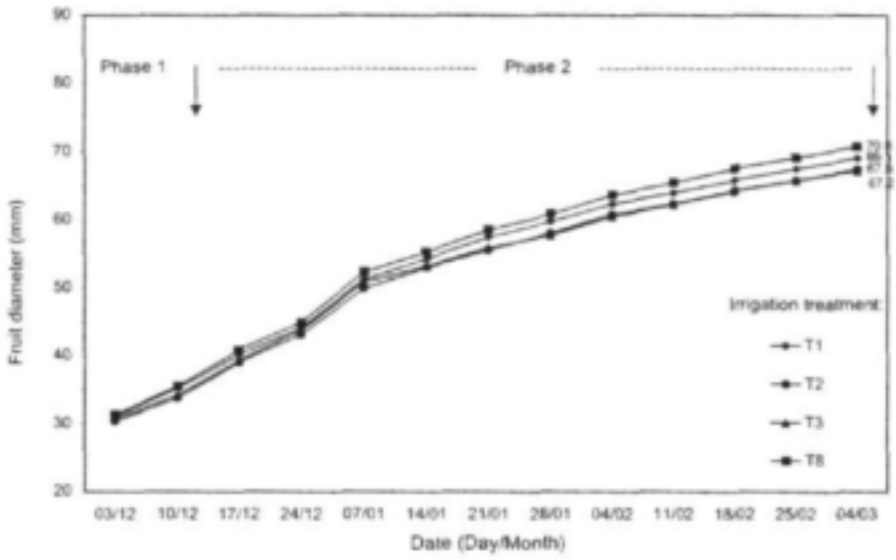


Figure 70. The effect of selected irrigation treatment level combinations on fruit growth of Golden Delicious apple fruit during the 1998/99 season. Refer to Table 4 for explanation of treatments.

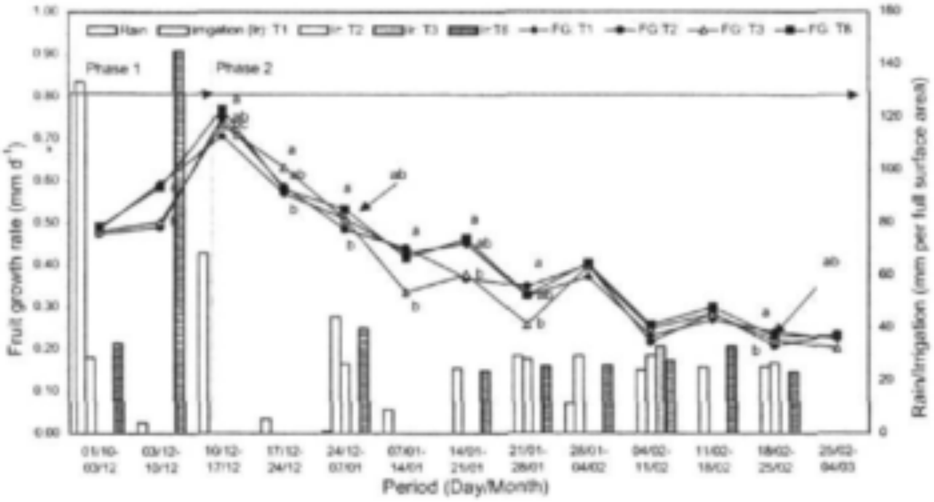


Figure 71. The effect of different irrigation treatment levels during phenological phase 1 and 2 on crop density corrected fruit growth rate (FG) of Golden Delicious apples at Elgin during season 1998/99. Refer to Table 4 for explanation of treatments.

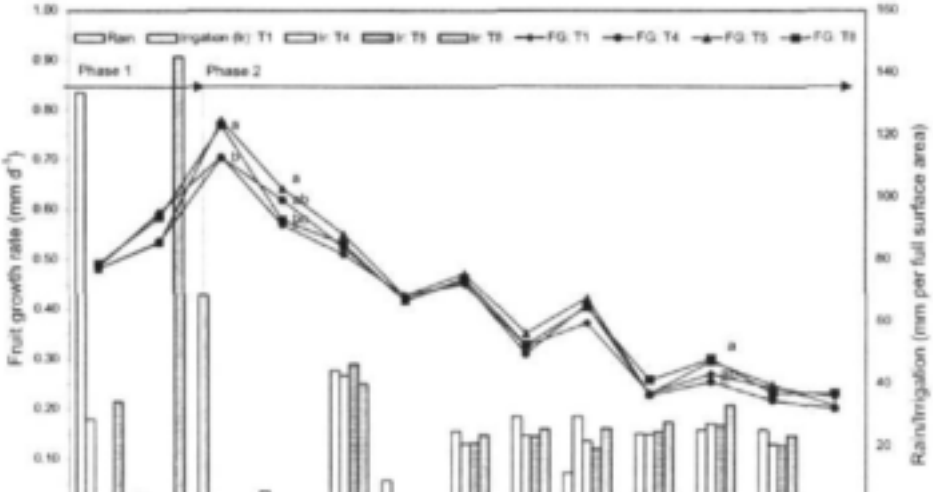


Figure 72. The effect of different irrigation treatment levels during phenological phase 1 on crop density corrected fruit growth rate (FG) of Golden Delicious apples at Elgin during season 1998/99. Refer to Table 4 for explanation of treatments.

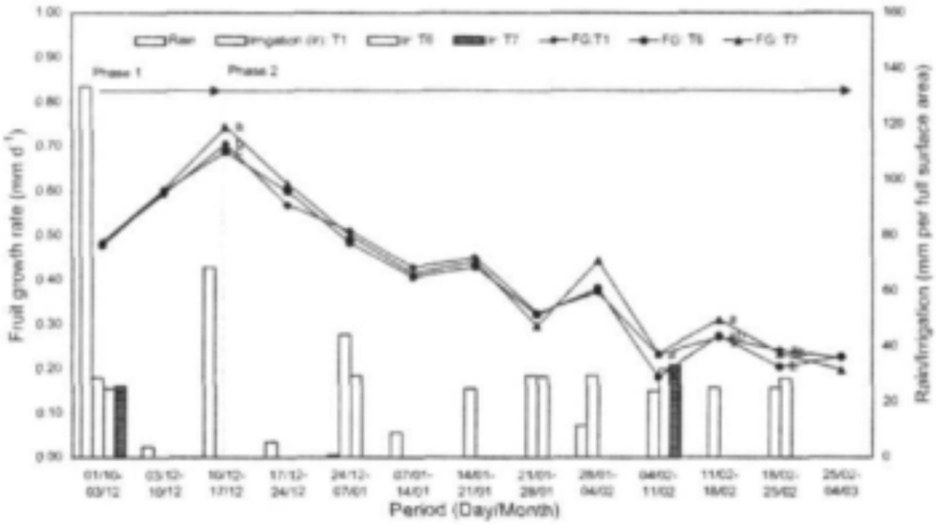


Figure 73. The effect of different irrigation treatment levels during phenological phase 2 on crop density corrected fruit growth rate (FG) of Golden Delicious apples at Elgin during season 1998/99. Refer to Table 4 for explanation of treatments.

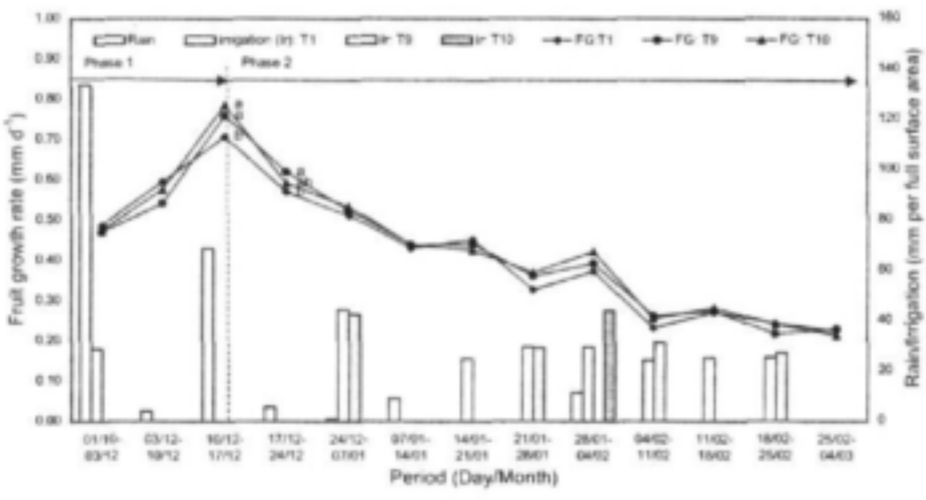
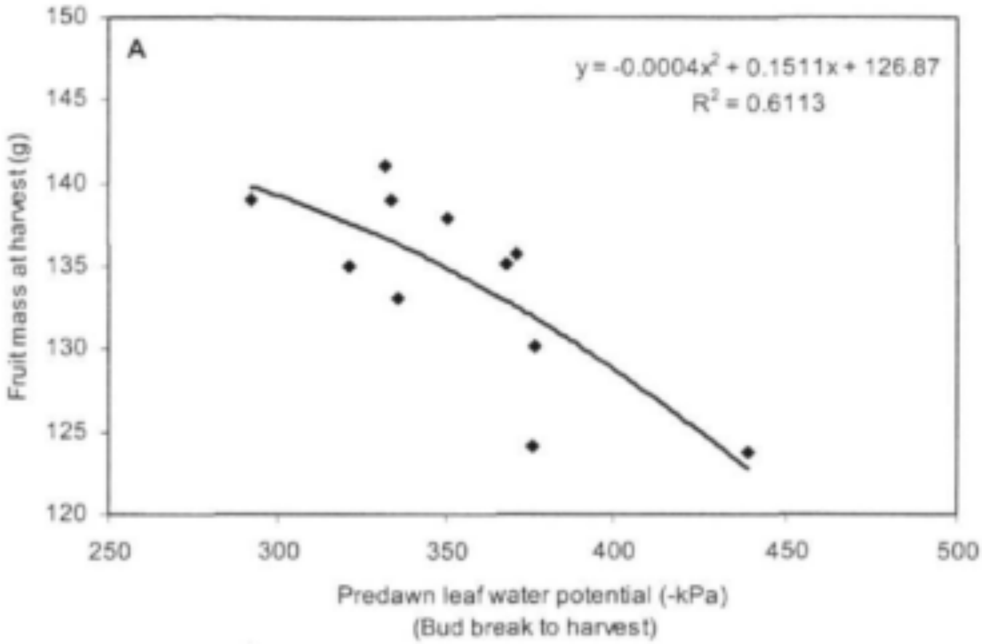


Figure 74. The effect of different irrigation treatment level combinations during phenological phase 1 and 2 on crop density corrected fruit growth rate (FG) of Golden Delicious apples at Elgin during season 1998/99. Refer to Table 4 for explanation of treatments.



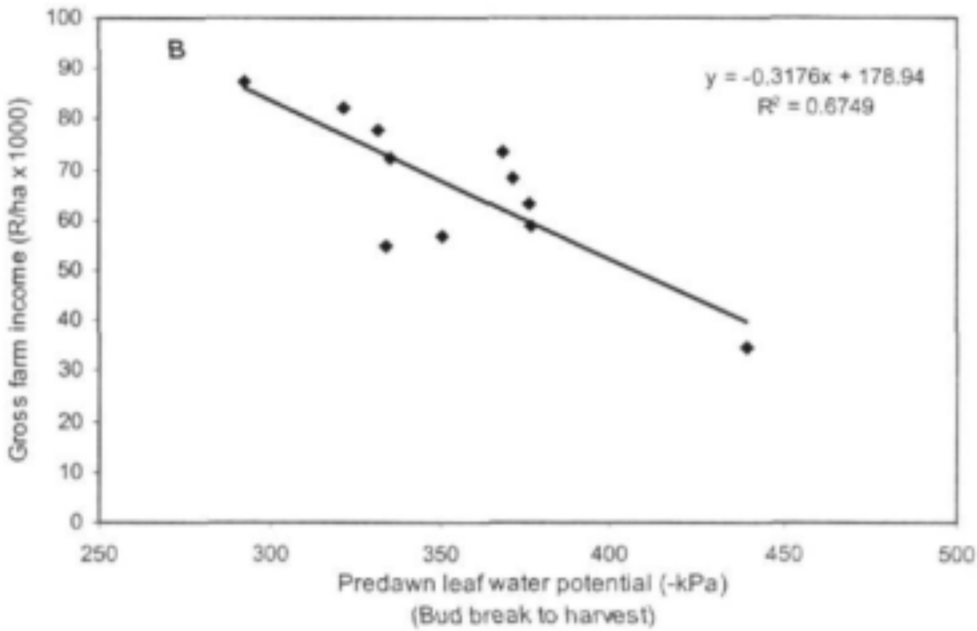


Figure 75. The relationship of predawn leaf water potential (-kPa) to (A) average fruit mass at harvest (g) and (B) gross farm income (R/ha) of Golden Delicious apple fruit during the 1998/99 season.

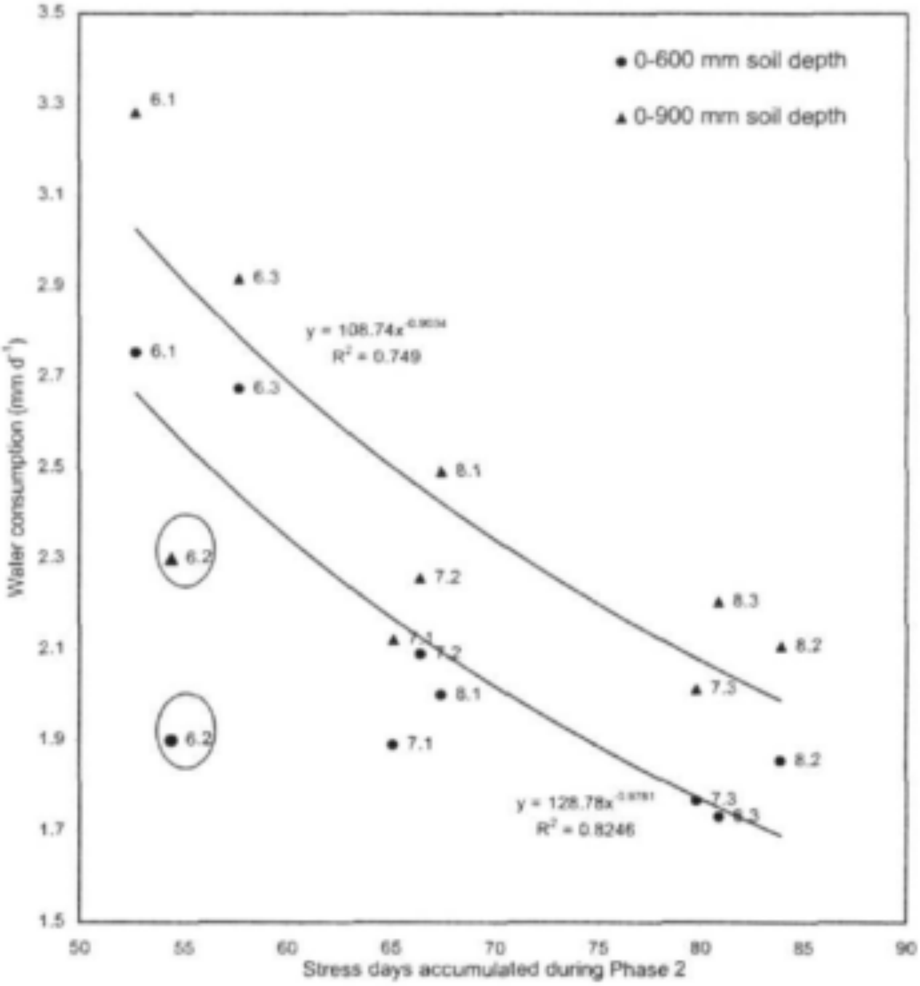


Figure 76.The effect of increasing accumulated stress days on water consumption (mm d^{-1}) of Golden Delicious apples from two soil depths at treatments 6,7 and 8 during the 2nd phonological phase of the 1997/98 season. Outliers are encircled and not included in the regression analysis

during the 1998/99 season because of inflow of water from sources other than irrigation and rain as discussed below.

Soil profile studies: According to an earlier report on classification of the soils of Elgin Experiment Farm (Wooldridge, 1983) the soil types include the Glencoe, Kroonstad and Pinedene forms. These forms are typical of wet conditions. Effective soil depth was indicated as 750, 600 and ±900 mm depth, respectively. Limiting factors reported for these soil forms include plinthite, fluctuating water tables and gleycutanic layers.

The recent soil profile excavations at the top of the slope above block 3 disclosed a prominent E horizon directly above a clay layer. This confirmed the presence of lateral water flow and extensive leaching over a long period. The E horizon was not as prominent above block 2. The differences between the two blocks are confirmed by the potential leaching depth that was estimated as the difference in depth from the first encountered clay and gravel layer from the soil surface (Tables 17 & 18).

The profile pit in block 3 furthermore showed seepage of water on a shallow clay layer at approximately 700 mm depth (Table 17). Root depth in both blocks extended to the clay layer (600 to 900 mm deep) which provided access to water. This water probably came from sources other than that received from irrigation or rain. Root distribution extended outside the wetted strip to the middle of the work zone next to the plastic sheeting.

The hypothesis is made that lateral flow from rain or irrigation of orchards located above the experimental orchard moves on a clay layer underneath the inserted plastic sheets from the top to the bottom of the slope. The clay gets shallower especially at the bottom of the slope of block three, which causes the water to accumulate in the experimental plots located near the bottom. Lateral movement of water could also occur from the area alongside the orchard where young pine trees were planted. The clay layer in the pit at the bottom of the slope of block 2 was located deeper, and the problem did not seem to be as pronounced as in block 3. The soil alongside the inserted plastic on the top of the slope also showed proof of leaching. An area of preferential flow was probably created when the soil was disturbed during installation of the plastic and water leached clay and silt particles, which resulted in a lightly coloured area. It seems as if the plastic did not successfully prevent the movement of water down-slope, and caused further artifacts in the soil water regimes.

4.4 CONCLUSIONS AND RECOMMENDATIONS

The lack of expected plant reaction could be ascribed to unsuccessful induction of treatments. This was due to a combination of cool weather, large variation in soil water holding capacity, variation in tree size and water obtained from a source other than rain or irrigation.

Water deficit irrigation trials should be executed in areas where the climate allows induction of all treatments. Since this experiment was intended to provide guidelines for deficit irrigation of apples in the

Table 17. Depth of the first encountered clay and gravel layer from the soil surface and estimated depth of the leached layer in soil profiles from the area above the three replicate blocks of the E10 orchard at Elgin Experiment Farm.

Replicate block number	Soil layer depth (m)		
	Clay	Gravel	Leached depth[1]
1	0.76	0.40	0.36
2	0.97	074	0.23
3	1.57	1.08	0.49

1 Leached depth was estimated as the depth difference between clay and gravel.

Table 18. Depth of the first encountered clay and gravel layer from the soil surface and estimated depth (m) of the leached layer in soil profiles from root distribution studies at the top and bottom of two replicate blocks of the E10 orchard at Elgin Experiment Farm.

Replicate block number	Profile pit location	Soil layer depth (m)		
		Clay	Gravel	Leached depth[1]
2	Top	0.88	0.51	0.37
	Bottom	1.07	0.48	0.59
3	Top	1.08	0.70	0.38
	Bottom	0.73	0.52	0.21

1 Leached depth was estimated as the depth difference between clay and gravel.

Elgin area, it must be concluded that the only period when this technique seems to be successfully applicable for this area is during midsummer (December to February). However, a large fraction of the vegetative growth of Golden Delicious apple trees is already completed near the end of December, which make the use of this technique questionable for this cultivar in this area. It must be kept in mind though, that the two seasons in question had rainfall in November and December much higher than the long-term average.

The large coarse component and variability in soils and percentage of orchards on slopes in this region will also cause problems with lateral movement of water in soils and subsequent lack of control over stress induction unless precision irrigation is practiced and/or provision for adequate drainage is made. Experimental plots for irrigation research purposes should in future preferably not be on soils prone to wetness or on a steep slope and include adequate border trees for different treatments, since inserted plastic can cause artificial conditions. No inflow from other water sources to the plot should be possible. Water consumption measurements should cover the whole area allotted to the tree (wetted strip and work row area) due to the presence of roots to the middle of the work row.

In situ soil water retention curves are needed to establish the relationship between soil water content and soil matric potential in soils with such a large coarse component. With regard to evaluation of the reaction of vegetative and fruit growth to stress, data should rather be expressed in terms of growth rates. This could provide much more insight about the reaction of the growth processes to stress than cumulative growth curves.

This project was terminated as the problems had been identified too late to redo the study on another plot. The remainder of the 1999/2000 budget was used to provide suitable infrastructure on farms of selected producers to evaluate the Soil Water Balance model.

CHAPTER 5

GENERAL DISCUSSION AND CONCLUSIONS

The cautious use of deficit irrigation for deciduous fruit could inhibit vegetative growth, reduce pruning costs and save limited irrigation water resources without reducing production and fruit quality. The response of twelve-year-old Neethling peach trees on seedling rootstock to deficit irrigation applied during different phenological stages in the Robertson production area, seems to confirm the findings of other researchers on the effect of water deficits on peach namely, that water stress induced during the slow fruit growth stage could inhibit vegetative growth without affecting production or fruit quality. In addition, substantial savings of irrigation water could be obtained by applying deficit irrigation during the post-harvest stage stage without affecting fruit size or production in the following season.

Several factors, however, should be taken into consideration when devising an irrigation strategy for conditions that differ from those under which the research was performed. The vegetative and reproductive growth patterns may differ for different fruit crops and/ or cultivars and should be considered when a deficit irrigation approach for the season is taken. It was clearly shown that crop load affected tree response to water deficits, a fact that has also been proved by other researchers for apple trees. Tree age should also be taken into account since young trees may be more susceptible to stress due to a limited root system. In this regard, local research on the effect of water deficits on young peach trees would be valuable. The soil water holding capacity of the root zone would also determine the strategy for the season, with a different approach needed for deep and shallow soils, respectively.

The study on deficit irrigation of apples was terminated before objectives were reached. A lack of expected plant reaction was ascribed to unsuccessful induction of treatments. This was due to a combination of cool weather, large variation in soil water holding capacity, variation in tree size and unquantifiable water seepage from higher ground influencing the soil water balance. These problems had been identified too late to redo the study on another plot and the remainder of the budget was re-applied to other aspects of the project.

A study similar in design to the present deficit irrigation approach for apple, provided it is performed on a suitable site, could be considered, since the objectives were not realised and guidelines for irrigation scheduling of apples could not be improved. Irrigation scheduling guidelines could improve water management by producers and it will be possible to apply limited water resources more effectively if definite deficit irrigation strategies are available.

REFERENCES

ANDERSEN, P.C. & BRODBECK, B.V., 1988. Water relations and net CO_2 assimilation of peach leaves of different ages. *J. Amer. Soc. Hort. Sci.* 113: 242-248.

ANON., 2000. Peach quality. Presse info. http://www.inra.fr/Internet/Directions/DIC/PRESSE/Juin00/Gb/nb1.htm. 4/12/2000.

AOAC., 1995. Official Methods of Analysis of Association of Official Analytical Chemists International, 16th edition, AOAC International, Maryland, USA.

ASSAF, R., BRAVDO, B. & LEVIN, I., 1974. Effects of irrigation according to water deficit in two different soil layers, on the yield and growth of apple trees. *J. Hort Sci* 49: 53-64.

ASSAF, R., LEVIN, I. & BRAVDO, B., 1975. Effect of irrigation regimes on trunk and fruit growth rates, quality and yield of apples. *J. Hort Sci 50*: 481-493.

BARTHOLOMEW, E.T., 1926. Internal decline of lemons. III. Water deficits in lemon fruits caused by excessive leaf evaporation. *Am. J. Botany* 13: 102.

BEUKES, D.J. & WEBER, H.W., 1982. The effects of irrigation at different soil water levels on the water use characteristics of apple trees. *J. Hort. Sci.* 57(4): 383–391.

BOLAND, A.M., MITCHELL, P.D., JERIE, P.H. & GOODWIN, I., 1993. The effect of regulated deficit irrigation on tree water use and growth of peach. *J. Hort. Sci.* 68 (2): 261-274.

BONANY, J., CAMPS, F. & BLANKE, M., 1998. Effects of different irrigation levels on apple fruit quality. Proceedings of the Second workshop on Pome fruit Quality, Bonn-Rottgen, Germany, 24-26 November, 1996. *Acta-Horticulturae* 466: 47-52.

BOYNTON, D., 1937. Soil moisture and fruit growth in orchards situated on shallow soil in the Hudson Valley, New York, in 1937. *Proc. Am. Soc. Hort. Science.* 34: 169.

BRAMLAGE, W.J., 1986. Use of a penetrometer to determine fruit firmness. In: Apple Maturity Program Handbook, Washington Apple Commission, Wenachee, U.S.A.

CHALMERS, D.J., MITCHELL, P.D. & JERIE, P.H., 1984. The physiology of growth control of peach and pear trees using reduced irrigation. *Acta Horticulturae* 146: 143-149.

CHALMERS, D.J., MITCHELL, P.D. & JERIE, P.H., 1985. The relation between irrigation, growth and productivity of peach trees. Acta Horticulturae 173: 283-288.

CHALMERS, D.J., MITCHELL, P.D. & VAN HEEK, I., 1981. Control of peach tree growth and productivity by regulated water supply, tree density and summer pruning. *J. Amer. Soc. Hort. Sci.* 106(3): 307-312.

CHALMERS, D.J., OLSON, K.A. & JONES, T.R., 1983. Water relations of peach trees and orchards. In: Kozlowski, T.T. (ed.). Water deficits and plant growth. Vol. VII, Academic Press, New York, pp. 197-232.

DECROIX, M., 1992. French experience of irrigation based on regulated water deficit. *Rivista-di-Frutticoltura-e-di-Ortfloricoltura* 54(6): 49-54.

DE KOCK, I.S., LOUW, M.B.S, & GELDERBLOM, H.J., 1977. Bepaling van grondvogspanning met behulp van drukplaat ekstraheerders. NIVV Prosedures en Tegnieke, No. 67. Fruit and Fruit Technology Research Institute, Stellenbosch, South Africa.

DE KOCK, I.S., Undated. Bepaling van tekstuur van grond met behulp van 'n hidrometer. NIVV Prosedures en Tegnieke, No. 56. Fruit and Fruit Technology Research Institute, Stellenbosch, South Africa.

EBEL, R.C., 1991. Apple tree and fruit response to drought stress. Ph.D. Diss., Washington State University, Pullman.

EBEL, R.C., PROEBSTING, E.L. & PATTERSON, M.E., 1993. Regulated deficit irrigation may alter apple maturity, quality and storage life. *HortScience* 28(2): 141-143.

EBEL, R.C., PROEBSTING, E.L. & EVANS R.G., 1995. Deficit irrigation to control vegetative growth and monitoring fruit growth to schedule irrigation. *HortScience* 30(6): 1229-1232.

EBEL, R.C., PROEBSTING, E.L. & EVANS R.G., 2001. Apple Tree and Fruit Responses to Early Termination of Irrigation in a Semi-arid Environment. *HortScience* 36(7): 1197-1201.

FERRERES, E. & GOLDHAMER, D.A., 1990. Deciduous Fruit and Nut Trees. *Agronomy* 30: 987-1012.

FERREIRA, M.I., VALANCOGNE, C., DAUDET, F., AMEGLIO, T., PACHECO, C.A. & MICHAELSEN, J., 1996. Evapotranspiration and Crop-Water Relations in a Peach Orchard. *In*, C.R. Camp, Sadler, E.J. and R.E. Yoder.. Proc. of the International conference on Evapotranspiration and Irrigation Scheduling, November 3-6, 1996, San Antonia, Texas, USA. pp 61-67.

FLORE, J.A., 1994. Stone Fruit. In, B. Schaffer and P.C. Andersen (eds.). Handbook of Environmental Physiology of Fruit Crops, Vol 1: Temperate crops. CRC Press: Florida, US. pp. 233-270.

FLORE, J.A. & LAKSO, A.N., 1989. Environmental and physiological regulation of photosynthesis in fruit crops. *Hort Rev.* 11: 111-146.

FLORE, J.A., MOON, J. & LAKSO, A.N., 1985. The effect of water stress and vapor pressure gradient on stomatal conductance, water use efficiency, and photosynthesis of fruit crops. *Acta Horticulturae*. 171: 207-218.

GARNIER, E. & BERGER, A., 1985. Testing leaf water potential in peach trees as an indicator of water stress. *J. Hort. Sci.* 60: 47-56.

GHRAB, M., SAHLI, A., MECHLIA, N.B. & MONET, R., 1998. Reduction in vegetative growth and fruit quality improvement in the peach variety "Carnival" through moderate watering restrictions. Proceedings of the fourth international peach symposium, Bordeaux, France, 22-26 June 1997. Volume 2. *Acta-Horticulturae* 465: 601-608.

GIRONA, J., MATA, M., GOLDHAMMER, D.A., JOHNSON, R.S. & DE JONG, T.M., 1993. Patterns of soil and tree water status and leaf functioning during regulated deficit irrigation scheduling in peach. *J. Am. Soc. Hort. Sci.* 118(15): 580-586.

GOODWIN, T., 2000. Irrigation scheduling for regulated deficit irrigation (RDI). Agriculture Notes. Series no. AG0299. http://www.nre.vic.gov.au/web/root. 4/12/2000.

GOSPODINOVA, M., 1997. Irrigation regime of regulated water deficit in peach drip irrigation. *Rasteniev"dni-Nauki* 34(9-10): 114-118.

GUELFAT-REICH, S., ASSAF, R., BRAVDO, B.A. & LEVIN, I., 1974. The keeping quality of apples in storage as affected by different irrigation regimes. *J. Hort. Sci.* 49: 217-225.

HENDRICKSON, A.H. & VEIHMEYER, F.J., 1950. Irrigation experiments with apricots. *Proc. Am. Soc. Hort. Sci.* 40: 13.

HSIAO, T.C., 1973. Plant response to water stress. *Ann. Rev. Plant Phys*, 24: 519-570.

IRVING, D.E. & DROST, J.H., 1987. Effects of water deficit on vegetative growth, fruit growth and fruit quality in Cox's Orange Pippin apple. *J. Hort. Sci.*, 62 (4): 427-432.

JERIE, P.H., VAN DEN ENDE, B & DANN, I.R., 1989. Managing tree vigour and fruitfulness in deciduous orchards. *Acta Horticulturae* 240: 127-134.

JOHNSON, R.S., HANDLEY, D.F. & DEJONG, T.M., 1992. Long-term response of early maturing peach trees to posthavest water deficits. *J. Amer. Soc. Hort. Sci.* 117: 881-886.

JONES, H.G., LAKSO, A.N. & SYVERTSEN, J.P., 1985. Physiological control of water status in temperate and subtropical fruit trees. *Hort. Rev.* 7: 301-335.

KARSTEN. J.H.M., DEIST, J. & DE WAAL, H.O., 1975. A method of predicting the calibration curve for a neutron moisture meter. *Agrochemophysica* 7: 49-54.

KARSTEN, J.H.M. & VAN DER VYVER, C.J., 1979. The use of a neutron moisture meter near the soil surface. *Agrochemophysica* 11: 45-49.

KOTZÉ, W.A.G., 1991. Irrigation guidelines for deciduous fruit trees during critical water shortages. FFTRI -INFO, 611, Fruit and Fruit Technology Research Institute, Stellenbosch, South Africa.

KUMASHIRO, K. & TATEISHI, S., 1966. Effect of soil moisture on tree growth, yield and fruit quality of Jonathan apples. *J. Jap. Soc. Hort. Sci.* 36: 9-20.

LAKSO, A.N. 1994. Apple. In, B. Schaffer and P.C. Andersen (eds.). Handbook of Environmental Physiology of Fruit Crops, Vol 1: Temperate crops. CRC Press: Florida, US. pp 233-270.

LANDSBERG, J.J. & JONES, H.G., 1981. Apple orchards. *In*, T.T. Kozlowski, (ed.). Water deficits and plant growth, Vol. VI. Academic, New York. pp 419-469.

LEWIS, M.R., WORK, R.A. & ALDRICH, W. W., 1935. Influence of different quantities of moisture in a heavy soil on rate of growth of pears. *Plant Physiol.* 10: 309-323.

LI, S.H., HUGUET, P.G., SCHOCH, P.G. & ORLANDO, P., 1989. Response of peach tree growth and cropping to soil water deficit at various phenological stages of fruit development. *J. Hort. Sci.* 64(5): 541-552.

LIEBENBERG, G.F. & UYS, P.M. 1995. Waterhulpbronne van Suid-Afrika. *Agrifutura Bulletin* 2(1): 31-34.

LÖTTER, J. DE V., BEUKES, D.J. & WEBER, H.W., 1985. Growth of quality apples as affected by different irrigation treatments. *J. Hort. Sci. 60(2):* 181-192.

MASSACCI, A. & JONES, H.G., 1990. Use of simultaneous anlaysis of gas-exchange and chlorophyll fluorescence quenching for analyzing the effects of water stress on photosynthesis in apple leaves. *Tree structure and function* 4(1): 1-8.

MCFAYDEN, L.M., HUTTON, R.J. & BARLOW, E.W.R., 1996. Effects of crop load on fruit water relations and fruit growth in peach. *J. Hort. Sci.* 71(3): 469-480.

MILLS, T.M., BEHBOUDIAN, M.H. & CLOTHIER, B.E., 1996. Preharvest and storage quality of 'Braeburn' apple fruit grown under water deficit conditions. *New Zealand Journal of Crop and Horticultural Science* 24: 159-166.

MILLS, T.M., BEHBOUDIAN, M.H., TAN, P.Y. & CLOTHIER, B.E., 1994. Plant water status and fruit quality in 'Braeburn' apples. *HortScience* 29(11): 1274-1278.

MITCHELL, P.D. & CHALMERS, D.J., 1982. The effect of reduced water supply on peach tree growth and yields. *J. Amer. Soc. Hort. Sci.* 107 (5): 853-856.

MITCHELL, P.D., CHALMERS, D.J., JERIE, P.H. & BURGE, G., 1986. The use of initial withholding of irrigation and tree spacing to enhance the effect of regulated deficit irrigation on pear trees. *J. Amer. Soc. Hort. Sci* 111(5): 858-861.

MITCHELL, P.D., JERIE, P.H. & CHALMERS, D.J., 1984. The effects of regulated water deficits on pear tree growth, flowering, fruit growth and yield. *J. Am Soc. Hort. Sci.* 109(5): 604-606.

MITCHELL, P.D., VAN DEN ENDE, B., JERIE, P.H. & CHALMERS, D.J., 1989. Response of 'Bartlett' pear to withholding irrigation, regulated deficit irrigation and tree spacing. *J. Amer. Soc. Hort. Sci.* 114(1): 15-19.

MURRAY, BIESENBACH & BADENHORST CONSULTING ENGINEERS INCORPORATED, 1997. Towards an irrigation policy for South Africa: Summarised results of irrigation workshops held in the Western Cape during May 1997.

PARKER, M.L. & MARINI, R., 1994. Drought assistance for fruit tree production. North Carolina Cooperative Extension Service, No. AG-519-11. http://www.ces.ncsu.edu/drought/dro-23.htm. 4/12/2000.

PERETZ, J., PROEBSTING, E.L., EVANS, R.G., 1986. Effects of manage water deficits on relative fruitfulness, growth and fruit quality of apples. pp 79-84. In: A.N. Lakso and F Lenz (eds.). Regulation of photosynthesis in fruit trees. Symp. Proc. Publ. New York State Agr. Expt. Sta., Geneva.

POWELL, D.B.B., 1974. Some effects of water stress in late spring on apple trees. *J. Hort. Sci.* 49: 257-272.

PROEBSTING, E.L., DRAKE, S.R. & EVANS, R.G., 1984. Irrigation management , fruit quality, and storage life of apple. *J. Amer. Soc. Hort. Sci.* 109(2): 229-232.

PROEBSTING, E.L. JR. & MIDDLETON, J.E., 1980. The behavior of peach and pear trees under extreme drought stress. *J. Amer. Hort. Sci.* 105: 380-385.

RAWASH, M.A.A.; ZEINAB, H.B.; HEGAZI, M.M. & MOSTAFA, M., 2000. Response of apple trees to some irrigation treatments in new reclaimed soils. 6th International Micro-irrigation Congress: "Micro-irrigation Technology for Developing Agriculture", South Africa, 22-27 October 2000. CD produced by: Document Transformation Technologies.

REUTHER, W., BEUTEL, J.A., MARSH, A.W., MEYER, J.L., ALJIBURY, F.K., AYERS, R.S. SCHULBACH, H., 1981. Irrigating deciduous orchards. Division of Agricultural Sciences: University of California. Leaflet 21212.

ROBITAILLE, H.A. & JANICK, J., 1973. Ethylene production and bruise injury in apple. *J. Amer. Soc. Hort. Sci.* 98(4): 411-413.

RYALL, A.L. & ALDRICH, W.W., 1944. The effect of water deficits in the tree upon maturity, composition and storage quality of Bosc pears. *J. Agr. Res.* 86: 121.

SYVERTSEN, J.P., 1985. Integration of water stress in fruit trees. *HortScience* 20(6): 1039-1043.

TOPPING, A.J. & LUTON, M.T., 1986. Cultivar differences in the bruising of English apples. *J. Hort. Sci.* 61(1: 9-13.

TRUTER, A.B., Undated. Die gebruik van sak-refraktometers vir die bepaling van suikerinhoud. NIVV Prosedure en Tegnieke, No. 53. Fruit and Fruit Technology Research Institute, Stellenbosch.

South Africa.

VAN DER MAAS, M.P., 1995. Control of growth and production of pit and stone fruit by water and nutrient supply. Annual Report 1995: Research Station for Fruit Growing. Wilhemina Dorp,The Netherlands.

VAN DER MAAS, M.P., 1996. Optimizing the water supply in relation to fruit quality and other aspects of apple and pear growing.. Annual Report 1996: Research Station for Fruit Growing. Wilheminadorp, The Netherlands.

ZAHNER, R., 1968. Water deficits and growth of trees. In: Kozlowski, T.T. (ed.). Water deficits and plant growth. Vol. II, Academic Press, New York, pp. 191-254.

WOOLDRIDGE, J., 1983. Progress report on mapping of FFTRI experimental farm apple orchard soils (VV 2441/05/1/4). Fruit and Fruit Technology Research Institute, Stellenbosch, South Africa.

LIST OF PUBLICATIONS AND OTHER TECHNOLOGY TRANSFER ACTIONS

The following papers were presented at seminars, congresses, information days or formal meetings.

BEUKES, O., 2000. Korrekte besproeiing en metodes van besproeiingskedulering. Information day: Evaluation of a water use model for irrigation scheduling, April 2000, Harry Molteno Centre, Elgin.

BEUKES, O., 2000. Die effek van beheerde beperkte besproeiing op die produksie en kwaliteit van perskes. CPA Technical Symposium, June 2000, Jannasch Hall, University of Stellenbosch, Stellenbosch.

BEUKES, O., 2000. Die effek van besproeiing op die produksie en gehalte van steenvrugte, met spesifieke verwysing na tekortbesproeiing (deficit irrigation). Stone fruit short course, November 2000, Ashton.

KARSTEN, J.H.M., 2000. Development and evaluation of a model for irrigation scheduling of peaches with the aid of meteorological data. Information day: Evaluation of a water use model for irrigation scheduling, April 2000, Harry Molteno Centre, Elgin.

STRYDOM, J.J., 2000. Die bedryf van 'n outomatiese weerstasie in 'n weerstasie netwerk (Robertson Wyn Vallei Trust as voorbeeld). Information day: Evaluation of a water use model for irrigation scheduling, April 2000, Harry Molteno Centre, Elgin.

VOLSCHENK, T., 2000. Navorsing aangaande 'n model vir voorspelling van waterverbruik van sagtevrugtebome met behulp van weerkundige data vir besproeiingskeduleringsdoeleindes. Information day: Evaluation of a water use model for irrigation scheduling, April 2000, Harry Molteno Centre, Elgin.

VOLSCHENK, T., 2000. Direkte en indirekte metodes vir besproeiingskedulering vir die verbouing van steenvrugte. Stone fruit short course, November 2000, Ashton.

VOLSCHENK, T. & DE VILLIERS, J.F., 2000. Bepaling van transpirasie van sagtevrugtebome vir besproeiingskeduleringsdoeleindes. CPA Technical Symposium, June 2000, Jannasch Hall, University of Stellenbosch, Stellenbosch.

VOLSCHENK, T. & DE VILLIERS, J.F., 2002. Water consumption: a short review. CPA Technical Symposium, June 2002, Endler Hall, University of Stellenbosch, Stellenbosch.

VOLSCHENK, T., 2000. Evaluation of a model for water use in deciduous fruit orchards and irrigation scheduling with the aid of meteorological data. Fieldsmans' Meeting, October 2002, Two-a-day Technical Centre, Elgin.

The following publications resulted from research undertaken:

BEUKES, O., 2002. The effect of regulated deficit irrigation on the production and fruit quality of peaches. M.Sc.- thesis. University of Stellenbosch, 7600 Stellenbosch, Republic of South Africa, November 2001.

BEUKES, O., 2000. The effect of regulated deficit irrigation on the production and quality of peaches. Die Krat 139: 5-6, June.

BEUKES, O., 2000. Korrekte besproeiing en metodes van besproeiingskedulering. Deciduous Fruit Grower, Volume 50:5, p.6-7. Publication of a handout of a lecture delivered at the Information

day: Evaluation of a water use model for irrigation scheduling, 13 April 2000, Harry Molteno Centre, Elgin.

BEUKES, O.& KARSTEN, K., 2000. The effect of regulated deficit irrigation on the production and fruit quality of peaches. Proceedings of the CPA Technical Symposium, 6 June 2000, Jannasch Hall, University of Stellenbosch, Stellenbosch. p.107-114.

BEUKES, O & KARSTEN, K., 2000. The effect of irrigation on the production and fruit quality of Stone Fruit – with specific reference to deficit irrigation. Stone fruit short course, 22 November 2000, Ashton Wine Cellar, Ashton.

BEUKES, O. & VOLSCHENK, T., 2000. Direkte en indirekte metodes vir besproeiingskedulering vir die verbouing van steenvrugte. Stone fruit short course, 22 November 2000, Ashton Wine Cellar, Ashton.

KARSTEN, J.H.M., 2000. Development and evaluation of a model for irrigation scheduling of peaches with the aid of meteorological data. Handout of a lecture delivered at the Information day: Evaluation of a water use model for irrigation scheduling, 13 April 2000, Harry Molteno Centre, Elgin.

STRYDOM, J.J., 2000. Die bedryf van 'n outomatiese weerstasie in 'n weerstasie netwerk (Robertson Wyn Vallei Trust as voorbeeld). Handout of a lecture delivered at the Information day: Evaluation of a water use model for irrigation scheduling, 13 April 2000, Harry Molteno Centre, Elgin.

VOLSCHENK, T., 2000. Navorsing aangaande 'n model vir voorspelling van waterverbruik van sagtevrugtebome met behulp van weerkundige data vir besproeiingskeduleringsdoeleindes. Handout of a lecture delivered at the Information day: Evaluation of a water use model for irrigation scheduling, 13 April 2000, Harry Molteno Centre, Elgin.

VOLSCHENK, T. & DE VILLIERS, J.F., 2000. Die bepaling van transpirasie van sagtevrugtebome vir besproeiingskeduleringsdoeleindes. Proceedings of the CPA Technical Symposium, 6 June 2000, Jannasch Hall, University of Stellenbosch, Stellenbosch. p.160-164.

VOLSCHENK, T. & DE VILLIERS, J.F., 2002. Water consumption: a short review. CPA Technical Symposium, 3 June 2002, Endler Hall, University of Stellenbosch, Stellenbosch. Submitted to CPA June 2002.

APPENDIX A

SOIL WATER RETENTION CURVES

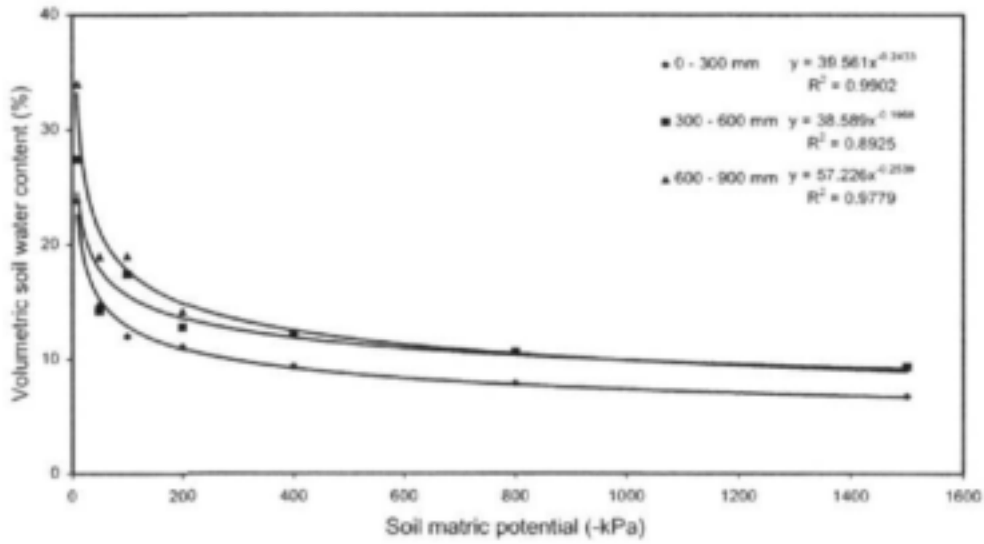


Figure I. Laboratory determined soil water retention curves for the 0 - 300, 300 - 600 and 600 - 900 mm soil depth increments of a typical sandy loam soil (Treatment A1, replicate block 1) at Robertson Experiment Farm.

APPENDIX B

ARCHIVING OF DATA

After careful consideration it was decided not to include long lists and tables with data in the report, but to archive raw data at ARC Infruitec-Nietvoorbij in hard copy and CD-ROM format in the project file in the project office. Data for research purposes can be obtained via the WRC from ARC Infruitec-Nietvoorbij.

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Two dimensional energy interception and water balance model for hedgegrow tree crops

Annandale JG • Jovanovic NZ • Mpandeli NS • Lobit P • du Sautoy N

Two types of model, both predicting crop water requirements on a daily time step, were developed for hedgerow tree crops. These models were incorporated into the Soil Water Balance (SWB) model. The models are:

- A mechanistic two-dimensional energy interception and finite difference, Richards' equation based soil water balance model; and
- An FAO-based crop factor model, with a quasi 2-D cascading soil water balance model.

The two-dimensional model for hedgerow crops calculates the two-dimensional energy interception, based on solar and row orientation, tree size and shape as well as leaf area density. Inputs required to run the two-dimensional canopy interception model are: day of year, latitude, standard median, longitude, daily solar radiation, row width and orientation, canopy height and width, skirting height and width, extinction coefficient, absorptivity and leaf area density. For the two-dimensional soil water balance model, the input required included starting and planting dates, altitude, rainfall and irrigation water amounts, as well as maximum and minimum daily temperature. To run the FAO-type crop factor model, the required input included planting date, latitude, altitude, maximum and minimum daily air temperatures, FAO crop factors and duration of crop stages. The two-dimensional SWB model evaluation consisted of checking internal consistency and units used, comparison of model output with independent data sets of real life observations and sensitivity analysis. Inspection of the qualitative behaviour of the model and its implementation was done by checking whether the response of the model output to changing values of a parameter conforms to theoretical insights. There was good agreement between predicted and measured daily soil water deficit for water-stressed and non-stressed treatments. Field measurements indicated that in hedgerow plantations the whole area across the row must be borne in mind when assessing soil water content. The reason for this is the effect of irrigation distribution and rain interception by the canopy, the variation in radiation interception by the canopy across the row, the irradiance reaching the soil surface as the season progresses, the presence of a grass sod or bare soil in the inter-row region and the root density across the row. It was found that there are significant amounts of roots in the inter-row region and thus this portion of the rooting volume must not be ignored when assessing the water balance.

The contribution to crop water uptake from the inter-row volume of soil can be high, particularly under high atmospheric evaporative demand, and thus needs to be accounted for in irrigation management in order to maximise rainfall use efficiency.

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