EXECUTIVE SUMMARY

Introduction

Irrigation technologies have changed dramatically over the past few decades. In intensive, high-value irrigated agriculture drip and micro-sprinkler irrigation systems have become popular. With these systems relatively high soil water potentials are maintained continuously (i.e. the soil is kept wet continuously) by means of high frequency water applications. Under such system there is always the danger that soils may be kept too wet. This would lead to oxygen deficiencies in the root zone and cause degeneration of trees and aggravate the incidence of root diseases. It would also waste scarce irrigation water. Excessive wetness has been observed by project team members in citrus orchards under drip or micro-sprinkler irrigation in South Africa and Swaziland, especially in marginal soils.

What is "too wet" and what soil water potential is "too high" both vary greatly between soils. It depends upon the physical characteristics of the soil, especially texture, structure and bulk density. A thorough understanding of soil-water-air-plant (SWAP) relationships in the wet range of plant-available water, therefore, becomes very important under high frequency drip or micro-sprinkler irrigation.

Objectives

The objectives of this study were to identify appropriate upper limits of plant-available water for different soil bulk density/soil water potential combinations and to identify the effects of soil compaction on citrus rootstock performance in the upper range of plant-available water. The aim was to improve irrigation management under high frequency drip or micro-sprinkler irrigation systems.

Soil Experiments

Soils were selected on the basis of (i) differences in physical characteristics, (ii) difficulties that have been experienced under irrigation on them and/or (iii) the demand for establishing citrus on such soils.

Rough lemon (RL) and Troyer citrange (TC) seedlings were grown in pots in a greenhouse in compacted and non-compacted soils at specific soil water potential levels. Soil water potentials were maintained using the "Pero" facility (an electronic system that monitors and regulates the soil water potential in pot experiments).

In the first study, consisting of two experiments, the effects of soil compaction and soil water potential on growth and development of TC (Experiment 1) and the effects of soil compaction on RL and TC rootstocks (Experiment 2) were investigated. In Experiment 1, TC performed best in the compacted soil at both soil water potentials (-6 and -30 kPa), indicating the tolerance of TC rootstocks to compacted soils. In the compacted soil, the seedlings grew better at the lower soil water potential while in the non-compacted soil those at the higher soil water potential performed better. In the second experiment, a soil water potential of -6 kPa was maintained both in compacted and non-compacted soil (Oakleaf form). The RL seedlings in compacted soil showed symptoms of stress later in the growing season. The

bottom leaves became yellow and the growth rate declined. Total mass, top dry mass, root dry mass, leaf area, projected root surface area, water consumption and water use efficiency (WUE) were all significantly reduced in the compacted soil. The air-filled porosity of the compacted soil at a soil water potential of -6 kPa was 10.5%, very near to the minimum threshold value for citrus. For TC on the other hand, soil compaction resulted in better seedling growth. This was probably due to better contact between soil and roots in compacted soil early in the season.

In the second study, RL was grown in compacted and non-compacted soil of the Hutton form at three different soil water potentials (-10, -20 and -40 kPa). Both soil compaction and soil water potential affected seedling growth. Their growth patterns in the compacted soil were irregular and fluctuated throughout the growing season. A consistent growth rate was found in seedlings grown in non-compacted soil. Soil compaction had a greater negative effect on seedlings at a soil water potentials of -10 and -40 kPa than at -20 kPa. In the non-compacted soil, a reduction of the soil water potential from -10 kPa to -20 kPa resulted in a significant negative effect on all plant parameters.

There were significant differences in the status of certain nutrient elements in plants as a result of different compaction/soil water potential treatments. At high soil water potential levels (wet conditions), N and K concentrations (% or mg.kg^{-1}) were higher in seedlings grown in compacted soil while the Ca:Mg ratio was significantly higher in those grown in non-compacted soil. However, nutrient contents (mg per pot) were generally higher in seedlings grown in the non-compacted soil. The lower concentrations of nutrients in non-compacted soil were partly due to the larger size of these seedlings, resulting in a "dilution" of the nutrients in the plants.

During a third study, comprised of three experiments, the upper limit of plant-available soil water was identified. In the first two experiments, different soil water potentials were maintained in compacted topsoil of the Sterkspruit form. These were -5, -10, -20, -40 and -50 kPa in the first experiment. In the second experiment the number of treatments was reduced to three (-10, -20, and -30 kPa) and the replications were doubled. In a third experiment these three soil water potential levels were maintained in both compacted and non-compacted treatments of the same soil.

In the first experiment, the seedlings at -50 kPa died in the first two weeks, probably due to drought stress. The seedlings at -5 and -40 kPa died three to four weeks later, due to excessively high and very inadequate soil water availability at -5 and -40 kPa, respectively. For some unknown reasons, the seedlings at -20 kPa did not perform well compared to those at -10 and -30 kPa.

In the second experiment, the seedlings at -20 kPa had a significantly higher total mass, WUE, leaf area and projected root surface area compared to those at -10 and -30 kPa. In the third experiment, soil compaction at -10 and -30 kPa resulted in a significant reduction in total mass, water consumption, leaf area and projected root surface area, compared with non-compacted soil. At -20 kPa only water consumption and leaf area were significantly lower as a result of soil compaction. In fact, most of the plant parameters measured at -20 kPa were relatively better for seedlings in compacted soil than in non-compacted soil, but these differences were not statistically significant.

Water Culture Experiments

Another series of experiments was conducted using water culture. The purpose of these experiments was to supplement the information from soil experiments and to make it possible to alter and/or maintain certain factors, such as the aeration and pH of the rhizosphere, which would be difficult if soil was used as a growing medium.

In the first study the main aim was to identify the effects of aeration and non-aeration of the rhizosphere on the performance of RL and TC rootstocks. In the second study the aim was to determine the effects of the rhizospherical pH (pH 4 and pH 7), aeration/non-aeration and their interaction on growth and development of seedlings. The third study was conducted in order to identify the effects of aeration and non-aeration on the nutrient status of TC seedlings and the possibility of this as a cause of differences in performance of this rootstock under different conditions.

The experiments highlighted the greater sensitivity of RL rootstock to anaerobic (e.g. poorly drained) rhizospherical conditions compared to TC rootstock. The data illustrate that the root system of both RL and TC is more sensitive to the effects of poor aeration than the top growth. These data also indicate that non-aeration affected both RL and TC more at pH 4 than at pH 7.

The effects of low pH on nutrient uptake from aerated and non-aerated nutrient solutions were inconsistent for both RL and TC. For most nutrient elements there was no significant difference in nutrient concentration (% or $mg.kg^{-1}$) as a result of aeration/non-aeration in TC. However, for most nutrient elements the nutrient content (mg per pot) was significantly higher in aerated than in non-aerated seedlings.

Conclusions

Soil compaction had negative effects on RL seedlings, especially at soil water potentials above -20 kPa. For most soils when compacted, the seedlings could not grow at soil water potentials above -10 kPa.

The root system and the root hydraulic conductivity were the most affected plant parameters in RL seedlings grown in compacted soil. The WUE was also negatively affected by both soil compaction and high soil water potentials. The leaf area and top dry mass were affected by soil compaction at both high and very low soil water potentials. The optimum soil water potential for rootstock development in most compacted soils was -20 kPa.

In non-compacted soil, an increase in soil water potential resulted in better seedling growth. However, a point was reached at which an excessively high soil water potential resulted in low WUE. Lower soil water potentials in non-compacted soil resulted in a poor hydraulic conductivity and thus poorly developed seedlings.

Rhizospherical stress conditions resulting from both soil compaction and very high soil water potential as well as non-aeration of the nutrient solution had some effects on the nutrient status of seedlings. The stressed seedlings had a higher concentration (% or $mg.kg^{-1}$) of most nutrient elements compared to the non-stressed seedlings, but non-stressed seedlings had higher nutrient contents (mg per pot).

The anaerobic rhizospherical conditions in water culture experiments resulted in poor seedling growth. Both the top growth and the root system were affected as a result of anaerobic conditions. The RL seedlings formed a thick and short fibrous root system when grown in non-aerated nutrient solution. Defoliation was excessive in both non-aerated RL and TC seedlings.

The pH of the solution had some effects on growth and development of both RL and TC rootstocks in aerated and non-aerated nutrient solutions. At pH 4, the effects of anaerobic conditions were not significant in TC while there was a significant decline in total mass of non-aerated seedlings at pH 7. A low pH of the aerated nutrient solution also resulted in reduced plant parameters. However, there were no differences between seedlings at pH 7 and pH 4 in non-aerated nutrient solution as they were negatively affected at both pH levels.

The effects of soil compaction were very similar to those of anaerobic rhizospherical conditions for both RL and TC. In both cases the root system was more negatively affected. On the other hand, the negative effects of soil water potential were more pronounced on the top growth than on the root system.

This project was concluded by an irrigation scheduling trial at the Moosrivier citrus estate. The recommendations made by the research team have been implemented since 1993 by the management at the estate and considerable savings in irrigation water and pumping costs, an increase in yield as well as a higher quality yield were obtained since the implementation of the programme.

This project concluded the PAWC research by Laker, Hensley, De Jager, Boedt and Vanassche in determining the upper and lower limits of plant-available water.

Recommendations

The results of this study indicate the necessity that each soil should be characterized carefully and dealt with separately for irrigation scheduling purposes. The irrigation scheduling experiment at the Moosrivier citrus estate illustrates the benefits that can be obtained when an efficient irrigation scheduling is implemented. The findings of this project can, therefore, be transferred by extension officers to other farmers. It is clear that if further research could be done on other crops such as avocado, mango, tea, etc. more farmers and indirectly the whole community would benefit, especially as water is becoming a scarcer commodity.

The results of all plant-available water related research should be incorporated in a database in order to make them accessible to researchers, extension officers and farmers.

There is still a need for (i) research on the influence of soil bulk density on hydraulic conductivity, (ii) root distribution patterns in different soils under various irrigation systems, (iii) real crop water requirements, especially under very hot and dry conditions, (iv) field studies, as well as the establishment of expert support systems, for practical in-field irrigation scheduling in order to improve the economics of water use and WUE in irrigated agriculture.