Calibrating soil-based irrigation norms of avocado using plant indicators

NJR Roets[1], SP Schoeman[2] and NR Murovhi[1]

[1]Agricultural Research Council – Institute for Tropical and Subtropical Crops,
Private Bag X11208, Nelspruit 1200, SOUTH AFRICA
[2]Soetkalmoes Consultation,
PO Box 44, Schagen 1207, SOUTH AFRICA
E-mail: nico@arc.agric.za

ABSTRACT

With water resources being predicted to become scarce and more expensive in future, there is a need to optimise water management for avocado. In this instance water requirements have to be determined for the current cultivars and rootstocks. The current soil-based irrigation norms has to be calibrated with the needs of the plant. During the past four years, trials were carried out mainly on 'Hass' where tree physiology was measured with the aim of determining stress levels. Parameters measured were photosynthesis, transpiration rate, stomatal conductance and stem xylem water potential with the latter being the focus of the study. All measurements were carried out during midday. Significant correlations were obtained between midday stem xylem water potential and the other physiological parameters. A trend was observed that trees started to stress at approximately -0.5 MPa, which was set as a threshold level. It was further found that trees reach midday stem xylem water potential values of -0.5 MPa and lower when more than 60% of easily available water is depleted from the soil. Tree water requirements and the norms determined in this study need further investigation for refinement.

INTRODUCTION

South Africa is located in a predominantly semi-arid part of world and water resources are therefore, in global terms, scarce. It is further predicted that the future effect of climate change will result in water becoming scarcer, especially in the south eastern parts of the country (Benhin, 2006) where most avocados are cultivated.

The agricultural sector is an extremely high consumer of water with 62% of South African water resources being used by this sector (National Water Resource Strategy, 2004). However, Nieuwoudt *et al.* (2004) have shown that agriculture is the least efficient user of water contributing only R1.50 per cubic metre of water used to the national GDP, compared to mining contributing R39.50/m^3, eco-tourism contributing R44.40/m^3 and industry contributing R157.40/m^3 water used. It is therefore inevitable that pressure will be placed on agriculture to drastically reduce water consumption to make more water available for other sectors. This will most probably manifest in stricter legislation and quotas and higher water prices for the agricultural sector. Therefore, there is an urgent need to reconsider irrigation practices in the avocado sector and investigate ways to save water and improve production. Currently soil-based irrigation norms are available for irrigation scheduling purposes (Kruger, 2011). The problem with soil-based irrigation scheduling is, however, that it does not provide a direct indication of the water requirements of the tree (Jones, 2004). It is therefore uncertain if water is applied according to the needs of the plant. Plant-based or plant physiological measurements should therefore be carried out in order to apply irrigation according to the needs of the plant (Winer, 2003).

Such a plant-based measurement can theoretically be any physiological parameter that can be linked to water relations and stress. A number of plant physiological parameters that can be used for this purpose is discussed by Jones (2004) and include stomatal conductance, photosynthesis, leaf and stem xylem water potentials, stem and fruit diameter, to mention a few. Each of the plant-based methods has advantages and pitfalls, but the most important pitfall for all plant-based scheduling approaches is the difficulty of on-farm application. Plant-based irrigation scheduling approaches should be used in research to fine-tune current soil based norms, which is easy to measure, to be certain that the water requirements of the tree is met.

The aim of this study was to calibrate irrigation of avocado using midday stem xylem water potential as plant physiological indicator. Midday stem xylem water potential was the parameter of choice as it showed highly significant correlations with a number of physiological parameters as well as with tree production in a number of other tree crops (Naor, 2000).

MATERIALS AND METHODS

Over the past four years, trials were carried out in the Nelspruit, Tzaneen and Levubu areas, mainly on the avocado cultivar 'Hass'. Some work was carried out on 'Pinkerton' and 'Maluma' as well, but only the results for 'Hass' will be discussed. At all sites, weather data (temperature, relative humidity, rainfall and wind speed) was obtained from weather stations in the vicinity of the trial sites.

Physiological measurements were taken at all sites on a regular basis. Physiological parameters that were measured were photosynthesis (CO_2-assimilation rate), transpiration rate, stomatal conductance and stem xylem water potential. All these measurements were carried out during midday (11:00 to 13:00). For midday stem xylem water potential measurements, leaves were firstly closed in a dark foil bag for approximately 90 minutes to allow the water potential of the leaf to come into equilibrium with the water potential of the stem of the tree. After the 90 minutes elapsed, the water potential of the leaf was measured in a pressure chamber (PMS Instruments, USA). In order to correlate the different physiological parameters, photosynthesis, transpiration rate and stomatal conductance was first measured with an infrared gas analyser (LCpro-SD, ADC BioScientific Ltd, UK) and immediately closed thereafter with the foil bag for water potential measurements.

Soil water content was measured with capacitance probes (DFM) and with a soil moisture kit (ΔT, SM150). The capacitance probes measured soil water content at 10, 20, 30, 40, 60 and 80 cm depths. All measurements were carried out in the root zones of the trees. In addition, soil analysis was carried out for the soils at each site and water retention curves obtained.

For all experiments carried out, appropriate experimental designs were obtained and data being analysed using appropriate statistical software.

RESULTS AND DISCUSSION

For the purpose of this article, the past four years' results will be placed into context with relevant literature to illustrate what is understood about avocado water relationships and progress made in calibrating irrigation on avocado. Furthermore, research that still needs to be carried out (gaps in knowledge) will then be discussed.

Water requirements of avocado

In terms of water requirements of avocado it was documented in studies done in Israel and California that avocado trees require between 8 000 and 9 000 m³ water/ha/annum (Gustafson *et al.*, 1979; Adato & Levinson, 1988). It would appear that it is slightly more in South African conditions. A study was carried out in the Crocodile River basin, where the water requirements for avocado was determined as 9 825 m³/ha/annum (Hoffman, 1999). However, in this study (Hoffman, 1999) it is uncertain if plant water

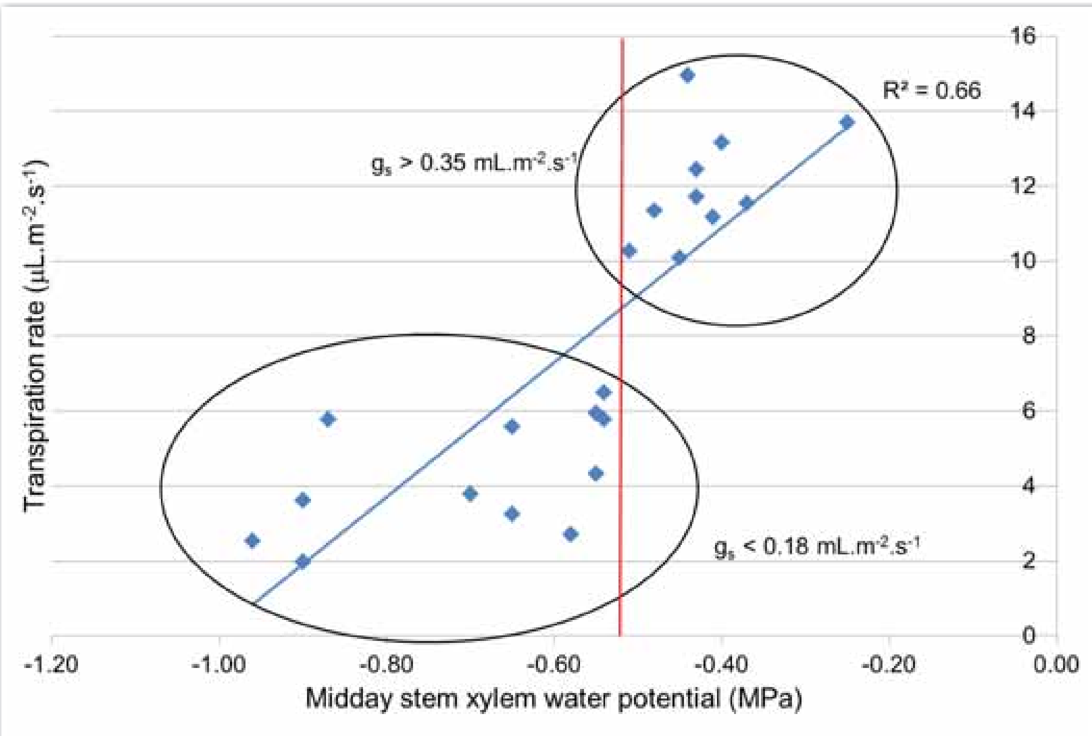

Figure 1. Correlation between transpiration and midday stem xylem water potential for 'Hass' avocado trees.

status was also measured (as in the California and Israel study) or if the study was based on soil-based measurement only. There is therefore a need to reconsider the mentioned figure and to determine water requirement for avocado under local conditions in different areas and with the cultivars and rootstocks currently used. As the water requirements of the trees strongly depends on environmental factors and phenology (Roets *et al.*, 2013), a model, containing environmental and phenological data as variables, will be constructed to be applied in the different production areas.

Calibrating current soil-based irrigation scheduling norms with midday stem xylem water potential

The first aim of this study was to determine a midday stem xylem water potential norm indicating the onset of plant stress. Correlations were obtained between transpiration rate and midday stem xylem water potential, and between midday photosynthesis and midday stem xylem water potential, which are depicted in Figures 1 and 2 respectively.

Considering the correlation between midday transpiration and midday stem xylem water potential depicted in Figure 1, the following can be seen:

- There is a significant linear correlation between these two variables with a decrease in transpiration rate as the midday stem xylem water potential decreased.
- However, considering the points on the graph there are two distinct groups of points indicating a sudden decrease in transpiration rate at a midday stem xylem water potential value of approximately -0.5 MPa. In this instance, the transpiration rate, as well as stomatal conductance, decrease by approximately 50%.
- This sudden decrease in transpiration rate and stomatal conductance indicates partial stomatal closure, which may be a response towards water stress. This response could be due to two reasons, namely 1) insufficient soil water availability, or 2) high transpiration rate due to high atmospheric demand that cannot be supported by the root system. Avocado roots naturally have a low hydraulic conductivity (Wolstenholme, 1987), but is still capable to supply water to the tree canopy at rates approaching or equalling transpiration losses as long as soil remained close to field capacity (Sharon *et al.*, 2001). It is, however, important to note that *Phytophthora* root rot infection will lead to impaired root activity and a quicker response to stress (Manicom, 2011), which may not necessarily be the case here.

Considering the correlation between midday photosynthetic rate and midday stem xylem water potential as depicted in Figure 2, the following can be observed:

- Photosynthetic rate followed a hyperbolic trend with a sharp decrease when midday stem xylem water potential decreased below -0.5 MPa.
- This decrease most probably corresponds with the decreased stomatal conductance, resulted in decreased gas exchange and therefore lower CO_2 availability for photosynthesis.

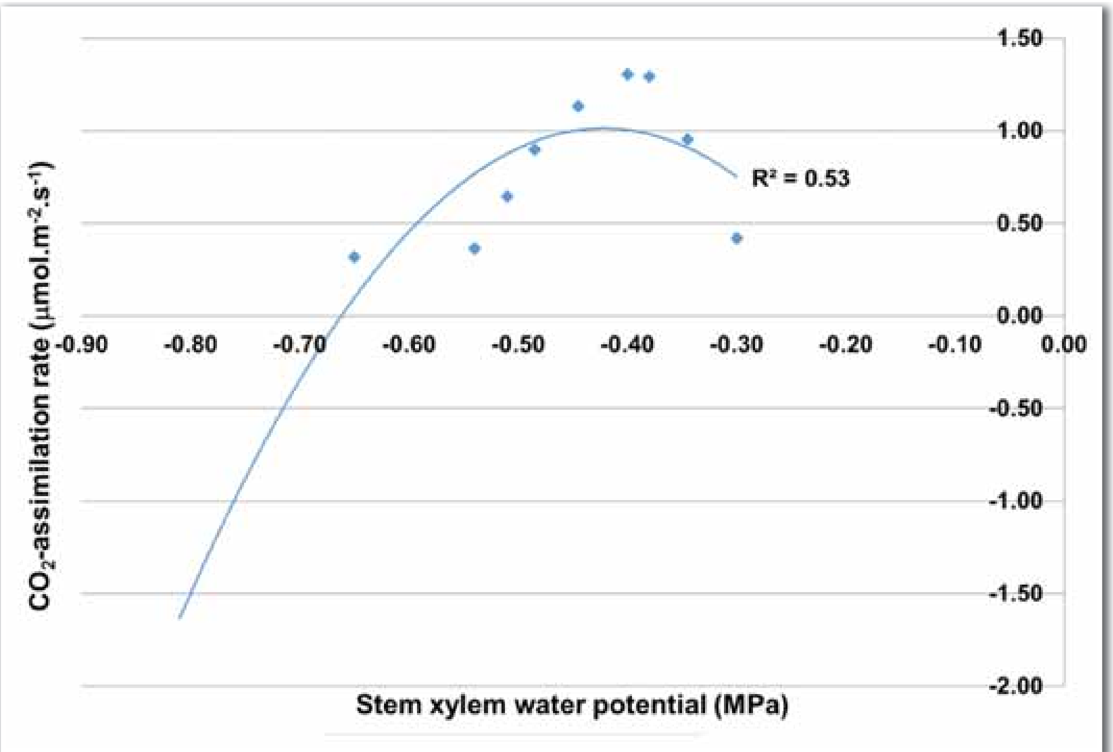

Figure 2. Correlation between photosynthesis and midday stem xylem water potential for 'Hass' avocado trees.

- In addition, as water are one of the substrates in the process of photosynthesis, lower water availability may have a direct effect on the photosynthesis process with decreased water availability resulted in a decreased rate of photosynthesis.

Kruger *et al.* (2015, unpublished data) also found a direct correlation between postharvest fruit ripening and midday stem xylem water potential. Unfavourable fruit ripening started to occur when midday stem xylem water potential values dropped below -0.5 MPa. This may be directly related to plant stress that occurs prior to harvest.

The second aim of this study was to establish if a correlation can be drawn between midday stem xylem water potential and soil water availability. If a significant correlation could be found, then soil-based norms could be calibrated with plant-based measurements. The correlation between midday stem xylem water potential and soil water availability is depicted in Figure 3. The following can be seen from the figure:

- A significant, but relatively weak correlation exists between midday stem xylem water potential and soil water content in the effective root zone of trees.
- The fact that soil water availability only contributes to 35% of the variation in the data, imply the effect of a number of other factors, which includes the atmosphere surrounding the tree (radiation, temperature, humidity and wind speed), the ability of the root system to take up water and nutrients, root health and hydraulic resistance in the xylem (Jones, 1990). It is therefore important during interpretation of plant-based data, that weather data is also included with the soil data, with knowledge on root-health (Goldhamer & Fereres, 2001; Roets *et al.*, 2014).
- However, it can be seen that with less than 50% depletion of easily available water, plants have not reached the threshold midday stem xylem water potential level of -0.5 MPa and it can be safely assumed that plants are not stressed at that level, regardless of weather conditions. However, for this data the flowering phenological stage was not measured and the demand may be higher for flowering as flower transpiration place an additional water need on the plant (Blanke & Lovatt, 1993).
- It can be seen that plants start to experience stress (midday stem xylem water potential values lower than -0.5 MPa) with approximately 60% depletion of easily available water, especially when atmospheric conditions are hot and dry. Under cool, moist atmospheric conditions, plants may not experience stress. But with 65% or more depletion of easily available water, it can be expected that most trees will experience stress under cool and hot atmospheric conditions.
- It is also important to note that this correlation follows a hyperbolic trend. Field capacity of the soil was at 32% while the graph already flattens at 29.5%. It is therefore not necessary to water

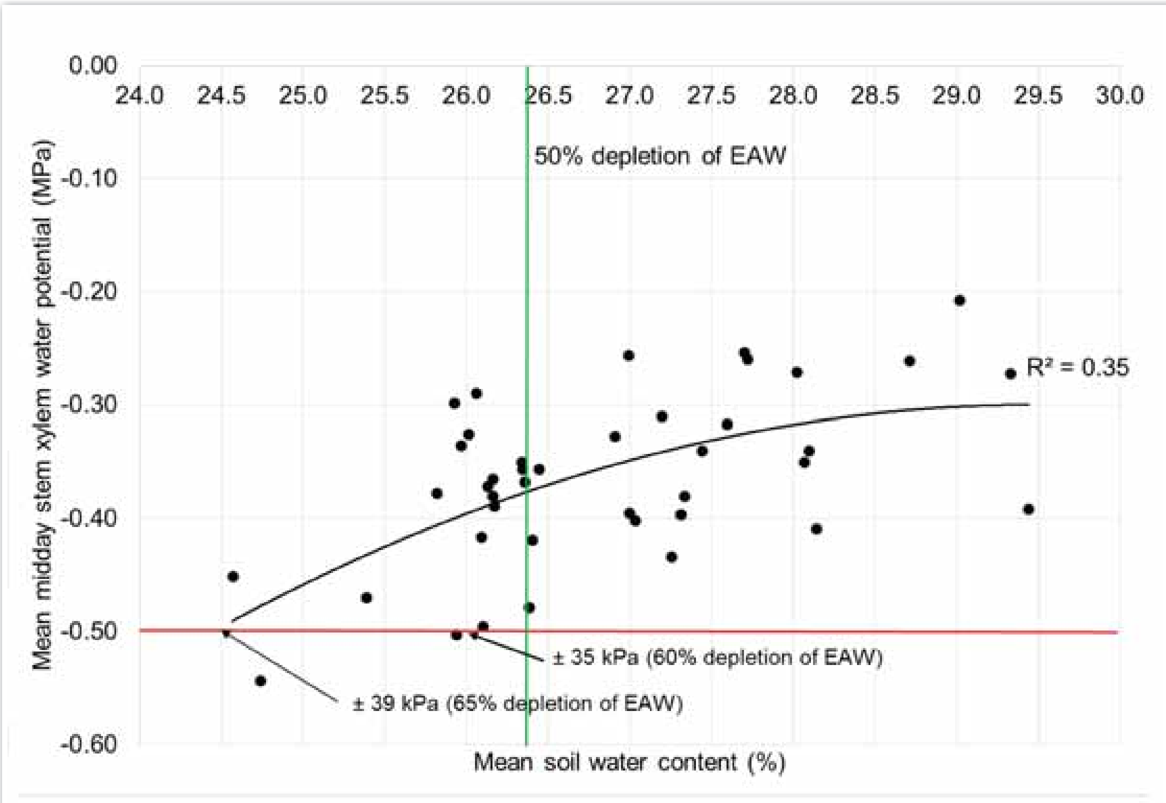

Figure 3. Correlation between midday stem xylem water potential and soil water availability for 'Hass' avocado trees planted on a sandy-clay soil (58% sand, 13% silt and 29% clay).

orchards to field capacity, except under very hot and dry conditions to help the roots of the tree to cope with the high transpiration demand (Sharon *et al.*, 2001). Pulse irrigation can therefore be considered to keep soil water content in a range of approximately 45 to 50% depletion of easily available water.

- Care should be taken not to overirrigate, as this will result in root oxygen starvation and higher susceptibility to *Phytophthora* root rot (Schaffer, 2006; Manicom, 2011).
- In this report, the relationship between tensiometer values and DFM capacitance probes was not made, but it is important when using DFM capacitance probes that they should be calibrated with a tensiometer or instrument that provides exact soil water content, as these probes only give relative and not exact soil water content values.

CONCLUSION

There was only one known study carried out on determination of water requirements of avocado trees in the Crocodile River basin area approximately 20 years ago. There is thus a need to determine the water requirements of avocado with the current cultivars and rootstocks. Such study can be carried out in one area and a model be constructed, which can be applied in other areas as well. Stem xylem water potential gave a reliable indication of the water status of the trees and showed significant correlations with transpiration, photosynthesis and stomatal conductance. It showed that the tree possibly started to stress below -0.5 MPa. Even though variation is large due to the effect of weather conditions on midday stem xylem water potential, a clear trend was obtained showing that trees reach midday stem xylem water potential values of lower than -0.5 MPa at approximately 60% depletion of easily available water.

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