Calibrating avocado irrigation through the use of continuous soil moisture monitoring and plant physiological parameters

NJR Roets[1], RB Cronje[1], SP Schoeman[2], NR Murovhi[1] and IM Ratlapane[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

The aim of this study was to determine soil moisture norms using stem xylem water potential as plant stress indicators to optimise irrigation. Patterns of water withdrawal by the roots of 'Hass' avocado trees were obtained using continuous soil moisture monitoring. The water withdrawal patterns obtained, correlated significantly with evapotranspiration. In addition, trends of higher water use during certain phenological stages were also evident. Correlations between soil water content and stem xylem water potential was low, due to wet soil conditions throughout the season, resulting in soil water content possibly not being a strong determining factor of stem xylem water potential. It is important to do further work under drier soil conditions in order to determine soil moisture norms for irrigation. Application of other technologies, such as stress detection with infrared imaging and WATPLAN (satellite imaging of evapotranspiration of any given area), should also be investigated.

INTRODUCTION

Irrigated agriculture is applied in many areas of the world and in many instances in an unsustainable and non-optimal manner (Fereres & Soriano, 2007). This has consequences of resulting in water wastage and non-optimal crop production. South Africa is a water scarce country and increasing population growth result in an increase in water demand, especially from the urban sector (National Water Resource Strategy, 2004). As approximately 62% of available water in the country is used for irrigated agriculture (National Water Resource Strategy, 2004), there is increasing pressure on the agricultural sector to reduce water use. This necessitates investigation into ways to maximise water use efficiency (precision irrigation) and reduce water use by the agricultural sector in general.

Even though avocados are produced in the higher rainfall areas of South Africa, dry periods and periods of insufficient rainfall frequently occur, especially during winter and spring. Supplementary irrigation is crucial during these periods. Currently, irrigation scheduling guidelines are available for avocado (Kruger, 2011), but these scheduling methods are based on soil moisture indicators. Using soil moisture indicators has the disadvantage that it does not provide a direct indication of the plant water status and needs of the plant (Jones, 1990; Lahav & Whiley, 2002). In addition, many soil moisture sensors are needed due to soil variation and sensors do not generally measure water status of the plant at root surface (Jones, 2004). As soil moisture monitoring only gives an indirect indication of the water status or requirements of the tree, there is therefore still a probability of over or under-irrigation using soil moisture indicators only.

Plant parameters offer the most direct means of obtaining information on the water status of plants, as well as the extent to which the plant experiences water stress. Different plant based methods measuring different plant physiological parameters have been investigated and reviewed with stem xylem water potential being highlighted as a highly reliable indicator of plant stress (Jones, 1990; 2004; Naor, 2000). Stem xylem water potential is in many crops also highly correlated to fruit size and quality, as well as stomatal conductance and photosynthesis (Naor, 2000). However, stem xylem water potential measurements also have some limitations due to variation as influenced by current weather conditions, as well as being time consuming, labour intensive and expensive (Jones, 1990). It is, however, possible to use stem xylem water potential monitoring together with soil moisture monitoring (Jones, 1990) to establish soil moisture norms that can serve as an indicator of plant stress and when irrigation should be initiated. If such norms are determined, irrigation efficiency will definitely be improved in avocado orchards, and can result in significant cost and water savings. The aim of this study over the past two seasons was to determine how continuous soil moisture monitoring and stem xylem water potential can be used to optimise irrigation of avocado orchards.

MATERIALS AND METHODS

During the 2011/12 season a trial with different delivery rates was carried out in a micro-irrigated orchard in the Schagen area. Three different treatments with delivery rates of 20 L/h, 30 L/h (control) and 40 L/h were used. Irrigation cycles were not controlled and were subjected to the irrigation programme of the grower. The trial was carried out on six-year-old 'Hass' avocado trees grafted on 'Bounty' rootstocks, planted on ridges at a spacing of 8 x 3 m. The soil at the trial site was a sandy-clay soil with 74% sand, 3% silt and 23% clay (Soil Classification Working Group, 1991). The experimental design was a randomised block design with ten single tree replicates per treatment. A continuous soil moisture probe (DFM probe) was installed for each treatment to monitor soil moisture. In addition, the amount of irrigation water applied, climatic data (obtained from an automatic weather station), stem xylem water potential, fruit set, retention, flush vigour and yield data was collected. Stem xylem water potential was measured by first enclosing a leaf (still attached to the tree) in a foil bag for approximately one hour, detaching it from the tree and measuring the tension with a pressure bomb (PMS Instruments Co., USA) (Jones, 1990). All data was analysed using analysis of variance.

During the 2012/13 season a trial with different irrigation intervals was carried out on the Nelspruit Experimental Farm of the Agricultural Research Council – Institute for Tropical and Subtropical Crops (ARC-ITSC) in a micro-irrigated orchard. The irrigation intervals were irrigation for six hours twice a week, once a week and once every three weeks. Delivery rates of micro-sprayers were 30 L/h. The trial was carried out on 18-year-old 'Pinkerton' trees grafted on 'Duke 7' rootstocks, planted at a spacing of 5 x 3 m. The soil at the trial site was a sandy soil (90% sand, 1% silt, 9% clay) (Soil Classification Working Group, 1991). The experimental design was a randomised block design with eight single tree replicates per treatment. A continuous soil moisture probe (DFM probe) was installed to monitor soil moisture, but soil moisture measurements were also taken next to each data tree at 10, 30 and 60 cm depths, using a delta-T SM 150 soil moisture kit. Stem xylem water potential (as described above), photosynthesis, stomatal conductance, transpiration (using an infrared red gas analyser – ADC BioScientific Ltd.) and climatic data (from an automatic weather station) were collected. All results were analysed using analysis of variance. Pearson correlation coefficients were calculated to describe correlations between different measured parameters.

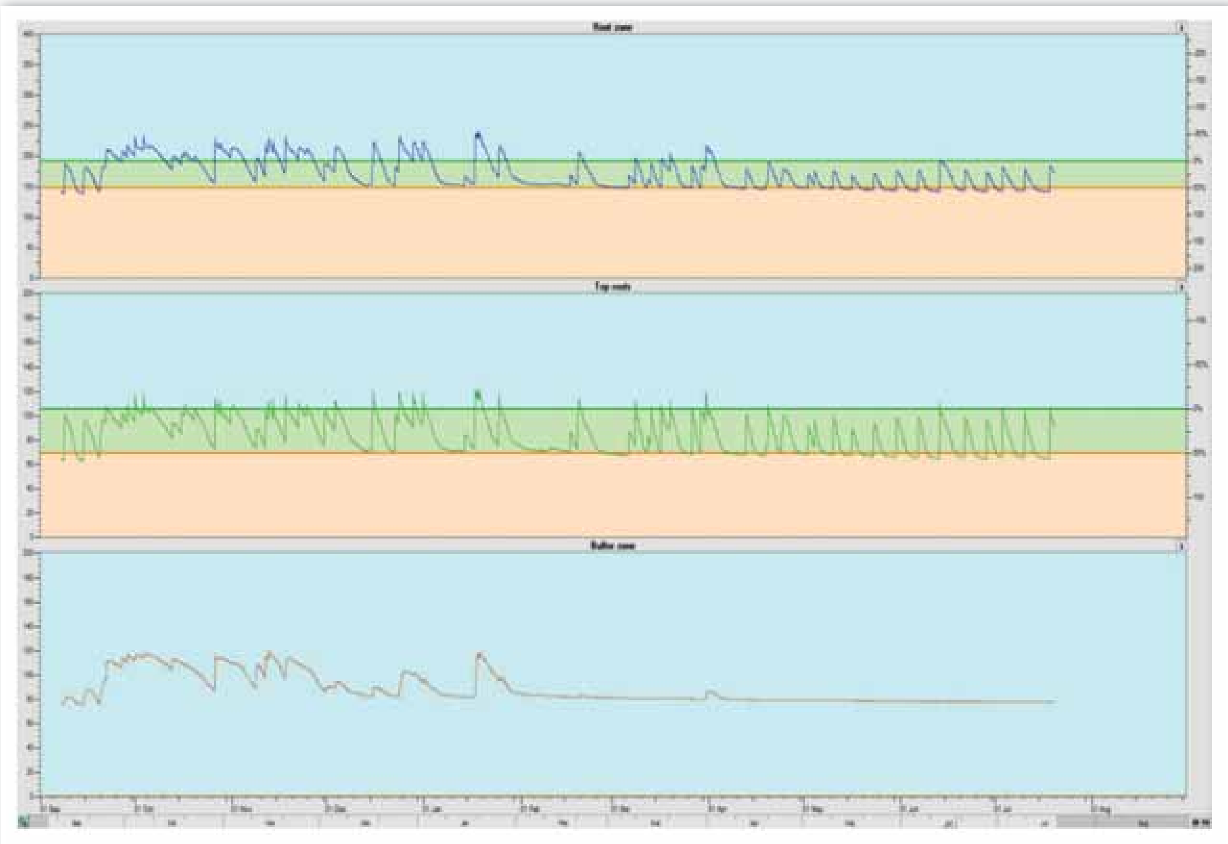

Figure 1. Soil water content patterns obtained with use of DFM continuous soil moisture probes for the Schagen site during the 2011/12 season.

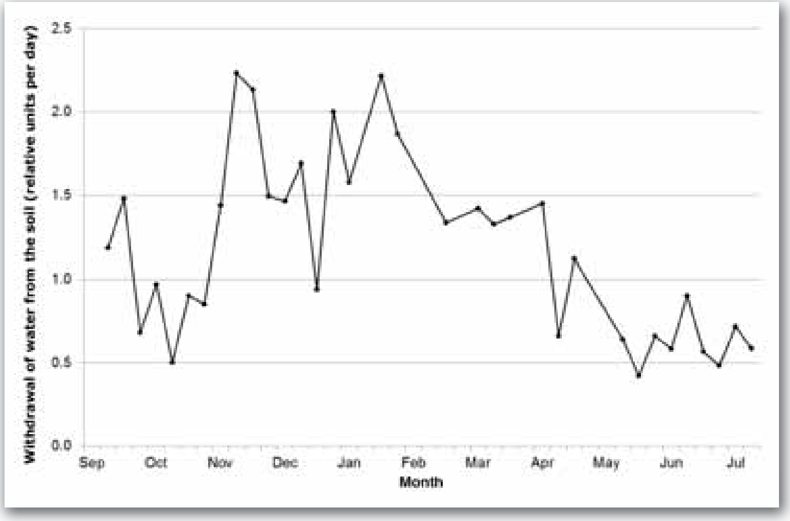

Figure 2. Monthly soil water withdrawal patterns of avocado trees at the Schagen site for the 2011/12 season.

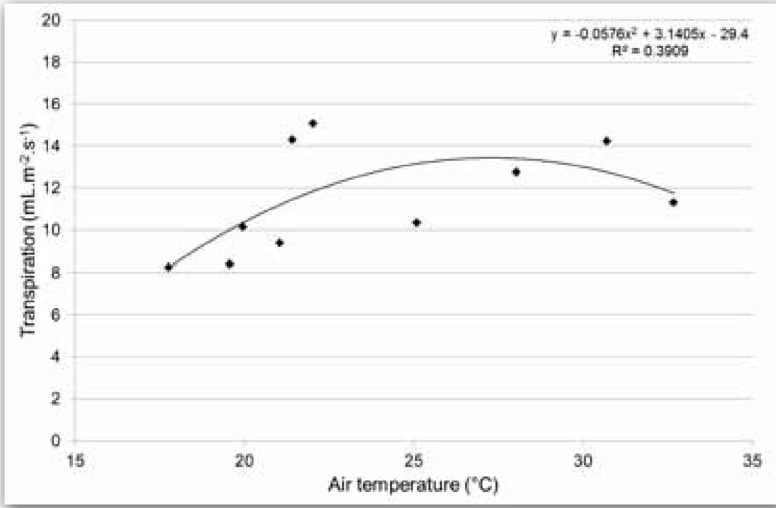

Figure 3. Correlation between transpiration of avocado trees and air temperature at Nelspruit during the 2012/13 season.

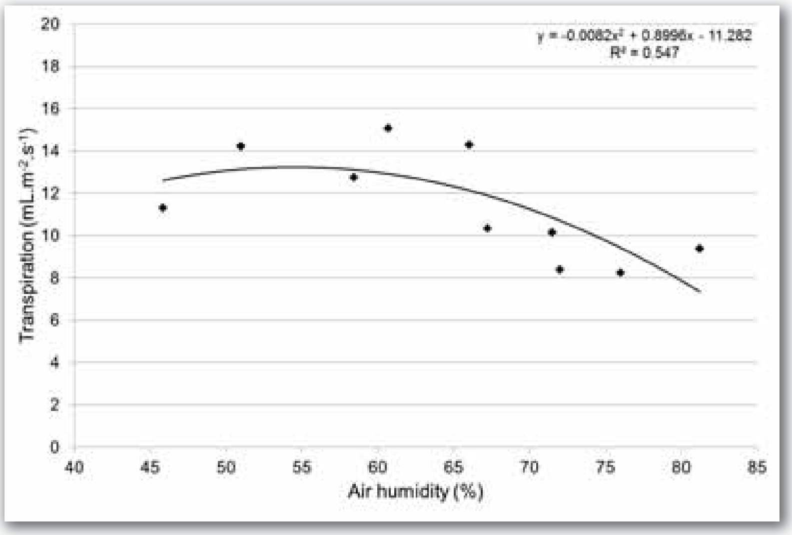

Figure 4. Correlation between transpiration of avocado trees and relative air humidity at Nelspruit during the 2012/13 season.

RESULTS AND DISCUSSION

Data collected until rapid fruit growth for the previous season has been reported by Roets *et al.* (2012). As with the reported results, the remaining results did not yield any significant differences between treatments for all parameters measured. From the 2011/12 data, it can be concluded that the different application rates did not differ substantially enough to result in any significant treatment differences. It was then decided to test different irrigation intervals during the 2012/13 season, as this would provide a higher likelihood to obtain tree stress levels that are needed to determine soil moisture norms. However, regular, and in most cases above average rainfall, resulted in no treatment differences being obtained during the 2012/13 season in all parameters measured.

However, considering soil moisture data obtained from the Schagen area, some important observations can be deduced. The DFM probe measures soil moisture at hourly intervals at six different depths (10, 20, 30, 40, 60 and 80 cm). The DFM software can then be programmed to calculate changes in the relative water content in the root zone, once the depth of the root zone is known. Withdrawal and re-filling of water in the root zone and percolation of water past the root zone (buffer zone) can then be observed from the graph (Fig. 1). Patterns of water use can therefore be deduced from these graphs that can aid in irrigation management. However, units on the graph are relative and are therefore not an indication of the amount of water being used.

Using this graphic representation, the rate of water withdrawal by the roots (root zone) can be obtained from calculating the slopes of each period between successive irrigation or watering events. The water withdrawal over time can therefore be calculated, giving an indication on how the tree uses water (Fig. 2). From the data obtained from Schagen, it can be seen that there is large variation in water withdrawal from the root zone (Fig. 2). However, a general pattern of higher water use in summer than in winter can be seen, which is expected (Fig. 2). The observed variation in water use can be ascribed to a number of different factors, which may be inter-related (Jones, 1990). These factors include soil moisture, root depth, health and distribution, hydraulic resistance and capacitance in the xylem, number of stomata and leaf area, atmospheric conditions (radiation, humidity, temperature and wind speed) and photosynthetic demand.

A preliminary experiment was carried out during this study, where the effect of temperature and humidity on transpiration was tested. During this experiment, the soil was wet to field capacity, thus soil moisture was not a limiting factor. Transpiration increased with increasing air temperature to a maximum of approximately 28°C, followed by a decrease at higher temperatures, probably due to stomatal closure (Fig. 3). Transpiration also decreased with increasing air humidity (Fig. 4), because of lower atmospheric demand for transpiration. However, this was a preliminary study and more detailed work will be carried out during the next season. In addition, when evapotranspiration is considered as a measure of atmospheric demand, a highly significant ($P < 0.001$) correlation was obtained between water withdrawal in the root zone and evapotranspiration (Fig. 5). In conclusion, it is highly possible to model the water use of avocado orchards using climatic data. Future research will focus also on this aspect in order to create a tool for growers to predict water use and to budget more accurately for cost of water.

Another critical aspect that should be taken into consideration, is the specific water need of the plant during different phenological stages. When water withdrawal is correlated with phenological stages, a trend can be seen, although to a large extend it is masked by the effect of evapotranspiration (Fig. 6). The first water withdrawal peak coincided with full flowering (Fig. 6). It has been shown that avocado flowers transpire (Blanke & Lovatt, 1993). In this instance it was found that avocado flowers contain approximately 78 to 96 stomata per flower with transpiration rates of 21.6 to 23.4 $mL.m^{-2}.s^{-1}$, which is higher than the transpiration rate of leaves of 12.6 to 19.8 $mL.m^{-2}.s^{-1}$ (Blanke & Lovatt, 1993). It is well known that a medium size avocado tree may bear thousands of flowers, which place a high demand for water on the tree. In addition, the period of flowering (early spring) may be characterised with fairly high maximum temperatures and low relative humidity, increasing transpiration even more. It is therefore crucial to ensure correct water management in order to obtain good fruit set. A sharp increase in water withdrawal was observed during rapid fruit growth. Again, although correlated to evapotranspiration, fruit growth requires water for cellular expansion. Although this may be true for avocado as well, it was shown that different water application amounts had little effect on fruit size (Adato & Levinson, 1988; Kurtz *et al*., 1992; Winer, 2003). Even though fruit

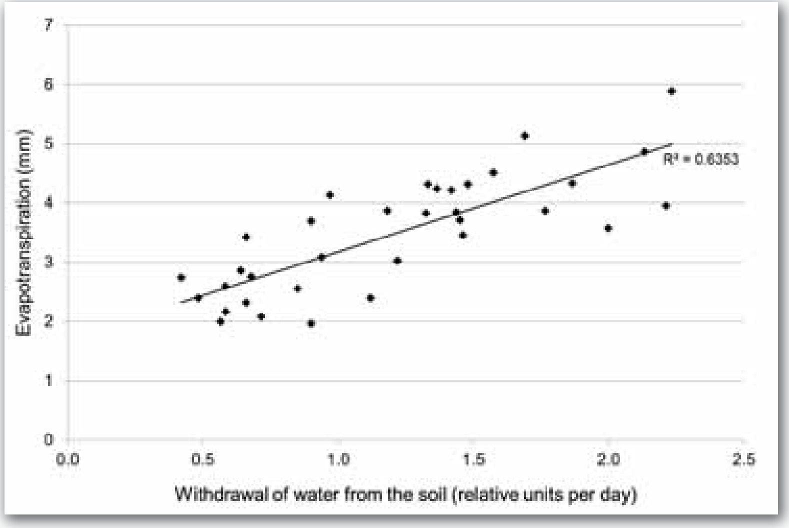

Figure 5. Correlation between soil water withdrawal by the roots of avocado trees and evapotranspiration at Nelspruit during the 2012/13 season.

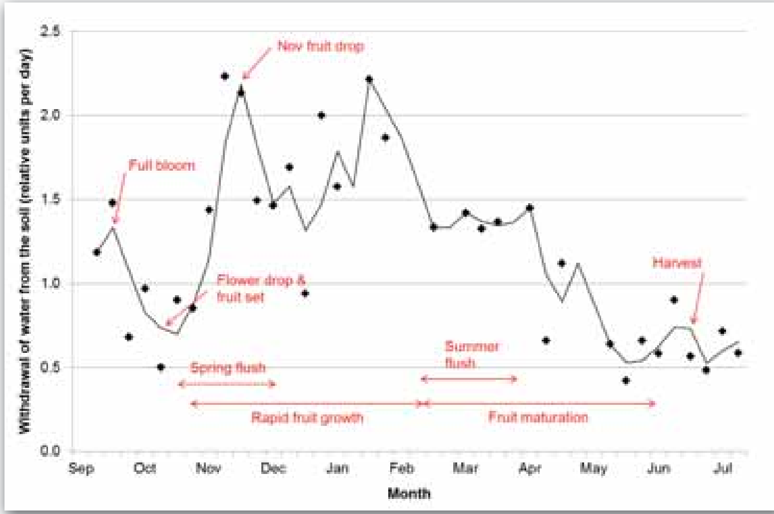

Figure 6. Monthly soil water withdrawal in relationship with phenology of avocado trees at Schagen during the 2011/12 season.

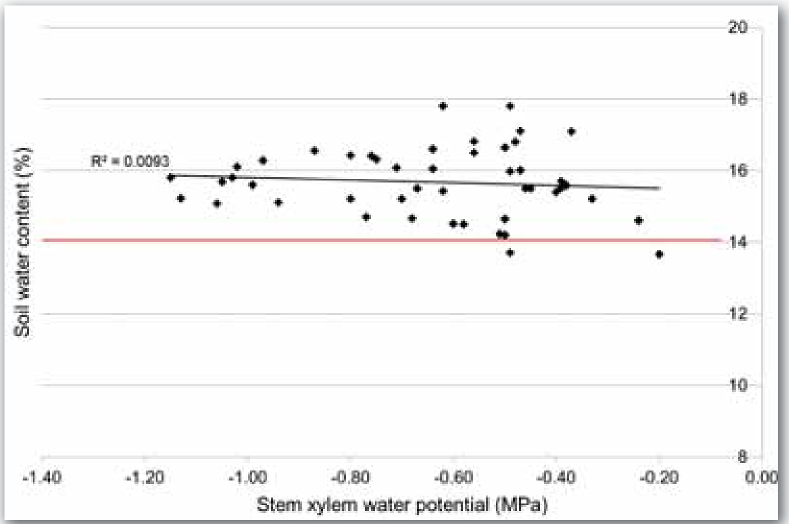

Figure 7. Relationship between soil water content and stem xylem water potential at flowering and fruit set for the avocado cultivar 'Pinkerton' at Nelspruit during the 2012/13 season (the red line indicates field capacity of the soil).

size may not be affected significantly, insufficient water during any stage of fruit development will result in poor post-harvest quality and ripening (Schaffer & Whiley, 2002; Kruger & Magwaza, 2012). It is therefore crucial to determine water needs of avocado for each specific phenological stage.

During the 2012/13 season an attempt was made to determine correlations between soil water content and stem xylem water potential during flowering and fruit set (Fig. 7) and rapid fruit growth (Fig. 8). For the specific soil on which the orchard was planted, field capacity was at 14.1%. For both phenological stages it can be seen that soil water content was in most cases higher than field capacity (Figs. 7 and 8), due to continuous and in most cases above average rainfall. Irrigation was only applied in the first week of October and November 2012 (150 L/tree). During flowering and fruit set, no correlation was obtained between soil water content and stem xylem water potential (Fig. 7). This could possibly be ascribed to two factors, namely variation in weather conditions during measurements, and a lack of functional feeder roots observed during flowering time. For avocado, water and nutrients are absorbed from the soil by feeder roots and if these feeder roots are not sufficient or healthy enough, it will result in an inability to absorb available water and nutrients with subsequent stress in the above ground organs. This could have contributed to the very low water potential values obtained during this time. Soil moisture also varied considerably in the orchard (data not shown) throughout the season, which could also have contributed to the large variation in stem water potential values.

During rapid fruit growth, a significant although weak correlation between soil water content and stem xylem water potential was obtained (Fig. 8). However, because the soil was wet above field capacity, soil water was not a limiting factor and root health and weather conditions could have been stronger factors influencing stem xylem water potential. Considerable feeder root development occurred after the spring flush. Due to more functional roots compared to flowering time, the water in the soil could have been utilised more effectively by the trees, therefore showing clearer tree reactions towards stress/non-stress situations, resulting in a better correlation between soil water content and stem xylem water potential at time of measurement. It might be possible to obtain a stronger correlation under drier soil conditions or a cut-off point indicating onset of plant stress. Determination of such a cut-off point will enable more accurate irrigation scheduling and irrigation management.

CONCLUSION

Results of the past two years were not conclusive enough to establish norms for optimum irrigation of avocados yet. Therefore, research needs to be continued in order to establish such norms. Norms should be coupled to phenological stage and climatic factors, such as temperature, relative humidity and irradiation. By using climatic factors, water use of avocado trees can be modelled to enable growers to predict or determine water use of their trees. In addition, soil moisture norms should be determined in relation to plant stress. This should be done for different soil types. Likewise, water retention curves for various soils to determine field capacity will assist in improving reliability of the norms. Such norms can also be integrated with the software programmes of continuous soil moisture probes. This can enable growers to determine the exact point when irrigation

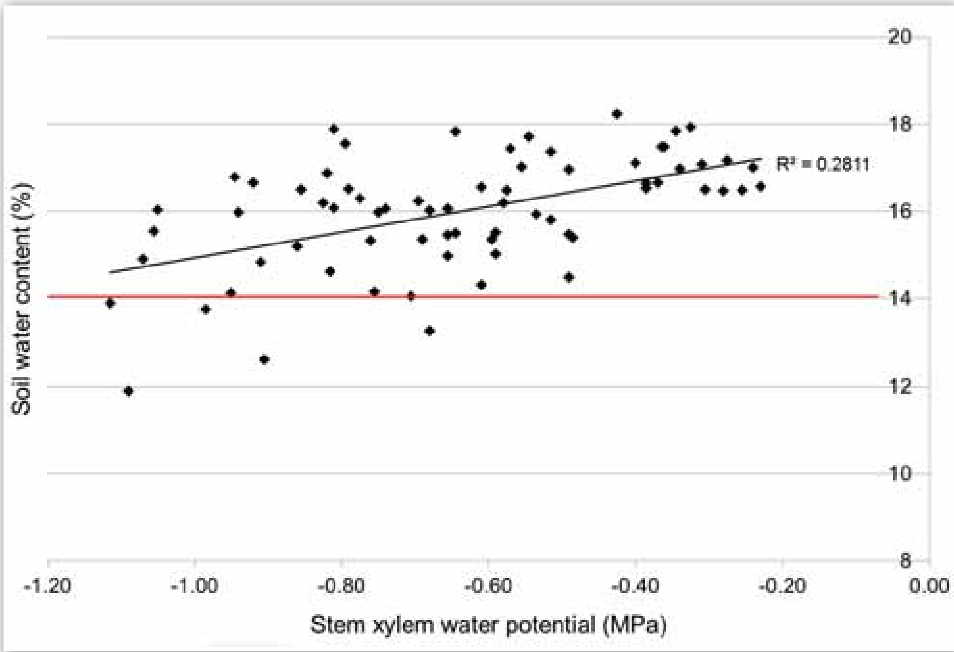

Figure 8. Relationship between soil water content and stem xylem water potential during rapid fruit growth for the avocado cultivar 'Pinkerton' at Nelspruit during the 2012/13 season (the red line indicates field capacity of the soil).

should start and finish. Other plant stress indicating tools, such as infrared imaging as well as the application of WATPLAN, should also be investigated.

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