Water use of avocado orchards – Year 2

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ABSTRACT
The success of agricultural production is highly dependent on the availability of water resources. With agricultural water use being the greatest consumer, it is imperative to determine the exact water requirements of any given crop. In avocado production, water needs of orchards are met through supplementary irrigation, hence knowledge of water use is vital for continued growth and expansion of the industry. The main objective of the study was to determine the water use of unstressed avocado trees under South African growing conditions. Measurements were in two orchards (intermediate and mature) at Everdon Estate, Howick, KwaZulu-Natal Midlands for 5- and 12-year old 'Hass' on 'Dusa' avocado trees. The intermediate orchard was first instrumented in April 2017 and the mature orchard in September 2017. Measurements continued to February 2019. Evapotranspiration (total water use) in both orchards was monitored using eddy covariance (EC). Grass reference evapotranspiration varied with season, ranging from 2 mm day^{-1} in winter to 7 mm day^{-1} in summer. Daily water use ranged from 1.5 to 8 mm day^{-1} with similar results recorded for both orchards. Predawn leaf water potential were greater than -0.3 MPa, hence, both orchards were not under water stress. Monthly crop coefficients (Kc) values ranged from 0.5 to 0.9 for both orchards.

INTRODUCTION
Generally, agriculture uses most of the available water globally and is the most inefficient consumer (Hsiao *et al.,* 2007). In South Africa, the agricultural sector uses almost 60% of the available water resources, with 90% of fruit orchards under irrigation (Taylor and Gush, 2009; Le Roux *et al.,* 2015). Urbanisation and industrialisation in the face of recurring droughts have increased competition for available water resources. The recent droughts experienced in South Africa has seen water restrictions in some areas. Erratic and spatially variable rainfall has exercabated the need for farmers to depend on irrigation, resulting in increased competition within the agricultural sector. This requires the adoption of efficient water use strategies.

The South African avocado industry is export-oriented, mainly targeting the European market. Avocado production is likely to increase, given the rising global demand for avocados. Currently, the national annual increase in area under production is approximately 1000 ha per year. This expansion needs to take place within a grower's existing water allocation, making proper water management vital. Tree growth, yield and fruit quality are dependent on a good supply of water at the right time. Under- and over-irrigation negatively affect avocado production, which in turn affects the economic returns of avocado growers. In general, the fruit industry has highlighted the need to accurately estimate water requirements and optimise water use efficiency and water productivity.

Estimating actual evapotranspiration (ET) can be an important aspect to ensure the proper use of water resources. Since few attempts to determine the water requirements of avocado orchards have been made (Carr, 2013), the main objective of the study is to determine the water use of unstressed avocado orchards.

MATERIALS AND METHODS
The study was conducted in two commercial orchards at Everdon Estate, KwaZulu-Natal Midlands, South Africa (29°26′37″S, 30°16′22″E, 1080 m a.s.l.). Details of the orchards are presented in Table 1. The orchards are approximately 1 km apart and were identified based on their canopy size and hedgerow formation. In this study, an intermediate orchard is defined as distinct trees with a hedgerow not fully formed. A mature orchard is defined as an orchard with full bearing trees with a canopy cover of 40-50%, with a fully formed hedgerow with trees that cannot be distinguished from one another (Fig. 1).

The orchards were irrigated following the farm protocols using capacitance probes (Aquacheck Cape Town, South Africa).

Weather variables
Daily weather data were obtained from an automatic weather station (AWS) system available on site,

Table 1. Details of the intermediate and mature full bearing orchards under study.

Orchard details	Intermediate	Mature
Cultivar	'Hass'	
Rootstock	'Dusa'	
Year planted	2013	2006
Tree spacing	4 m x 7 m	
Irrigation	Microsprinkler (50 L h^{-1})	
Average tree height	3.8 m	7.4 m
LAI	2.95 m^2 m^{-2}	4.75 m^2 m^{-2}
Soil type	Hutton	

Figure 1. Five-year old intermediate bearing 'Hass' orchard (A) and 12-year old, mature full bearing orchard (B) at Everdon Estate.

which is maintained by the Agricultural Research Council (ARC) and situated over a Kikuyu pasture. The recorded variables include rainfall, wind speed, air temperature, relative humidity and solar irradiance. Rainfall was measured at a height of 1.2 m while the other variables were measured at a height of 2 m. Reference evapotranspiration (ET_o) was calculated for short grass using the FAO-56 Penman-Monteith equation (Allen *et al*., 1998). Crop coefficients (Kc) were calculated as:

$$Kc = \frac{ET}{ET_o}$$

Evapotranspiration (ET) is the combined loss of water by evaporation from the soil and transpiration from plants.

Water use measurements

In this study, orchard water use is defined as evapotranspiration (ET) derived from latent flux measurements using the EC system. The intermediate and mature full bearing orchards were instrumented in April and September 2017, respectively.

In the intermediate orchard, the EC system consisted of an open path infrared gas analyser Li-7500 (LI-COR Inc., Lincoln, Nebraska, USA) to measure CO_2/H_2O concentration and latent flux, and a three-dimensional sonic anemometer (CSAT3, Campbell Sci. Inc., Logan, Utah, USA) measuring the wind components. Additional sensors connected to the same system included a four-component net radiometer (CNR1, Kipp & Zonen, The Netherlands) and four soil heat flux plates (HFP01, Hukseflux, Delft, The Netherlands) in parallel with soil thermocouples (Campbell TCAV-L). Volumetric water content was measured at three depths (80, 300 and 600 mm) using CS616 water reflectometers. Sensors were connected to a 6-m lattice mast. In the mature orchard, all sensors were the same except that a Campbell EC150 CO_2/H_2O open path gas analyser was used. The sensors were connected to a 12-m lattice mast. EC measurements for both orchards were sampled at 10 Hz and sensors were connected to a Campbell CR3000 data logger. High frequency data were post processed using EddyPro software version 6.2.2 for corrected fluxes. Daily water use (ET) was calculated from daily latent heat flux (LE) by the latent heat of vaporisation of water (2.45 MJ kg^{-1}).

Predawn leaf water potential was measured on selected days to confirm the absence of water stress.

RESULTS AND DISCUSSION

Daily weather variables recorded from April 2017 to February 2019 are shown in Figure 2. There was a clear seasonal pattern for

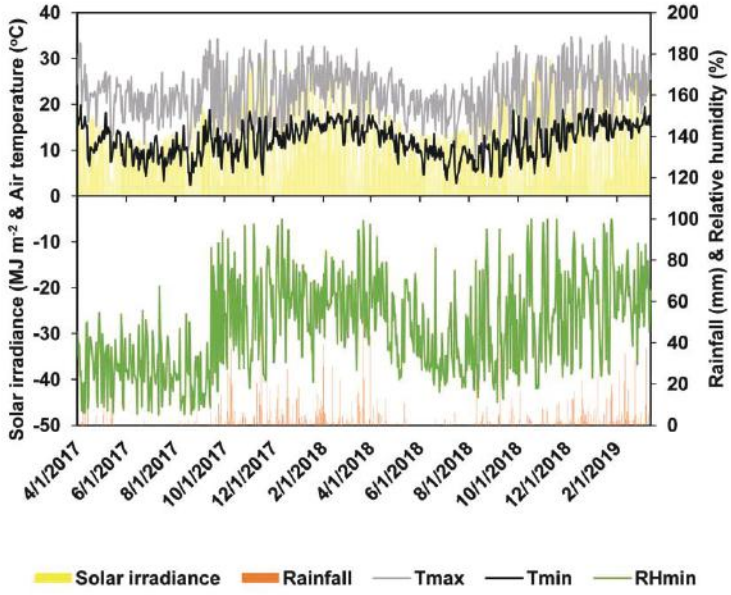

Figure 2. Daily weather variables recorded at Everdon Estate from April 2017 to February 2019.

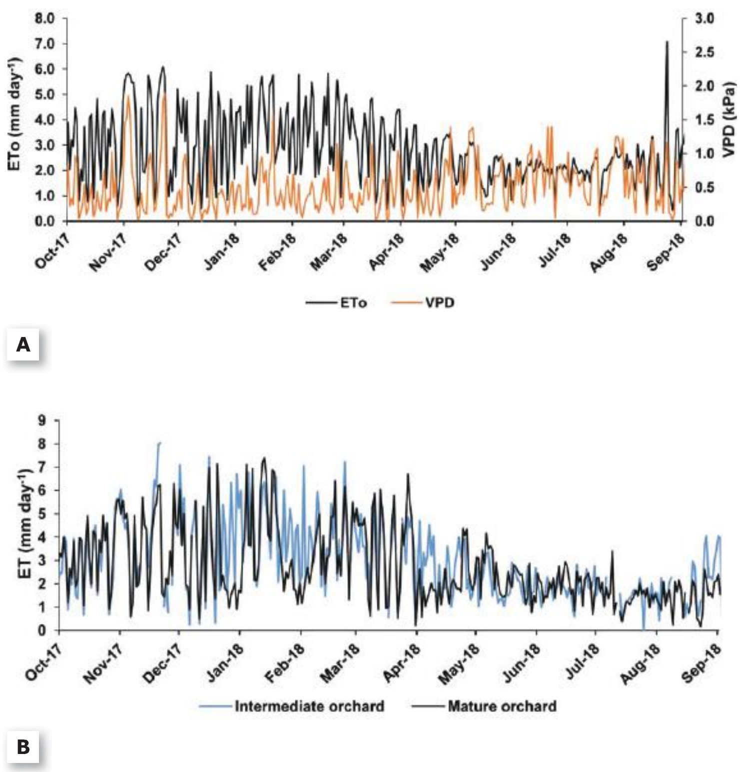

Figure 3. A) Daily grass reference evapotranspiration (ET_o) and water vapour pressure deficit (VPD) calculated from the AWS system. B) Daily evapotranspiration (ET) of the intermediate and mature orchard at Everdon Estate from October 2017 to September 2018.

solar irradiance, minimum air temperature (Tmin) and maximum air temperature (Tmax), indicating the availability of energy to drive ET. Total rainfall for 2017 and 2018 was 1222 and 967 mm respectively, with most rainfall being received in summer. The maximum air temperature for this period was 35.4°C, with a minimum of 2.4°C.

Cumulative ET_o was 722 and 1079 mm for 2017 and 2018, respectively. Daily ET_o varied between 0.2 mm day^{-1} and 7 mm day^{-1}. The evaporative demand (ET_o) followed a seasonal trend, with high values in summer of 3.65 mm day^{-1} and lower values in winter of 2.1 mm day^{-1} in winter (Fig. 3A). ET_o increased with an increase in water vapour pressure deficit (VPD), however, the response of ET was not further investigated to determine the stomatal response to VPD. Daily water use ranged from 0.2 to 8 mm day^{-1} (Fig. 3B). ET for both orchards followed a similar pattern to ET_o. ET values for both orchards were similar regardless of the different canopy sizes, which is likely to be due to the contribution of soil evaporation. The greater area exposed to solar radiation between trees in the intermediate orchard most likely resulted in higher evaporation rates in this orchard. Hence the importance of partitioning ET between transpiration and evaporation when quantifying orchard water use.

The monthly crop coefficients (Kc), determined from ET and ET_o, varied between 0.46 and 0.90 for the mature orchard and between 0.58 and 0.88 for the intermediate orchard from October 2017 to September 2018. Kc values varied from one year to the next, supporting the need to account for plant and soil contributions using the dual crop coefficient method. Kc values were slightly higher than those recommended for irrigation in California (Kc = 0.7) (Carr, 2013).

CONCLUSIONS

Evapotranspiration from both orchards was similar for the different canopy sizes and highly indicative of the prevailing weather conditions.

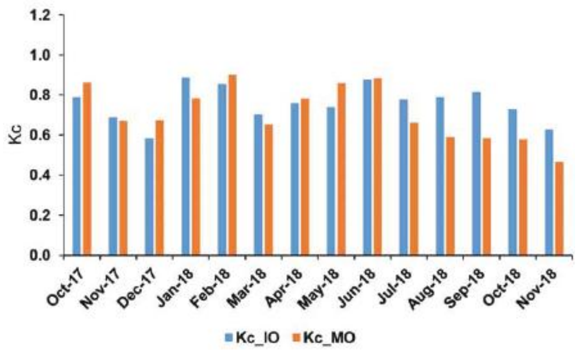

Figure 4. Monthly crop coefficients for the intermediate (IO) and mature orchards (MO).

Transpiration measurements will provide the exact tree water use and allow the calculation of the contribution of soil evaporation to the total orchard water balance. These field-scale ET data and crop coefficients will be critical for irrigation management of avocado orchards and are the first water use results in South Africa using the eddy covariance method in an avocado orchard. Locally derived Kc values will ensure determination of precise estimates of water use for the sustainability of the industry. More measurements are currently underway to partition ET into evaporation (using mini-lysimeters) and transpiration (using sap flow method).

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