WATER USE OF AVOCADO ORCHARDS – YEAR 4

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ABSTRACT

The availability of irrigation water is key to the sustainability and growth of the avocado industry in South Africa. In the context of recent droughts and expansion of the industry, sustainability depends on growers being as water use efficient as possible. In order to achieve this, accurate estimates of water use of avocado orchards are required. This study therefore aimed to estimate the water use of four different avocado orchards located in two provinces in South Africa (KZN and Limpopo). Measurements were undertaken during the 2017/18, 2018/19 and 2019/20 seasons. Evapotranspiration (total water use or ET) was monitored using the Eddy covariance technique, whilst transpiration was monitored using the heat ratio method of the heat pulse velocity technique. Whilst both ET and transpiration (T) were dependent on local weather conditions, the rate of increase of T with increasing vapour pressure deficit (VPD) or reference evapotranspiration (ET_o) was not constant and tended to decrease as VPD and ET_o passed certain thresholds, suggesting some form of physiological control over T. This was confirmed when calculating transpiration crop coefficients (K_t), which tended to be higher in winter than in summer. The influence of canopy size on transpiration and K_t values was clear, with both increasing as canopy size increased. The opposite was true for evaporation, which tended to decrease as canopy size increased, largely as a result of shading of the orchard floor by larger trees. In young orchards, evaporation forms a very large proportion of ET and as a result the potential for water savings in these orchards by reducing the evaporation component is quite high. By combining ET measurements with yield, it was possible to determine water use efficiency and water use productivity for two orchards in Howick over two seasons. Water use efficiency for orchards varied between 1.18 and 1.62 kg m^{-3}, whilst water use productivity varied between R24.39 m^{-3} to R53.06 m^{-3}. On average it took 150 to 200 L of water to produce a 250 g avocado fruit in two orchards in Howick.

INTRODUCTION

The sustainability and growth of the avocado industry is highly dependent on the availability of adequate water for irrigation. However, it is highly unlikely that the water allocation to agriculture will increase and as a result growers need to become more efficient in how they use water. The demand for more efficient water use is also occurring at a time when climate change is predicted to increase the incidence and severity of droughts. The onus is on irrigated agriculture to manage water as efficiently as possible, to conserve water, soil and energy, whilst maximising productivity. In order to do this a thorough understanding of water use of avocado orchards is required. This will allow growers to make informed decisions regarding irrigation system design and irrigation scheduling, in addition to assisting in the Validation and Verification of Lawful Water Use.

In South Africa, very few attempts have been made to determine the water requirements and crop coefficients for avocado. In Burgershall, for 'Fuerte' grafted on 'Duke 7' rootstocks, water use (evapotranspiration – ET) varied from 50 m^3 ha^{-1} day^{-1} (5 mm day^{-1}) during summer, decreasing to 15 to 20 m^3 ha^{-1} day^{-1} (1.5 to 2.0 mm day^{-1}) in winter (Hoffman and Du Plessis, 1999). For 'Hass' grafted on 'Duke 7', average water use was 40 m^3 ha^{-1} day^{-1} (4.0 mm day^{-1}) during summer, decreasing to 15 m^3 ha^{-1} day^{-1} (1.5 mm day^{-1}) in winter. Annual water use for 'Fuerte' was calculated as 10 200 m^3 ha^{-1} annum^{-1} (1 020 mm annum^{-1}), while it was 8 900 m^3 ha^{-1} annum^{-1} (890 mm annum^{-1}) for 'Hass'. These numbers need to be put into perspective, as a simple water balance was used to determine ET. Evapotranspiration was calculated by adding together the amount of irrigation applied to soil from 50% depletion of easily available water to field capacity and effective rainfall on the "wetted area" (precipitation more than 5 mm and 70% was considered effective) (Hoffman and Du Plessis, 1999). This was therefore a representation of applied water and not actual water evapotranspired from the orchard. Studies have also been done in Israel and California, and the water requirements have been determined to be between 8 000 and 9 000 m^3 ha^{-1} $annum^{-1}$ (Adato and Levinson, 1988; Gustafson, 1976). Cantuarias (1995) showed that under conditions of high evaporative demand (reference evapotranspiration or ET_o = 7 to 15 mm day^{-1}) in the Negev, Israel, actual transpiration (T) of the trees only reached 3 mm day^{-1} and the ratio of T/ET_o (K_t or transpiration crop coefficient) remained low, between 0.13 and 0.21.

The main aim of this project was therefore to determine the unstressed water use of different sized avocado orchards and how this water use is partitioned between transpiration and evaporation. The manner in which the prevailing weather and size of the canopy impacts water use could then be determined, which in turn could provide valuable information on the most appropriate modelling approach to follow. In addition, by taking into account yield, the water use efficiency and water use productivity of the orchards could be determined, which allows benchmarking to facilitate overall improved water use efficiency in the avocado industry.

MATERIALS AND METHODS

Site description

The study was conducted in four commercial orchards. Three of these are situated at Everdon Estate, KwaZulu-Natal Midlands (29° 26′ 37″ S, 30°16′22″ E, 1 080 m.a.s.l.) and the fourth is at McNoon Estate, Westfalia, Tzaneen (23°43′49.51″ S, 30° 8′12.35″ E, 835 m.a.s.l.). Details of the orchards are presented in Table 1. The orchards in Howick were chosen to represent different canopy sizes. An immature or non-bearing orchard was defined as an orchard that had yet to bear a commercial crop with a canopy cover of less than 15%. An intermediate orchard was defined as an orchard with distinct individual trees that had yet to form a hedgerow and a canopy cover of 40 and 50%. A mature orchard was defined as an orchard with full bearing trees that had formed a complete hedgerow, with a canopy cover exceeding 60% (Fig. 1). The orchards were irrigated following the farm protocols using capacitance probes (Aquacheck Cape Town, South Africa). Daily weather data were obtained from automatic weather stations (AWS) situated on the respective farms. The one at Everdon is operated by the ARC-SCW, whilst the one in Tzaneen is located close to the Westfalia Technological Services offices and was operated by the project team. Reference evapotranspiration (ET_o) was calculated for short grass using the FAO-56 Penman-Monteith equation (Allen *et al*., 1998).

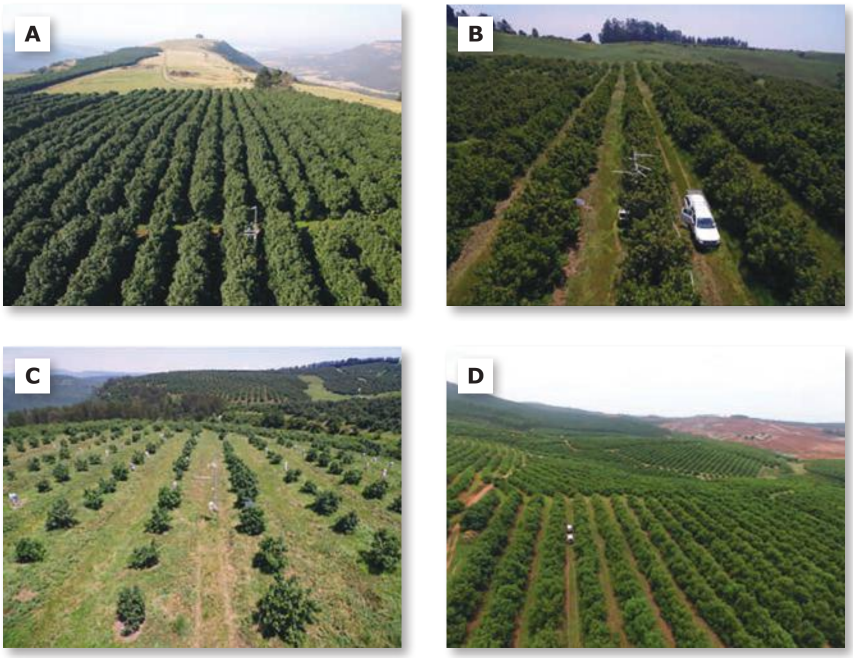

Figure 1: (A) 6-year old intermediate bearing 'Hass' orchard; (B) 12-year old, mature full bearing orchard; (C) 3-year old non-bearing 'Harvest' orchard in Howick, KwaZulu-Natal Midlands; and (D) 7-year old mature orchard at McNoon, Tzaneen.

Table 1: Details of the intermediate and mature full bearing orchards in Howick and Tzaneen where water use measurements were conducted

Orchard details	Non-bearing	Intermediate	Mature	Mature
Cultivar	**'Harvest'**	**'Hass'**		
Rootstock	'Dusa'			'Dusa' and R0.06
Year planted	2017	2013	2006	2012
Tree spacing	4 m x 7 m			8 m x 4 m
Irrigation	Microsprinklers (50 L h^{-1})			Microsprinklers (30 L h^{-1})
Average tree height	1.7 m	3.8 m	7.4 m	4.0 m
Canopy cover	0.17	0.43	0.92 to 0.55 following heavy pruning	0.60
Soil type	Hutton			Not determined

Water use measurements

Orchard water use or ET was derived from latent flux measurements using an Eddy covariance system, and were conducted in three orchards in Howick. The intermediate and mature full bearing orchards in Howick were instrumented in April and September 2017, respectively, with monitoring in the non-bearing orchard beginning in November 2019. Details of the measurements have been provided in Mazhawu *et al*. (2019). Transpiration was measured in three orchards using the heat ratio method (Burgess *et al*., 2001), while transpiration in the non-bearing orchard was determined using the thermal dissipation method (Granier, 1987). Predawn leaf water potential was measured on selected days to confirm the absence of water stress in the orchards in Howick, whilst midday stem water potential measurements were performed in Tzaneen. Measurements of leaf area index (LAI) were conducted in the orchards in Howick, whilst measurements of canopy cover using aerial photography were conducted in Tzaneen. Crop coefficients (K_c) were calculated as

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

where ET is evapotranspiration, which is the combined loss of water by evaporation from the soil and transpiration from plants. Transpiration crop coefficients (K_t) were determined as

$$K_t = \frac{T}{ET_o}$$

Water use efficiency (WUE) was determined by dividing yield per ha for the mature and intermediate orchards in Howick by ET determined for a season (September to September). Water use productivity was also determined by determining the value of the output and dividing by the seasonal ET. The value of the product was determined by considering the proportion of grade 1, 2 and 3 fruit harvested per ha and multiplying by the average price per kg for each grade.

RESULTS AND DISCUSSION

Weather variables

Average monthly weather variables recorded from April 2017 to October 2020 for Howick are presented in Figure 2, whilst the same data is presented for Tzaneen in Figure 3. In Howick, average temperature was fairly similar over the three production seasons (taken as September to September) with the mean temperature being 17.1 °C, 17.7 °C and 17.6 °C during the 2017/18, 2018/19 and 2019/20 seasons respectively. During all three seasons of measurement, the highest average temperatures were recorded from December to March and were approximately 4 - 5 °C higher than the respective mean annual temperature. However, in each season some of the highest maximum temperatures were recorded from September to December. Daily maximum temperatures exceeded 35 °C on 5 days over the three seasons. Mean daily solar radiation was slightly higher in the 2018/19 season (15.99 MJ m^{-2} day^{-1}) and 2019/20 seasons (15.90 MJ m^{-2} day^{-1}), as compared to the 2017/18 (15.07 MJ m^{-2} day^{-1}) season. Highest daily solar radiation coincided with the highest mean daily temperatures, occurring from December to March in both seasons. Mean annual rainfall was significantly higher during the 2017/18 season (1 180 mm), compared to the 2018/19 (1 013 mm) and 2019/20 (1 080 mm)

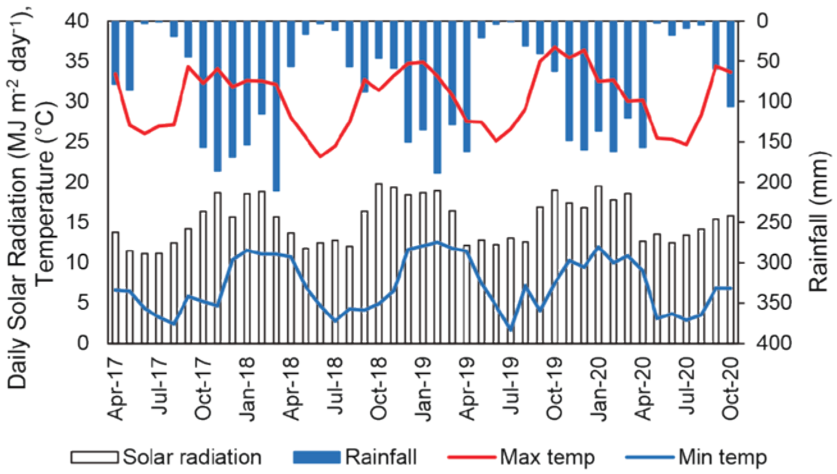

Figure 2: Monthly average daily solar radiation and maximum and minimum temperatures, together with total monthly rainfall in Howick for three seasons (April 2017 to October 2020).

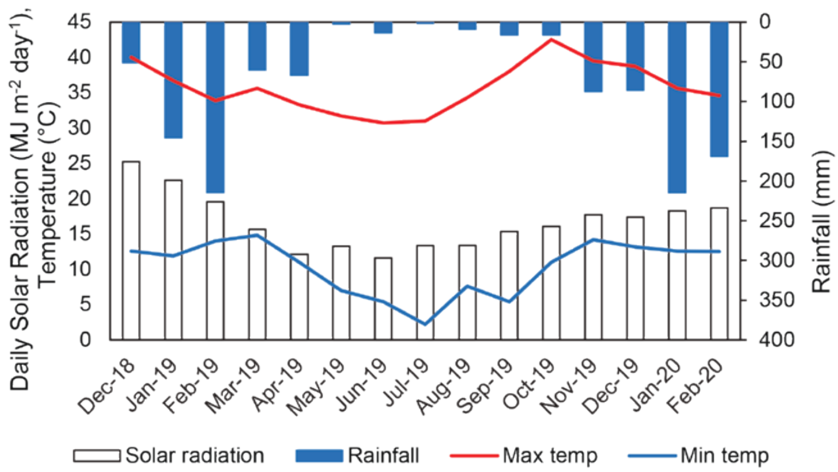

Figure 3: Monthly average daily solar radiation and maximum and minimum temperatures, together with total monthly rainfall for a single season (December 2018 to February 2020).


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seasons. Annual rainfall in all three seasons was very close to the long-term average of 1 074 mm for Howick (https://en.climate-data.org/africa/south-africa/kwazulu-natal/howick-27052/).

Average annual ET_o for the three seasons was 1 060 mm, with a daily average of 2.84 mm day^{-1}. Average daily vapour pressure deficit (VPD) was 0.86 kPa.

A second site in Tzaneen was chosen for a single season of measurements in a mature avocado orchard in order to have a dataset in a contrasting climatic region for modelling purposes. Average daily temperature during this season was 20.6 °C, with daily maximum temperatures of over 35 °C recorded on 46 days and an absolute maximum of 42.5 °C. Typically the highest daily temperatures occurred between December and March and were typically 2 - 5 °C higher than the annual average. This period coincided with highest average daily values for solar radiation, with an average daily solar radiation over the measurement period of 16.6 MJ m^{-2} day^{-1}. In the 2019 calendar year 719 mm of rainfall was recorded, which is below the average annual rainfall for Tzaneen of close to 881 mm per annum (https://en.climate-data.org/africa/south-africa/limpopo/tzaneen-15345/). Annual ET_o was 1 261 mm, with an average of 3.45 mm day^{-1}. Average VPD was 1.25 kPa.

It is evident from these data that conditions were generally hotter and drier in Tzaneen than Howick. These two sites therefore provided contrasting weather conditions needed for the validation of modelling approaches.

Water use measurements

A summary of seasonal average ET and T for the four study orchards is provided in Table 2. Total T for the mature orchard for the 2018/19 season (September to September) was 678 mm, with ET during this season 752 mm. Measurements of ET in this orchard began before the

Table 2: Average daily transpiration (T) and evapotranspiration (ET) rates (mm day^{-1}) across multiple seasons in the mature orchard (MO), intermediate orchard (IO) and non-bearing (NB) avocado orchards in Howick and the mature orchard in Tzaneen

Orchard	Season	2017/18		2018/19		2019/20	
		T	ET	T	ET	T	ET
MO	Spring		3.35	1.75	2.12	-	3.12
	Summer		3.46	2.01	2.57	-	4.28
	Autmn	2.45	2.65	2.02	2.01	-	3.25
	Winter	1.75	1.62	1.67	1.55	-	1.93
	Average	**2.10**	**2.77**	**1.86**	**2.06**	**-**	**3.15**
	TOTAL (mm)	**-**	**1063**	**678**	**752**	**-**	
IO	Spring	-	3.13	0.88	3.20	-	-
	Summer	1.13	4.19	1.14	4.29	-	-
	Autmn	1.02	2.82	1.11	3.19	-	-
	Winter	0.80	1.80	0.81	1.96	-	-
	Average	**0.98**	**2.98**	**0.99**	**3.16**	**-**	**-**
	TOTAL (mm)	**-**	**1087**	**359**	**1152**	**-**	**-**
NB	Spring	-	-	-	-	0.04	-
	Summer	-	-	-	-	0.08	3.71
	Autmn	-	-	-	-	0.10	3.03
	Winter	-	-	-	-	0.10	2.17
	Average	**-**	**-**	**-**	**-**	**0.08**	**3.06**
	TOTAL (mm)	**-**	**-**	**-**	**-**	**30.0**	**1124**
Tzaneen	Spring	-	-	-	-	1.09	-
	Summer	-	-	1.75	-	-	-
	Autmn	-	-	1.34	-	-	-
	Winter	-	-	1.05	-	-	-
	Average	**-**	**-**	**0.98**	**-**	**-**	**-**
	TOTAL (mm)	**-**	**-**	**476#**	**-**	**-**	**-**

#December 2018-December 2019

transpiration measurements and, in the 2017/18 season, the orchard ET was 1 063 mm (Table 2). This reflects the changes in canopy size between the two seasons as a result of pruning. The maximum transpiration rate recorded in this orchard was 4.32 mm day^{-1} (121 L day^{-1}) and the lowest was 0.17 mm day^{-1} (4.8 L day^{-1}). Average daily ET varied between 1.55 mm day^{-1} in winter and 3.46 mm day^{-1} in summer over the two seasons of measurements.

The trees in the intermediate orchard were smaller than the trees in the mature orchard and as a result, seasonal T in this orchard was 359 mm in the 2018/19 season, with T varying between 0.02 mm (0.6 L day^{-1}) and 2.51 mm (70 L day^{-1}). In the 2017/18 season ET was 1 087 mm, whilst in the 2018/19 season it was 1 152 mm (Table 2). Average daily ET varied between 1.80 mm day^{-1} in winter and 4.29 mm day^{-1} in summer over the two seasons of measurement. The orchard in Tzaneen had a canopy size intermediate between the mature and intermediate orchards and this was reflected in the seasonal T of 476 mm (Table 2). Transpiration ranged between 0.06 and 2.63 mm day^{-1} in the Tzaneen orchard (1.9 - 74 L day^{-1}).

In the non-bearing orchard, transpiration rates were very low, but when the tree size is considered relative to the area allocated to the tree, these rates are reasonable (Table 2). Transpiration rates varied between 0.036 and 0.156 mm day^{-1} (1 - 4.4 L day^{-1}), with a seasonal total of 30.0 mm. Importantly, ET of this orchard was very comparable to ET of the mature orchard. In the same period ET in the non-bearing orchard was 914 mm, whilst ET of the mature orchard was 1 033 mm. In Mediterranean climates Lahav *et al*. (2013) recommend mid-winter daily water application rates of 4 - 8 L day^{-1} $tree^{-1}$ for avocado trees in year 1 and 8 - 15 L day^{-1} $tree^{-1}$ for trees in year 2. These values are higher than those reported in the current study (maximum of 4 L day^{-1} $tree^{-1}$), but given that Lahav *et al*. (2013) recommends water application rates and not tree water use, the transpiration rates determined in this study are realistic.

The other important component of the orchard water balance is evaporation from the soil and transpiration from the understory vegetation (weeds and interrow grass cover), together referred to as evaporation (E_s). This is referred to as non-beneficial consumptive water use, whilst transpiration is considered beneficial consumptive water use, as it is linked to dry matter production. In this study, the non-beneficial consumptive water use (E_s) was calculated as a residual of measured ET and T. In all orchards E_s was higher in summer than winter, when rainfall was higher (Table 3).

Evaporation was also dependent on canopy cover, with the highest E_s rates found in the non-bearing orchard (95 - 98% of ET) and the lowest rates in the mature orchard (6 - 22% ET). The high E_s rates in the intermediate and non-bearing orchards are a reflection of more sunlight reaching the orchard floor, which resulted in a good grass cover between tree rows and more energy available to evaporate water from the soil. However, in the mature orchard at the start of the trial the trees were large and canopy cover was 0.9, resulting in very little light penetrating to the orchard floor, a very sparse cover of grass existing between rows, and lower amounts of energy reaching the orchard floor to evaporate water. Whilst the cover crop in the non-bearing orchard can stabilise ridges and contribute to soil organic matter, the contribution of transpiration of this cover crop to the orchard water balance cannot be ignored. In future, careful management of this evaporative component in young

Table 3: Evapotranspiration (ET) and evaporation (E_s) estimates, together with rainfall received and irrigation applied for the mature, intermediate and non-bearing avocado orchards in Howick

Orchard	Season	Average E_s (mm day^{-1})	Average ET (mm day^{-1})	%E_s of ET	Rain (mm)	Irrigation (mm)
Mature	Spring	0.45	2.11	20	193	35#
	Summer	0.60	2.57	22	473	0
	Autumn	0.35	2.26	11	566	0
	Winter	0.11	1.58	6	106	130
Intermediate	Spring	2.31	3.19	68	194	0
	Summer	3.15	4.28	77	784	0
	Autumn	1.94	3.01	68	595	1
	Winter	1.08	1.88	53	106	34
Non-bearing	Spring	3.46	3.51	98	284	28
	Summer	3.63	3.71	98	458	0
	Autumn	2.93	3.03	97	279	0
	Winter	2.10	2.17	95	32	81

#The irrigation sensor in the intermediate orchard failed in November 2018 orchards could lead to significant water savings. Similar results have been found in young apple orchards by Dzikiti *et al*. (2018).

It should be noted that rainfall in this region is quite high (average rainfall for the three seasons was 1 090 mm) and, although it is a summer rainfall region, some rain was still received in winter. This contributed significantly to water available for evaporation in the orchards, with E_s rates often being elevated following rainfall events in all three orchards. As a result of this high rainfall, very little irrigation occurs on this farm, with the majority of irrigation occurring during the dry winter months. In areas with lower rainfall, E_s is likely to be lower, especially if irrigation occurs within the shaded area of the trees.

When examining the response of daily T to daily weather conditions for three different orchards located in two different regions, it is evident that for many of the variables there was an initial linear increase of T with an increase in the variable, but at higher levels the rate of increase in T slowed relative to the increase in the variable (Fig. 4). This was particularly noticeable for VPD and ET_o (Figs. 4 C & D). As soil water was unlikely to be limiting during the study (as indicated by soil water measurements and predawn leaf water potential or midday stem water potentials), this response indicates that stomata of avocado trees may regulate water loss under high evaporative demands, suggesting that it is more a supply-limited system than a demand-limited system. A supply limitation implies that the rate of transport of water from the roots to the leaves cannot match the rate of water loss from the leaves, as determined by the water potential gradient out of the leaf. As a result stomata start to close to limit water loss and prevent embolism formation (Campbell and Turner, 1990; Sperry *et al*., 2002). This has previously been reported for citrus and macadamia (Smit *et al*., 2020; Taylor *et al*., 2015; Vahrmeijer and Taylor, 2018). The rate of increase of daily T decreased as daily VPD increased above 0.5 - 1.0 kPa for all three orchards. For ET_o, the change in the rate of increase of T occurred at approximately 2 mm day^{-1}. However, unlike VPD where the rate of increase decreased significantly after the threshold value, T still increased when ET_o was above 2 mm day^{-1}. The ratio between ET_o and T therefore varied with prevailing weather conditions and not just canopy size, and this should be considered if a crop coefficient approach is used to estimate water use of avocado orchards. The response of T to increases in R_s and T_{air} was more consistent within the entire range of these variables,

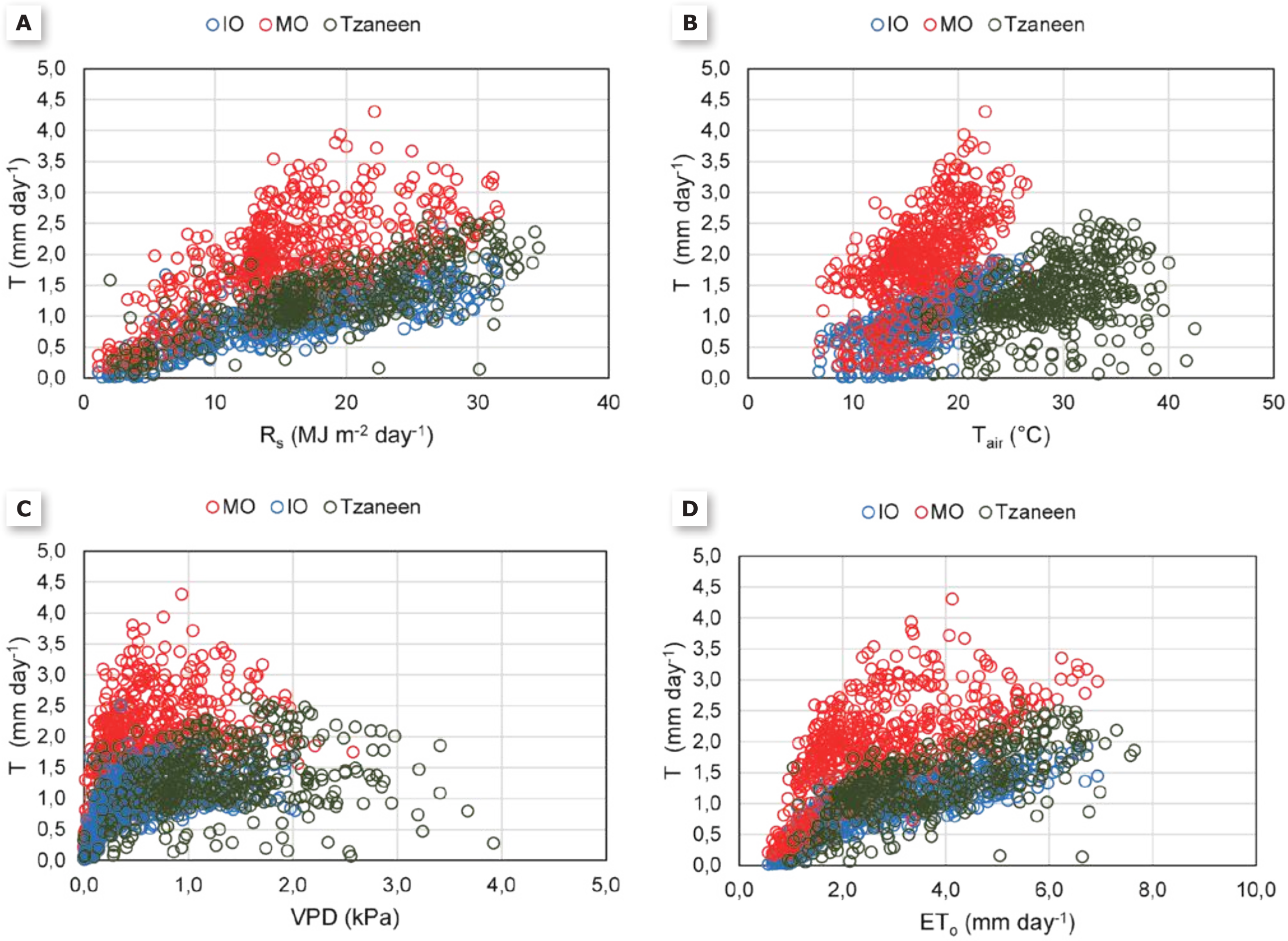

Figure 4: Relationship between daily transpiration (T) and (A) solar radiation (R_s), (B) air temperature (T_{air}), (C) vapour pressure deficit (VPD) and (D) reference evapotranspiration (ET_o), for the mature (MO) and intermediate (IO) avocado orchards in Howick and the orchard in Tzaneen.

with T typically showing a steady increase as R_s and T_{air} increased. However, the response to these variables was more scattered, possibly indicating that at higher levels of both of these variables, they are not placing a limit on transpiration.

Avocado crop coefficients

Crop coefficients (K_c), to determine ET from estimates of ET_o, were very similar between the three orchards in Howick, with values varying from 0.7 to 1.4, with an average of 1.0 (Fig. 5). These values will be quite specific to the study orchards, due to the nature of the understorey vegetation and the frequency of rainfall events that have a large impact on the E_s component of the water balance. In addition, the size of the canopy will have a large impact on the T component of the water balance. As a result, it is advised that the T and E_s components be considered separately (Kool *et al*., 2014). In this study we considered the T component by estimating transpiration crop coefficients (K_t).

In all three orchards monthly K_t values were typically higher in winter than in summer (Fig. 6), which has been previously noted for citrus (Taylor *et al*., 2015). Importantly the trend was the same for all three orchards and reflected differences in canopy size between the three orchards. However, although the trees in Tzaneen had a larger canopy cover than the intermediate orchard in Howick, the K_t values were very similar (Fig. 6 A). Monthly average K_t values for the mature orchard varied between 0.60 and 1.11, between 0.25 and 0.53 for the intermediate orchard and between 0.26 and 0.57 for the orchard in Tzaneen. The differences in crop coefficients for different orchards is not surprising as these values are often orchard specific and vary according to canopy height, ground cover, leaf area index, method of estimating reference evapotranspiration, microclimate and irrigation method and frequency (Naor *et al*., 2008; Snyder and O'Connell, 2007). The reason for the higher K_t values during winter than summer is most probably related to the response of T to ET_o and VPD (Fig. 4). It is evident from Figure 6 B that in Tzaneen, the highest values of K_t corresponded to the lowest values of ET_o and VPD and vice versa. Caution must therefore be exercised when using a constant K_t or K_c value to schedule irrigation throughout a season, as this will likely lead to an overestimation of water use in summer, when Phytophthora root rot can be a problem.

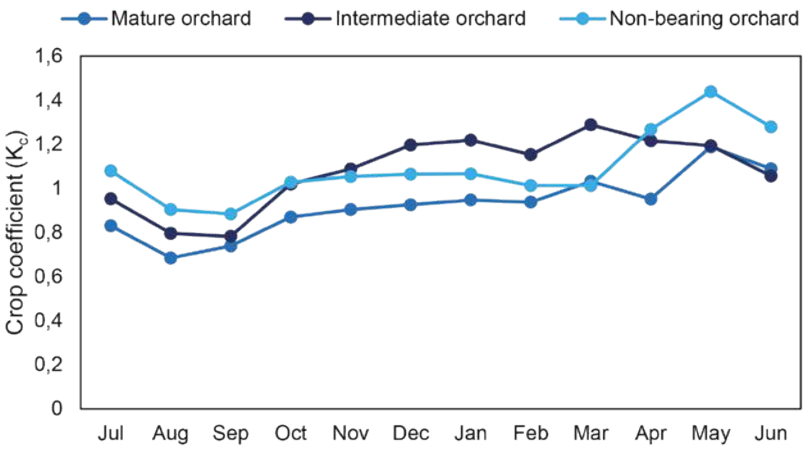

Figure 5: Crop coefficients (K_c) for orchards with varying canopy covers.

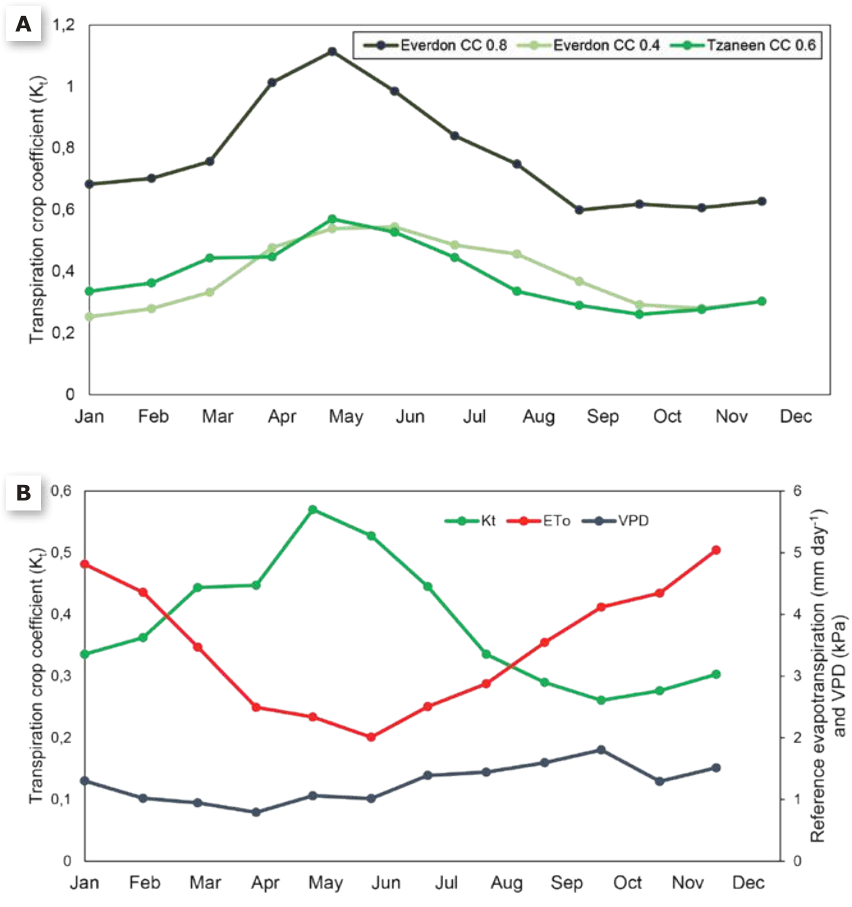

Figure 6: (A) monthly comparison of transpiration crop coefficient (K_t) values for the three orchards and (B) comparison of monthly K_t values for the orchard in Tzaneen with monthly vapour pressure deficit (VPD) and reference evapotranspiration (ET_o). CC is canopy cover.

Water use efficiency and water productivity

The determination of water use efficiency (WUE) allows the assessment of how efficiently water is used to produce a crop and can be used for benchmarking exercises in the industry. The added advantage to calculating water use productivity (WUP) is to put a value to the water used to produce a crop. In this study water use was defined as ET. Evapotranspiration for the two seasons in the intermediate orchard was very similar (1 087 – 1 152 mm for the 12 month period from September to September). As a result of the increased yield in the second season, WUE_{ET} was higher in the 2018/19 season (1.62 kg m^{-3}) than the 2017/18 season (1.18 kg m^{-3}) (Table 4). Water use productivity was also higher in the second season as a result of the increased yield and higher prices for this season and varied from R30.47 m^{-3} to R53.06 m^{-3}. Interestingly, the amount of water evapotranspired for every kg of fruit produced was 845 L kg^{-1} in the first season and 617 L kg^{-1} in the second season. This is considerably lower than the 2 000 L per kg reported in the popular press, but doesn't take into consideration all the water used in production, which includes water in the packhouse and for spray applications. In addition, if you consider an average fruit mass of 250 g, then it takes approximately 150 - 200 L to produce a single avocado in this orchard.

Evapotranspiration in the mature orchard was 1 009 mm for the 12 month period from September 2017 to September 2018 and 752 mm for the same period in 2018-2019. As a result of the slightly lower yield and lower ET, WUE_{ET} in the mature orchard was 1.23 kg m^{-3} in the first season, which was marginally higher than the intermediate orchard (Table 5). However, due to the lower volume of grade 1 fruit from the mature orchard, WUP_{ET} was lower in the mature orchard, with a value of R24.39 m^{-3}. In the second season due to lower ET and only slightly lower yield, WUE_{ET} increased to 1.61 kg m^{-3} and due to better prices WUP_{ET} increased to R50.64 m^{-3}. To produce 1 kg of fruit, 622 to 810 L of water was required, based on ET. If you consider an average fruit size of 250 g, then it takes approximately 150 - 200 L to produce a fruit, which is the same as for the intermediate orchard.

Table 4: Parameters used in the calculation of water use efficiency (WUE_{ET}) and water use productivity (WUP_{ET}) across two cropping seasons for the intermediate avocado orchard, based on evapotranspiration (ET) measurements

	2017/18 Season	2018/19 Season
Total ET (mm)	1087	1152
Total ET (m^3)	10870	11520
Total Yield (kg ha^{-1})	12857	18659
Total Net Income (R ha^{-1})	R331 245.33	R611 217.37
WUE_{ET} (kg m^{-3})	1.18	1.62
WUP_{ET} (R m^{-3})	30.47	53.06

Table 5: Parameters used in the calculation of water use efficiency (WUE_{ET}) and water use productivity (WUP_{ET}) in a mature avocado orchard across two cropping seasons in 2017/18 and 2018/19. Values are calculated using evapotranspiration (ET)

	2017/18 Season	2018/19 Season
Total ET (mm)	1009	752
Total ET (m^3)	10090	7520
Total Yield (kg ha^{-1})	12 442	12 085
Total Net Income (R ha^{-1})	R246 140	R380 846
WUE_{ET} (kg m^{-3})	1.23	1.61
WUP_{ET} (R m^{-3})	24.39	50.64

CONCLUSION

There have been very few systematic attempts to quantify water use of avocado orchards on a seasonal basis and for different sized canopies, which can then be combined with yield data to estimate WUE and WUP. This study therefore represents a significant contribution to our understanding of avocado orchard water use. As with many other tree crops, T is largely dependent on canopy size. However, as with many other subtropical evergreen tree crops, weather variables also play a large role in determining orchard water use, but this relationship varies depending on how hot and dry it is. Preliminary data suggests that there is a threshold for VPD and ET_o at which the rate of increase of T with these variables starts to decrease, which possibly reflects physiological control over T.

There were also significant periods during the study when ET and T measurements overlapped and this has provided great insight into the partitioning of ET into T and E_s in avocado orchards, which will be applicable to a wide range of orchards. When canopy cover is less than 70%, E_s composes a significant proportion of total ET, which will also increase depending on the vigour of the vegetation between the tree rows. Importantly, in young orchards the vast majority of ET consists of evaporation from the soil and transpiration from the other vegetation in the orchard. Understanding the water balance in these orchards could go a long way to making water savings, especially during very dry years when water quotas are reduced.

Translating all this orchard specific information into water use models for various applications is critical to make this information useful to growers, consultants, grower associations and governmental departments. Models that are easier to use and provide information for strategic decisions need to considered, together with those models that provide accurate estimates on shorter timescales for tactical decision making.

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