Water use of avocado orchards – Year 3

E Mazhawu[1], AD Clulow[1], MJ Savage[1] and NJ Taylor[2]

[1]Discipline of Agrometeorology, School of Agricultural, Earth and Environmental Sciences, University of KwaZulu-Natal, Private Bag X01, Scottsville 3208, SOUTH AFRICA
[2]Department of Plant and Soil Sciences, University of Pretoria, Private Bag X20, Hatfield 0028, SOUTH AFRICA

E-mail: nicolette.taylor@up.ac.za

ABSTRACT
The aim of the study was to estimate the water use in four different avocado orchards located in two provinces in South Africa (KwaZulu-Natal Midlands and Limpopo). Measurements were undertaken during the 2017/18, 2018/19 and 2019/20 seasons. Evapotranspiration (total water use) was monitored using the eddy covariance technique, whilst transpiration was monitored using the heat ratio method of the heat pulse velocity technique. The grass reference evapotranspiration (ET_o) ranged between 0.26 mm and 7.07 mm day^{-1}. Average daily water use or evapotranspiration (ET) ranged between 0.49 mm and 7.81 mm day^{-1} for the intermediate orchard and from 0.09 mm to 5.53 mm day^{-1} for the mature orchard. Transpiration ranged from 0.02 mm and 4.08 mm day^{-1} for both orchards. Monthly crop (K_c) and transpiration coefficients (K_t) values varied from 0.2 to 1.1, with differences in K_t values reflecting differences in canopy size. Measurements in the non-bearing orchard at Everdon Estate and mature orchard at McNoon are currently underway.

INTRODUCTION

With South Africa currently facing severe water shortages and climate change scenarios suggesting large variability in terms of rainfall, agriculture is clearly at high risk of depleted available water resources in future. Rapid urban growth and industrialisation are also great contributors to the pressure being placed on existing water resources. These pressures have led to a global interest in finding ways to use the available resource more efficiently. Agriculture is perceived as an inefficient consumer and may not always be a priority when it comes to future allocations. Justifying volumes of water required for production might therefore become mandatory.

In South Africa, avocados are mainly grown in high rainfall areas, receiving over 1 000 mm per annum. However, due to climate change and seasonal variability, rainfall distribution has become erratic and insufficient for avocado production, resulting in a need for supplementary irrigation to cover the gap. When combined with the increased area planted to avocados, in response to the rising global demand, growers are faced with the need to irrigate a larger area with limited resources. As a result, there is a need to improve irrigation management. In the face of scarce water resources, knowledge of water volumes used to produce avocados becomes important. To sustain the avocado industry, water use has to be well accounted for by accurately estimating evapotranspiration (ET). Very few attempts to determine the water requirements of avocado orchards have been documented (Carr, 2013). Studies have 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). In South Africa, in the Crocodile River basin, Hoffman and Du Plessis (1999) determined the water required to be 9 825 m^{-3} ha^{-1} annum^{-1}, considerably higher than the other places. However, correct quantification is still a problem due to changes in season and climate (Carr, 2013). The main aim of the project is to determine the unstressed water use of different sized avocado orchards, which can be used to derive crop coefficients in the South African context, which in turn can be used to improve water management in avocado orchards.

MATERIALS AND METHODS

Site description

The study has been conducted in four commercial orchards. Three of these are situated at Everdon Estates, KwaZulu-Natal Midlands (29° 26′ 37′′ S, 30° 16′ 22′′ E, 1 080 m a.s.l.) and the fourth is at McNoon Estates, 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 at Everdon Estates were identified based on canopy size. In this study, an immature orchard is defined as an orchard that has yet to bear fruit. An intermediate orchard is defined as an orchard with distinct individual trees that have yet to form a hedgerow. A mature orchard

Table 1: Details of the intermediate and mature full bearing orchards understudy

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	Microjet sprinkler (50 L h^{-1})			Microjet sprinkler (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

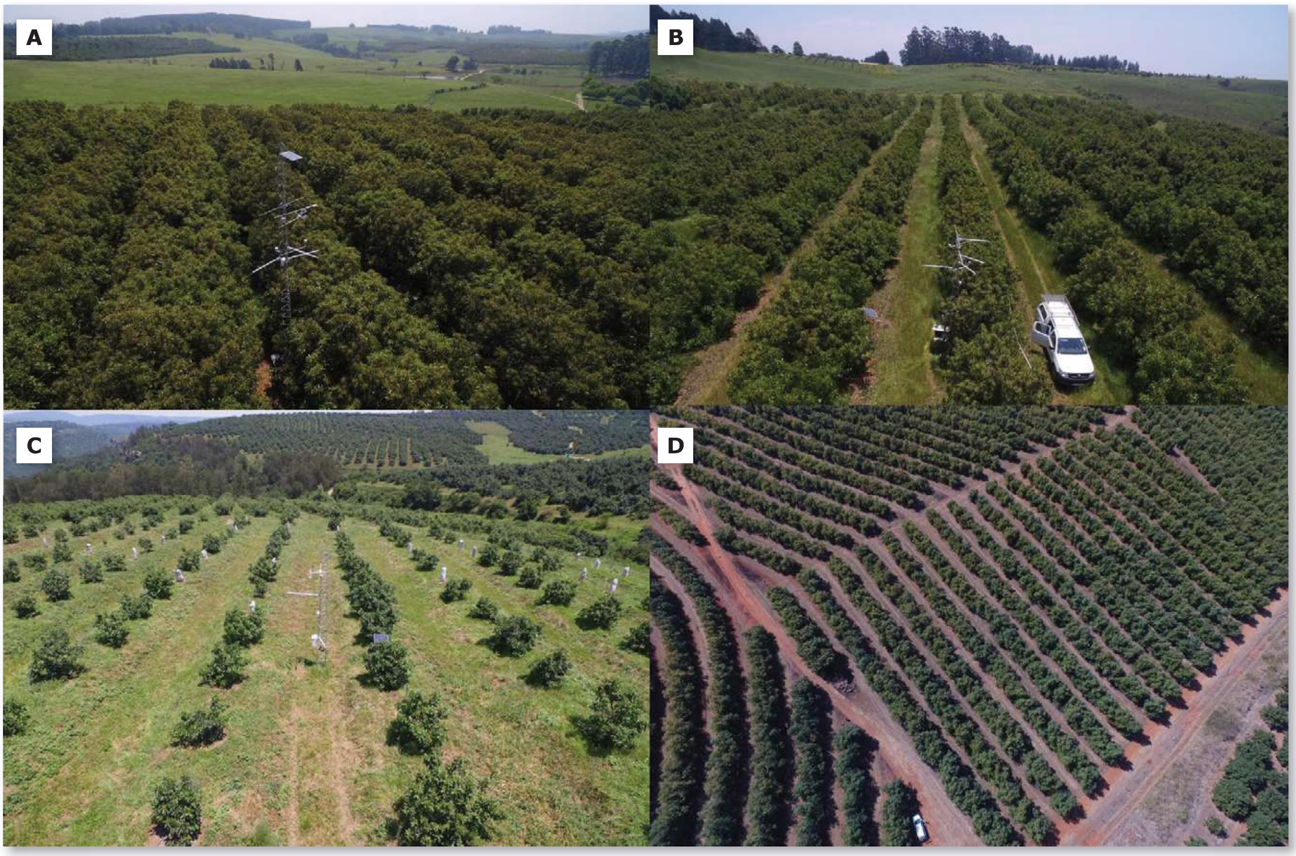

Figure 1: (A) 6-year old intermediate bearing 'Hass' orchard; (B) 12-year old mature full bearing orchard; (C) 2-year old non-bearing 'Harvest' orchard at Everdon Estates, KZN Midlands; and (D) 7-year old mature orchard at McNoon Estates, Tzaneen

is defined as an orchard with full bearing trees with a canopy cover of 40-50%, with a fully established hedgerow and 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). Daily weather data were obtained from automatic weather stations (AWS) on the farms. The one at Everdon is operated by the Agricultural Research Council, whilst the one in Tzaneen is located close to the Westfalia Technological Services' offices and is 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).

Water use measurements

In this study, orchard water use is defined as evapotranspiration (ET) derived from latent flux measurements using an Eddy covariance system. The intermediate and mature full bearing orchards at Everdon were instrumented in April and September 2017, respectively, with monitoring in the immature orchard beginning in November 2019. Details of the measurements have been provided in Mazhawu *et al*. (2019).

Transpiration has been measured in three orchards using the heat ratio method (Burgess *et al*., 2001), while transpiration in the immature orchard is determined using the thermal dissipation method (Granier, 1987). These measurements have yet to be finalised,

GEFOKUS

EERBAAR BETROUBAAR

HFR Vervoer se sleutelwaardes is getrouheid, goeie maniere, wedersydse respek en integriteit. Ons besigheidsmodel fokus op deurlopende groei en stabiliteit deur middel van uitstekende klientediens, voldoende toerusting, opgeleide personeel en die nuutste tegnologie en beplannings metodes. HFR Vervoer is toegewyd en deur konstante kommunikasie en samewerking met ons kliente verseker ons die konstante bevrediging van hulle veranderende behoeftes.

HFR Vervoer is die voorloper in onafhanklike nasionale en oorgrens vervoer met 'n verskeidenheid van korporatiewe en onafhanklike kliente regdeur Suiderlike Afrika. Ons fokus is verkoelde vragte, maar ons vervoer ook droë, sowel as waardevolle en bederfbare produkte. Dit bestaan uit kommersiële produkte sowel as seisoenale produkte soos groente en vrugte.

HFR se verspreidingsarea is regdeur Suid Afrika sowel as ons buurlande, nl. Namibië, Botswana, DRC, Zambië, Zimbabwe, Malawi, Mosambiek, Swaziland en Lesotho.

Ons goed opgeleide en betroubare personeel, sowel as ons vooruitbeplande instandhoudingsprogram en 24/7 opsporingseenheid maak ons die voorloper in die industrie. Al ons sleepwaens is gestandariseerde 30 pallet, hoë volume liggewig waens met 'n kapasiteit van oor die 29 ton.

HFR lewer op temperatuur en op tyd, altyd.

> 'Ons roetes en bestemmings is gerieflik vir beide groot en klein besighede wat betroubare en bekostigbare temperatuur gekontrolleerde vervoer benodig.'

as a number of parameters are required, which can only be determined at the conclusion of measurements. Preliminary data will be included for comparative purposes between orchards and regions. 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 of the soil and transpiration from plants.

Transpiration coefficient (K_t) was determined as:

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

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

RESULTS AND DISCUSSION

Weather variables

Average seasonal weather variables recorded from April 2017 to February 2020 at Everdon Estates, namely solar radiation (Rs), maximum air temperature (Tmax), minimum air temperature (Tmin), average air temperature (Tavg), vapour pressure deficit (VPD) and wind speed are shown in Table 2, with similar weather variables for Tzaneen reported in Table 3. Total rainfall for 2017, 2018 and 2019 was 1 222 mm, 967 mm, and 1 080 mm, respectively, with most rainfall being received in summer. The maximum air temperature for the period was 36.8°C, with a minimum of 2.4°C. Average daily solar irradiance values were higher in summer and lowest in winter, which indicates the available energy to drive water use. The average seasonal VPD varied between 0.8 and 1.9 kPa. Low windspeeds were recorded over the study period. What should be evident from the comparison of the two regions is that Tzaneen has typically been hotter than Howick and that rainfall during the measurement period was much lower than the long-term annual average for Tzaneen.

Water use measurements

The cumulative ET_o from April 2017 was 718 mm, 1 075 mm and 1 081 mm for 2017, 2018 and 2019, respectively. For this period daily ET_o varied between 0.2 and 7 mm day^{-1}. The average seasonal ET_o was highest in summer (3.68 mm day^{-1}) (Table 4) and followed a clear seasonal trend (data not shown). Average seasonal total water use (ET) varied between 1.60 and 4.30 mm day^{-1} with maximum rates recorded in summer (7.81 mm day^{-1}) in the intermediate orchard (ET_IO) and 5.53 mm day^{-1} in the mature orchard (ET_MO).

Table 2: Seasonal weather data for Everdon Estates from April 2017 to February 2020. Rs – solar radiation, Tmax – maximum temperature, Tmin – minimum temperature, Tavg – average temperature, VPD – vapour pressure deficit

Year	Season	Rainfall	Rs	Tmax	Tmin	Tavg	VPD	Windspeed
		(mm)	(MJ m^{-2} day^{-1})	°C	°C	°C	kPa	m s^{-1}
2017	Spring	387.1	16.4	34.3	4.7	16.3	1.3	1.2
	Summer	169.2	15.7	31.8	10.4	17.3	1.7	1.0
	Autumn	164.1	12.6	33.4	6.5	16.5	1.1	0.8
	Winter	22.8	11.6	27.1	2.4	13.8	0.8	1.2
2018	Spring	193.3	18.4	33.2	4.1	16.2	1.3	1.1
	Summer	418.5	18.7	34.7	11.1	19.6	1.9	0.9
	Autumn	284.0	13.7	32.1	7.0	17.2	1.5	0.9
	Winter	71.6	12.4	27.5	2.7	13.2	0.9	1.0
2019	Spring	250.7	17.8	36.8	4.1	17.6	1.4	1.1
	Summer	483.1	18.1	36.4	9.4	19.0	1.8	0.9
	Autumn	311.4	13.8	30.8	7.5	17.8	1.6	0.9
	Winter	34.8	12.6	29.1	1.7	15.0	0.9	1.1

Table 3: Seasonal weather data for Tzaneen from December 2018 to February 2020. Rs – solar radiation, Tmax – maximum temperature, Tmin – minimum temperature, Tavg – average temperature, VPD – vapour pressure deficit

Year	Season	Rainfall	Rs	Tmax	Tmin	Tavg	VPD	Windspeed
		(mm)	(MJ m^{-2} day^{-1})	°C	°C	°C	kPa	m s^{-1}
2018/19	Spring	113	16.2	42.5	2.0	20.9	1.6	0.77
	Summer	411	20.0	40.0	11.9	23.6	1.4	0.62
	Autumn	130	13.5	35.6	7.0	19.3	0.9	0.60
	Winter	24	12.8	34.3	2.2	15.6	1.2	0.73

Table 4: Seasonal averages for reference evapotranspiration (ET_o), evapotranspiration (ET) and transpiration (T) for the mature (ET_MO and T_MO) and intermediate orchard (IO_ET and IO_T) between March 2018 and September 2019

Parameter	Autumn	Spring	Summer	Winter	Max	Average
	mm day^{-1}					
ET_MO	2.10	1.96	2.76	1.60	5.53	2.01
ET_IO	2.86	3.15	4.30	1.88	7.81	2.82
T_IO	1.18	1.15	1.34	1.08	2.91	1.17
T_MO	2.29	2.01	2.31	1.82	4.08	2.08
ET_o	2.43	3.45	3.68	2.22	7.07	2.75

Despite differences in tree size, the intermediate orchard used more water on average than the mature orchard, which is likely due to high evaporation rates linked to greater surface area exposed in the intermediate orchard. The total seasonal ET average was

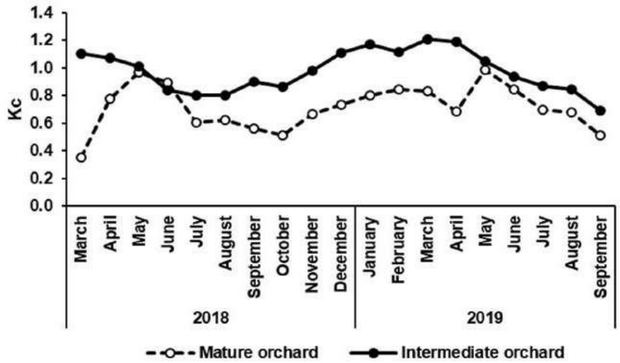

Figure 2: Monthly crop coefficients (Kc) for the mature and intermediate orchard (2018-2019)

1 020 mm (10 200 m^3) for the intermediate orchard and 865 mm (8 650 m^3) for the mature orchard. Daily transpiration for the intermediate orchard varied between 0.05 and 2.91 mm day^{-1} and 0.12 and 4.08 mm day^{-1} for the mature orchard (Table 4).

There was year to year variation in K_c values in both orchards (Fig. 2), which was attributed mainly to pruning (mature orchard) and the growth of the young trees in the intermediate orchard. The higher K_c values in the intermediate orchard, despite smaller tree size, were most likely due to the higher evaporative component in this orchard. As the trees were smaller in this orchard, more solar radiation reached the orchard floor, providing the energy to evaporate water from the soil and drive transpiration from the grass cover between rows.

The daily transpiration rate was linearly correlated with daily solar radiation (Fig. 3A and B). However, the relationship between transpiration and VPD (Fig. 3B and C) was non-linear, with transpiration rates increasing at a slower rate once VPD exceeded approximately 1.5 kPa. The relationship between solar radiation and

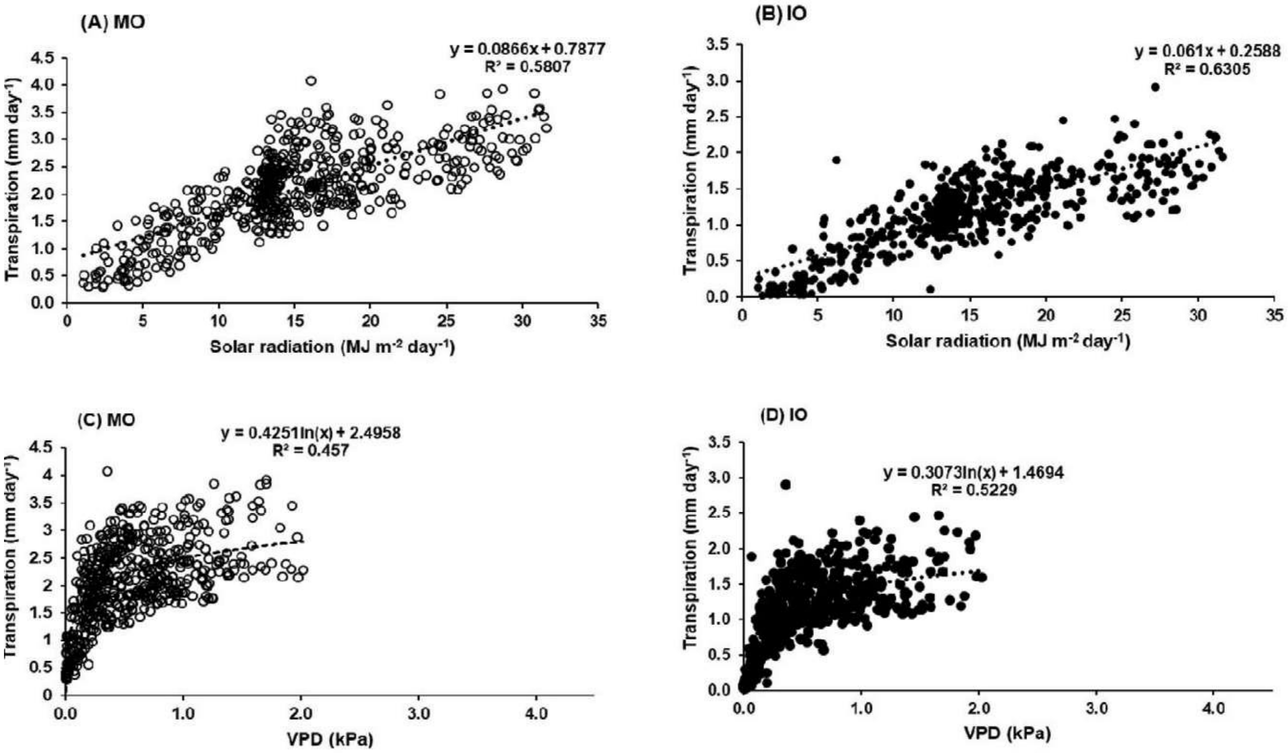

Figure 3: The response of transpiration in the A) Mature orchard to solar radiation; B) intermediate orchard to solar radiation; C) mature orchard to VPD; and D) intermediate orchard to VPD at Everdon Estates

transpiration accounted for 58% of the variation in the mature orchard and 63% in the intermediate orchard. In the mature orchard, VPD accounted for 46% of the variation. A similar response of transpiration to VPD was observed in the orchard in Tzaneen (Fig. 4), however, much higher VPD values were recorded in Tzaneen and a decrease in transpiration rates was observed at the most extreme levels of VPD.

Monthly average of K_t varied with canopy size, as shown in Figure 5, with the orchards with bigger canopies having higher K_t values. However, despite relatively constant canopy size over a season, there were significant differences in K_t values over a season, with values being highest in autumn and winter and lowest in mid-summer. This trend was very consistent across the three orchards, in two different growing regions. This is likely linked to prevailing weather conditions, more specifically ET_o. In this regard, the highest K_t values corresponded with the lowest ET_o values, which represents atmospheric evaporative. As the atmospheric demand increased, the ratio between atmospheric demand and transpiration decreased, which suggests some kind of physiological control over transpiration. This is also seen in the response of transpiration to VPD in the three orchards in Figure 3 and 4. The higher VPD values experienced in Tzaneen could also explain why the K_t values for the intermediate orchard at Everdon Estates and the mature orchard in Tzaneen are so similar, despite differences in canopy cover.

By comparing ET and T values it is possible to gain some understanding of the evaporative component of the total water balance of an orchard. This component will include evaporation from the soil surface and transpiration from any vegetation in the work row and under the trees. This is where water savings within orchards can possibly be made, as it is viewed as a non-beneficial water use. The manner in which this component varies in orchards can be clearly seen when comparing ET and T in the three orchards at Everdon Estates. In the mature orchard, the ET and T components mirrored each other, suggesting that transpiration from the trees is the major component of ET in this orchard (approximately 81%), where the trees are very large and shade the orchard floor for most of the day (Fig. 6A). However, in the orchards with lower canopy cover, transpiration makes up a much lower percentage of ET. In the intermediate orchard, T is approximately 50% of ET (Fig. 6B) and in the non-bearing

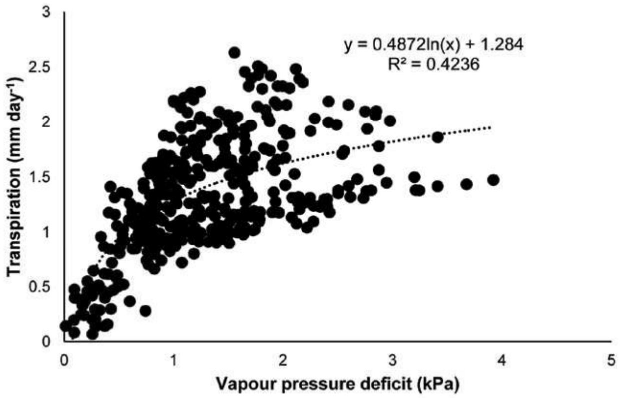

Figure 4: The response of transpiration in the mature orchard in Tzaneen to VPD

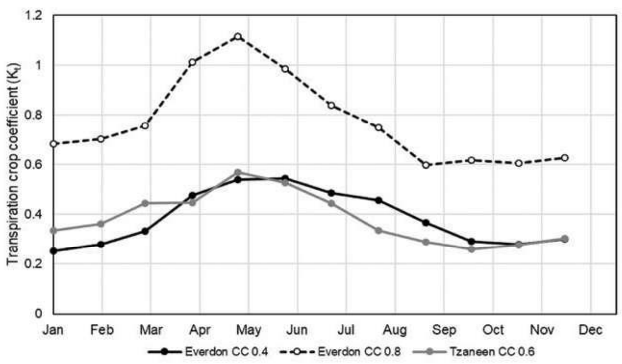

Figure 5: Transpiration crop coefficients (K_t) for the mature and intermediate orchard at Everdon Estates and the mature orchard in Tzaneen. CC – canopy cover or fraction of the soil surface covered by the tree canopy

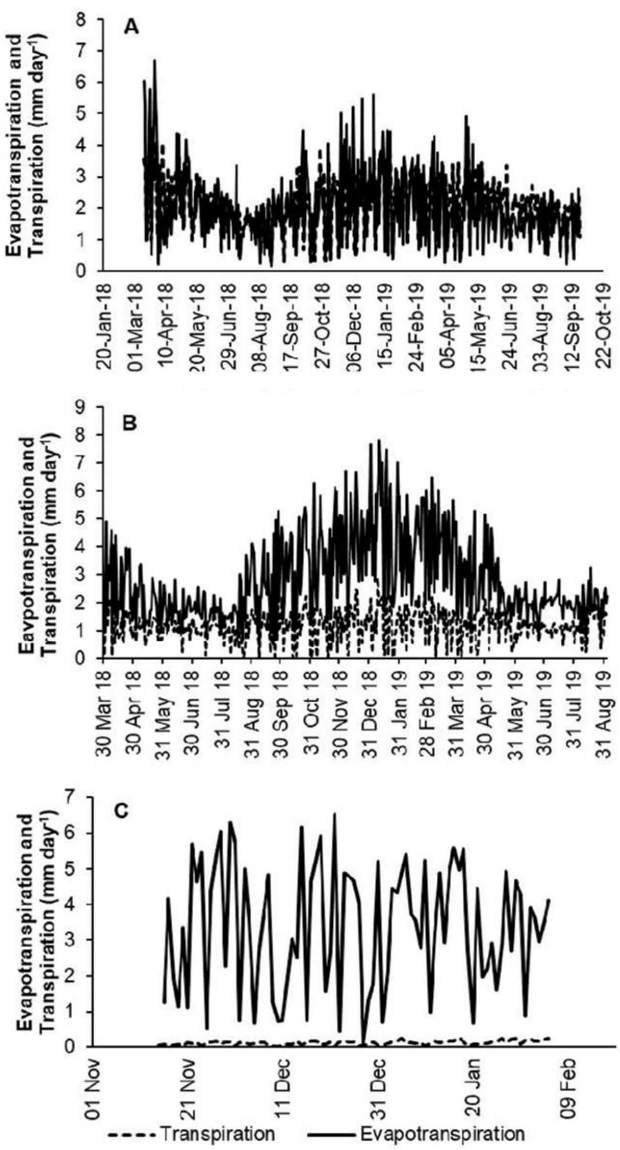

Figure 6: Daily evapotranspiration and transpiration (mm day⁻¹) in the A) mature; B) intermediate; and C) non-bearing orchards at Everdon Estates

orchard transpiration is only approximately 5% of ET (Fig. 6C). If water savings are needed, it may therefore be best to target reducing evaporation in young orchards. Numerous strategies are available, which include, for example, the use of mulches.

CONCLUSION

The study is providing estimates of water use of different sized avocado orchards, which includes both ET and transpiration and represents some of the first long term water use data using micrometeorological and sap flow measurements in the world. Whilst it is evident that transpiration volumes are dictated by canopy size, ET of orchards is not so straightforward and the high rates of evaporation from young orchards can result in very similar and even higher ET values from orchards with smaller canopies. Taking both transpiration and evaporation into account in future modelling exercises will be critical for accurate estimates of water use of avocado orchards. In addition, the transpiration model would also need to account for physiological control over transpiration, as initial results seem to indicate that transpiration of avocado trees is not linearly related to atmospheric demand.

Acknowledgements

The authors would like to thank the Water Research Council (Project No K5/2552//4) and South African Avocado Growers' Association (SAAGA) for funding. A special mention to the Agricultural Research Council for their AWS data and Everdon Estates and Westfalia Estate (all part of Westfalia fruit) management for access to the farm and a great deal of assistance during the study.

REFERENCES

ADATO, I. & LEVINSON, B. 1988. Influence of daily intermittent drip irrigation on avocado (cv. Fuerte) fruit yield and trunk growth. *J. Hortic. Sci.* 63(4): 675-685.

BURGESS, S.S., ADAMS, M.A., TURNER, N.C., BEVERLY, C.R., ONG, C.K., KHAN, A.A. & BLEBY, T.M. 2001. An improved heat pulse method to measure low and reverse rates of sap flow in woody plants. *Tree Phys*. 21: 589-598.

CARR, M.K.V. 2013. The water relations and irrigation requirements of avocado (*Persea americana* Mill.): a review. *Exp. Agric*. 49(02): 256-278.

GRANIER, A. 1987. Evaluation of transpiration in a Douglas-fir stand by means of sap flow measurements. *Tree Phys*. 3: 309-320.

GUSTAFSON, D. 1976. Avocado water relations. *Calif. Avo. Soc. Yearb.* 60: 57-72.

HOFFMAN, J. & DU PLESSIS, S. 1999. Seasonal water requirements of avocado trees grown under subtropical conditions. *Revista Chapingo Serie Horticultura* 5: 191-194.

MAZHAWU, E., CLULOW, A., SAVAGE, M. & TAYLOR, N. 2019. Water use of avocado orchards – Year 2. *SAAGA Yearb*. 42: 48-51.