Water use of avocado orchards – Year 1

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

[1]Agrometeorology, School of Agricultural, Earth and Environmental Sciences, University of KwaZulu-Natal, Private Bag X01, Pietermaritzburg 3201, SOUTH AFRICA
[2]Department of Plant and Soil Sciences, University of Pretoria, Private Bag X20, Hatfield 0028, SOUTH AFRICA

ABSTRACT
Currently there is a considerable knowledge gap on water use of avocado orchards. This information is critical for the issuing of water licenses, adequate irrigation system design and irrigation scheduling. As a result of this need, the Water Research Commission directed, funded and managed a project (K5/2554//4) on the water use of avocado orchards, with co-funding by SAAGA. The water use or evapotranspiration (ET), which includes both transpiration and evaporation, of an intermediate sized 'Hass' avocado orchard is currently being estimated in the KwaZulu-Natal Midlands using the eddy covariance technique. In the first season of measurements it was evident that ET closely mirrored the atmospheric demand, measured as reference evapotranspiration (ET_o), with water use being higher in summer than winter. Average daily water use for the season was 2.69 mm day^{-1}, with a summer daily average of 3.98 mm day^{-1} and a winter daily average of 1.64 mm day^{-1}. The calculation of crop coefficients indicated a good correlation between ET and ET_o, implying that crop coefficients could be used to provide reasonable estimates of ET for avocado orchards. Future measurements will focus on quantifying both ET and transpiration of three different orchards with different canopy sizes in order to parameterise and validate water use models for avocado.

INTRODUCTION
South Africa is a semi-arid country, with finite water resources which are shared between agriculture, industry and the ever growing population. As agriculture is the biggest user of fresh water in the country, increased pressure is being placed on agricultural industries to justify their use of water. This is likely to result in policies which lead to improved water use efficiencies in agriculture. Further expansion of the avocado industry must therefore occur without an increase in water use and the only way to do this is to improve water management in existing and new orchards. The continued expansion of the avocado industry is therefore dependent on the availability of good quality irrigation water and the judicious management thereof in terms of irrigation planning and scheduling.

In order to achieve this, knowledge of orchard water use is a critical requirement. However, there are very few reports of avocado water use and even these reports raise questions concerning the methodology used. Lahav *et al*. (2002) provide the following recommendation for mid-summer application rates in Mediterranean climates for young trees: year 1: 4-8 L $tree^{-1}$ day^{-1}; year 2: 8-15 L $tree^{-1}$ day^{-1}; year 3: 20-50 L $tree^{-1}$ day^{-1} and year 4: 80-150 L $tree^{-1}$ day^{-1}. In year 4, at 400 trees per ha, this equates to 3.2 to 6.0 mm day^{-1}. In southern California, in years with annual rainfall between 250 and 500 mm, avocado growers typically apply between 450 and 1500 mm irrigation water, depending on location (Faber, 2006). For mature orchards a K_c of 0.7 is recommended in this area, with a 10% leaching fraction, depending on water quality. In Australia, irrigation volumes for avocado vary considerably among regions, from 300-500 mm in the high rainfall areas of northern Queensland to 800-1800 mm in areas further south and Western Australia (Carr, 2013). These figures are unlikely to be readily transferable between different climatic regions and orchards with different canopy sizes. It is important for the South African avocado industry to quantify water use of avocado orchards and develop water use models to allow the extrapolation of measured data to a wide range of orchards. It was as a result of this need that the Water Research Commission directed, funded and managed a project on avocado water use, with co-funding from SAAGA.

The aim of this five-year project is therefore to quantify the water use (including both transpiration and evaporation) of unstressed orchards from planting to maturity and then to develop appropriate water use models to extrapolate measured data to a wide range of orchards. In this article we report on the first year of measurements from an orchard of an intermediate canopy size.

MATERIALS AND METHODS
Site description
Water use measurements were conducted in a 4-year old 'Hass' avocado orchard grafted on 'Dusa' rootstocks, which was planted in 2013 in a south east – north west direction (Fig. 1). The orchard is

Figure 1: A) The 4-year old 'Hass' avocado orchard at Everdon Estates and the B) micrometeorlogical equipment used to determine the evapotranspiration of the orchard.

situated at Everdon Estate, Westfalia Estates at Howick (29° 26'37''S, 30°16'22''E, 1080 m altitude), which is approximately 30 km from Pietermaritzburg. The orchard is approximately 2.91 ha and is planted at a population of 357 trees ha^{-1} (spacing 7 x 4 m i.e. 28 m^2 per tree). The orchard is irrigated using 50 L h^{-1} microsprinklers, with a wetted diameter of 1.7 m. Average tree height at the start of measurements was 3.8 m with an orchard leaf area index of 2.95 $m^2\ m^{-2}$. Intermediate-sized orchards are defined as bearing orchards, which have not formed a hedgerow. Separate trees are therefore distinguishable. Average yields for these orchards are approximately 7 t ha^{-1} and canopy cover between 40 and 50%. The work row consisted of a mixture of weeds and grasses which was mown periodically.

Weather variables

Weather data was obtained from an existing automatic weather station (AWS) system at the site, which is maintained by the Agricultural Research Council. The daily data from the AWS system includes rainfall, air temperature, relative humidity, solar radiation, wind speed and direction. Reference evapotranspiration was calculated using the FAO 56 Penman-Monteith equation for a short grass reference surface, as described by Allen *et al*. (1998) and Pereira *et al*. (2015). Crop coefficients (K_c) were calculated as

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

Water use measurements

Total evaporation or evapotranspiration (ET) was quantified using the eddy covariance technique (Fig. 1B). The micrometeorological system was installed at the centre of the intermediate orchard to measure total evaporation based on the energy balance method. The EC system comprises a three-dimensional sonic anemometer, an open path CO_2/H_2O gas analyser, four soil heat flux plates, two CS616 soil reflectometers, two sets of soil temperature averaging probes, as well as a relative humidity/temperature sensor and two infrared thermometers. A sonic anemometer, infrared gas analyser, 4-component net radiometer and a 2-component net radiometer were placed 5.5 m above the ground or 2 m above the canopy. A datalogger (Campbell CR3000) sampled measurements at a frequency of 10 Hz with an output interval of 30 minutes. High-frequency data of the covariances between wind speed (*u, v* and *w*), sonic temperature (T_s), CO_2 and H_2O densities were stored on a 2 GB memory card and downloaded every two weeks. The high frequency data was processed using the LI-COR EddyPro software version 6.2.0 to derive the corrected fluxes. The correction involved density fluctuations, tilt correction, time lag compensation and quality check according to Foken *et al*. (2004). Sensible (H) and latent (LE) heat fluxes were corrected using the Webb-Pearman-Leuning correction procedure. The additional measurements, as well as the averaged 30-min unprocessed flux data, is downloaded remotely and are available in near real-time at http://agromet.ukzn.ac.za:5355/EverdonLiCor/index.html.

A water meter was installed within an irrigation line at the beginning of a tree row to measure the volume of irrigation water applied to a tree row, whilst a PS-1 Irrigation Pressure switch attached to an EM50 logger (Decagon Devices Inc, Pullman, WA, USA) was used to monitor irrigation timing and duration. Soil water matric potential is monitored using Watermark sensors at various depths and positions across the row. Readings from the sensors are logged using an AM16/32B multiplexer and a CR1000 logger.

RESULTS AND DISCUSSION

Weather variables

Weather at Everdon Estates followed a typical seasonal pattern for a cool subtropical climate (Fig. 2). During the measurement period (April 2017 to February 2018), 940 mm rainfall was received at the site, with an average ET_o of 2.88 mm day^{-1}. The maximum temperature recorded during this period was 35.4 °C and the minimum was 2.4 °C. Conditions were generally much more variable in summer than winter, due to the greater presence of cloud cover and rain during the summer months. This is evident from the large variation in daily solar radiation at this time (Fig. 2A).

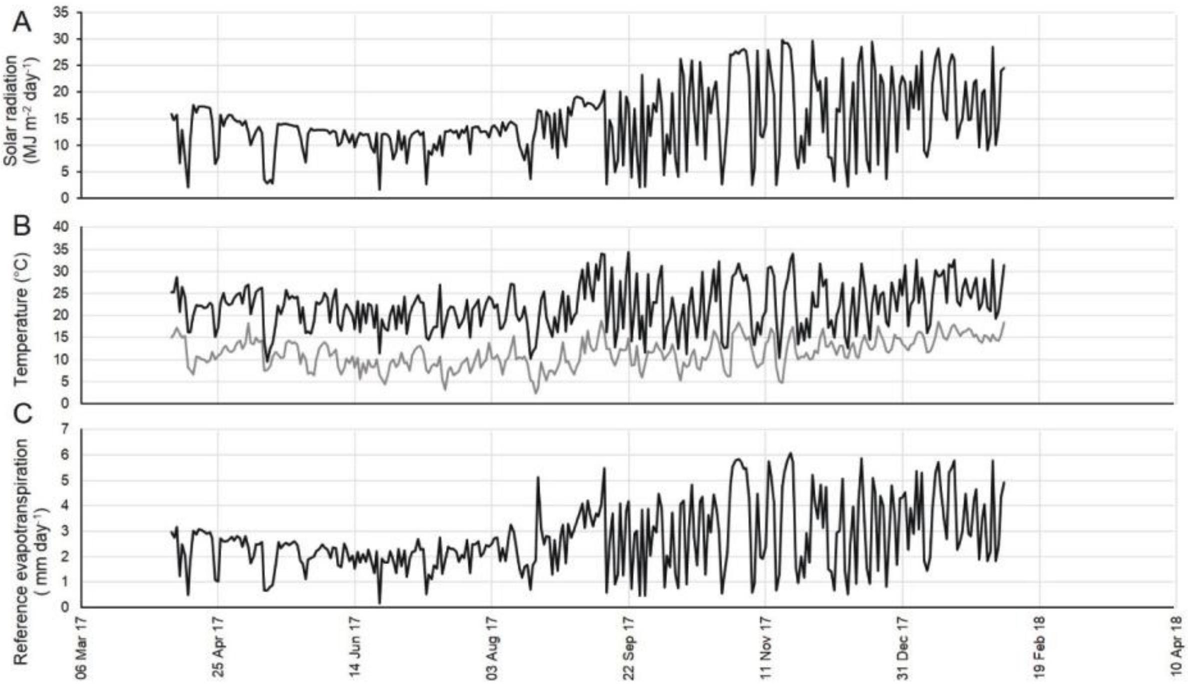

Figure 2: A) Daily solar radiation, B) minimum (grey line) and maximum (black line) daily average air tempertures and C) daily total reference evapotranspiration (ET_o) over the course of the measurements at Everdon estates from 8 April to 6 February.

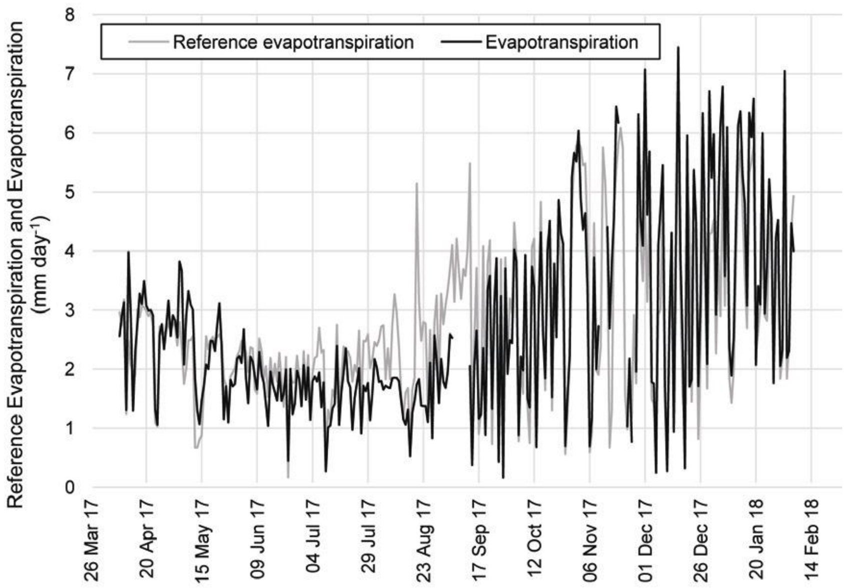

Figure 3: Evapotranspiration and reference evapotranspiration of the 4-year old 'Hass' avocado orchard at Everdon Estates from 8 April 2017 to 6 February 2018. Missing ET data is largely a result of rainy days when measurements are not possible due to free water on the sensors.

Water use

Evapotranspiration, consisting of both transpiration by the trees and cover crop, and evaporation from the soil, varied between 0.17 and 7.44 mm day^{-1} over the course of the measurement season, with an average of 2.69 mm day^{-1}. There was a fairly good relationship between ET and atmospheric evaporative demand, which is represented by ET_o (Fig. 3), indicating that the prevailing weather conditions drive water use and it is important to quantify weather variables on farms when determining irrigation requirements. As expected from the weather data, water use varied more in summer than in winter, with lower rates observed in winter when conditions were cooler and the days were shorter. The ET_o followed a similar pattern to the ET in summer but was noticeably higher than ET in the winter months, when evaporation from the soil was most likely lower due to a drier soil as a result of lower rainfall in this period.

Crop coefficients (Fig. 4), calculated according to equation (1), fluctuated seasonally, being highest in summer and lowest in the winter months, showing that it would be appropriate to use seasonal or monthly crop coefficients for avocado crops to determine ET from ET_o. On a daily basis K_c values varied between 0.34 and 1.81 (Fig. 4), whilst seasonal variation was between 0.8 and 1.15 (Table 1). Seasonal K_c values were higher in summer and autumn and lower in winter and spring and tended to follow the typical four stage curve proposed in FAO-56 (Allen *et al.*, 1998). These crop coefficients are considerably higher than that recommended for irrigation in California, where a K_c of 0.7 is suggested (Carr, 2013). Carr (2013) also suggests that for mature trees, K_c values are generally in the range of 0.4-0.6. Variation in K_c values between different studies is not surprising, as crop coefficients are impacted by variety, rootstock, tree spacing, canopy height, ground cover, leaf area index, microclimate, irrigation method and frequency and measuring crop evapotranspiration (Naor, 2006; Pereira *et al.*, 2015). In addition, these studies were largely conducted in winter rainfall regions where soil evaporation would be much lower in summer months, resulting in lower ET at this time and therefore lower K_c values.

Due to the large day-to-day changes in ET, caused largely by fluctuating environmental conditions, more meaningful values can be obtained by calculating seasonal averages (Table 1). Daily average ET in summer was 3.98 mm day^{-1}, whilst in winter daily average ET was 1.64 mm day^{-1}. These values agree with those of Hoffman and Du Plessis (1999), who found that in summer in Burgershall 'Hass' orchards used 4 mm day^{-1}, whilst in winter values were below 1.5 mm day^{-1}. However, it is unclear how big the trees were in this study, which is an important determinant of orchard water use and therefore comparisons between these two studies are not entirely valid and more definitive knowledge on avocado water use is required.

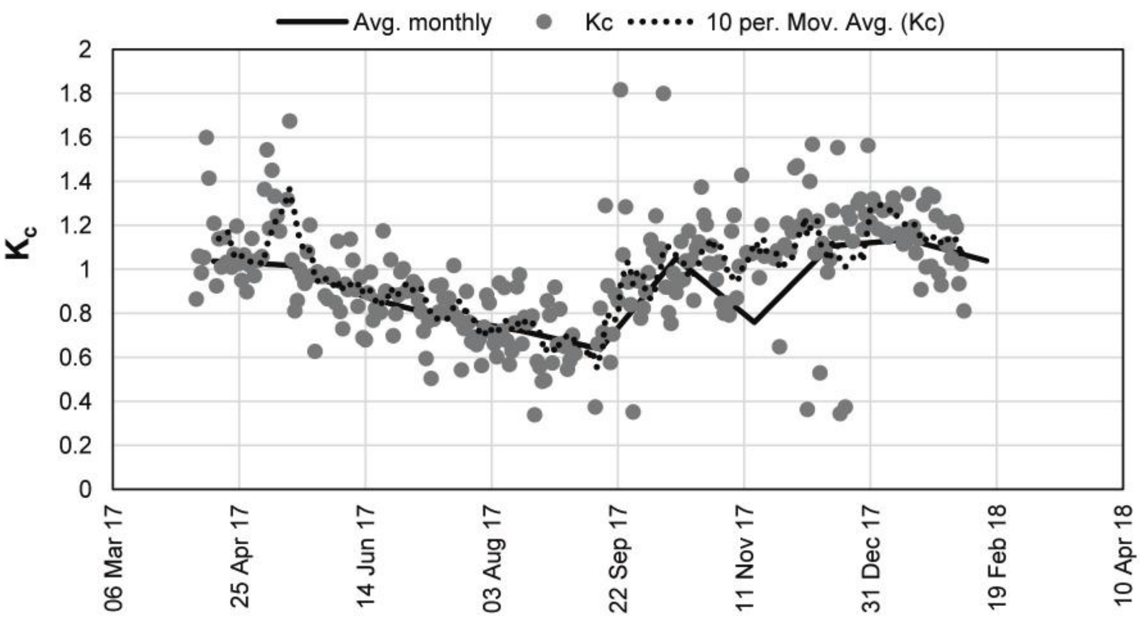

Figure 4: Daily crop coefficients for the 4-year old 'Hass' avocado orchard at Everdon Estates from 8 April 2017 to 6 February 2018. The grey dots represent daily K_c values, the dotted line is a 10-day moving average of K_c values and the black line represents a monthly average K_c.

Table 1: Average seasonal temperature, reference evapotranspiration (ET_o), evapotranspiration (ET) and crop coefficients (K_c) for the 4-year old 'Hass' avocado orchard.

	Spring	Summer	Autumn	Winter	Average
Temperature (°C)	16.3	18.5	17.6	13.8	17.0
ETo (mm day^{-1})	3.17	3.42	2.66	2.10	2.88
ET (mm day^{-1})	2.97	3.98	2.45	1.64	2.69
K_c	0.98	1.15	1.08	0.80	0.98

CONCLUSIONS

Evapotranspiration from orchards is highly variable and dependent on the prevailing weather conditions, canopy size, planting distances, pruning strategies, irrigation method and scheduling, presence of a cover crop and frequency of rainfall. As a result it is likely to be challenging to transfer the results from this study to all orchards. However, by measuring all the driving variables for water use, it will be possible to parametrise models which can estimate water use under a wide range of conditions. Preliminary results indicate that seasonal or monthly crop coefficients might provide reasonable estimates of ET of avocado orchards. This data set does, however, represent one of the first of avocado orchard ET determined using eddy covariance measurements and therefore is of great value. Future measurements will include ET measurements in a mature orchard and in a non-bearing young orchard, transpiration measurements in all three orchards and ecophysiology measurements to understand the regulation of water relations in avocado trees.

Acknowledgements

We wish to acknowledge funding from the Water Research Commission and the South African Avocado Growers' Association (SAAGA) and we would like to thank Westfalia Fruit and Everdon Estates for access to commercial orchards and assistance in the orchards.

REFERENCES

ALLEN, R.G., PEREIRA, L.S., RAES, D. & SMITH, M. 1998. Crop evapotranspiration: guidelines for computing crop water requirements, Irrigation and Drainage Paper 56, 56. United Nations FAO, Rome http://www.fao.org/docrep/X0490E/X0490E00.htm.

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

FOKEN, T. *et al*. 2004. Post-field data quality control, Handbook of micrometeorology. Springer, pp. 181-208.

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

LAHAV, E., WHILEY, A.W., SCHAFFER, B. & WOLSTENHOLME, B.N. 2002. Irrigation and mineral nutrition. *The avocado: botany, production and uses* 259-297.

NAOR, A. 2006. Irrigation scheduling and evaluation of tree water status in deciduous orchards. Horticultural reviews-Westport then New York 32: 111.

PEREIRA, L.S., ALLEN, R.G., SMITH, M. & RAES, D. 2015. Crop evapotranspiration estimation with FAO56: Past and future. *Agricultural Water Management* 147: 4-20.