Quantifying water use of mature pecan orchards in selected irrigation areas of the Northern Cape – research report

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The pecan water use project, jointly funded by the Water Research Commission (K5/2814//4) and SAPPA, is in its fourth year and we now have three full seasons of measurements of pecan water use in the Vaalharts region and two full seasons of measurements in an orchard close to Groblershoop. In addition to water use measurements, we also have four seasons of data quantifying the impact of water stress at different phenological stages on yield and quality of pecans. COVID-19 travel restrictions have a had a slight impact again this past season, but we were very fortunate to not lose any data, thanks to assistance from Hardus du Toit, Marnus Groenewald and Alvin Archer. Since the last report some measurements for the finalisation of transpiration measurements have taken place and slightly more realistic transpiration values are presented, together with the preliminary analysis of the environmental control of transpiration and the partitioning of evapotranspiration into transpiration and evaporation. Results of the water stress trial will also be discussed.

Water use of pecan orchards

The aim of this research is to answer the following questions. How much water do mature 'Wichita' and 'Choctaw' trees use in a day and over the entire growing season in the Vaalharts and Upington regions? How does water use change with changing environmental conditions, canopy size and canopy development? Based on canopy size and local conditions how much water will your trees use in a month and over the season? What is the water use efficiency (kg m^{-3}) and water productivity (R m^{-3}) of pecans?

Where and what are we measuring?

We are measuring water use in two regions in the Northern Cape that were chosen based on the importance of the production regions and the prevailing climate. The aim was to select regions that were significantly hotter than where previous water use research was conducted in Cullinan, in order to ensure that our water use model is suitable for all production regions in South Africa. By examining the accumulation of growing degree days or thermal time (base temperature of 15.5 °C) and seasonal and average daily reference evapotranspiration and average daily vapour pressure deficit (VPD) across the two study sites, it is clear that in both the 2019/20 and 2020/21 seasons we were working in two contrasting environments (Table 1). This has given us confidence that we have made good choices of experimental sites. An aerial view of the two pecan orchards in Vaalharts and Groblershoop is shown in Figure 1. Maximum canopy size of the trees has fluctuated over the two seasons as a result of pruning of the trees.

Table 1 Comparison of weather variables in Vaalharts and Groblershoop in the 2019/20 and 2020/21 seasons. ET_o – reference evapotranspiration, VPD - vapour pressure deficit

Season	Region	Growing degree days	Seasonal ET_o (mm)	Avg. daily ET_o (mm day^{-1})	Avg. daily VPD (kPa)
2019/20	**Vaalharts**	1740	1479	4.9	1.9
	Groblershoop	2110	1674	5.5	2.3
2020/21	**Vaalharts**	1680	1318	4.4	1.8
	Groblershoop	2040	1561	5.2	2.1

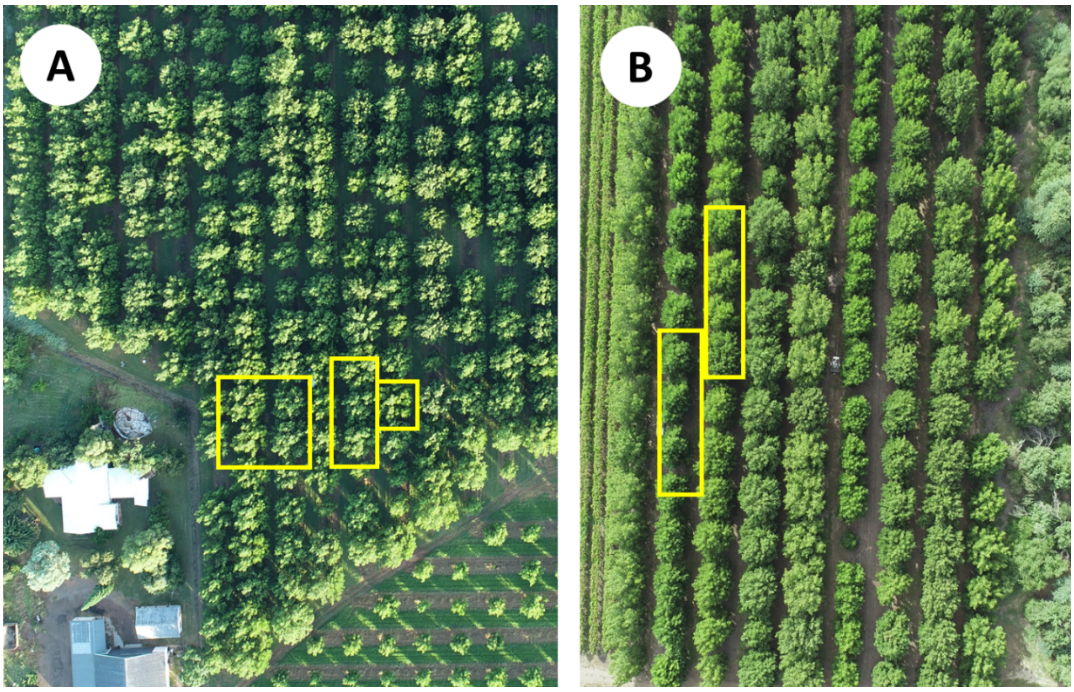

Figure 1 Aerial view of the pecan orchards in A) Vaalharts and B) Groblershoop where water use measurements are being conducted. The yellow rectangles indicate the trees used for sap flow measurements.

What have we found?

Transpiration (T), evapotranspiration (ET) and reference evapotranspiration (ET_o) in Vaalharts and Groblershoop clearly followed a seasonal pattern (Figure 2), with highest values in summer and lowest values in winter. This matched both changes in canopy size and atmospheric evaporative demand, as indicated by ET_o. Both ET and T varied with weather conditions, with ET following ET_o more closely than T. Typically T did not increase at the same rate in summer as both ET and ET_o. Seasonal ET (1 September to 30 June) in Vaalharts was 1245 mm for the 2019/20 season and 1103 mm for the 2020/21 season. The lower ET in the second season reflects the slightly cooler season, with seasonal ET_o approximately 150 mm lower in the 2020/21 season (1318 mm) as compared to the 2019/20 season (1479 mm). Evapotranspiration in the Groblershoop orchard (1245 mm) was approximately 150 mm higher than in Vaalharts for the same season, which reflected the higher ET_o for this region in the 2020/21 season (1561 mm). Seasonal ET therefore reflected atmospheric evaporative demand. As expected, seasonal T reflected both atmospheric evaporative demand and canopy size.

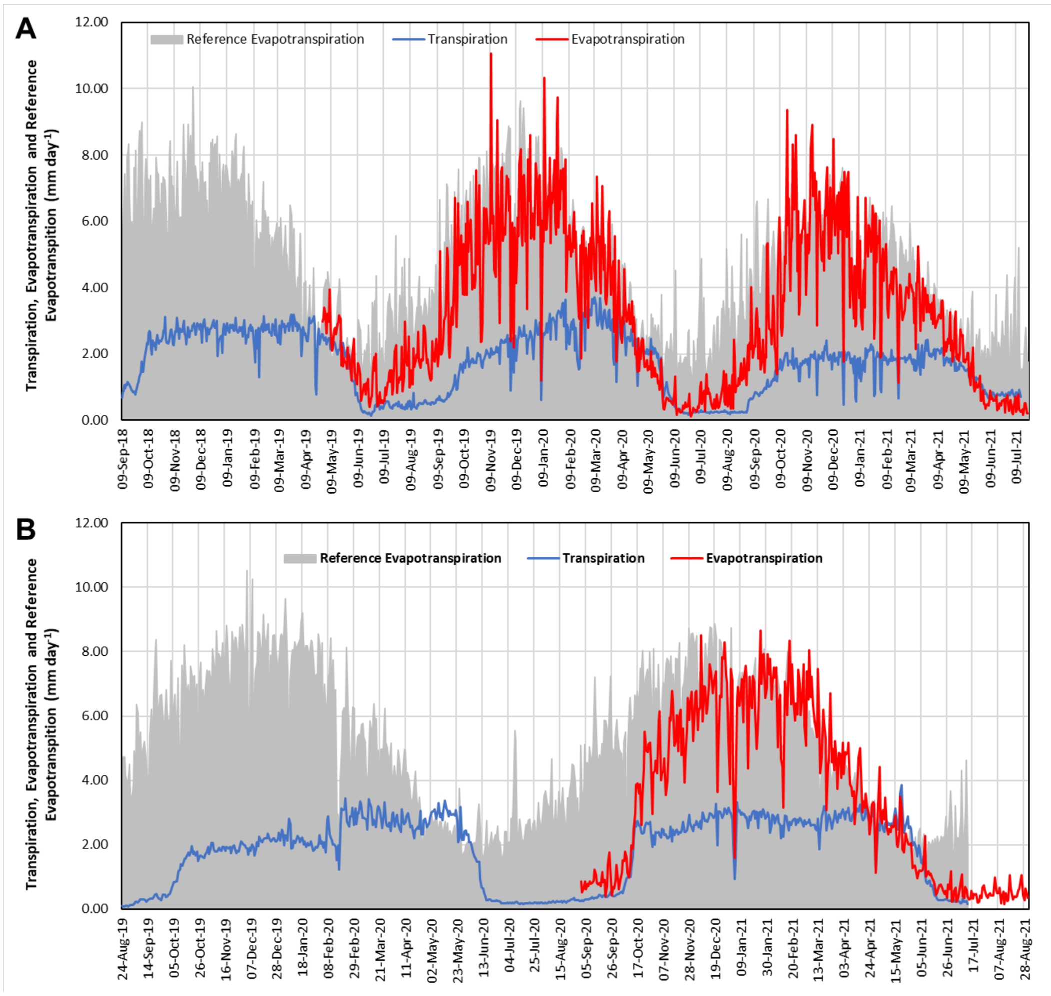

Figure 2 Daily evapotranspiration, transpiration and evapotranspiration (mm day^{-1}) from A) Vaalharts and B) Groblershoop

The reason why T does not increase at the same rate as ET becomes apparent when assessing the response of hourly daytime tree transpiration to ET_o and VPD, over the summer period when canopy size is at its maximum (Figure 3). It is clear that transpiration increases with both these variables initially, however, the rate at which transpiration increases with increasing ET_o and VPD is not constant. As ET_o increases above approximately 3 mm h^{-1} and VPD above 2-2.5 kPa, there is a reduction in the rate of increase of transpiration and a maximum transpiration rate is reached. This maximum transpiration rate was very similar for the two regions and two cultivars. This suggests that under very hot and dry conditions, pecan tree transpiration cannot meet atmospheric evaporative demand and stomata start to close to limit water loss. As a result, differences in water use in the very hot regions of South Africa (e.g. Upington vs Vaalharts) may not differ too much on a daily basis for trees with a similar canopy size.

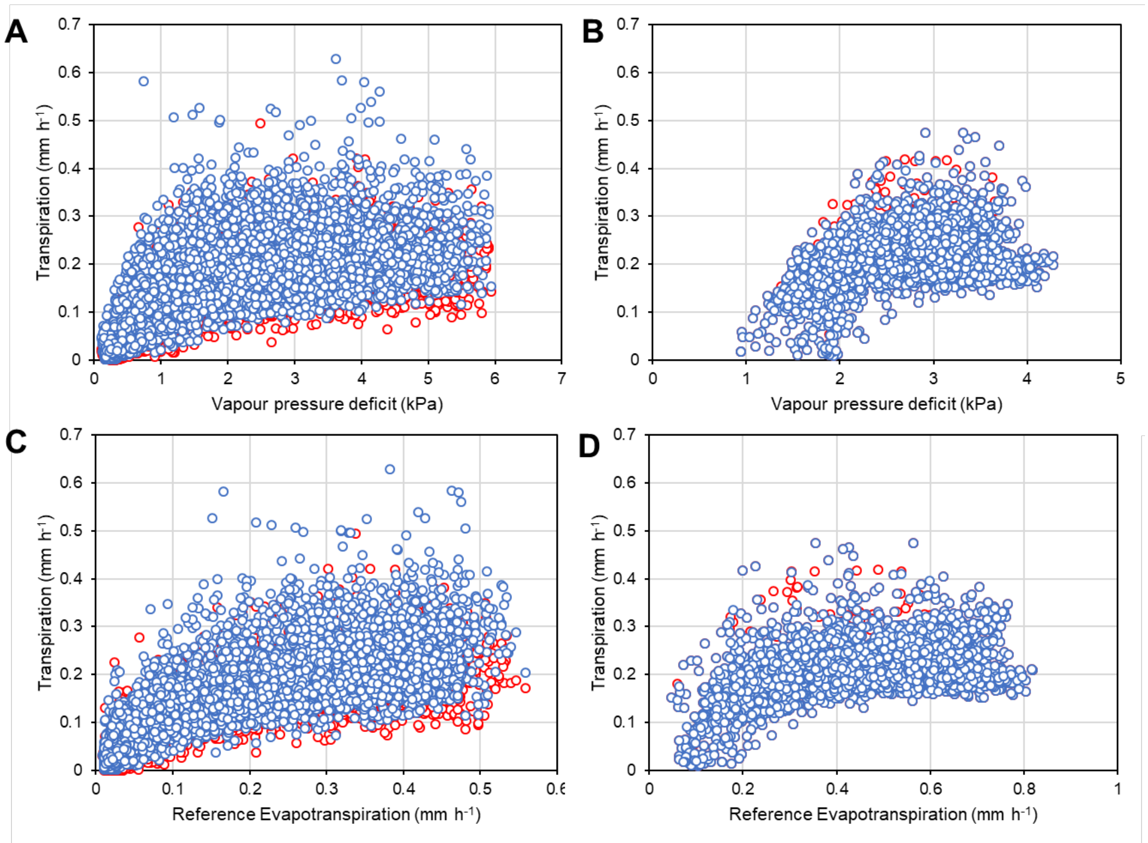

Figure 3 The response of hourly daytime transpiration of 'Choctaw' (blue circles) and 'Wichita' (red circles) pecan trees to A and B) vapour pressure deficit (VPD) and C and D) reference evapotranspiration (ET_o) in the A and C) Vaalharts and B and D) Groblershoop regions for the summer period.

One of the more accurate ways to model orchard water use is to consider transpiration from the trees and evaporation from the soil (E_s) separately. This is because management practices will impact these two components of water use independently. For example, pruning reduces canopy size thereby reducing transpiration, but as a result of more solar radiation penetrating down to the orchard floor, evaporation is likely to increase. In addition, the type of irrigation system will influence evaporation rates as it will determine the fraction of the orchard floor that is wetted and the frequency of wetting. Estimates of E_s are therefore very important in order to parameterise a model. As we have determined both ET and T, we can obtain an estimate of evaporation by subtracting T from ET. On average, over two seasons, evaporation made up 50% of ET in the orchard in Vaalharts and over one season in Groblershoop evaporation was 43% of ET. In addition, E_s was typically a greater proportion of ET in spring and summer. Evaporation is typically viewed as a non-beneficial consumptive water use and in times of drought when water savings need to be made, reducing this component could allow for some water savings. This could be especially important in young orchards, as a large part of the orchard surface is not shaded by trees. It is also important to note that we are still finalising transpiration values and so these evaporation values are also not final.

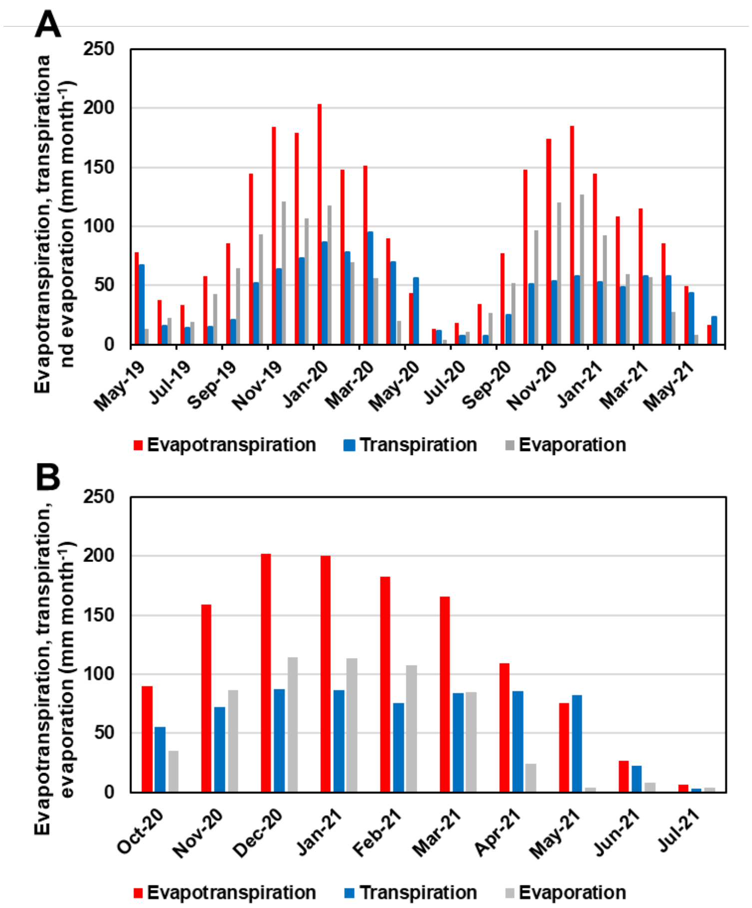

Figure 4 Comparison of monthly evapotranspiration, transpiration and evaporation rates from the orchard in A) Vaalharts and B) Groblershoop. Evaporation was determined by subtracting transpiration from evapotranspiration.

The impact of water stress at different phenological stages on yield and quality of pecans

Where and what are we measuring?

We have completed four full seasons of measurements for the water stress trial conducted on the University of Pretoria's Hatfield Experimental Farm, recently renamed Innovation Africa@UP. In this trial a mild water stress is implemented at four phenological stages, which include flowering and nut set, nut sizing, nut filling and shuck dehiscence. These treatments are compared to a well-watered control, with irrigation scheduled by monitoring soil water potential and pre-dawn and midday leaf water potentials. Yield from each replicate is determined after each season, together with a number of quality parameters.

What have we found?

According to predawn leaf water potentials and midday stem water potentials water stress was successfully implemented at each phenological stage for the first three seasons, aprt from shuck dehiscence in the first season. Unfortunately, despite our best efforts' rainfall cannot be excluded from treatments during very heavy rainfall events and this can hinder our efforts at inducing a stress. In addition, there were occasions when pipes burst to the different irrigation treatments, which impacted the control early on the 2019/20 season. In the 2020/21 season we also experience a large amount of water stage fruit split, in which close to 50% of the nuts dropped from all the 'Wichita' trees in late January, which drastically reduced the yield in all treatments and negated the impact of the water stress treatments during this season (Figure 5). During this time, 140 mm of rain fell and overcast conditions were experienced for approximately two weeks. However, over the first three seasons we have a good data set for understanding the impact of stress on yield and quality of pecan orchards. Yield per hectare for various treatments over the four seasons is shown in

Table 2. In the first two seasons yield was reduced at the flowering and nut set stage, which was as a result of increased abortion of female flower and increased nut drop at this time. In the third season, irrigation to the control broke down early in the season, which resulted in a stress that could have reduced yield. As a result, there was no difference between this treatment and the control. In three of the four seasons nut size was reduced when a water deficit was imposed during nut sizing, but there was no impact on yield. Yield was reduced in three of the four seasons when trees were stressed during nut filling, with quality negatively impacted in all four seasons (increased number of pops and poorly filled nuts). This stage is therefore particularly sensitive to water stress in terms of both yield and quality. Stress during shuck dehiscence had no impact on yield but the proportion of stick tights increased in two seasons as a result of the stress.

Table 2 Average in shell yield (t ha^{-1}) for the different stress treatments in the (a) 2017/2018 season, (b) 2018/2019 and (c) 2019/2020 season. Yield was adjusted to 4% moisture content. Treatments with the same letter are not significantly different from each other ($p < 0.05$).

	Yield (t ha^{-1})			
Treatment	**2017/18**	**2018/19**	**2019/20**	**2020/21**
Control	1.70a	1.53a	2.68a	0.67a
Flowering and nut set	0.89b	1.01b	2.78ab	0.43a
Nut sizing	1.37ab	1.42a	3.19a	0.83a
Nut filling	1.05b	1.15ab	2.21b	0.71a
Shuck dehiscence	1.66a	1.44a	3.06a	0.51a

Figure 5 Water stage fruit split in 'Wichita' trees in late January 2021.

The impact of stress at each phenological stage in terms of both yield and quality is well illustrated by comparing gross income received for the yield from the different stress treatments (Table 3). This gross income is based on average nut size in the random 1 kg sample taken from each treatment. In the first two seasons it is clear that income was reduced at all the stages when a water stress was imposed and this was particularly noticeable when a stress was imposed during flowering and fruit set and nut filling. In the third season income was only reduced for the nut filling stage. As mentioned previously, this was probably due to the breakdown of irrigation in the control during flowering and fruit set. Gross income for the fourth season was impacted by the water stage fruit split which resulted in very low yields. Over the four seasons it is evident that water stress had a negative impact on either yield or quality, or both, at each phenological stage evaluated, as seen in the cumulative data. The potential for water savings during the season is as a result quite low, but in years where water supply is reduced, there may be some potential to save some water during nut sizing and shuck dehiscence. Stress should be avoided as much as possible during flowering and fruit set and nut filling. By continuing with this trial for another year, it will also be possible to further our understanding of the carry over effects from stress in one season to the next and the long-term effects of water stress on pecan orchards.

Table 3 Total gross income received as a result of imposing a water stress at different phenological stages. This value considers both yield and quality

Season	2017/2018	2018/2019	2019/2020	2020/21	Cumulative income
Control	R 102 150	R 91 609	R136 680	R35 683	R366 122
Flowering and nut set	R 53 700	R 60 396	R141 780	R23 075	R278 951
Nut sizing	R 82 350	R 76 410	R130 790	R44 127	R333 677
Nut filling	R 54 340	R 59 386	R112 710	R37 525	R263 961
Shuck dehiscence	R 99 900	R 86 247	R143 820	R27 318	R357 285

Where to now?

We are currently busy with the fourth season of measurements in Vaalharts, the third season of measurements in Groblershoop and the fifth season of measurements in the Pretoria water stress trial. The focus for the 2021/22 season is improved canopy size measurements and prediction of canopy development, evaporation measurements and an improved understanding of the environmental and physiological control of transpiration. This will include the parameterisation of a radiation interception model for pecans. Finally, we are in the process of evaluating remote sensing applications for the spatial determination of stress and yield in pecan orchards.

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