DISCLAIMER

This project was conducted with financial assistance from a grant from the Metropolitan Water District of Southern California (Metropolitan), the U.S. Bureau of Reclamation, the Environmental Protection Agency, the Central Arizona Project, the Southern Nevada Water Authority, the Southern California Gas Company, and the Western Resource Advocates through Metropolitan's Innovative Conservation Program (ICP). The ICP provides funding for research to help document water savings and reliability of innovative water savings devices, technologies, and strategies. The findings of this project, summarized in this report, are solely from the project proponent.

Final Report: Measuring sap flow in avocado to reduce irrigation

DATE: Submitted 28 December 2018; revised 21 January 2019

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California Avocado Commission (Dr. Tim Spann, Research Program Director); Cal Poly Pomona (Dr. Valerie Mellano, Chair, Plant Sciences Department); Dynamax Inc. (Mike van Bavel, president)

INTRODUCTION

The goal of the research conducted for this grant from the Innovative Conservation Program was to find ways for avocado growers in southern California to save irrigation water and improve water efficiency in avocado orchards. We approached this by measuring the actual water use of avocado trees using sap flow sensors, thereby generating information that can be used for determining irrigation needs. Avocado trees are among the most water-demanding tree crops in California, and the water footprint of a single avocado fruit is about 60 gallons (Mekkonnen & Hoekstra 2011). The challenge for growing such water-demanding crops is to supply exactly the right amount of water needed by the plants and avoid wasteful watering. Avocados are strongly affected by both drought stress and overwatering, both of which lead to fruit drop (Carr 2013). They are also sensitive to salinity, and irrigation intervals must allow for accumulated salts to be leached out of the root zone.

The best ways to meet such challenging requirements are to irrigate based on direct measurements of plant water use, or at least soil water and meteorological data. However, irrigation in California avocado orchards today is typically not based on such data and often impacted by practical constraints, such as the availability of irrigation water and labor. No avocado growers in California are currently known to use plant-based measures of water need, and few conduct soil moisture measurements. Where irrigation water is available and not too expensive, as in the coastal areas of southern California, where avocados are grown, current irrigation practices tend to err on the side of over-irrigation. In such areas, innovative technology that measures actual plant water use can potentially result in large water savings.

The research conducted for this grant determined the actual water use of avocado trees at Pine Tree Ranch, near Santa Paula, Ventura, County, in four different treatments based on sap flow measurements. Treatments included two different planting densities and a comparison of trees grown on berms – a method designed to prevent root rot – vs. not on berms. We also conducted education about these experiment and outreach to growers in collaboration with the California Avocado Commission (CAC), which leases 11 acres of the Pine Tree Ranch property from its owner, Cal Poly Pomona to serve as demonstration orchards for avocado growers. The sap flow technology used in this project is used in some vineyards in Northern California (Su 2014; Scholasch 2018) and has been tested on almond and mandarin orange trees (Mike van Bavel, Dynamax Inc., pers.comm.), but it had never been used on avocados.

The annual water demand (evapotranspiration) at the site is about 53” per year, with standard avocado irrigation about 70% of that (i.e., the recommended crop factor, k_c, is 0.7), about 32 acre feet of irrigation per year for the 11 acre lease. Until now, irrigation in this orchard has been done via micro-sprinklers once a week for 8 hours. Based on local soil moisture measurements, the root zone at the soil surface is filled up after 2 hours, so with the current irrigation schedule up to 75% of water may have been wasted. Infrequent and long irrigation periods (0.5-2 times a week for many hours) are common practice in California avocado orchards, largely due to when irrigation water and staff are available. Estimates for the current irrigation water use on the >50,000 acres planted with avocado in Southern California (CAC 2014) are between 2.5 and 3 acre feet per year per acre (Bender & Engle 1988), and it seems likely that in many orchards between 25 and 80% of this water is lost as runoff. These amounts could potentially be saved while maintaining current avocado production or alternatively, production could be increased by about the same percentages while maintaining current irrigation levels.

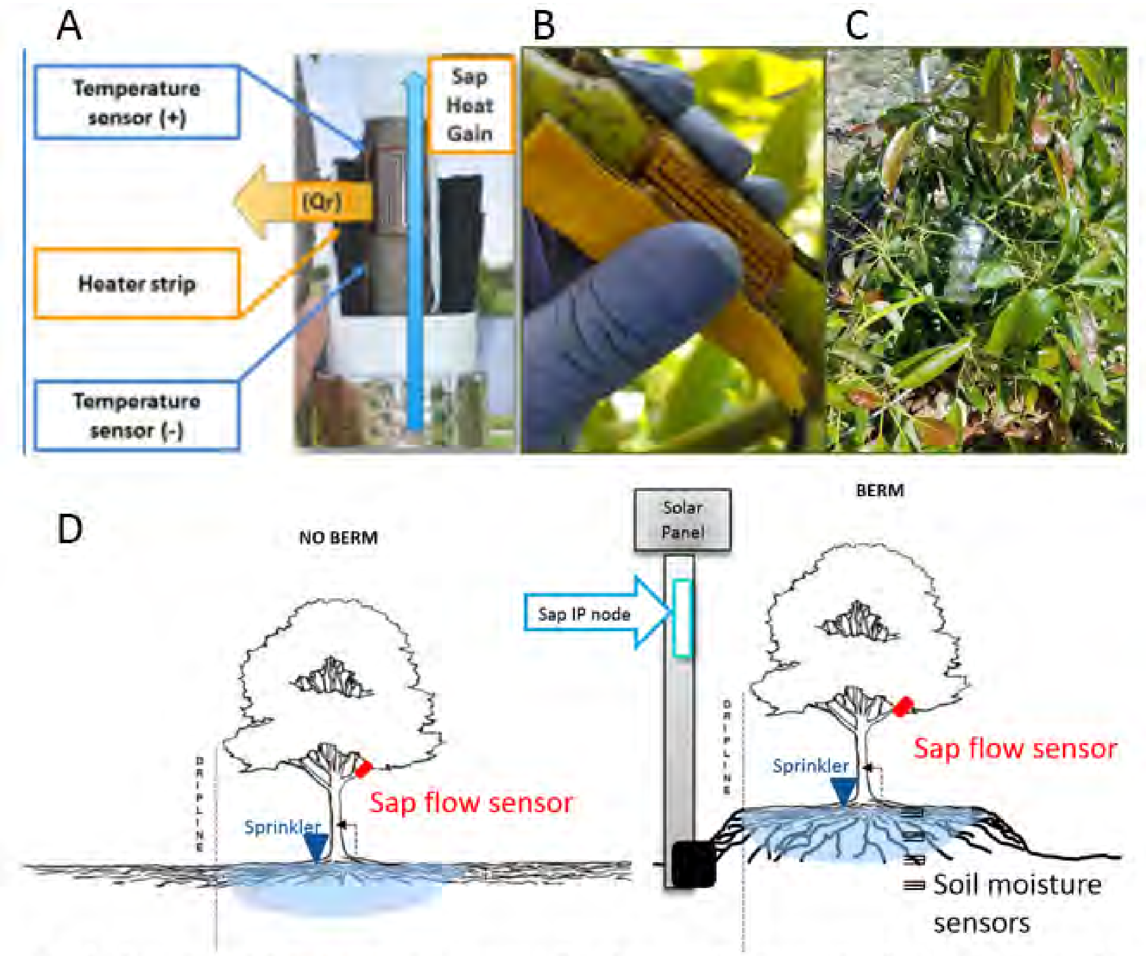

Fig. 1. Experimental design to measure sap flow in avocado trees using Exo-Skin sensors. A. Basic principles of the sap flow sensors: A heater strip provides permanent heat to the stem, and two temperature sensors are used to calculate the heat flux caused by sap flux in the stem. B. Installation of the sensor on a stem. C. Installation covered by aluminum insulation on an avocado branch. D. Experimental setup at the field site, showing the treatment comparison between trees on regular soil (no berm) and on soil berms. Superficial root systems are thought to be more restricted on soil berms and possibly better positioned to take up irrigation water from micro-sprinklers under the tree canopy than roots on flat soil that spread more widely.

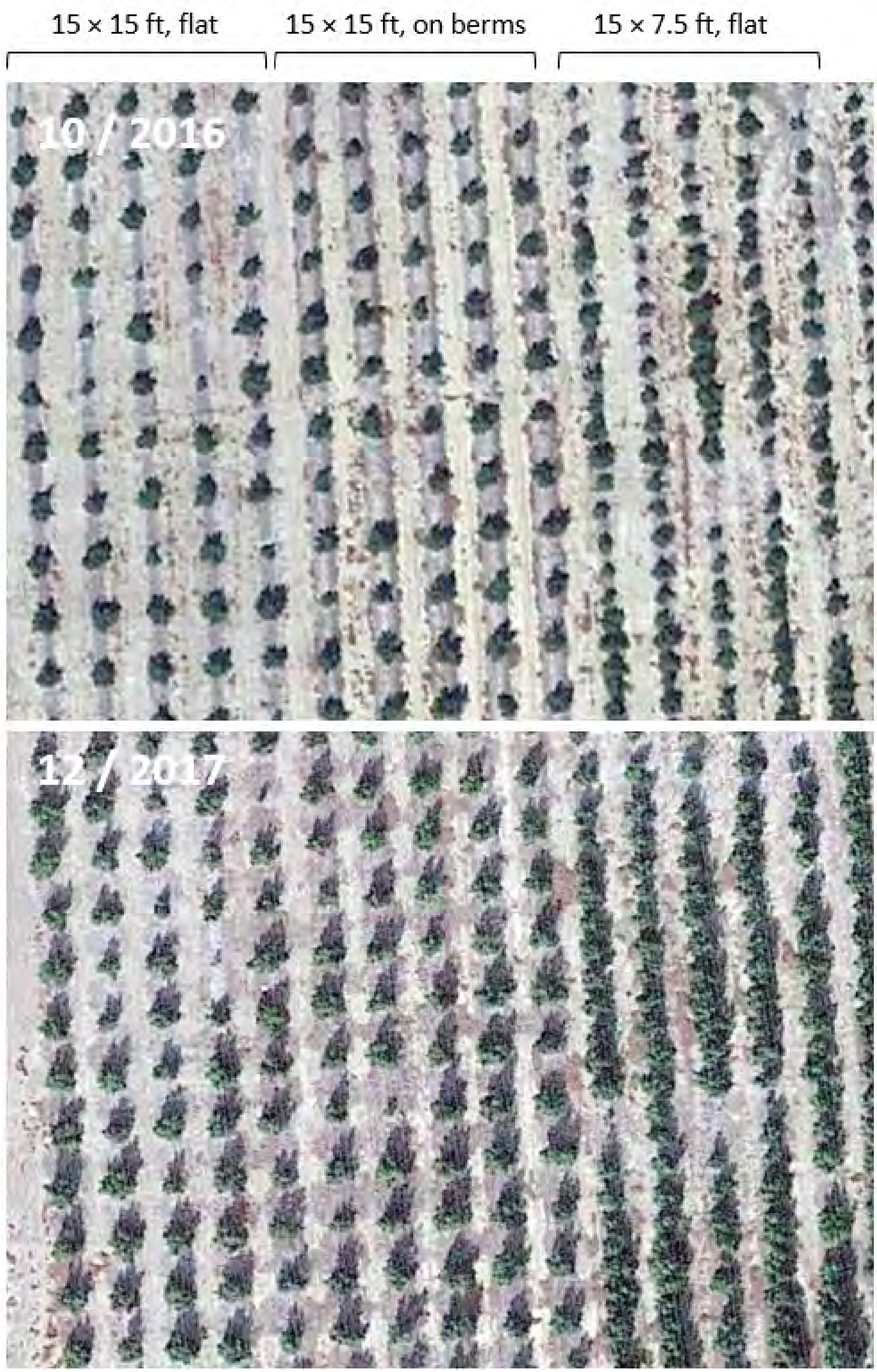

Fig. 2. Aerial photographs of the study site at Pine Tree Ranch, Santa Paula, California, in October 2016 and December 2017, obtained from Google Earth Pro. The soil berms are clearly visible in the upper image from 2016.

PROJECT ACTIVITIES

The research was conducted as proposed and included measurements of sap flow in stems to determine the actual water needs of 3-year-old (in 2016) Hass avocado trees in four treatments, incl. a comparison of treatments at low density on regular soil vs. trees grown on about 2-foot-tall soil berms measured from January to November 2017 and two different planting densities (15 × 15 ft and 7.5 × 15 ft.) on regular soil measured from March to December 2018. Evaporative demand, ET_0, at the site is 53 inches, about 1,350 mm per year, and about 4.4 acre feet per acre per year. Annual precipitation in the three years was 10.0 inches in 2016, 15.2 inches in 2017, and 7.8 inches in 2018. The irrigation water source is groundwater supplied by the Community Mutual Water Company in Santa Paula, which supplies 400 acres of orchards. Irrigation was applied once a week for 8 hours using one 9.4 gallon-per-minute micro-sprinkler per tree, except during rainy periods.

Sap flow was measured using a SapIP system (Dynamax Inc., Houston, TX) with 8 1-inch diameter heat balance Exo-Skin stem gauges, comparing two different treatments with four trees each. Data were transmitted wirelessly to a gateway and were available online. See Fig. 1 for the experimental setup. Meteorological data were available from a nearby CIMIS weather-station in Santa Paula (incl. reference evapotranspiration, ET_0, for a standard grass-covered surface). The findings were used to quantify the actual tree water use, T_a, as a fraction of ET_0, for each treatment.

Quantification of total water use per tree and per area involved the following four steps:

1) Basal diameters of all major branches on each measured tree were measured at 4-8 week intervals to enable extrapolation of sap flow results from one measured branch to the whole plant (van Bavel 2016).

2) Sap flow sensors were installed on four replicate trees per treatment. Real-time monitoring was done by wireless transmission of data to a gateway, which transmitted to an existing web site. Data were accumulated over 15-minute measurement intervals, extrapolated to the entire trees, and then averaged for all replicates in an experimental treatment. This resulted in the variable T_a – actual transpiration, the amount of water actually used by the trees. Water use was scaled up to an area-basis (volume per area, in mm) based on the planting density of trees.

3) The reference evapotranspiration, ET_o, (in mm) was obtained from the nearby CIMIS weather station in Santa Paula.

4) A stress coefficient, K_s, was then calculated from daily water use T_a and daily ET_o as $T_a/ET_o = K_s$. This K_s varies during the season and week by week, for the entire year and depends on planting density and tree sizes. T_a and K_s only accounts for tree water use, not water loss through soil evaporation, E_{soil}, which must be added to calculate the so-called crop factor, K_c, and to determine irrigation need as $(T_a + E_{soil})/ET_o = K_c$. The innovation here is that tree water use is determined on site for the particular conditions of an orchard instead of estimated based on published data for the whole region.

RESULTS

The avocado trees were 3-years-old in early 2016, with a canopy cover of about 13% in late 2016 (Fig. 2). The trees grew rapidly during the study period, reaching about 20% canopy cover in December 2017 (Fig. 2) and about 25% in December 2018. The sap flow system was installed and tested immediately in 2016 upon learning that the ICP grant had been awarded, with data collection commencing in November 2016

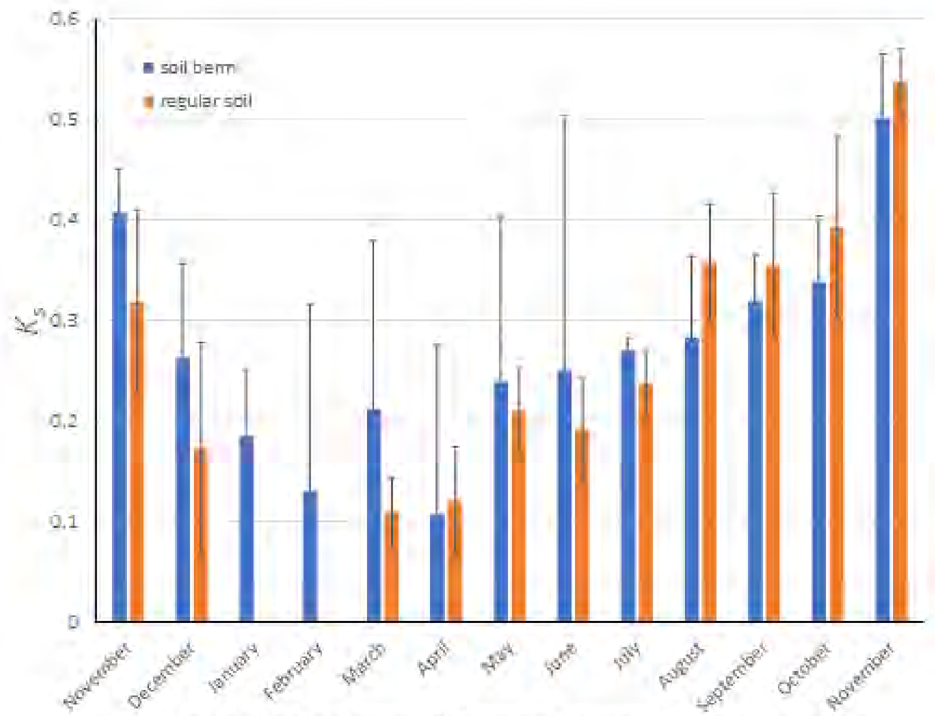

Fig. 3. Water use by 4-year-old avocado trees shown as K_s, a fraction of potential evapotranspiration, ET_0. Data from November 2016 to November 2017, showing trees grown at 15 × 15 ft. density regular, flat soil and on soil berms.

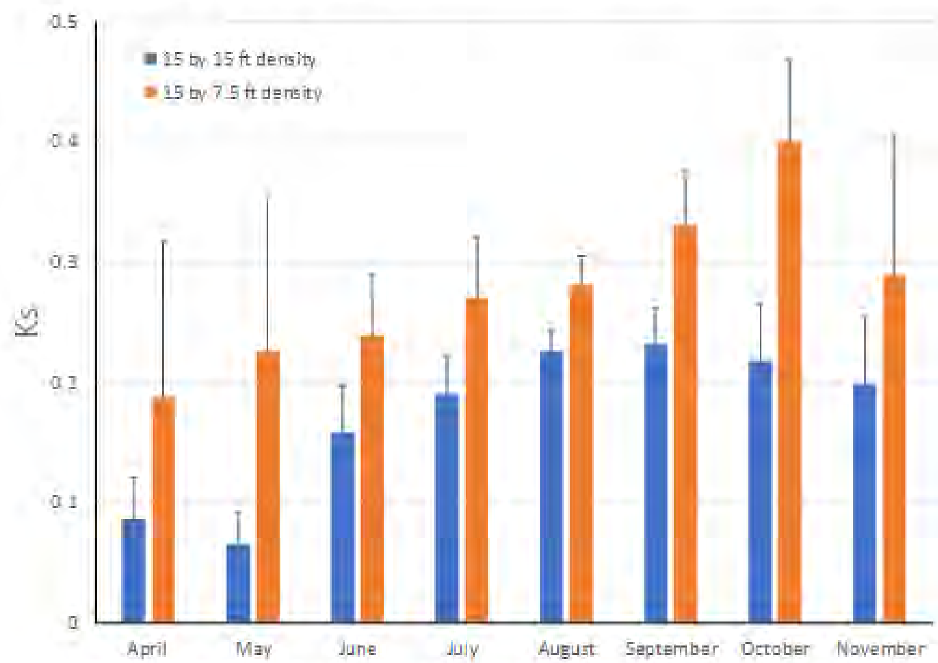

Fig. 4. Water use by 5-year-old avocado trees shown as K_s, a fraction of potential evapotranspiration, ET_0. Data from April 2018 to November 2018, showing trees grown at 15 × 15 ft. and 15 × 7.5 ft. Density, both on regular, flat soil.

for trees growing at a spacing of 15 by 15 ft in a control treatment on regular soil and on 2 ft soil berms (Fig. 1). Sap flow on four trees per treatment was monitored continuously until November 2017, but due to initial technical difficulties, some data are missing for January and February 2017.

Tree water use in 2017, which was a year with average rainfall, ranged from close to 10% of potential evapotranspiration, ET_o, in February and April 2017 to about 50% in November 2017, with a distinct increase in water use (Fig. 3) that probably was caused in part by the rapid growth of the trees over the summer. There was no significant difference in water use between the two treatments.

In 2018, sap flow sensors were installed on trees planted at the standard 15 by 15 ft density (same treatment as in 2016-17, but on different trees) and a high-density treatment at 15 by 7.5 ft density. Sap flow measurements on four trees per treatment commenced in April 2018 and continued until November 2018. This year, which was very dry, tree water use in the 15 by 15 ft. density treatment was lower than the previous year, ranging from about 8% to about 25% of potential evapotranspiration, ET_o. The high-density treatment predictably had higher water use, ranging from about 20% to 40% of ET_o. Water use in both treatments increased from April to September, again most likely partly due to tree growth (Fig. 4).

DISCUSSION

The main objective of this project was to determine the feasibility of using heat-balance sap flow sensors for determining the actual water use of avocado trees in four treatments. The second objective was to educate avocado growers about using this technology and its potential for determining irrigation needs of avocado trees. For this reason, the research was set up at the demonstration orchard of the California Avocado Commission at Pine Tree Ranch, where it was shown to growers at an event in 2017. The choice of Pine Tree Ranch as the study site meant that the sensors were installed on newly-planted trees that were 3-years-old in 2016 and grew rapidly over the study period. The leased property did not contain a well-maintained mature avocado orchard in 2016, so the water use data are not directly representative for mature avocado orchards, where tree canopies typically cover 75% or more of the ground. However, the same sap flow technology can be easily installed on mature trees, and the current study successfully demonstrated the feasibility of using sap flow sensors on avocado trees.

Our findings of water use in young avocado trees agree mostly with previous studies. Published crop factors, k_c, for mature avocado vary from 0.4 to 0.85, with 0.64 recommended in coastal orchards in the Ventura area (Grismer et al 2000). Pine Tree Ranch is further inland, about 16 miles away from the coast, so there is more sun and a slightly higher potential evapotranspiration than at the immediate coast, where marine layers and fog are more prominent, especially in late spring and early summer. Young avocado orchards with about 25% cover are expected to use about half of the water used by mature orchards with 75-100% cover (Witney and Bender, 1992), so the predicted crop factor for the trees studied at Pine Tree Ranch based on the literature is about 0.3 to 0.35, or 30-35% of potential evapotranspiration, ET_o. Irrigation amounts allowed by the nearby Fox Canyon Groundwater Management Agency (FCGMA), which does not include the Pine Tree property, are between 36 and 43% of potential evapotranspiration for young avocado orchards with up to 20% ground cover. Considering that water loss through soil evaporation was not determined in our study, our findings of average tree water use of 20-30% agree with well with those previous findings, recommendations, and allowances. Any irrigation above 35% ET_0

may currently be wasted, although some of that would percolate back into the groundwater, where it came from, and in the process leach excess salt from the surface soil.

Cost-Benefit·Analysis

The potential water savings to be achieved in avocado orchards without reducing production depend on the current irrigation practices and can range from 0% in ideally irrigated orchards to higher than 80% in less efficiently watered orchards. The average water savings will be somewhere in between. In our study, actual irrigation needs were between 30 and 35% of potential evapotranspiration, ET_o, assuming some loss to soil evaporation in addition to the 20-30% of ET_o used by the trees. However, it was not the main goal of this project to irrigate more efficiently specifically at Pine Tree Ranch, but to provide avocado growers in southern California with tools and information to reduce irrigation water use.

To put potential irrigation costs into a larger perspective, within the boundaries of the nearby Fox Canyon Groundwater Management Agency (FCGMA), the crop year irrigation allowance for the young avocado orchards was 38% of ET_o in 2017, which had average rainfall, and 43% of ET_o in 2018, which was a dry year. Irrigation that does not exceed these allowances within the FCGMA costs only $12.50 per acre foot. Any irrigation above the allowed amounts faces substantial surcharges starting at $1,461 per acre foot. These calculations do not apply directly to Pine Tree Ranch, but they are representative for a larger area in Ventura County.

Irrigation water costs and rules vary between different regions, and over-irrigating could potentially become very costly, especially in drought years. The retail cost for a 4-gauge sap flow system configured as for this project is about $7,500, which would be a significant expense for most growers, but less than the cost of water potentially wasted at a rate of more than $1,000 per acre foot on a 10-acre orchard. Added to the equipment cost, a service contract from Dynamax Inc. to install and maintain sap flow equipment and access online data currently costs about $3,300 per year. The equipment can be moved and reused in different orchards and on different crops, so depending on the local conditions the determination of actual orchard water needs could save substantial amounts of water and money.

CONCLUSIONS

Our study confirms that simply abiding by the current crop factor recommendations for avocado orchards and watering based on recent research and on ET_0 data available from the CIMIS system is likely to meet the irrigation needs of the trees and save water without incurring equipment costs. However, not every orchard has a CIMIS station in close vicinity and site conditions can vary widely, depending on location, slope, aspect, and soil type. Direct measurement of actual tree water use is by far the best way to determine irrigation needs and achieve water savings and using sap flow measurements to achieve savings could be a cost-effective method, especially in large operations where a sap flow system could be used in several different orchards and to determine effects of orchard management on avocado water use. Moreover, the sap flow system also works well for determining water use of citrus (Wieber 2015), which is often planted together with avocado. Overall, substantial irrigation water savings are possible in avocado orchards of southern California, ideally by determining actual tree water use or alternatively by basing irrigation schedules on meteorological data and recommended crop factors for avocado. However, it will take incentives for growers to adopt these strategies and achieve these savings.

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