HRM - Heat Ratio Method to Measure Sap Flow in Papaya & Oil Palm

Performance of the heat ratio method (HRM) to measure sap flow in Papaya (Carica papaya L.) "Pocosí" hybrid, and Oil Palm (Elaeis guineensis Jack.) compact clones.

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Introduction and research objectives

Water use by crops is an important component of the water cycle, a major determinant of yield quantity and quality, and a useful indicator of water status, employed in the assessment of the soil-plant-atmosphere conditions. Sap flow is an indicator of whole-plant physiological performance because it integrates the joint structure and function of the absorbing root system, the conducting stem, and the gas-exchanging leaf canopy. Sap flow measurement techniques allow the estimation of daily and seasonal trends of water use to provide sound irrigation recommendations, and to aid in the early diagnosis of stress and its prevention. Water use and yield are tightly correlated, because they are functionally connected through the activity of the stomata and the trade-off between water loss and photosynthetic carbon gain and partitioning to the harvestable sinks.

A variety of sensors is currently available to measure sap flow in the field, and progress in instrumentation and data processing allows the recording and use of sap flow and environmental data in real time. In contrast to other heat-based techniques, such as Granier's heat dissipation probes (Granier 1985) and Cermack's heat balance technique (Čermák et al. 1995), the heat ratio method (HRM) sap flow meter (ICT International, Australia) tracks the speed of heat pulses (tracers) released by a heating element radially implanted in the conducting xylem, and its detection up- or down-stream by thermistors implanted in the xylem as well (Burgess et al. 2001, Green et al. 2003). By measuring the ratio of heat transported to these two symmetrically located probes, the magnitude and direction of sap flux is calculated. This allows the measurement of reverse, low and zero flows, and the recording of radial differences in sap flow in stems and roots.

Our first area of application of the HRM deals with the morpho-physiological attributes responsible for the superior vigor of the papaya hybrid "Pocosí". We are exploring whether the hybrid type displays higher photosynthesis, water use efficiency, and biomass partitioning to fruits and seeds, and lower costs of maintenance than the two parental pure lines. To answer these questions, we are combining sap flow data with analyses of growth, gas exchange, sex expression and crop yield and fruit quality along the crop commercial life cycle.

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Our second area of application of the HRM has to do with the diagnosis, early detection and treatment of a putatively physio-pathological disorder known as "PC", affecting compact, high-yielding oil palm clones in Coto 47, Costa Rica. PC, "la pudrición del cogollo", is a major disorder of unknown origin, which causes decline of new leaves, whole crowns, and eventually leads to plant death. It is currently a major limiting factor in oil palm-producing areas of Central America and South America, among other localities.

In combination with other eco-physiological techniques and observations, we are currently characterizing the morphological and physiological expression of the PC syndrome in Coto 47, Costa Rica. This project represents a joint effort between the University of Costa Rica and ASD-Costa Rica to respond to specific requests from the oil palm producing sector, and includes thesis projects for university students.

Materials and methods

Locations and plant material

Assessment of HRM performance in papaya plants was conducted at Fabio Baudrit Experiment Station, Alajuela, Costa Rica (10 N, 840 m elev.). Papaya local hybrid “Pocosí” was used for comparison of gravimetric versus electronic sap flow measurements (Figure 1).

Figure 1. Experimental set-up for gravimetric verification of sap flow measurements performed by the HRM. Whole papaya plants growing in pots filled with potting mix were wrapped to prevent soil water evaporation (see Gutiérrez, Harrington, Meinzer and Fownes, 1994).

HRM probes were implanted at the base of five plants, which were weighed every hour to record water loss due to transpiration. Because all transpired water must travel the length of the stem to reach the leaves, transpiration is a surrogate of stem sap flow and leaf area.

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Field measurements in oil palm plantations are conducted in Coto 49, South-Pacific of Costa Rica. Sap flow measurements are being performed on compact, highly productive clones affected by PC (Figures 2 and 3). Verification of the HRM performance is being conducted using "whole-leaf potometers" (see Gutiérrez and Santiago, 2006) monitored gravimetrically in a greenhouse.

Figure 2. HRM probes installed at the base of a fully expanded leaf in a 1-year-old oil palm growing in the field in Coto 49, Palma Tica, South Pacific of Costa Rica. An oil palm leaf at this age may be 2,5 m long.

Figure 3. HRM probes installed at the base of leaves of different age and health, in a 1 year-old oil palm growing in the field in Coto 49, Palma Tica, South Pacific of Costa Rica. Oil palm leaves near the center of the crown are affected by a disorders of unknown origin known as PC.

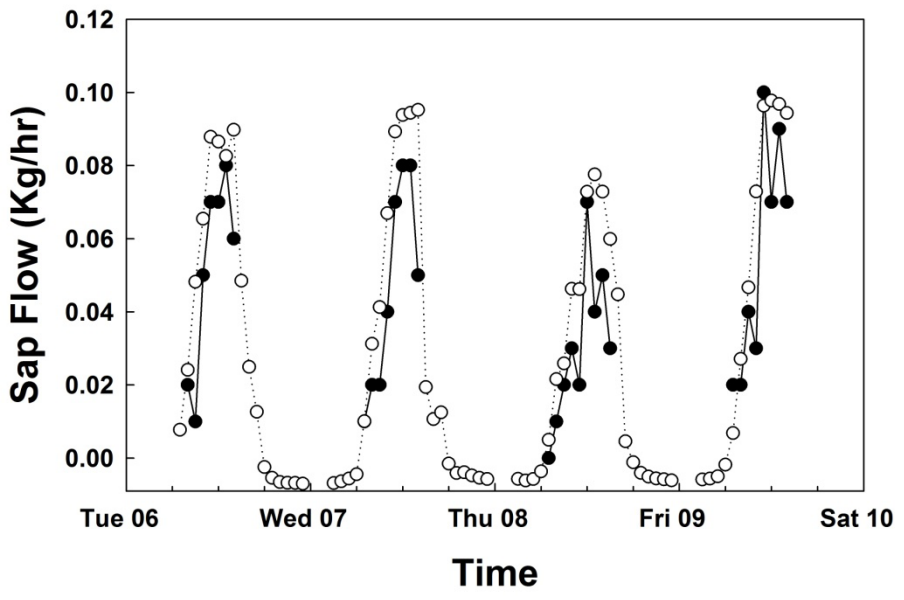
Probe implantation methodology for both species was developed and completed by the determination of papaya and oil palm tissue density, water content, and conducting xylem in stems and, in the case of oil palms, leaf rachis. A variety of dye uptake experiments have been conducted to examine the relationship between growth, phylotaxy, and patterns of water uptake and movement (Figure 4).

Figure 4. Cross-section through the middle stem a 5-year-old oil palm, showing the movement of a dye (acid fuchsine) injected down-stream into the xylem. Coto 49, Costa Rica. February 2012.

Preliminary results and conclusions

Our first results show good agreement between the two procedures in papaya plants

Figure 5. Sap flow measured using the HRM (°) and gravimetric water loss (•) of papaya plants growing in pots. September 6 through 9, 2011. Fabio Baudrit Experiment Station.



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The anatomical examination of stems and leaf tissues is required for the determination of the conducting xylem of papayas and oil palms, both of which are semi-perennial, soft-wooded plants. Collecting this information specifically for the two plant species under study, and recording morphogenetic changes during plant development and aging was essential for the correct installation and performance of the HRM probes. For example, papaya plants are giant, semi-perennial herbs with a non-woody stem composed of very light tissues. The stem contains only a narrow ring of conducting xylem located between a thick sub-epidermal fiber sheath and the central pith cavity. Stem density is very low and water content is very high.

Measurements are relatively simpler in oil palm stems and leaves in which, once the outer fibrous cover is removed, virtually the whole cross-section is sap-conducting. The large size of the oil palms allows the use of HRM in several organs of the plant in addition to the stem, such as the base of fruit bunches, leaves of different ages, and leaves with different health conditions (Figure 6).

After probe removal, it is equally important to examine the scars left by the sensors and verify the distance between probes and the extent of the scar tissue, for further refinement of the calculations using the support software (Sap Flow Tools) provided by the manufacturers.

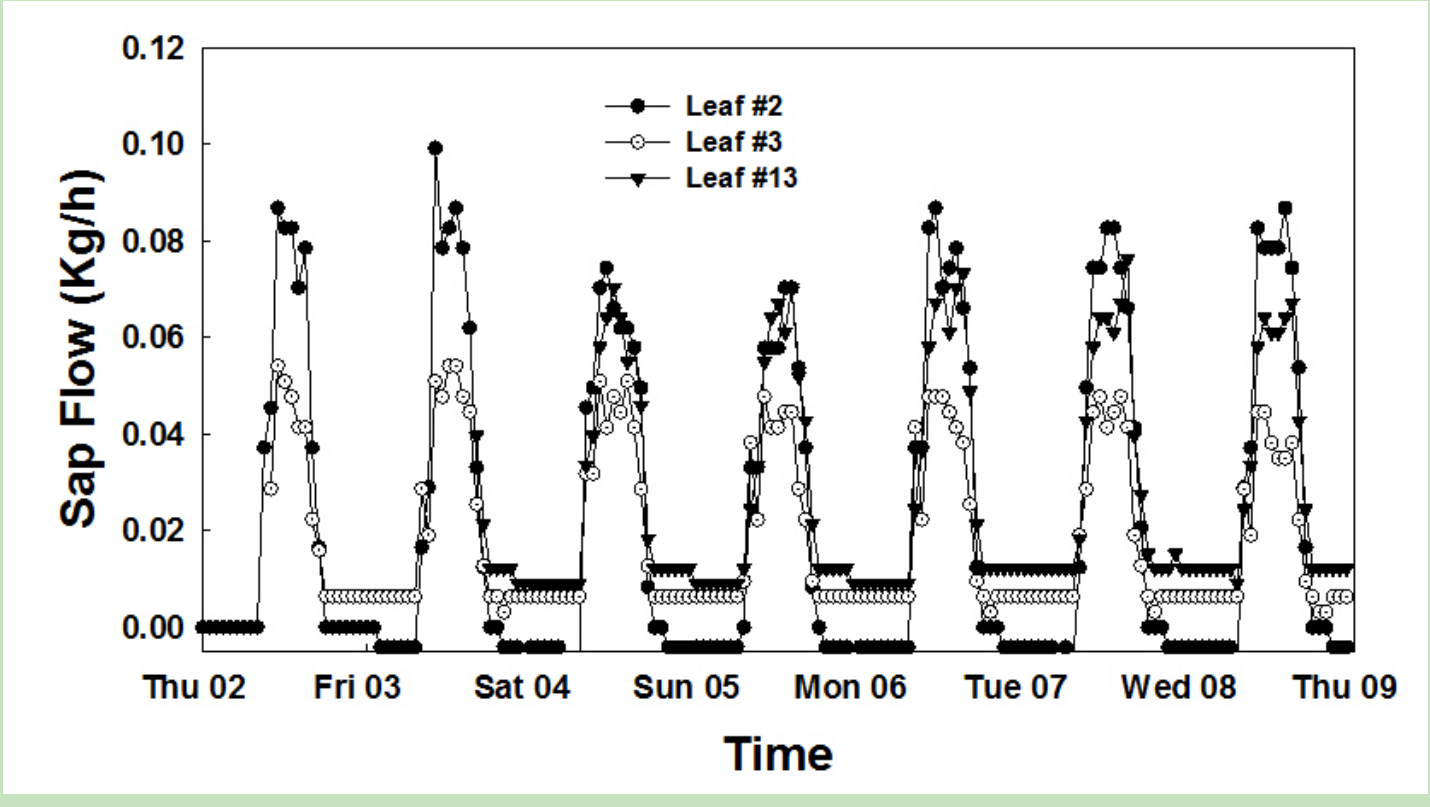

Figure 6. Daily course of sap flow measured in leaves No. 2, 3 and 13 of a reproductive, 1-year old compact oil palm growing in the field in Coto 49, Costa Rica. A mid-day depression in sap flow is observed. Data shown are from Thursday 2 through Thursday 9, February 2012.

We are pioneering the use of HRM probes in tropical semi-perennial, relatively short-lived, "soft-wood" crops, which include monocots like the oil palm and giant dicot herbs like the papaya plant. Tissue properties, vasculature and the hydraulic architecture of both species are unique, and differ substantially from the typical woody structure of trees and other woody perennials in which HRM has been used more frequently in the past.

Acknowledgements

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