Principal Índice Áreas

PRELIMINARY EVALUATION OF SAP FLOW DATA BY STEM HEAT BALANCE METHOD[1]

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INTRODUCION ,

Cermak et al. (1973) developed the first version of the heat balance method (HBM), which involves continuous application of heat in a stem segment and quantifying losses by axial and radial wood conduction. The heat flow carried out by the sap is determined from the difference between input power and axial and radial heat losses from the heated stem segment. Currently, this method follows Sakuratani (1981) and Baker & Van Bavel (1987), who modified the first HBM version by applying a constant power on the gauge, so reducing the electronic requirements for the measurements.

The HBM is an absolute method that requires simple equipment and some basic procedures in order to minimize errors (Baker & Nieber, 1989; Steinberg et al., 1990; Valancogne & Nasr, 1993; Weibel & de Vos, 1994). However, it is difficult to evaluate sap flow measurements in field conditions since reference methods, such as lysimeters, soil water balance and other techniques are normally difficult to apply, especially for big plants. This paper focuses on this problem and considers some procedures to evaluate data supplied by HBM when reference methods are not available.

MATERIAL AND METHODS

To exemplify some of the considerations made here, sap flow data were collected in a coffee plant (*Coffea arabica* grafted on stock *Coffea canephora*) with leaf area of 9.3m 2 and stem diameter of 5.5 cm, irrigated by a drip system to assure maximum transpiration.

A commercial gauge (SGB50, Dynamax) was used. Before the installation, a small amount of G4 silicone insulating compound (G4, Dow Corning) was applied on the stem, which was then covered with smooth plastic film. Then, the gauge was wrapped over the plastic film and covered with four layers of foil sheet to improve thermal insulation. To prevent water entry in the upper part of the gauge a layer of silicone glue was applied between foil sheets and stem. Moreover, an additional weather shield was put over the gauge, using a conical structure coated with foil sheet, such that the narrowest part of cone was juxtaposed to the upper extremity of gauge (Gutiérrez et al. 1994).

Equation (1) was used to determine the volumetric water flow in the stem segment covered by the gauge :

$$Fs = [P - (Qa - Qr)]/[dT \; cp] \quad (1)$$

where P is input power (W); Qa is axial heat flow in the stem (W); Qr is the radial heat flow; dT is the temperature difference between lower and upper gauge ends (dT represents the temperature increase of the sap) and cp is specific heat of water (4.186 10 -3 J kg -1 o C -1).

Qa represents the sum of heat flows up and down from gauge and it can be determined by gradient temperature measurements from a pair of thermocouple junctions installed just above and below the gauge heater strip (equation 2). For commercial gauges both upward and downward flows are calculated together, with a total Qa value for the axial heat losses, given by:

$$Qa = [Kt \; A \; (BH - AH)]/[dx \; C_s] \quad (2)$$

where Kt is the stem thermal conductivity, AH and BH are voltage differences proportional to temperature difference between the thermocouple junctions; dx is the distance between them; and C s is the Seebeck coefficient for copper-constantan (assumed 38 m V o C -1 in range of 0 o C to 100 o C). In dataloggers with algorithms for voltage temperature conversion, the Cs value in equation 2 must not be used. The electrical signals were measured by a datalogger (CR7, Campbell Scientific, Inc.) using a sixth degree polynomial to calculate temperature differences.

RESULTS AND DISCUSSION

Two filters must be applied to sap flow data in order to correct discrepant measurements, being one for conditions of high transpiration rates and another for low transpiration rates (Dynamax, 1999). The low rates filter was used at moments where dT values come down close to zero, which occurs when gauge reaches high temperatures due to low water flow. When the heat conduction by sap (Qf) is low, dT tends to zero and the results given by Equation 1 are unrealistic. According to Grime & Sinclair (1999), although the low rates filter algorithm seems to be arbitrary, it agrees with error analysis made by Sakuratani (1981, 1982).

The filter for high transpiration rates also takes in account the hyperbolic relation between sap flow and dT values, considering that maximum sap flow is obtained with minimum dT values. This filter is based on the assumption that there is a maximum sap speed in stem (V max), near to 0.042 cm s -1 . Following Grime & Sinclair (1999), this boundary value seems to be less than an ideal value for several species.

The radial flow (Qr) is considered the variable with the highest degree of uncertainty in the HBM and it is normally determined by a fluximeter built by thermocouple junctions glued on a cork sheet. The temperature differences between two faces of the fluximeter (D T av) are multiplied by the radial thermal conductivity, Kr (W o C -1), in order to calculate Qr. Kr values were determined with equation 3 from data obtained during pre-dawn, when sap flow is near to zero under conditions of high soil water availability. In these conditions, there are two ways to compute Kr, one taking the minimum value of a sequence of measurements at the end of the nigh (Valancogne & Nars, 1993) and other taking an average Kr value between 3h and 5h a.m. every day (Gutiérrez et al., 1994).

$Kr = (Qv - P)/\Delta T_{av}$ (3)

where D T av is the temperature difference of the two faces of the fluximeter (o C).

The adoption of a minimum Kr value for all measurement sequence is theoretically more appropriate because equation 3 can only be used in null sap flow conditions, which only occurs in well-watered plants and provide low Kr values. However, for practical purposes the Gutiérrez's approach seems to be better to prevent systematic bias in sap flow data due to a single Kr measurement. By finding a Kr value for each day, there is a distribution of measurement errors along all sap flow data. Besides, some differences among Kr daily values can be acceptable but the variability cannot be extreme on subsequent days, which could indicate problems with sap flow gauge and soil drying.

For the coffee plant, the Gutiérrez´s approach gave sap flow values similar to those obtained using that of Valancogne & Nasr (1993). Following the procedure described by Valancogne & Nars (1993), the minimum Kr value observed for the period from 0h to 6h a.m. was equal to 0.171 W o C -1 . The average values of the period from 3h to 5h a.m. ranged from 0.178 W o C -1 to 0.225 W o C -1 , with an overall average of 0.197 W o C -1 and standard deviation of 0.0138 W o C -1 . The difference between the values computed by the two procedures is about 15%.

Experience shows that subsequent measurements of Qa and Qr with high instability denote problems with the gauge that can be due to several causes, such as: presence of large amount of water over internal electrical parts of gauge such as thermocouple junctions and heater strip, problems with wiring or an AC magnetic field near the gauge or datalogger. Thus, a useful criterion to judge Qa and Qr data is to observe their temporal stability throughout periods of time with small or no environmental changes.

In normal conditions, Qa tends to rise during nighttime due to internal stem heating and decreasing after sunrise. The daily minimum value of Qa and the time of its occurrence are related with gauge installation characteristics, plant transpiration rate and power applied to the gauge.

Follow Gutiérrez et al. (1994), another way to evaluate HBM is to verify the dT daily curves by installing the gauge and turning off the heating, in a attempt to check and correct the environmental influence on measurements and effectiveness of thermal gauge insulation. Grime & Sinclair (1999) argument that this procedures to correct the environment introduced bias is constrained by similarity in the configuration and environment of the heated and unheated gauges and also consider that this option represents a highly inefficient use of resources.

In normal conditions, dT values during nighttime range from 5 o C to 7 o C, indicating good thermal insulation. During sunset, depending on the species anatomy and transpiration rate, dT values goes up around 10 o C, in a transient increase normally observed also in the early morning, ascribed to the beginning ascent of cold sap reaching the downstream cross-sectional end of the heated segment and the subsequent heating of sap when it crosses the heated segment. These peaks normally do not reveal substantial errors in sap flow data, since others flows are also raised in these moments indicating null sap flow. Dynamax (1999) considers that dT rise during sunrise may not exceed 8 o C and the occurrence of higher values suggests the necessity of some reduction in voltage of the power supply.

The subsequent fall of dT in the early morning may result in errors because it is inversely proportional to sap flow (equation 1) and when it tends to zero, abnormally high values are computed. At these moments, the filter for high transpiration rates is important in order to correct this type of error. During daylight, one expects some degree of stability of dT values until sunset, when it starts to increase until it reaches the dawn levels. Dynamax (1999) suggests that dT values do not fall below 0.3 o C during daylight.

However, Dynamax (1999) emphasizes that excessive power may not result in sap flow error, but may cause overheating of the stem and damage of the plant. Some weeks after the measurement period, the coffee plant stem remained apparently health, but it presented some decline in vegetative vigor and leaf yellowing. Afterwards (three or four months later), the leaves wilted and started to fall out. The same occurred with other coffee plants with different age and also with adults rubber trees, in which sap flow gauges were installed. Symptoms of leaf curling and premature leaf fall were reported by Wiltshire et al. (1995) on ash trees. Although the pressure of the gauge and over-heating of the trunk are possible causes of the trunk damages, including trunk constriction, they consider the hypothesis of the G4 silicone compound was the cause of this problem.

In well-watered plants a simple procedure is to compare sap flow data with net radiation (or incoming solar radiation) measured over the studied plant. It allows a coarse selection of sap flow data, especially when there is a great variability of radiation values. The comparison is based on the assumption that net radiation and transpiration have a similar diurnal trend.

The measurement of the heat storage is important and may affect the time constant of the gauge (Grimme & Sinclair, 1999). Thus, to know the diurnal course of the transpiration, with high temporal resolution, the heat storage measurement seems to be essential, specially in big stems (Grime et al., 1995).

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