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Comparison of two sap flow methods for the estimation of tree transpiration

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Abstract – The purpose of this note is to compare two sap flow methods for estimation of transpiration on the tropical tree *Gliricidia sepium*. The first one is based on heat dissipation around a heater probe, and the second is based on complete stem energy balance. Under our conditions, no significant differences between daily transpiration measurements were shown using the radial fluxmeter method and the heat balance method. Thus, these two methods can be used alternately or in a complementary way according to their specific advantages. (© Inra/Elsevier, Paris.)

transpiration / sapflow / radial fluxmeter/ energy balance / ***Gliricidia sepium***

Résumé – Comparaison de deux méthodes de flux de sève pour l'estimation de la transpiration d'arbres. Deux méthodes de flux de sève on été comparées sur des arbustes tropicaux (*Gliricidia sepium*). La première méthode consiste à suivre la dissipation de chaleur d'une sonde chauffante, et la seconde est basée sur l'établissement d'un bilan d'énergie complet d'une portion de tige. Dans nos conditions et durant plus de dix jours, aucune différence significative de transpiration journalière n'a été trouvée entre la première méthode du fluxmètre radial et la seconde du bilan de chaleur d'une section de tige. Les deux méthodes peuvent donc s'utiliser indifférement ou de façon complémentaire en fonction de leurs avantages respectifs. (© Inra/Elsevier, Paris.)

transpiration / flux de sève / fluxmètre radial / bilan de chaleur / ***Gliricidia sepium***

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1. INTRODUCTION

A good knowledge of crop water cycle is required to manage cropping systems, particularly under limited conditions. To evaluate the productivity or the adaptability of a species to different environmental and technical conditions, knowledge on transpiration is needed. Transpiration can be estimated or measured using several methods. Application of micrometeorological methods for example is not possible under particular conditions, such as small area, steep slope or sparse canopy. The in situ measurement by sap flow techniques is the only way, and different techniques exist [11].

The basis of the use of energy budget to measure sap flow was established by Sakuratani [10]. The method is now widely used [1, 6, 7]. Later a simplified method based on the same principle of energy dissipation by conduction and convection with sap flow per unit of sapwood area was suggested by Granier [4].

Both methods have been tested and validated separately [4, 10]. They present specific characteristics for their utilisation with regards to adaptability to stem diameter, energy requirements, connections to a datalogger, etc. Moreover, due to the different advantages and disadvantages (*table I*), it is interesting to use the two methods in a complementary way and also to compare the results from the same stem.

In this note, a comparison of the two methods on the same trunk has been reported.

2. MATERIALS AND METHODS

The measurements were made on two 2-year-old *Gliricidia sepium* trees managed in alley crop with Pangola grass (*Digitaria decumbens*). The trunk diameter was 0.04 m and the height 1 m. Granier's sensors were set at the bottom of the trunk at about 0.4 m from the soil (method 1). A home-made gauge for the energy balance method was fitted on the top (method 2). The comparison was made during 11 days in 1994 using the two techniques alternately or simultaneously as shown in *table II*.

2.1. Description of methods

2.1.1. Method 1

Method 1 proposed by Granier [4] consisted of two cylindrical probes of 2 mm in diameter, which were inserted 0.02 m into the sapwood of the bole, one above the other (0.2 m). The upper probe contained a constantan heating element which was heated at constantan power. Each probe contained a copper-constant an thermocouple, connected together in opposition, in order to measure temperature difference. The latter was influenced by the sap flow density u. Sap flow was calculated with the following equation:

$$F = 0.0428 \times SA \times K^{1.231} \quad (1)$$

where F is the sap flow ($L.h^{-1}$), SA the sapwood area at the level of heated probe (cm^2), and K the flow index (dimensionless):

$$K = [\Delta TM - \Delta T(u)] / \Delta T(u) \quad (2)$$

where ΔTM is the temperature difference between probes without any sap flow (K) and $\Delta T(u)$ is the temperature difference with sapflow u (K).

The sensors can be built as described by Granier [4] or purchased (UP GmbH, Schirmgasse, D-84028 Landshut) and present some specificities (*table I*). Low electric power of 0.2 W is used whatever the stem diameter. Therefore this method is particularly adapted to large diameter trees up to 0.6 m [5]. Only one differential temperature measurement with datalogger is required if the intensity is precisely known and constant, otherwise two. Sapwood area must be known. It is estimated by dye impregnation of wood and stemcores [5]. The precision in the estimation of the transpiration depends on the accuracy of the differential temperature measurement. The thermocouples must be protected against direct radiation.

In the case of our installation with home-made Graniers probe close to the soil surface, it is important to take into account the natural temperature gradient between the two probes without any heating. This gradient is due to soil conduction along the trunk and wood heat capacity. This difference is less than 0.15 K, against values of 3.8 K during night period of heating. The difference recorded during days without any artificial heating was deduced from measured gradient, in order to take into account the natural gradient. The adjusted daily transpiration was 3 % higher than direct measurement and evolves at the same pace as photosynthetically active radiation.

2.1.2. Method 2

Method 2 is more complete and is based on the energy balance of a part of the stem as described by Sakuratani [10], Valancogne and Nasr [12] and van Bavel and van Bavel [3].

This method has been tested and validated on *G. sepium* trees [9]. The apparatus consists of a flexible heater encircling the stem and providing a small steady and known amount of heat (Pin). The heated segment is insulated. The outward heat flow is partitioned into three conductive fluxes: up and down the stem (Qv), radial conduction into the insulation (Qr) and mass heat transport by the sap stream (Qf). As shown previously [9, 6, 7] heat storage is not taken into account in our case due to small considered volume and tropical steady state temperature conditions.

Pairs of thermocouples inserted above and below the heater allow the measurement of the conduction flux (Qv). The radial outward flow (Qr) is calculated from thermopile measurements. The thermopile was composed of four thermojunctions in series, located on either side of a 2 mm thick rubber. The sheath conductance of the gauge is calculated during the night when no sap flow occurs between 2300 and 0400 hours.

The sap flow rate (F) is calculated as follows [2, 10]:

$$F = (Pin - Qv - Qr) / Cp\, dT \qquad (3)$$

where Cp is the heat capacity of the xylem sap and dT the temperature increase of the sap through the heater.

This apparatus can be made as described by Sakuratani [10] or is commercially available by Dynamax Inc., Houston, Texas. In our case, it requires five connections to our datalogger and an energy source of 0.64 W. *Table I* summarises the advantages and disadvantages of the method.

The methods were applied successively or simultaneously as showed in *table II*. A 21X datalogger (Campell Scientific, 1420 Field Street Shepshed, LE129AL, UK) scanned the sensors every 10 s and recorded average values every 15 min.

3. RESULTS AND DISCUSSION

Both methods appeared to be reliable, and were used without any problems during the experiment.

Table I. Advantages and disavantages of each method.

Method	Advantages	Disadvantages
Sakuratani (1981)	no calibration homogeneously heated all input and output controlled	power proportionally to diameter sensor adapted to stem diameter 5 plogs necessary
Granier (1985)	0.2 W of energy 2 plogs same sensor whatever the diameter	knowledge of sap flow area calibration heterogeneity around the diameter

Sap flow showed maximum daily values ranging from 0.15 to 0.25 $L.h^{-1}.tree^{-1}$ according to the climatic demand. These variations were principally caused by the variation of air vapour pressure deficit [5], and seem more stable than PAR fluctuations. Some difference could be caused by the effect of shadow due to the row structure.

Sap flow density was about 2 $kg.dm^{-2}.h^{-1}$ and was similar to those previously measured in Guadeloupe [9] and French Guyana [5]. This density represented about 0.5 $mm.day^{-1}$ of transpiration for a LAI of 0.5 and was comparable with values observed by Leroux [8] in Lamto savanna (Ivory Coast).

Method 1 was quite easy to use owing to the easy control of the sensors, the low energy needs and the low number of datalogger connections. The transpiration was calculated on the basis of sapwood area which represented 90 % of the cross-sectional area at the heating probe level. The last 10 % corresponded to heart wood and to the central medulla.

As in the second method, the rate of transpiration showed large variations between consecutive measurements. These variations were probably due to the short measuring time interval (15 min) and the influence of direct radiation close to the temperature probe, even with the shield. This event could be particularly important in the case of an isolated tree, or in an orchard owing to sun course.

Method 2 was successfully used and produced good results on *G. sepium* [9].

Both methods worked well without interferences as shown in *figure 1*. Respective functioning of each method was not deteriorated by the other.

The relationship obtained with the comparison of the two methods over the whole period (n = 589) is presented in *figure 2*. The slope of the regression line was 0.98 and the determination coefficient 0.89. Residuals, with a mean of $8.4.10^{-4}$ $l.h^{-1}$ showed a very good agreement between the two methods.

At the scale of a quarter of an hour, the difference between the two transpiration

Table II. Comparison of transpiration of *Gliricidia sepium* estimated by two methods.

DOY		208	209	210	211	212	213	214	215	216	217	218*
ETP Penman		5.6	5.1	5.1	4.3	5.1	5.3	5.5	5	4.2	5.5	5.2
Gli.1	M.1**	1.13	1.04				1.55	1.56	1.23	1.53	1.30	0.63
	M.2***	1.06	1.23	1.35	1.13	1.54	1.67	1.69			1.35	0.63
Difference %		–7.2	11.0				7.3	7.4			2.9	–1.1
Gli.2	M.1	1.03	1.04			1.29	1.44	1.53	1.21	1.38	1.34	0.84
	M.2	0.94	0.96	0.93	0.83	1.20	1.42	1.48			1.32	0.86
Difference %		–9.4	–8.9			–7.8	–1.9	–3.6			–1.9	1.6

* Transpiration between 0630 and 1400 hours only.
** Granier's method.
*** Heat balance method.

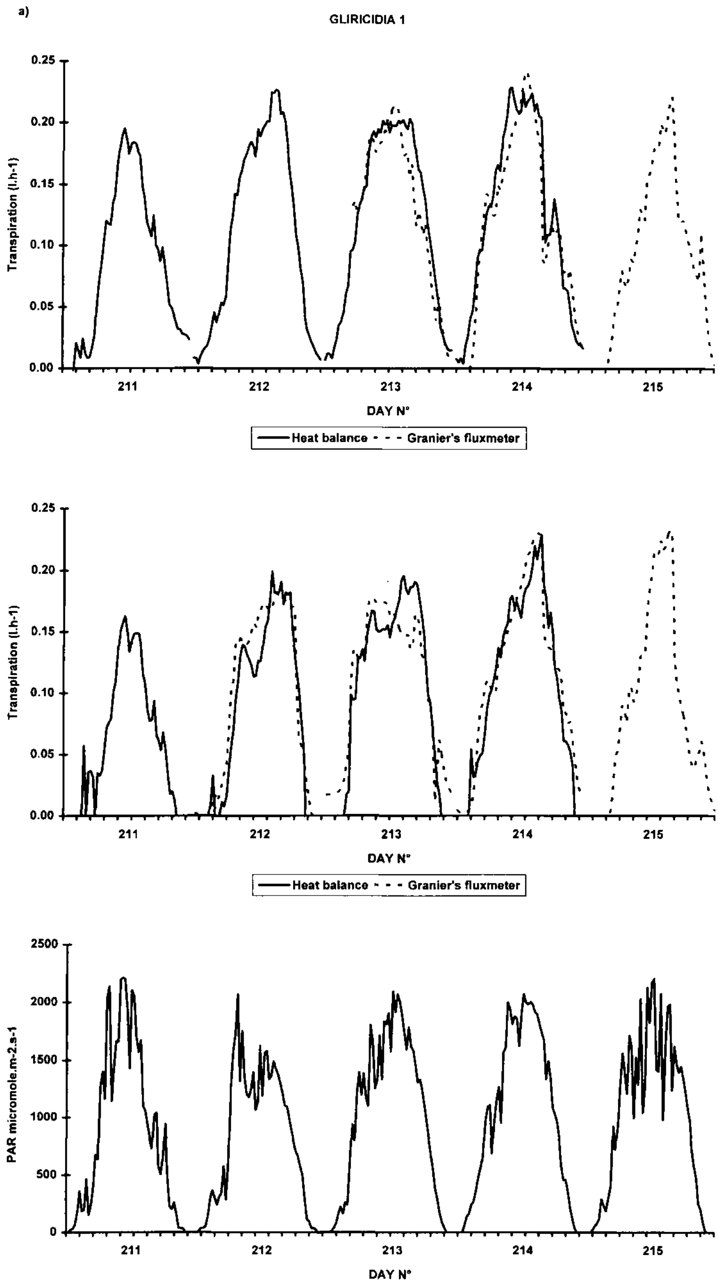

Figure 1. Daily water flux measured with heat balance (__) and with Granier's fluxmeter (...) on (a) gliricidia 1 and (b) gliricidia 2 in comparison with PAR variations (c).

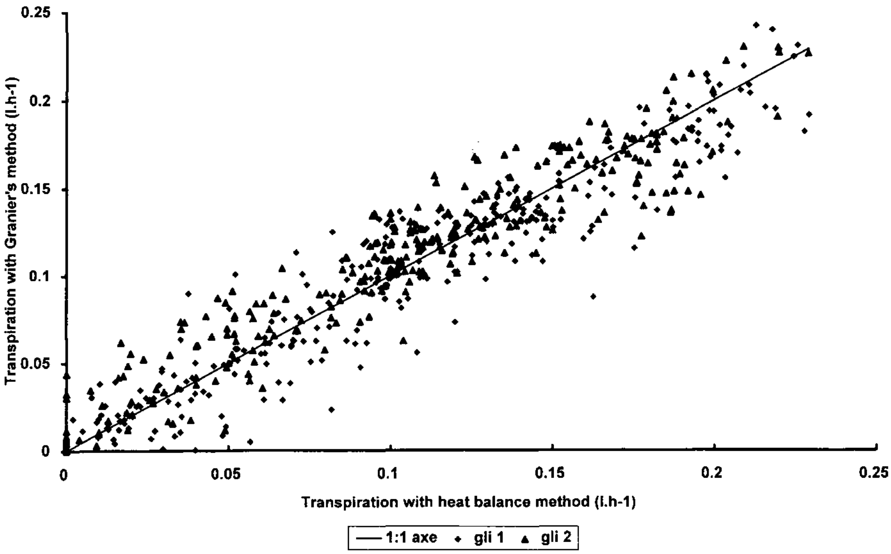

Figure 2. Comparison between the two methods of sap flow measurements for gliricidia 1 (◆) and 2 (▲) for all the obseriations (n = 589).

measurement reached 30 % and sometimes more than 100 % for some points corresponding to low transpiration rate, particularly in the morning. This difference decreased by less than 20 % at the hourly scale. In a daily scale, the maximum difference was registered during the first 2 days of the experiment and reached 8 %, probably due to the time necessary to obtain the steady state condition. The average of differences was about 4.5 % for trees 1 and 2. No physical explanation could account for these differences.

4. CONCLUSION

This experiment showed an accuracy of greater than 10 % for the two methods, when comparing daily fluxes from the two methods of sap flow measurement. At an hourly rate, the difference could reach 20 %, particularly for the small amount of transpiration in the morning. This study confirmed the possibility of using one or the other method in accordance with the objectives, and the equipment. The major problem is still the choice of samples required for an accurate estimation of transpiration.

The combination of the two methods seems possible in the same experiment. The heat balance for the small trunks, and transpiration calculation for small periods and Granier's method for the large ones and at a daily scale, without problems of sap flow measure compatibility.

REFERENCES

[1] Allen S.J., Grime V.L., Measurements of transpiration from savannah shrubs using sap flow gauges, Agric. For. Meteorol. 75 (1995) 23–41.

[2] Baker J.M., Van Bavel C.H.M., Measurement of mass flow of water in the stems of herbaceous plants, Plant Cell Env. 10 (1987) 777–782.

[3] van Bavel M.G. van Bavel C.H.M., DynagageTM Installation and Operation Manual, Dynamax Inc., 1990, 80 p.

[4] Granier A., Une nouvelle méthode pour la mesure du flux de sève brute dans le tronc des arbres, Ann. Sci. For. 42 (1985) 81–88.

[5] Granier A., Huc R., Barigah S.T., Transpiration of natural rain forest and its dependence on climatic factors, Agric. For. Meteorol. 78 (1996) 19–29.

[6] Grime V.L., Morison J.I.L., Simmonds L.P., Including the heat storage term in sap flow measurements with the stem heat balance method, Agric. For. Meteorol. 74 (1995a) 1–25.

[7] Grime V.L., Morison J.I.L., Simmonds L.P., Sap flow measurements from stem heat balances: a comparison of constant with variable power methods, Agric. For. Meteorol. 74 (1995b) 27–40.

[8] Leroux X., Étude et modelisation des échanges deau et dénergie sol-végétation-atmosphère dans une savane humide (Lamto, Côte-d'Ivoire), thèse Université Paris VI, 1995, 203 p + annexes.

[9] Ozier-Lafontaine H., Tournebize R., Mesure des flux de sève par bilan thermique appliquée à lestimation de la transpiration dun arbuste (*Gliricidia sepium*) et dun peuplement de canne à sucre (*Saccharum officinarum*) Cahiers Agriculture, 2 (1993) 197–206.

[10] Sakuratani T., A heat balance method for measuring water flow in the stem of intact plant, J. Agric. Meteorol. 37 (1981) 9–17.

[11] Swanson R.H., Significant historical developments in thermal methods for measuring sap flow in trees, Agric. For. Meteorol. 72 (1994) 113–132.

[12] Valancogne C., Nasr Z., Une méthode de mesure du débit de sève brute dans de petits arbres par bilan de chaleur, Agronomie 9 (1989) 609–617.