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Transpiration of apple trees in a humid climate using heat pulse sap flow gauges calibrated with whole-canopy gas exchange chambers

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Abstract

For scientific study and practical irrigation management, the estimate of plant transpiration and water use rates is needed. Several methods are available to measure water use by plants, and among them, sap flow estimation techniques are currently popular, although the interpretation of data may be complex due to several assumptions. In this study, we present a combined approach to measure transpiration rates in mature, field-grown dwarf apple trees ('Empire'/M.9) in a humid climate. Sap flow gauges (heat pulse method) were used to estimate sap flow rates on apples, over a period of 10 weeks. The gauges were first calibrated with simultaneous measurements of whole-canopy gas exchange using chambers mounted on the same plants for short periods (5 days). Mid-summer transpiration rates were peaked at about 2.5 l day^{-1} m^{-2} of leaf area but generally averaged about 2 l day^{-1} m^{-2} of leaf area. Calculated basal crop coefficients were generally lower than those reported in literature, variable and were a function of the vapor pressure deficit, thus confirming the concerns of using crop coefficients with reference grass in humid climates especially when applied to tall, discontinuous canopies that are well coupled with the bulk air.

Keywords: Orchard; Plant water relations; Gas exchange; Crop coefficient; Water use

1. Introduction

Water demand and availability are among the most important factors influencing adaptation, development, and growth of terrestrial plants, as well as the productivity and economics of agricultural systems. The assessment of water use by plants is thus of relevant importance to understand the underlying plant physiological processes and their regulatory mechanisms (like for instance, stomatal regulation), as well as of primary importance for the agricultural practice (for instance, in designing irrigation systems and scheduling irrigation).

Several techniques are currently available to measure or estimate water use in plants, and amongst

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them the use of sap flow gauges is a common method to estimate water flow through plant stems (Wullschleger et al., 1998). This approach offers several advantages: direct measurement of the water stream inside the plant (or smaller sections of the water pathway), potentially high number of replicates, continuous and long term monitoring, no disruption of the plant's canopy or root environment, and automated calculation of transpiration estimates. Three general types of gauges are currently available: heat dissipation, heat balance and heat pulse (Sakuratani, 1981; Granier, 1985; Smith and Allen, 1996). All of them rely on the thermal dissipation properties of the water flow through the stem to estimate the sap flow density.

However, these methods are still subject of uncertainty because of the difficult-to-prove assumptions used to convert measured parameters to mass flow (Shackel et al., 1992; Braun et al., 1999; Clearwater et al., 1999; Ferrara and Flore, 2003). Also, anatomical analysis of the test plant stem may be needed in order to obtain estimates of mass flow; when this is not possible (or highly undesirable), because for instance of the economical value of the chosen plants (e.g. fruit trees), the uncertainty due to the technical difficulties and theoretical assumptions may lead to significant errors in sap flow estimates. Moreover, plant specific characteristics (e.g. the very high flow velocities, variable stem structure and large diameter trunks in trees) can introduce additional errors (Braun and Schimd, 1999; Tarara and Ferguson, 2001).

It is questionable to always assume that sap flow gauges are accurate on large in-field plants unless they are tested and calibrated with an alternative technique or a high number of probes (generally expensive) are used to statistically handle with variability and technical difficulties. Direct calibration can be easily performed on potted plants by weighing, but it is only feasible with large lysimeters in the case of field-grown plants, like in mature fruit crops, vineyards or forests (Lascano et al., 1992; Wullschleger et al., 1998; Williams and Bravdo, 2000; Mpelasoka et al., 2001).

One of the approaches available to directly measure the transpiration rates of large field-grown plants is the use of whole-canopy gas exchange chambers with infrared gas analyzers and datalogging (Corelli and Magnanini, 1993; Lakso et al., 1996; Wunsche and Palmer, 1997; Ferrara and Flore, 2003). This method relies on few verifiable assumptions, and therefore is less prone to systematic errors than sap flow gauges; however, the chamber establishes an artificial environment around the plant limiting the generalization of the results to undisturbed conditions. This method has technical difficulties, especially measuring high flow flux rates. To the best of our knowledge, there are only few studies comparing canopy gas exchange to other methods. Ferrara and Flore (2003) compared whole-canopy gas exchange and gravimetric measurements on young potted trees. In their work, the canopy gas exchange technique systematically overestimated the daily transpiration rates for half of the observation period, while agreeing with the gravimetric measurements in the other half. However, their estimates of transpiration rates from canopy gas exchange were from the chambers only for short intervals. Therefore, the extrapolation from a few measurements with altered microclimate to daily totals is likely the cause of the discrepancy between the two methods.

In this study we tested and applied a combined approach; the sap flow method was used to provide data on the patterns of transpiration for the entire experiment period, while canopy gas exchange chambers were used for two short periods to provide a direct calibration of the sap flow gauges for absolute values, and then removed to allow undisturbed measurements to be taken.

2. Materials and methods

All the experiments took place in experimental orchards at Cornell University's New York State Agricultural Experiment Station in Geneva, NY, USA. Measurements were conducted on 8-year-old dwarf 'Royal Empire' apple trees on M9 rootstock, trained as a conical form with a central leader stem, with a height of 2.5–3 m. The orchard rows were north–south oriented, and the spacing between rows and between trees was 4.28 and 1.83 m, respectively, giving 1280 tree ha^{-1}. Four trees were selected to be representative of the average tree size in the orchard, but no differential treatments were imposed; trunk diameters were 6–7 cm.

2.1. Heat pulse sap flow gauge

Sap flow density in each tree was estimated using the compensation heat pulse technique (Green and