Short Communication

Comparison of Pressure Chamber and Thermocouple Psychrometer Determinations of Leaf Water Status in Tomato

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Although the pressure chamber has gained wide acceptance as a convenient method for the measurement of plant water status, the relationship between the pressure observed in the chamber and other parameters of plant water status remains unclear. If one assumes that the spatial arrangement of water in the shoot is the same under pressure as it was in the intact plant, the positive pressure (P) and xylem solute potential (ψx) are acting in the chamber to restore the excised shoot to its original volume. In the case of leaf samples, Boyer (4) proposed that P and ψx are related to the original leaf water potential (ψL) by equation 1:

\[ \psi_L = \psi_x - P \]  

(1)

The structural difference between xylem and mesophyll cells, as well as other thin walled cells in the leaf blade, suggests that measurements on leafy samples should be in close agreement with equation 1. A leaf on a petiole or stem is analogous to a balloon on the end of a rigid tube, in that the leaf is elastic and has a capacitance, whereas the xylem is a rigid tube with little capacitance. In this discussion, capacitance (C) is defined by equation 2:

\[ C = \frac{\partial V}{\partial \psi} \]  

(2)

where V is tissue water content, or volume, and ψ is the water potential. Because of the difference in capacitance between xylem and mesophyll cells, only the leaf blade will undergo a significant change in volume when pressure is applied in the chamber, and there will be a unique relationship between P and leaf volume, which with the correction for sign and ψx, will be the same as the relationship between ψL and leaf water content. Volume changes in parenchyma tissues of the petiole or stem are expected to be relatively small.

Several workers have compared pressure chamber determinations of P with the value of ψL obtained in a thermocouple psychrometer (2, 4, 6, 8-10). The relationship found between P and ψL has been variable, and it is generally recommended that the pressure chamber be calibrated with a psychrometer before use in precise studies. The observed value of P is frequently higher than that expected from equation 1, and resistance to water flow between the leaf cells and cut end of the xylem is thought to cause an overshoot in the estimation of P (4, 8). The data presented here show that the relationship between P and the value of ψL obtained with a thermocouple psychrometer can be precisely that expected from equation 1 in tomato. Measurements on tomato plants infected with Fusarium oxysporum Schlect f. sp. lyco- persici (Sacc.) Snyd. and Hans., a pathogen which causes a large increase in resistance to water flow (7), are included to evaluate the effect of resistance on the observed relationship.

MATERIALS AND METHODS

Tomato plants (Lycopersicon esculentum Mill.) of the variety Bonny Best were grown in soil in a controlled environment chamber (85 w m⁻² of light in the 300-700 nm wave band for 16 hr day at 30 ± 1°C and 60 ± 5% relative humidity). Four weeks after seeding, some plants were inoculated with fungus by the root dip technique while remaining plants were treated in the same manner with sterile water (12). Between 5 and 7 weeks after seeding, the youngest fully expanded leaf of a plant was used for measurement. Leaves were washed and allowed to dry on the plants for 1 hr before use. An individual leaflet, with 0.5 cm of petiulole, was excised from a plant under normal growing conditions and promptly placed in a pressure chamber for the determination of P. Walls of the chamber were covered with wet paper to prevent water loss during the determination. The entire leaflet was subsequently used to line the walls of the Peltier-cooled thermocouple psychrometer, which was employed to measure ψL. Xylem sap was collected from whole plant tops in the pressure chamber (4) and ψx was measured with a vapor pressure osmometer (Mechrolab Model 3011A). The variation in ψL was due to disease development in inoculated plants and to a withholding of water from the soil of healthy plants.

RESULTS AND DISCUSSION

Reference to Figure 1 shows that there was a linear relationship between ψL and P in both healthy and diseased tomato plants. Linear regression analysis showed that the relationship can be expressed by the equation

\[ \psi_L = -0.456 - 1.004 P \]  

in healthy plants \((r^2 = -0.981)\), and by the equation

\[ \psi_L = -0.694 - 0.983 P \]  

in diseased plants \((r^2 = -0.986)\). Vapor pressure osmometer determinations of ψx were made on a number of shoots which had values of P between 2 and 14 bars. The value of ψx was independent of P (see also 4), and average values of ψx for all values of P were −0.51 ± 0.20 and −0.57 ± 0.23 bars in healthy and diseased plants, respectively. These averages approximately equal the ψL intercept of the regression equations, and thus, the ob-

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served values of $\psi_s$, $\psi_L$, and $P$ are related to each other in the manner predicted by equation 1.

Steady-state measurements of transpiration and $\psi_s$ have shown resistance to water flow in Fusarium-infected tomato plants to approach infinity as wilt symptoms occur (7). A portion of this high resistance is probably located in the leaflet and first 0.5 cm of petiole, for the resistance of diseased leaflets with 2 cm of petiole was as much as 10 times the resistance of healthy leaflets, and variation between 0.5 and 2.0 cm in the length of petiole or rachis had little effect on the rate of water uptake by wilted leaflets when transpiration was zero. Thus, the similarity between healthy and diseased leaflets in the present study suggests that resistance to water flow is not a major source of error in the determination of $P$. It should be noted that the rate of pressure increase in the chamber was less than 1 bar per 15 sec. Boyer (4) attempted to avoid possible error from resistance by comparing $P$ and $\psi_L$ in shoots where water loss was zero. Apparently this precaution is not necessary, because the difference in water potential between the xylem and mesophyll cells, which must exist to some degree in transpiring plants, had little effect on the relationship between $P$ and $\psi_L$ in tomato.

The manner in which tissue is sampled can affect the relationship between $\psi_s$ and $P$. When a leaf is excised from a plant, mesophyll cells gain water from the xylem, because mesophyll cells are elastic and have capacitance. When pressure is applied in the chamber, water is forced from the mesophyll to refill the xylem, and release of the pressure again allows the mesophyll to gain water. Thus, when pieces of leaf tissue are cut for the psychrometer, after a leaf or shoot has been excised from the plant, $\psi_s$ is expected to be greater than $\psi_s - P$. The error was minimized in this study by excising only a short piece of petiole with the leaf blade. However, when measurements were made on whole leaves from healthy plants, $\psi_s$ was found to be 1.1 to 1.8 bars greater than $\psi_s - P$. Calculation of the volume of water in the leaf blade (excluding major veins and ribs), relative to the volume of xylem in the rachis, and the relationship between $\psi_L$ and $\theta_i$ indicate that complete removal of water from xylem in the rachis by the leaf blade would have increased $\psi_L$ by approximately 1 bar. There was no evidence that the pressure chamber caused abnormal amounts of water to fill petiole tissues (4), and it was concluded that water from the xylem caused $\psi_s$ to be spuriously high in whole leaves.

Differences in procedure probably account for the differences in results between this and previous studies. For example, Barrs et al. (2) used whole tomato leaves in the pressure chamber and found $\psi_L$ to be 0.5 to 2.2 bars greater than $-P$ in leaves of 4-month-old plants, but found $\psi_s$ to be 1.0 to 4.5 bars greater than $-P$ in leaves of 2-month-old plants. While water from the xylem must have caused some error in the determination of $\psi_L$, there probably was not enough xylary water in the leaf to cause the larger differences they found between $\psi_s$ and $-P$. Barrs et al. (2) obtained low values of $\psi_L$ by allowing excised leaves to transpire. Perhaps this procedure contributed to the disparity between $\psi_L$ and $-P$, since they found the disparity to increase with $P$. Kaufman (8, 9) excised shoots from woody plants and also allowed them to transpire to obtain low values of $\psi_L$. Leaves were subsequently used in the psychrometer and another portion of the excised shoot was used in the pressure chamber. He observed $\psi_s$ to be greater than $\psi_s - P$ and noted that the disparity increased with the length of stem used in the pressure chamber (9). The variation he found with stem length suggests that the volume of xylem which was refilled to obtain $P$ was a source of error. The change in the relationship between $\psi_s$ and $P$ with age, observed by both Barrs et al. (2) and Kaufman (9), may have been due, in part, to a change in leaf elasticity or capacitance (11).

While caution must be exercised in establishing the relationship between $\psi_s$ and $P$, the results presented here show that the pressure chamber can yield accurate measurements of $\psi_L$ where $\psi_s$ is known. The results also show that thermocouple psychrometer determinations of $\psi_L$ can be misleading. The observed value of $\psi_L$ will depend on the manner in which tissue is sampled, as described in the foregoing discussion. Furthermore, slicing leaf tissue has been shown to increase the value of $\psi_L$ observed in a psychrometer (3). It is conceivable, depending on the volume of xylem in the leaf blade, that a movement of water from xylem to mesophyll cells may also contribute to this increase in $\psi_L$. Because errors can occur in sampling, as well as in the psychometric technique itself (e.g., 1, 5, 10), the pressure chamber may sometimes be preferable to the thermocouple psychrometer for determination of plant water potential.

LITERATURE CITED