Evaluation of the Pressure Chamber Method for Measurement of Water Stress in Citrus[1]

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Abstract. Comparisons of xylem pressure potential of branch tips measured with a pressure chamber and leaf water potential measured with a thermocouple psychrometer indicate that the pressure chamber method is useful for evaluating water stress of 'Washington' navel and 'Valencia' orange trees. No difference of the comparisons due to varieties was observed when measurements were made on tissue nearly a year old, but a significant varietal difference did occur with tissue not yet fully expanded. Significant differences also were observed within the varieties due to age of tissue at the time of sampling. The regression lines and equations representing the comparisons are useful in obtaining meaningful estimates of plant water potential from xylem pressure potential measurements.

INTRODUCTION

SINCE plant growth and various internal plant processes are related more directly to plant water stress than to soil water stress, the most suitable measurement of water stress is that made on the plant (7). Field evaluation of water stress in plants has always been a difficult problem. The dye or Schardakov method has been used in some cases, but it is somewhat cumbersome and time-consuming. Some researchers have measured relative turgidity or water deficit (4, 10) but problems arise in this technique because of differences in leaf age and type of environment (6) and in temperature between the plant at sampling time and during the measurement period (9). The thermocouple psychrometer (11) is generally considered to provide the most accurate measurement of plant water stress, but its use is restricted to the laboratory.

The usefulness of the pressure chamber technique described by Scholander et al. (12) has been widely recognized by researchers. The method is readily adapted for measurement of plant water stress in the field as well as in the greenhouse or laboratory and has been evaluated by Boyer (2) and Kaufmann (5) for a variety of species. This paper presents an evaluation of the pressure chamber technique for 'Washington' navel and 'Valencia' oranges on sweet orange rootstocks.

The terminology used by Kramer et al. (8) in studying water relations of plants will be followed in this report. Water stress is expressed in terms of water potential, a negative number equal in magnitude to the diffusion pressure deficit but opposite in sign, so that water potential decreases as water stress increases. Osmotic or solute effects are expressed as solute potential which is equal in magnitude to osmotic pressure but also opposite in sign. As the concentration of the xylem or cell solution increases, its solute potential decreases. The effects of hydrostatic pressure are expressed in the term pressure potential, which is generally positive in a plant cell (i.e., turgor pressure) but is usually negative in the xylem.

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Materials and Methods

The pressure chamber method is based upon measuring the tension, or pressure potential, in the xylem of a leaf or branch tip. Tension, which results from transpiration, causes water to recede from the cut surface when a branch is removed from a plant. By inserting the branch into a pressure chamber with the cut end exposed to the outside, pressure can be applied to the sample until water is forced back to the cut surface. By increasing pressure at the rate of 1 bar every 4 to 5 seconds (1 bar = 0.987 atmosphere = 14.5 lb. per inch^2) and observing the cut surface with a hand lens, the amount of pressure required to force water back to the surface can be determined. The amount of pressure required is taken as an estimate of the pressure potential in the xylem of the plant.

Under most conditions pressure potential in the xylem will be equal to or slightly higher (less negative) than water potential in the leaf cells. By comparing xylem pressure potential with leaf water potential, the accuracy of the pressure chamber technique can be evaluated for each species or variety. Leaf water potential measured with a thermocouple psychrometer is assumed to be accurate when corrections are made for errors caused by leaf diffusion resistance and by heating of respiration (1). The leaf diffusion resistance error was determined experimentally using the isopiestic technique (3). For old tissue (see below) the error was 18.0%, while for young tissue it was 11.3%.

Experiments were performed by sampling large branches from mature trees, placing them in polyethylene bags to minimize transpiration, and bringing them to the laboratory. Branches selected had at least 2 branch tips located adjacent to each other. Pressure potential measurements were made by using one of these branch tips bearing 4 to 8 leaves, while a single leaf was removed from the other tip for measurement of water potential with the psychrometer. By sampling as the branches dried in the laboratory, comparisons of values from the 2 techniques could be obtained over a range of water stress. Comparisons were made on samples collected on several different days during each of the sampling periods. Samples collected in January or February, representing growth of the previous year, were nearly a year old; tissue collected in April was from the current year.

Results and Discussion

The pressure chamber and psychrometer comparisons are shown in Fig. 1 and 2. Most comparisons between techniques differed by less than 3 bars. The maximum differences were 3.9 bars for navel and 5.0 bars for 'Valencia' oranges. Similar differences between methods have been observed for other species, although with some species the agreement may be much poorer (2, 5). Boyer (2) combined the pressure potential measurement with a psychrometric

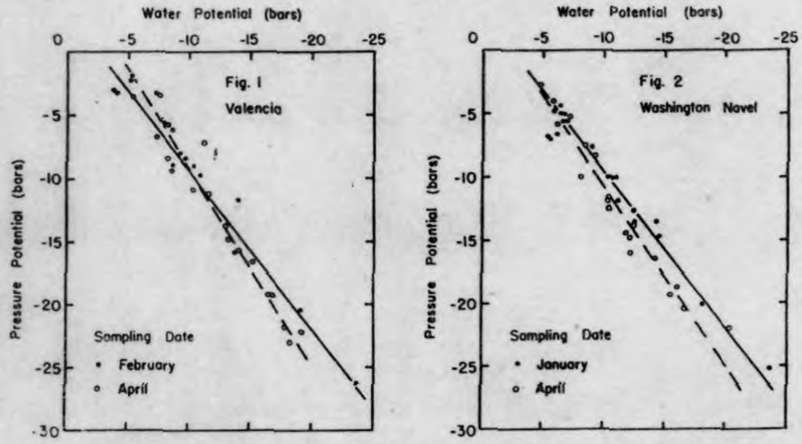

Fig. 1 and 2. Comparisons of psychrometer measurements of leaf water potential with pressure chamber measurements of xylem pressure potential for 'Valencia' and 'Washington' navel oranges. Solid lines are regression lines for comparisons made on older tissue; broken lines are for young tissue (see text).

measurement of osmotic potential to estimate xylem water potential, and then compared this value with leaf water potential. Many of the pressure potential measurements reported here appear to be more negative than leaf water potential, especially in the lower range of water potential (Fig. 1 and 2). This indicates that an error exists in the pressure chamber technique (5); because of this error it is not profitable to make the additional measurement of osmotic potential in order to estimate xylem water potential.

Linear regression analyses of comparisons with the previous year's tissue (sampled in January or February) indicated that varietal differences were not significant ($P = .05$) and that one equation could be used to define both sets of data. Similar analyses showed that significant differences did exist between varieties when comparisons were made on young tissue (sampled in April). The tests for tissue age effects within each variety were more interesting. These analyses indicated that tissue age of citrus is an important factor affecting the psychrometer-pressure chamber comparisons. Thus, 3 different sets of slope and intercept are required for the equations which show the relationship between leaf water potential and xylem pressure potential, 1 for older tissue and 2 for young tissue. These equations are given in Table 1.

The general similarity of comparisons for the 2 citrus varieties is not surprising. Kaufmann (5) observed that 2 species of the same genus have similarly shaped curves, although the position of the curves may be slightly different. The variability in pressure chamber measurements among samples from the same branch or tree was generally less than 1 bar for several forest tree species.

Table 1. Regression equations for Fig. 1 and 2.

Variety	Equation[a]
Old tissue (sampled in January or February)	
Valencia and Washington Navel	$\hat{Y} = -2.52 + 0.79\ X$
Young tissue (sampled in April)	
Valencia	$\hat{Y} = -4.05 + 0.64\ X$
Washington Navel	$\hat{Y} = -2.49 + 0.70\ X$

[a]$\hat{Y}$ = Estimated leaf water potential (bars).
X = Measured xylem pressure potential (bars).

The cause for differences of the curves for tissue of 2 different ages is not clear, but changes in strength of the cell wall and in the permeability of membranes to water are important factors. Knipling (6) found that the relationship between water deficit and water potential of dogwood leaves changed as the leaves aged. Most of the change occurred when the tissue was quite young; very little change in the relationship occurred after early June. The tissue used here represented the extreme differences in age that will be encountered in the field. The older tissue, nearly a year old, had been subjected to both summer and winter conditions, including temperatures at or below freezing on several occasions, while the young tissue had not quite reached mature size. It is likely, on the basis of Knipling's work, that the curves for the older tissue in Fig. 1 and 2 are more representative of the usual psychrometer–pressure chamber relationship than are the curves for young tissue.

The amount of tissue used in measuring pressure potential is important. The data shown in Fig. 1 and 2 were collected using short branches representing one flush of growth and having 4 to 8 leaves. When longer branches having several flushes of growth and 10 to 15 leaves were used, more pressure was required, i.e., values were below the curves in Fig. 1 and 2. Differences between the pressure chamber and psychrometer values were as large as 8.8 bars. Boyer (2) observed a similar error with rhododendron. It is important to standardize the pressure chamber technique as much as possible with respect to sample size, the time required to place samples in the chamber, and the rate of pressure increase during the measurement. A uniform sampling point on individual trees is equally important in many studies.

Boyer (2) and Kaufmann (5) have suggested that curves relating psychrometer and pressure chamber comparisons can be used as calibration curves for the pressure chamber method. The data presented here indicate that a change in tissue age can alter the comparison so that different curves are required, depending upon the age of the tissue.

For experimental work with 'Valencia' and 'Washington' navel oranges, xylem pressure potentials can be converted to leaf water potentials using the appropriate curves or regression equations. This conversion will provide the researcher with meaningful estimates of plant water status which can be used in the study of water stress in citrus.

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