Relation of Slice Gap Width in Oranges and Plant Water Stress

Merrill R. Kaufmann, University of California, Riverside

Abstract. Since turgor pressure of orange fruits is important in determining fruit growth, a method of evaluating plant water stress which is based on fruit turgor is desirable. When a fruit is cut halfway through along a plane perpendicular to the axis, a gap forms as a result of fruit turgor. Measurements of the width of the gap indicate that it is strongly influenced by the degree of water stress in the plant. Gap width is also affected by fruit size. A gap will form in fruits which have an endocarp at least 1 cm in diameter; this occurs when fruit diameter is 2 cm or greater. Gap width can be measured through the parts of the growing season during which most of the growth occurs and may be useful, therefore, in determining the need for irrigation. Measurements of gap width during an irrigation cycle demonstrate that the width decreases as water becomes less available but increases after re-irrigation.

Introduction

A SIMPLE method for evaluating water stress in fruits is not available for researchers or growers of the citrus industry. This paper offers a simple technique for measuring the relative turgor of growing fruit. Three basic cell water values are involved in the water relations of plant tissue. These are pressure potential ($\Psi_p$) or turgor pressure, which is a hydrostatic pressure; solute potential ($\Psi_s$), reflecting the concentration of osmotically active substances; and water potential ($\Psi_w$), the sum of pressure and solute potentials, important in determining the direction of water movement:

$$\Psi_w = \Psi_p + \Psi_s$$

Of these, turgor pressure is probably the most critical in determining cell enlargement and growth of plant tissue, including fruits. Work by Clark (2), showing that a squash fruit could support a weight of 5000 pounds, indicates that turgor pressure in fruit can be quite large. For a more thorough discussion of the water relations terminology used in this report, the reader is referred to Kramer et al. (6).

Methods

When orange fruits are cut in half along a plane perpendicular to the central axis, the pulp appears to swell, making the cut surface convex. When the 2 halves are placed together, a gap remains around the circumference. When the type of cut is modified so that it extends only halfway through the fruit (to the axis), a wedge-shaped gap occurs, again the result of turgor. The width of this gap can be measured with a small ruler 5 to 10 seconds after cutting. The formation of the gap is nearly complete within 2 to 3 seconds after cutting.

A series of experiments was designed to evaluate the dependence of this measurement of gap width on various parameters. Experiments were performed on mature 'Valencia' and 'Washington' navel orange trees on sweet orange rootstocks. In order to be of value, the width of the gap must reflect the degree of water stress in the tree. Plant water stress of citrus can be estimated in the field by using the pressure chamber method (8). This method was calibrated for navel and 'Valencia' orange trees by Kaufmann (4). Pressure chamber measurements of xylem pressure potential (a tension, not to be confused with turgor pressure) were made in the field on navel orange trees. Two measurements were made on each of 11 trees, and the mean of each pair of measurements was converted to leaf water potential, which is equal to diffusion pressure deficit but opposite in sign, using an appropriate curve (4). By sampling trees at different times after irrigation and at several different times of the day, a range of leaf water potentials was obtained. Immediately following the xylem pressure potential measurements, 10 fruits of uniform size (5.0 to 5.5 cm diam) were selected on the same part of the tree; the fruits were cut and the gap width was measured. Fruits generally were still attached to the tree during the measurement, although removal did not seem to alter the results.

The relationship between fruit size and gap width was determined by making width measurements over a range of fruit diameters on each of 3 navel orange trees. This was done on 3 occasions to determine the effect of changes in the soil and shoot environment on the width of the gap.

Gap widths were also measured through an irrigation cycle. On navel orange trees, 2 fruits were cut from each of 3 size classes: 4.0 - 4.5 cm, 5.0 - 5.5 cm, and 6.0 - 6.5 cm. On 'Valencia' oranges, only the 2 smaller size classes were measured. Five different trees of each variety were used for each set of measurements. Data were collected 3, 8, 10, 15, and 17 days after irrigation (August 27), and 1 day after the following irrigation (September 17) to determine the amount of recovery. Measurements of gap width were made 2 to 3 hrs after sunrise, before environmental conditions of the day could affect water stress in the plants appreciably.

Results and Discussion

The effect of the degree of water stress in the tree on width of the gap is shown in Fig. 1. As water potential decreases and water stress increases, the gap width also decreases. The reason for the change in slope at a water potential of ~8 bars is not clear. It seems reasonable, however, that at higher (less negative) water potentials turgor within the fruit may be sufficiently large to overcome a structural resistance of the tissue, while at lower water potentials tissue structure is strong enough to prevent a gap from forming.

Gap width is also related to fruit size (Fig. 2). Measurements were made on 3 trees having approximately the same degree of water stress. As size of

---

1Received for publication October 20, 1968. Supported in part by NSF Grant GB-7621.
2Assistant Plant Physiologist and Lecturer, Department of Horticultural Science.

exposed to the sun, and highest (least stress) on the shaded north side. For instance, mean water potential on the south side was \(-14.5\) bars, while water potential on the north side was \(-13.2\) bars. Early in the morning, however, no difference is observed between the 2 exposures.

The gap width measurements in Fig. 3 and 4, taken early in the morning, demonstrate that drying of the soil in the latter part of an irrigation cycle results in a decrease in the width of the gap. After the tenth day following irrigation, the gap width progressively decreased. One day after re-irrigation, however, the width increased because of the increased availability of water in the soil.

Knowledge of the degree of water stress is essential for proper management of irrigation. The ideal evaluation of the need for irrigation of citrus orchards should involve a measurement of water stress within the plant (5). The tensiometer method for estimating irrigation need is much more satisfactory than qualitative observation of trees and soil or basing irrigation on time intervals, but the tensiometer estimates water stress only in the soil. Tensiometer measurements do not reflect the influence of atmospheric factors, such as temperature, wind speed, and vapor pressure, on the internal water stress of the trees. Furr and Taylor (3) and others have measured fruit growth rate and have suggested that irrigation is required when growth decreases or stops. Measurements of fruit growth are cumbersome, however, and are not particularly suited to determining the need for irrigation because they do not directly indicate the degree of water stress in the plant.

To be useful as a tool for estimating plant water stress, the width of a gap formed in a fruit after cutting must reflect the level of water stress in the plant. If the width of the gap is a function of fruit turgor, a decrease in turgor will result in a decrease in the width of the gap. Osmotic potential is nearly constant over a relatively wide range of water potential, so that a change in water potential generally indicates a similar change in turgor pressure. On the basis of laboratory work it can reasonably be assumed that leaf water potential is roughly equal to water potential of the fruit pericarp. Therefore, a change in leaf water potential indicates a change in fruit turgor, and the decrease in gap width as water potential decreases (Fig. 1) supports the hypothesis that gap width is related to fruit turgor.

Thus, the width of the gap can be used to indicate the degree of water stress in the leaf and fruit. Evidence to be presented in another paper indicates that turgor stretches the pericarp and that the gap caused by cutting results primarily from shrinkage of the pericarp.

The effects of the shoot environment during the hours preceding the measurement of gap width may be quite significant, as shown in Fig. 2. These measurements, and also the observations of the effect of time of day and exposure on water potential, indicate that care must be used in selecting the time of day and location on the tree for measuring gap width. Since the differences in environment from north to south sides of trees are sufficient to cause differences in water stress, certainly day-to-day changes in weather conditions will also affect water stress. Night conditions, however, tend to be more uniform and
favor the development of an equilibrium in water potential throughout the tree and between tree and soil. Thus, the measurement of fruit gap taken early in the morning will reflect the degree of water stress in the soil. Conversely, measurements made during the afternoon will indicate the maximum water stress experienced by the plant.

It is not clear why gap width increased during the third to tenth day after irrigation (Fig. 3, 4), but translocation of photosynthetic to the fruit may be involved. In stems, carbohydrate translocation is reduced by a water stress (7). Undoubtedly, translocation to fruits is also reduced, and new photosynthesis may accumulate in the leaves. If this is so, relieving the water stress could permit the carbohydrates to move toward the fruit, resulting in an increased concentration (lower solute potential) in the fruit. The lower solute potential would cause an increase in fruit turgor, resulting in a larger gap during the intermediate part of the irrigation cycle.

Gap width can be used successfully over a fairly broad range of fruit size and is useful, therefore, through a large portion of the growing season. Extrapolation of the lines to the abscissa in Fig. 2 suggests that no gap would occur for fruit 2 cm or less in diameter. In preliminary studies it was found that in fruits about 2 cm in diameter the gap was generally less than 1.0 mm wide, even when water stress was low. In fact, a gap was observed only in those fruits in which the pulp was about 1 cm wide; small fruits have a very small pulp (l) and thus lack the tissue which causes a gap to form. Thus, gap width measurements can be made as soon as fruits reach a diameter of about 2 cm. In Riverside, California, this normally occurs around July 1 for navel and July 15 for 'Valencia' oranges.8 Gap width measurements can also be made on large mature fruits. Measurements will be meaningful as long as (a) water is supplied to the fruit through the abscission zone, (b) the membranes of the juice sacs permit the development of adequate turgor, and (c) there is no large change in the concentration of osmotically active substances in the juice sacs. Thus, it is likely that gap width can be used as an indicator of water stress through most of the fruit growing season.

These results provide evidence that water stress can be evaluated in citrus during the important seasons of the year by measuring the width of a gap formed in a fruit as the result of a knife cut. With further refinement, the gap width technique is potentially useful to researchers interested in the effects of fruit water stress on response to various physiological and cultural treatments and to growers needing a suitable measure of plant water stress to determine the need for irrigation.

Literature Cited


*Unpublished data of Walter Reuther.


Determination of Need for Potato Irrigation Using Refractometric Index of Sap from Frozen Leaves

E. E. Ewing and L. Farkas,
Cornell University, Ithaca, New York

Abstract. A modified technique for detecting plant moisture stress through refractometric measurement of expressed cell sap was evaluated for potato, Solanum tuberosum L. The difference between readings of unwatered and watered plants, defined as the Deficiency Index, was used as the basis for determining need for irrigation. The Deficiency Index was found to be greater in young than in old leaves. It reached maximum levels in the late morning and then declined. Irrigation based on the Deficiency Index increased potato yields during 2 of 3 years. Deficiency Indices made before August 5 were negatively correlated with soil moisture block readings, but no correlation was found later in the season. Contrary to earlier reports, the refractometer method does not appear well suited for use by potato growers.

Introduction

LOBOV (20) proposed the concentration of expressed cell sap as an indication of irrigation requirement for tomato, potato, cabbage, and other crops. Lobov's method can be performed in the field using a hand refractometer and has received widespread attention in the Soviet Union and other parts of Europe, but little has been written about it in America (8, 10, 12). Some investigators (1, 3, 20) have suggested that by taking samples under standardized conditions critical refractometer readings could be established for a given crop. Many workers (6, 17, 23, 25, 26) have pointed to the necessity of varying the critical levels based on the time of year or age of crop. Filippov (15) states that adjustments of 1.0 to 1.5% (on the per cent sucrose scale) may be necessary depending upon fluctuations in temperature and relative humidity. Most workers report diurnal changes and specify that the time of readings should be standardized. Other environmental variables reported to affect readings include leaf nitrate and soil salinity (8), soil fertility (6), light intensity (10, 23), and levels of photosynthesis and respiration (29).

Both the diffusion pressure deficit (suction pressure) of intact tissue (18, 24) and the osmotic pressure of the expressed sap (2) have also been taken as indicators of irrigation requirement. It is generally assumed that the refractometer readings, which are easier to perform, are closely correlated with these parameters. Filippov (15) found good evidence of such correlations in cotton and apple, but Slavik (28) concluded the correlations were applicable only for a given crop over a limited period of its development. NeCas (22) reported that for