Stem Diameter in Relation to Plant Water Status

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ABSTRACT

An instrument containing a linear variable differential transformer was constructed to obtain continuous, nondestructive measurements of both short term changes in stem diameter and long term growth. In cotton plants, stem diameter, leaf water potential, and leaf relative water content are all closely related to net radiation at the top of the canopy. Leaves from the east and west sides of a plant show slight, but consistent differences in diurnal water potential patterns.

Stem diameter and leaf water potential are not related by a single-valued function, since there is a diurnal hysteresis between the two, and growth causes an increase in diameter each night. However, the instrument can be used to monitor long term stem diameter growth.

Continuous, nondestructive measurements of plant water status are potentially more useful in providing information about effects of water status on plant growth and development than are destructive measurements made at particular times during an experiment. Diurnal changes in water status, related to both the environment of the shoot and that of the roots, are so dynamic that spot measurements are not as easy to interpret as continuous measurements. Such devices as a leaf beta-gauge, a dendrogram, or a linear variable differential transformer (5, 6) allow continuous nondestructive estimates of parameters which are related to plant water status. This work concerns the relationship of changes in cotton stem diameter determined with an LVDT1 to changes in leaf water status as measured with a pressure chamber.

MATERIALS AND METHODS

Experiments were conducted in the Auburn rhizotron (7) on two 3-month-old cotton plants (Gossypium hirsutum L. “Auburn 7-683”) growing in Cahaba loamy fine sand in a compartment 1.8 m deep, 1.2 m wide, and 0.6 m from front to rear. Net radiation at the top of the plant canopy was measured continuously with a miniature net radiometer (2) and was integrated over 3-min periods to obtain the data reported. Water potential was measured periodically (generally hourly) with a pressure chamber (4) using detached leaves from both east and west sides of the plant. In the early morning, dew was blotted with absorbent tissue at sampling time and leaves were wrapped in absorbent tissue while they were in the pressure chamber.

This procedure minimized errors in estimates of relative water content (1), which was determined for duplicate samples of 10 discs each, punched from leaves after they had been removed from the pressure chamber. The average value for the two samples is reported.

The LVDT, used to measure stem diameter, was attached to the plant with a special holder (Fig. 1), which allowed accurate measurement of both diurnal changes and long term growth. All parts are of nonmagnetic stainless steel except for the nonmagnetic beryllium-copper spring (k) and the glass rod with low thermal expansion, which is attached with epoxy cement to the LVDT core and to the front stem positioner (f). The micrometer head (b) has a range of 25 mm with 0.01-mm subdivisions and is attached to the holder with a setscrew (c) and stabilized by a locking nut. The rear stem positioner (d) is silver-soldered to the rod which presses against the micrometer head. The LVDT used in this study had 6 mm maximum linear travel; 2.5 mm maximum travel is useful for petioles. To attach the instrument, the holder (a) is secured to an anchored rod with clamps on the side arm (j) and is installed on the stem (e) at a position which has been previously measured with a micrometer caliper. The front stem positioner, the LVDT barrel (h) and core (i) are positioned so that the core is centered in the barrel. A stainless steel worm gear hose clamp (g) stabilizes the LVDT barrel after alignment. The plant is tied to the holder with soft rubber tubing to minimize movement in the wind. The spring (k) keeps the front stem positioner pressed against the stem so that the core will retract if the stem shrinks. To minimize hysteresis when measuring soft tissues, springs with small spring constants are used. As the stem grows, the micrometer is turned to recenter the core and the amount of growth is recorded. Thus, the instrument has both a high level of precision and a large range. The output from the LVDT is amplified and recorded on a strip-chart recorder. Calibration can be done in situ by merely moving the micrometer head a known distance and recording the change in output. The holder is stable to changes in ambient temperature; it indicates a spurious swelling of the object being measured to the extent of about 0.001 mm per degree C.

The LVDT was positioned about 20 cm below the terminal bud where stem diameter was about 7.5 mm. Data on diurnal patterns in stem diameter, water potential, and relative water content were taken on July 20, 1970, from a plant 110 cm high. Stem diameter and water potential were measured on August 4 to 6 for a different plant 145 cm high. In both experiments, the soil was well watered.

RESULTS AND DISCUSSION

All three plant properties measured on July 20 were closely related to net radiation (Fig. 2). Stem diameter decreased with high radiation and increased again in the evening. Leaf water

1 Abbreviation: LVDT: linear variable differential transformer.
Fig. 1. Instrument used to measure changes in stem diameter with an LVDT: (a) holder, (b) micrometer head, (c) setscrew, (d) rear stem positioner, (e) stem, (f) front stem positioner, (g) worm gear hose clamp, (h) LVDT barrel, (i) LVDT core, (j) sidearm for stabilization, (k) spring.

Fig. 2. Net radiation, stem diameter, leaf water potential, and relative water content during July 20, 1970. Times are C.D.T.

Potential and relative water content showed the same pattern, but minimum stem diameter occurred 1 to 2 hr later than minimum leaf water status. A cloudy period occurred from 1500 to 1600 hr and the reduction in radiation load was reflected in the plant properties. The stem ceased shrinking at 1430 hr and began swelling during the cloudy period. When net radiation increased again, the stem shrank slightly before it began slowly swelling at the end of the day. The leaf sampled at 1600 hr on the east side of the plant had a higher water content than would be expected from the remainder of the curve. Relative water content data are more erratic than the other two plant parameters.

The relationship between leaf water potential and stem diameter (Fig. 3) is not single-valued, but shows a hysteresis loop. A given stem diameter corresponds to a higher leaf water potential in the evening. For example, at 1100 hr, stem diameter was 7.41 mm and leaf water potential was -12 bars, whereas when the stem hydrated to that diameter at 1930 hr, leaf water potential was greater than -6 bars. This discrepancy is explainable. A similar hysteresis is known for soils, and a hysteresis between leaf water potential and relative water content has also been found (L. N. Namken, personal communica-
tion). In fact, one would not expect dehydration and hydration to show the same pattern unless stem diameter changes were due entirely to effects of xylem potential on cross-sectional area of xylem elements. Wet stem tissue contains a continuous column or network of water which, as stress in the xylem progresses, becomes redistributed within surrounding tissue. Presumably, during the morning hours, there develops a steeper and steeper potential gradient from the nonvascular parts of the stem to the xylem vessels. The small, low resistance, rapidly changing xylem could develop a low potential quickly, but surrounding parenchymatous tissues would lose their water more slowly, i.e., stem diameter would decrease more slowly than would xylem water potential (or, in the case of these data, leaf water potential). In the late afternoon, the xylem would receive water from the roots through a low resistance pathway along a steep potential gradient and thus would increase in potential more rapidly than stem diameter. Furthermore, if any air-water interfaces were formed during dehydration, such as would occur if water in individual vessels or in intercellular spaces cavitated, the water in the plant would behave during hydration the same as it does in a soil, and would show a hysteresis of the type observed.

The fact that the stem continued to swell until about 0800 hr, even though dawn occurred about 0500 hr (Fig. 3), was investigated further by sampling leaves from both sides of a plant on three successive mornings (Fig. 4). The LVDT was attached as before. On the first morning (August 4), there was a light dew; on the second there had been rain during the night and a heavy fog and dew; and on the third morning there was a moderate dew. Each day dew disappeared by 0900 hr. Figure 4 shows that stem diameter continued to increase for 2 to 3 hr after dawn, and the amount of the increase was greater on the wetter mornings. It also clearly indicates that leaf water potential can increase about 1 bar after dawn. This increase appears to be related to the amount of dew. Presumably, leaf stomata open at dawn and water enters until the dew disappears. An increase in water potential of tree leaves at sunrise has been measured (3).

East and west leaves consistently show the same difference in hysteresis pattern on sunny mornings. If the three traces in Figure 4 were connected with continuous data, the resulting curve would show loops of varying shapes, depending upon the environment of the day, with each successive loop displaced to the right as long as the stem continued to grow.

From these data, it is clear that stem diameter is by no means related to plant water status by a single-valued function. In the first place, there is a diurnal hysteresis between leaf water potential and stem diameter (Fig. 3), and a similar hysteresis presumably exists between xylem potential and stem diameter. Secondly, it is clear from Figure 4 that, if a plant is still growing, a water potential of -4 bars on one morning may correspond to a diameter which is related to a water potential of -18 bars the next afternoon.

Still, measurements of stem diameter appear to be more sensitive than the other plant parameters to changes in net radiation. In short term experiments, effects of sprinkling leaves with water or of holding a large black cloth to shade plants are measured almost immediately as an increase in stem diameter. These treatments probably reduce evaporation, thereby increasing stem xylem water potential. This reverses the gradient between the xylem and surrounding parenchyma cells, which then take up water from the xylem. The greatest change observed in the experiments reported in this paper was a change of 0.14% of the stem diameter (0.01 mm in a 7.50-mm stem) over a 5-min period. To effect this change over a 1-cm segment of stem would require only $5 \times 10^4$ cm$^2$ of water; this quantity could easily be transported over a 5-min period. We think that the stem diameter changes reflect changes in stem tissue hydration. It is also possible that part of the immediate change in volume results from changes in xylem vessel cross-sectional area, which might occur with changes in xylem tension.

**LITERATURE CITED**