RESEARCH PROJECT TECHNICAL COMPLETION REPORT

Institution: University of Connecticut  Date of Report: November 3, 1970

OWRR Project No.: A-027CONN  OWRR Agreement No.: 14-31-0001-3007

Project Title: Changes in Resistance to Flow of Water Through a Soil-Plant System

Principal Investigator(s): B. E. Janes, G. W. Gee

Project Began (Mo. - Yr.): July 1969  Project Ended (Mo. - Yr.): June 1970

PROJECT OBJECTIVES:

To obtain information on the physical nature of barriers to water movement in plants growing in soil.

To estimate the magnitude of resistance and changes in resistance to flow of water in plants as a function of changing soil-water potentials and corresponding transpiration rate changes for plants grown in a controlled environment.

ACHIEVEMENT OF OBJECTIVES:

The research objectives of this project were partially completed. New techniques needed to perform the research were developed and proven. A limited amount of data was obtained and has been prepared for publication.

There were important educational benefits obtained. It enabled two graduate students to participate in and contribute to an important research project.

RESEARCH PROCEDURES USED:

Buchner type polyethylene funnels, 91 mm i.d., were modified to act as hanging water columns and soil column containers. Millipore filters with 0.45 μm pore diameter were sealed with a silastic rubber seal to the perforated plate of the funnels and then tested with a hanging water column to ensure that they would not leak at water potentials of 0.06 bar or higher. B horizon material from a Melrose loamy sand (73% sand, 20% silt, 7% clay) was used for the soil columns. All columns were packed to an average bulk density of 1.50 g/cm³ and to an average height of 4 cm above the Millipore filter.
Pepper plants (Capsicum annum L. var. California Wonder) were grown from seed in a growth chamber until they were approximately 2 weeks old. These seedlings were then placed in a small, 8.8 cm i.d., plastic container filled with ca 2.5 cm of potting soil in which 1/2 strength Hoagland solution was controlled at -0.06 bar water potential by means of a tension table. The root system was confined to the small soil volume by means of a Millipore filter sealed to the bottom of the container. When the plants had reached an average age of 7 weeks, they were 6 to 8 inches in height and had twelve to fifteen leaves with a total leaf area that averaged 3.5 dm² per plant. The soil was washed carefully away from the root mat and each plant was transplanted into a similar 8.8 cm i.d x 5.0 cm deep plastic container in which a field type thermocouple psychrometer was located. The thermocouple psychrometer was placed on 2-3 mm of soil above the Millipore filter just below the center of the root mat. The root mat was kept moist by saturating the underlying soil. Enough potting soil was added to bring the level to approximately 2.5 cm above the Millipore filter. The container was sealed by covering the top with black vinyl sheeting over which aluminum foil was placed and sealed to the container. A small vapor gap was left near the stem to allow for gas exchange. Samples of gas were taken from the root zone of the test plants periodically and tested for oxygen content by means of gas chromatography. It was found that in no case did the oxygen fall below 15% even under the wettest soil conditions and in most cases the oxygen content was greater than 19%. From this it was concluded that no deleterious effect was caused by sealing the root zone.

The prepared plant was placed on the top of the funnel containing the soil column and the level of the water supply was then adjusted to obtain a -0.06 bar water potential. The plant was made stationary by bolting a two piece plastic frame to the plant container and funnel. This arrangement insured good contact between the bottom of the plant container and the surface of the soil column. The soil-plant system was then returned to the growth chamber for one week.

Light intensity, humidity, and temperature were controlled in the growth chamber. In the high light experiment light intensity at plant height was 10.5 x 10⁴ erg/cm²/sec for 18 hrs/day at a humidity of 55 ± 5% and a temperature of 26 ± 2°C. In the low light experiment the light intensity was 2.5 x 10⁴ erg/cm² sec for 18 hrs/day at a humidity of 80 ± 10% and a temperature of 24 ± 2°C.
Plants were subjected to a drying cycle by removing the hanging water column, draining the water from underneath the soil column and stopping the funnel outlet. Transpiration was monitored daily on the plants in the microenvironmental chamber described by Janes. In this chamber light intensity, relative humidity, and temperature were kept constant at 2.4 x 10^4 erg/cm²/sec, 40%, and 27°C respectively. Temperature and root zone water potential were monitored daily until the plants were near or at the stage of permanent wilting. Because of observed temperature fluctuations in the root zone and inherent calibration errors it is estimated that the field type thermocouple psychrometers could measure the water potential in the root zone with an absolute accuracy of ± 1 bar although the precision was much better than this for any single reading (± 0.2 bar). Plants were kept in darkened humidity chambers overnight after first signs of wilting were observed allowing the plants to approach a water potential equilibrium between roots and top. This process was repeated until the lower leaves showed no visible signs of recovery. These plants are designated as set I.

In set II the Melrose soil column was removed and plants were subjected to controlled levels of total water potential by addition of the appropriate polyethylene glycol (PEG) solution to the root zone. The PEG solutions were made by mixing full strength nutrient solution with appropriate amounts of polyethylene glycol, mol. wt. 400, necessary to bring the osmotic potential to the desired level. Solutions with osmotic potentials of -2.5, -5.4, -9.9 bars as measured by an osmometer were used. The hanging water column was simultaneously flushed with the same PEG solution as the root zone. It was determined that flushing the root zone three times with volumes of PEG approximately equal to the total soil volume produced an osmotic concentration not detectably different from that of the original solution. The plant was then returned to the hanging water column.

The hanging water column maintained a constant high matric potential (-0.06 bars) and a constant high soil water conductivity. It also provided an ample reservoir for supplying and maintaining at the root surfaces a solution of essentially constant osmotic and hence constant total water potential. An osmometer check of samples collected from the under side of the Buchner funnel after the plant was sampled revealed that there was essentially no change in the solution concentration during the one day test period. A thermocouple psychrometer was placed in the root zone of one of these set II plants as a check on the root zone water potential. There was satisfactory agreement between psychrometric values and the osmometer measurements indicating that the root zone and hence root surfaces were controlled at a water potential value that could be estimated by the osmotic potential of the solution.
Sampling took place in a humidity chamber where the stem was severed about 3 cm above the root mat. The upper stem segment and attached leaves are hereafter designated as plant top, the lower stem segment and attached roots are designated as plant roots. The plant top, plant roots, and the mature detached leaves of each plant were sampled for hydrostatic pressure using a Scholander type pressure bomb. A rapid curing liquid silicone rubber worked well as a pressure sealant and prevented damage to the petioles and stems as pressure was applied. Plant materials were covered with a thin plastic wrapping to retard vapor loss both in the humidity chamber and in the pressure bomb. On each plant in set I, the hydrostatic pressure was measured first on the plant top, then on the plant roots and finally on the petioles of the three detached leaves. All the leaves were sampled for relative water content and some leaves were sampled for water potential using a psychrometric sample changer similar to the one described by Campbell et al. The attached soil column was also sampled for water content at three depths, 0.2, 1, and 3 cm. Soil column water potentials were inferred from a previously determined desorption curve.

RESULTS OR CONCLUSIONS:
In set I experiments when the water potential of the root zone was plotted against plant leaf water potential (inferred by hydrostatic pressure measurements) for conditions near zero transpiration, a 1:1 relationship was observed indicating that for near equilibrium conditions there was no significant water potential difference between root-zone and leaves. As the water potential in the root zone decreased, the difference between water potential in the soil column and root zone increased. In all plants of set I a relatively large water potential gradient between root zone and soil column was obtained.

Hydrostatic pressure measurements were used to estimate water potential gradients throughout the plant. There was a measurable hydrostatic pressure difference between root and top in all the plants measured. The negative hydrostatic pressures (water potential) in the roots were in all cases higher than the water potentials in the tops. The readings appeared to be more erratic, often dropping several bars within 15 minutes after the initial reading. Since the pressure could be read with a precision of at least ± 0.1 bar in the plant top and in the individual leaves and was found to be time independent, it was decided to test the time dependence of the hydrostatic pressure measurement in the plant roots. The time dependence of the root segment for set I data show that manipulation of the roots in placing them in the pressure bomb can dramatically alter the pressure reading. This would suggest that care must be taken to insure minimum disturbance of the root system when hydrostatic pressure measurements are used to infer root water potentials.
After observing these changes in negative hydrostatic pressure in plants whose root systems had been disturbed, a separate series of 8 plants were grown in small containers (5 cm i.d.) which could fit inside the pressure bomb without disturbing the roots. The plants were allowed to dry to various stages with no attempt to equilibrate the soil and plant before measuring. In the 5 cases where the negative hydrostatic pressure (water potential) was below -6 bars, the water potential measurement in the roots agreed well with the measured plant-top water potentials and were stable within ±0.5 bar for periods up to 1 hour. After this time they increased slowly until after a period of 6 hours they were higher by as much as 3 bars. The other three plants were tested while they were still turgid (water potential in tops was higher than -6 bars). In each of these cases the water potential measured in the roots was higher by at least 2 bars and within 6 hours the water potential increased to near zero (0.2 bar). It appears from this data that there might be more than one mechanism causing the change in hydrostatic pressure readings. In the cases where water potential is high (turgid plants) root pressures appear to be operating which contribute to the total pressure inside the vascular system of the plant. As long as this is operative and there is still adequate water at the root surface, water continues to move into the plant under the influence of the pressure gradient tending to lower the pressure between exterior and interior and reducing the measured pressure. As water is continually supplied the plant transports water to the cut stem until exudation or bleeding occurs. In the drier plants the mechanism becomes more complicated, root pressure if operating does so with much less influence on the total pressure. It appears that with time the drying soil tends to equilibrate at a rate depending on the soil water conductivity and as the water flows slowly to the root surface, the water potential at the cut surface adjusts accordingly. It is felt then that root disturbance, root pressure, and soil water conductivity all contribute to influence the measurement of root water potential.

It is apparent that in order to measure the water potential gradients in plants, not only must the plant be subjected to adequate environmental control, but the proper measuring techniques must be used and their limitations assessed before relying on the certainty of the measured gradients. Soil-root contact resistance appears to be a critical resistance in the flow path of water from soil to atmosphere via the plant. It also appears that the root hydrostatic pressure may not be a reliable index of water potential in the root because even slight damage to the root system can cause considerable reduction in the hydrostatic pressure readings. Also, there is the uncertain contribution of root pressure and soil water conductivity. In all cases the negative hydrostatic pressure root overestimated the water potential in the root zone. The hydrostatic pressure in the leaf petiole gave reliable estimates of the water potential in plants that had been equilibrated overnight in a humid chamber but overestimated the water potential in plants that were sampled immediately after being subjected to a high light condition.
PUBLICATIONS:

ACKNOWLEDGMENT:
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ABSTRACT:
A method employing the use of both a hanging water column and a field type thermocouple psychrometer was developed to control and measure water potential gradients in pepper plants with confined root systems. Small soil containers were constructed with Millipore filters arranged so that they confined the root system but allowed water transport to the roots. Water flow rates were measured by placing the soil-plant system in a microenvironmental chamber where temperature, light, CO₂, and humidity were controlled. Test plants near or at permanent wilting showed an increasing water potential gradient between roots and adjacent root free soil as the water potential in the root zone decreased. This was accompanied by a decreasing relative water content in the leaves and a decreasing negative hydrostatic pressure in the leaf petioles. Hydrostatic pressures in leaf petioles were in agreement with those found in the plant top and agreed well with the psychrometrically determined root zone water potential measurements. On the other hand, water potentials inferred from hydrostatic pressure measurements averaged 4 bars higher in the plant roots than in the plant tops. A nonlinear relationship between transpiration rate and decreasing root zone water potential was observed for plants allowed to dry to wilting and also plants controlled at a high matric potential but subjected to controlled decreases in total water potential. In the latter test, the total water potential was controlled by adding polyethylene glycol solution directly to the soil.

KEYWORDS:
barriers
water movement in plants
resistance
water potential
transpiration