RESEARCH CIRCULAR 101 APRIL 1961

The NEOTOMA ECOLOGICAL and BIOCLIMATIC LABORATORY

Special Report No. 5

A PRELIMINARY INVESTIGATION OF INTERNAL WATER RELATIONS OF TREE STEMS BY ELECTRIC RESISTANCE

by

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A PRELIMINARY INVESTIGATION OF INTERNAL WATER RELATIONS OF TREE STEMS BY ELECTRIC RESISTANCE[1]

Jerry A. Koch*

This paper is concerned with a preliminary study of the internal water dynamics of living woody stem tissues as indicated by their electric resistance. The investigation was conducted at Neotoma, a forested valley in south-central Ohio where extensive bioclimatic and ecological studies have been conducted for more than 20 years (Wolfe, Wareham, and Scofield, 1949; Wolfe and Gilbert, 1956; and Gilbert, 1961).

Two woody individuals, Tulip-tree (**Liriodendron tulipifera** L.[2]) and Chestnut Oak (**Quercus prinus** L.), were chosen for study. Both were located within the Mixed Mesophytic community of the lower northeast-facing slope of the problem area (sta. 1, Fig. 1) and were within 30 feet of each other. Their crowns were included in the canopy, the top of which occurs approximately 80 feet above the forest floor.

Resistance measurements of a portion of the inner bark and outer xylem of each tree were continuously recorded throughout a 21-day period in late August and early September of 1959. Water content of the tissues is expressed in ohms resistance and relative changes are graphically correlated with one another, environmental data, and radial change data (Figs. 2, 3, and 4).

ASSOCIATED INVESTIGATIONS

The following environmental factors were continuously measured throughout the period of the investigation:

1. Air temperature of mid-canopy level (Serdex hygrothermograph).

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[1] A special report of the Neotoma Ecological and Bioclimatic Laboratory jointly sponsored by the Ohio Agricultural Experiment Station, The Ohio State University, and the United States Atomic Energy Commission [Contract No. AT(11-1)-552].

[2] Nomenclature that of Gray's Manual of Botany (with exception of capitalization of specific epithets), 8th edition (Fernald, 1950).

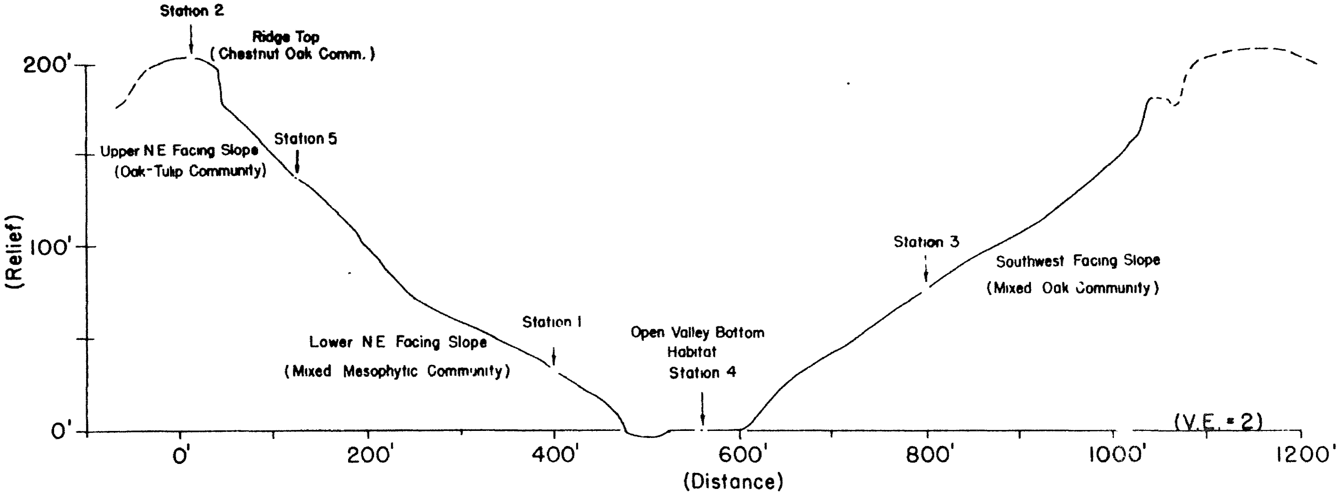

Fig. 1. Cross section of central portion of Neotoma indicating distribution of vegetation types and location of permanent study areas (distance and relief in feet).

2. Atmospheric water vapor content of mid-canopy level (Serdex hygrothermograph)
3. Solar radiation 10 feet above canopy (Eppley pyrheliometer)
4. Soil temperature at six inch depth (30 gage copper-constantan thermocouple)
5. Soil moisture at five inch depth (Colman soil moisture unit)
6. Precipitation 10 feet above canopy (Friez tipping-bucket rain gage)

Stem temperature at one inch stem depth of both study trees was constantly measured throughout the investigation along with constant measurement of radial change of the Tulip-tree individual by use of Fritts dendrograph (Fritts and Fritts, 1955). Radial change data, also obtained by Fritts dendrograph, of a Chestnut Oak canopy individual of the Mixed Oak community of the opposing slope is here included since 1) the dendrograph of the Chestnut Oak included within the stem resistance studies was inoperative, and 2) previous studies revealed that radial change patterns of Chestnut Oak individuals occurring within the forest community study areas (sta. 1, 2, and 3, Fig. 1) are similar although of different magnitude.

METHODS

Twenty-four gage nickel-plated steel needles were used as electrodes since they were of small size, corrosion resistant, and of sufficient physical stability. Each needle was provided with a lead wire soldered at the eye end, and all but one-sixteenth inch of the tip was encased in a snug-fitting tubular plastic insulator. The completed electrodes were approximately one-sixteenth inch in diameter.

Bark (here considered as all tissues exterior to xylem) thickness of the two trees was determined by obtaining several bark samples by use of cork borer. A drill the same outside diameter as the electrode was used to drill to, but not penetrate the tissue to be measured. The electrode was then positioned in the hole and lightly tapped to drive the exposed electrode tip into the tissue to be studied. The distance between the members of the electrode pair placed in the inner bark was approximately one-half inch, while approximately two inches separated the electrodes measuring xylem resistance.

The two pairs of electrodes were separated by a vertical distance of seven inches. The electrodes of each electrode pair were placed in a horizontal plane on the east-facing side of the stem approximately three feet above the soil surface. The exposed electrode ends and adjacent bark were sprayed with several coats of acrylic resin to insure against resistance readings across the bark when wet and prevent water from moving into the tree along the electrodes.

Lead wires were extended to a recording 60 cycle, alternating current ohmmeter located within the central recording station at station 4 (Fig. 1).

GENERAL CONSIDERATIONS OF PLANT TISSUE RESISTANCE

The aqueous component of plant tissues is a solution of both electrolytes and non-electrolytes, the former enabling flow of electric current when an electromotive force is impressed upon the tissue. In general, electric resistance of living tissue is dependent upon a number of factors which are here considered to be of two major categories, namely 1) water content and 2) other factors.

Water content. — Both amount and location of water within tissues influence electric resistance, location of water being partially dependent upon total amount of water present. For example, in xylem tissue water may be within cell walls, in intra-cellular spaces of both living and non-living cells, as well as in inter-cellular spaces. Gibbs (1935) states that the cell walls of wood under natural conditions are saturated with water because of both their imbibition pressure and the presence of free water somewhere in the wood. Myer and Rees (1926) progressively dried wood samples and found that "free water" of wood cavities was depleted before cell wall water content decreased.

Both studies point out that fluctuations in water content of plant tissues involve shifts in location of water which in turn affect electric resistance. Myer and Rees also found that resistance and physical dimensions of wood changed little until free water was eliminated, but as cell wall water content decreased, resistance increased progressively as did physical shrinkage. During the present studies electric resistance of bark and xylem tissue was also well correlated with change in their physical dimensions as indicated by dendrograph measurements.

In summary, decreased water content probably influences resistance most directly by decreasing total conducting medium, restricting electric conduction more to bound water of cell walls, and reducing electrode area in contact with conducting medium.

Another effect of decreased water content upon electric resistance is a possible change in electrolyte concentration. Water loss from tissue directly by evaporation would in effect increase electrolyte concentration, causing decreased resistance. However, decreased water content resulting from mass movement of the aqueous component would not influence resistance strictly as a function of electrolyte concentration. During the present studies decreased water content was correlated with increased resistance suggesting that either no significant changes in electrolyte concentration occurred or that both reduced conducting medium and electrode area nullified any effects of increased electrolyte concentration.

Other factors. — As previously stated, several additional factors not directly dependent upon water content may affect electric resistance of living tissues. For example, the relative proportion of electrolytes in the aqueous component of tissues can vary; however, Dixon (1916) states that effects of such variations on resistance are so slight that they may be discounted. Temperature effects upon solution resistivety are pronounced, the temperature coefficient of resistance of aqueous electrolytic solutions is negative with magnitude dependent upon concentration and nature of conducting ions. It is believed that a correction factor or factors can be derived to correct for temperature induced resistance changes; however, this was not attempted during the studies here reported.

DISCUSSION

The data utilized in this analysis are graphically presented in Figures 2, 3, and 4. All curves were derived from hourly values of the respective data except soil temperature which was derived from bi-hourly values. The resistance values of bark and xylem were of considerably different magnitude and consequently have been graphically adjusted in order that the resultant curves have the same approximate displacement. The curves of radial change have been inverted so that decreases in radius, which actually indicate decreased water content, now appear as increases; consequently, fluctuations in water content as indicated by both resistance and radial change are graphically similar in direction. The curve of soil moisture was derived from resistance values but has been expressed as percent dry weight.

This investigation was initiated on August 21, 1959, and was continued without interruption for a period of 21 days. The two-week period immediately preceding the initiation of these studies was characterized by frequent rains, high soil moisture, and considerable cloudiness, which represent factors favoring high internal water content of trees.

The effects of the environmental conditions associated with the one-inch rain which occurred on the first day of this investigation are clearly demonstrated by the abrupt increase in water content of the two trees. The duration of the investigation was characterized by essentially no precipitation, clear days of high atmospheric vapor pressure deficit and decreasing soil moisture. During the first 9 days of the investigation soil moisture decreased 15 percent (dry weight) and throughout the following 12 days decreased but 3.5 percent. The greatest decrease of soil moisture during a 24-hour period occurred on the 31st of August, the day of highest transpiration potential during the first six days. Both dendrograph and resistance curves indicate a progressive decrease of stem moisture throughout the investigation and are correlated with decreased soil moisture. Both curves exhibit diurnal fluctuations which are clearly correlated with environmental factors influencing transpiration potential.

A number of relationships between bioclimatological patterns and internal water dynamics of the two study trees are here inferred and discussed.

Chestnut Oak. – Distinct diurnal fluctuations in Chestnut Oak inner bark resistance occurred during the period of this investigation, daily maxima occurring during middle or late afternoon. Daily fluctuations of bark resistance lagged corresponding changes in vapor pressure deficit at the 60-foot (in canopy) air level by several hours.

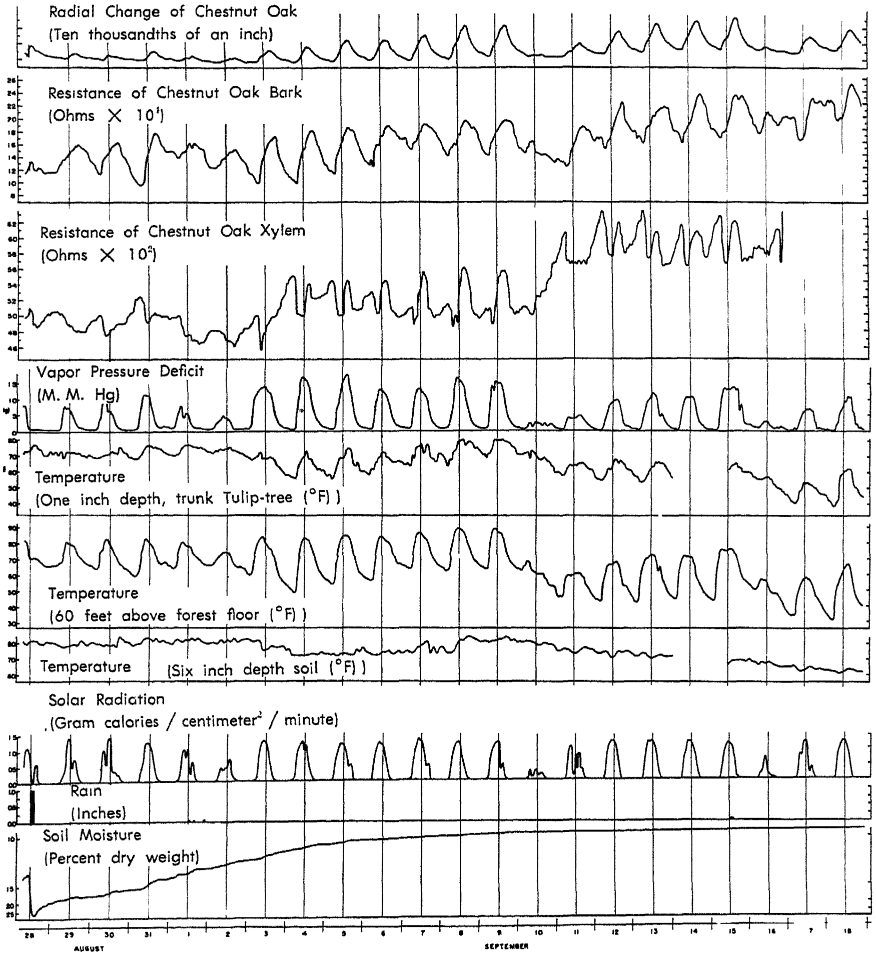

Fig. 2. Electric resistance and radial change of Chestnut Oak and associated bioclimatic data.

During the nights of September 16 and 17 bark resistance increased, the increases being negatively correlated with air and stem temperature which suggests a direct temperature influence upon the resistance of water.

Bark resistance is well correlated with water content as indicated by radial changes of the stem. The maxima of the two curves occur at approximately the same time each day and the daily initial increases occur at nearly the same time. They are not as well correlated at night, however, as the degree of relative depression of the two curves differs. The curve of radial change returns to the same approximate value each night while the bark resistance curve, as

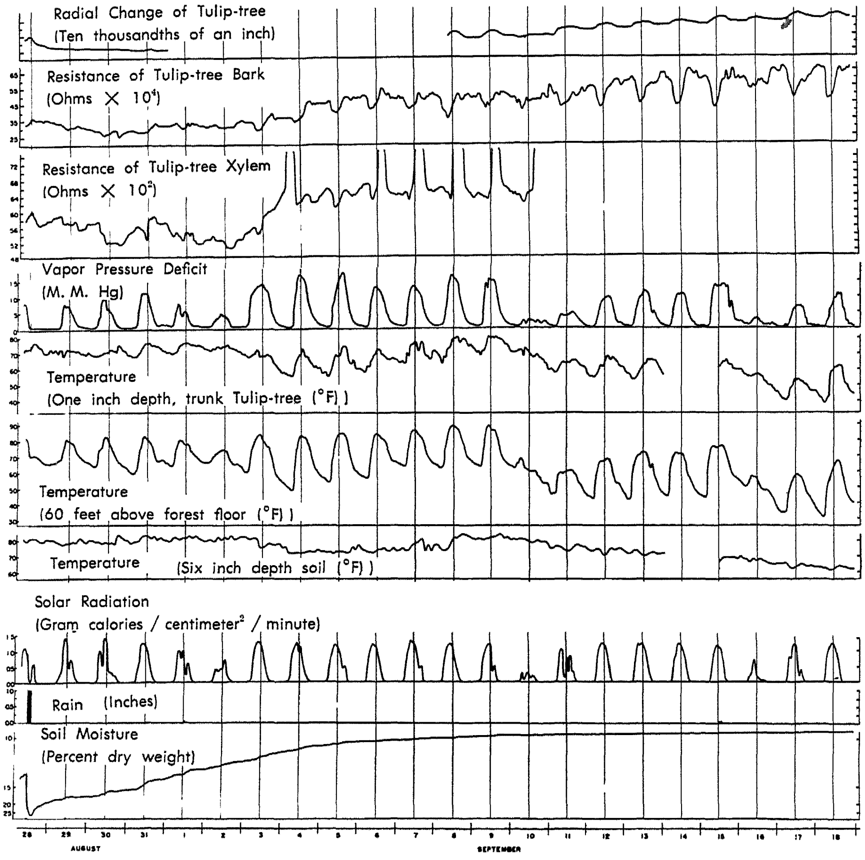

Fig. 3. Electric resistance and radial change of Tulip-tree and associated bioclimatic data.

mentioned, varies with night temperature. It appears, due to similarities between the curves, that radial change and bark resistance values were generally indications of the same phenomenon, i.e., bark water content.

The pattern of xylem resistance was quite different from that of bark. During the first seven days fluctuations of xylem resistance appear at first glance quite erratic. These fluctuations, however, are negatively correlated with stem temperature suggesting that fluctuations in water content were so slight that direct temperature-induced resistance variations were of greater magnitude. Following the initial seven-day period and beginning on September 4, daily increases of xylem resistance occurred indicating decreased water content. During the nights, however, negative correlations existed between xylem resistance and temperature indicating direct temperature influences on resistance. On September 4 the entire xylem resistance curve shifted upward. Soil temperature decreased on this day, and soil moisture content had decreased to a value near the minimum value which persisted for the remainder of the study period.

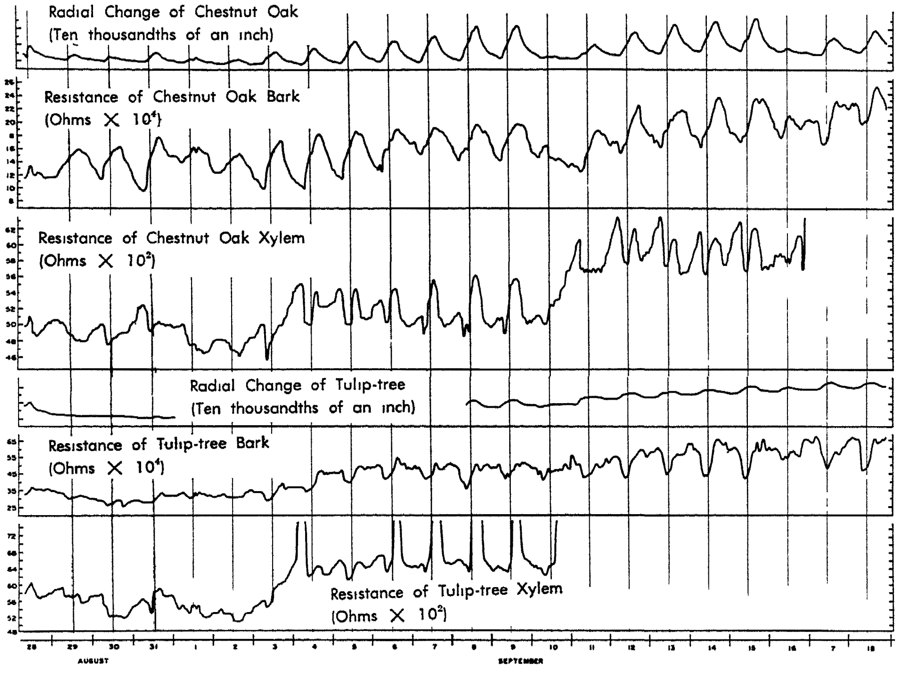

Fig. 4. Electric resistance and radial change of Chestnut Oak and Tulip-tree.

Water uptake may have been affected by the lower soil temperature (Kramer, 1942) as well as decreased soil moisture, but average stem temperature also decreased which would have the same effect on resistance. A second general increase of xylem resistance occurred on September 10 under similar conditions. The degree of total resistance change caused by direct temperature effects on resistance and/or by changes in water content is again not possible to determine. Resistance values indicate that the daily minimum water content of xylem was reached several hours before that of bark. Following these minimum values, the water content of bark increased at a much slower rate than did xylem.

On August 28, during a one-inch rain, xylem resistance began to decrease at least one hour before that of bark. Since bark water content replenishment is nearly completely dependent upon the xylem, increases in bark water content would be expected to follow that of xylem. Following September 16 the resistance of xylem increased to a point within the range of the recorder which was not functioning properly and consequently data were not obtained during the final two days.

Tulip-tree. — Corresponding data concerning the Tulip-tree individual are less complete than those of Chestnut Oak since radial change and xylem resistance values of the Tulip-tree were not obtained during a number of days of the investigation. Those values of Tulip-tree xylem resistance which were obtained are generally similar to Chestnut Oak xylem resistance in over-all pattern although several differences occurred which may be significant. The rate of xylem water content increase during the one-inch rain of August 28 was greater in Chestnut Oak than in Tulip-tree, and both daily and total decreases in water content were greater in Tulip-tree xylem. Ecologically, these differences of the two individuals may be important as an indication of their efficiency in maintaining a "favorable" water content.

As in the Chestnut Oak xylem, direct temperature effects upon Tulip-tree xylem resistance appear to have occurred.

The radial change of Tulip-tree was generally similar to radial change of Chestnut Oak although some specific differences did occur. The total amount of shrinkage during the entire investigation was greater in the Tulip-tree although the daily fluctuations were not as great as those of Chestnut Oak.

The daily variations in Tulip-tree bark resistance are graphically similar to those of xylem although of greater absolute resistance. The pattern of Tulip-tree bark resistance change exhibits nocturnal increases in resistance which appear to be temperature induced and which are not present in the curve of Chestnut Oak bark resistance. This difference may be explained on the basis of temperature effect upon resistance of an electrolytic solution contained in a material such as wood or cork. The resistance varies as temperature varies but the relation between resistance and temperature is not linear. The greater the resistance the greater the influence a unit change in temperature has, and since the resistance range of the Tulip-tree bark was of greater magnitude than of Chestnut Oak a given change in temperature would have had more effect on Tulip-tree bark resistance.

SUMMARY

This paper concerns a preliminary investigation of the measurement of internal water dynamics of plant tissues as indicated by their electric resistance. Resistance of portions of the inner bark and outer xylem of two canopy individuals of the Mixed Mesophytic community of Neotoma (Tulip-tree and Chestnut Oak) was continuously recorded for a 21-day period, and relationships between these resistance values and environmental data are here suggested. Environmental factors influencing transpiration potential and water uptake of plants were found to be well correlated with tissue resistance. Diurnal changes in radius of the Chestnut Oak as indicated by dendrograph measurements appear to be caused largely by fluctuations in bark water content. Under similar environmental conditions, decreases in water content of the Chestnut Oak stem appeared less than those of Tulip-tree. The results of this investigation indicate that productive studies concerning internal woody stem water dynamics based on electric resistance measurements are possible, but additional studies are necessary to further elucidate relationships between resistance values and actual tissue water content.

ACKNOWLEDGMENTS

Sincere appreciation is hereby expressed to Dr. Edward S. Thomas for use of his land, to Mr. John Freeman for use of his land and power equipment for haulage of heavy equipment, to the Ohio Power Company for extension of electrical service into the study area, and to the United States Atomic Energy Commission for its financial support of the Neotoma basic research program.