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BRIEF COMMUNICATION

Geophytoelectrical current in trees of a subtropical rainforest in Mexico

L. YÁÑEZ-ESPINOSA*[1], T. TERRAZAS*, L. LÓPEZ-MATA* and L. FUCIKOVSKY**

Programa en Botánica and Programa en Fitopatología**, Colegio de Postgraduados, km 36.5 carr. México-Texcoco, Montecillo, Estado de México, 56230 México*

Abstract

The geophytoelectrical current of three evergreen tropical tree species is studied as an indirect measure of their relative water content. Two intermediate shade-tolerant species (*Aphananthe monoica* and *Pleuranthodendron lindenii*), distributed in the middle and upper canopy strata, and an understory shade-tolerant species (*Psychotria costivenia*) were examined. The annual rhythm of geophytoelectrical currents per cm of diameter (DBH) is seasonal, with the highest occurrence in the winter and summer. There is a significant association between maximum temperature, moisture in the environment, and geophytoelectrical current per cm of DBH in the three species, as shown by multiple regression analysis. This finding suggests the existence of various geophytoelectrical current patterns which differs from that reported for temperate species.

Additional key words: *Aphananthe monoica,* evergreen tropical trees, *Pleuranthodendron lindenii, Psychotria costivenia,* water content.

The difficulty of using the pressure chamber method to evaluate stem water potential in tropical trees has encouraged the use of variations in electrical resistance as an indirect measure of relative water content in stem tissue (Borchert 1994a). This simple, non-destructive method has been used in the field to monitor changes in tree water status (Fensom 1966, Dixon *et al*. 1978). The variations in electrical resistance depend on secondary phloem, vascular cambium, and sapwood hydration, since the resistance to a low-frequency alternating current essentially depends on ion content and amount of sap released into the apoplast by damaged cells, as the electrodes are inserted (Dixon *et al.* 1978, Borchert 1994a). Variations in the electrical resistance of stem tissues have also been used to estimate vigor, growth periodicity, and decay of trees (Wargo and Skutt 1975, Shortle *et al*. 1977, Davis *et al*. 1979, Wisniewski *et al*. 1985, Wargo *et al*. 2002).

Rajda (1992) developed another method to assess tree vigor, by measuring the natural electrical current between the tree and the ground. This current, called the geophytoelectrical current, is present throughout the plant's entire life. Its intensity increases as the plant ages, varying as the seasons change. It shows specific peaks in the summer in the case of trees in temperate climates. The geophyto-electrical current also depends specifically on secondary phloem and vascular cambium thickness at the base of the tree trunk and on its diameter (Rajda 1992).

The relationship between electrical resistance and stem tissue hydration in trees can be understood as the correspondence between an increase in moisture or water potential and a decrease in electrical resistance (Dixon *et al.* 1978). In experiments where increased electrical currents were applied to plants, the leaf area increased

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Abbreviations: DBH - diameter at breast height; GPEC - geophytoelectrical current; GPEDC - geophytoelectrical current per cm of DBH.
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[1] Corresponding author present address: Unidad de Recursos Forestales, Instituto de Ecología, Xalapa, Veracruz, 91070 México; fax: (+52) 228 84218006108, e-mail: lauray6711@prodigy.net.mx

and vessel diameters were 40 % wider, in direct relation to the transpiration rate (Rajda 1986).

Most physiological studies on water stress in woody plants have been conducted in markedly seasonal climates (Doley 1981). Electrical resistance has been used as an indirect measure of relative water content in tropical dry forest species (Borchert 1994a,b), temperate forest species and cultivated plants (Dixon *et al*. 1978). Studies have been carried out on the geophytoelectrical current in some temperate forest species such as *Alnus glutinosa*, *Betula pendula*, *Fagus sylvatica*, *Quercus robur*, in cultivated plants (Rajda 1986, 1992), and in the mangrove species *Rhizophora mucronata* (Kathiresan and Rajendran 2000).

The purpose of this research was to evaluate the use of the geophytoelectrical current as an indirect measure of relative stem water content in three evergreen tree species distributed in a subtropical rainforest. The relationship between geophytoelectrical current and tree diameter was studied, describing the pattern of annual variation in stem water content and the relationship with several environmental variables.

The study was conducted in a subtropical rainforest located in central Veracruz, Mexico (19°49'37"N, 96°32'37"W, 420 m a.s.l.). Mean annual temperature was 22.4 °C and total annual rainfall was 2217 mm. The rainy season lasts 4 months (June to September), and 15 % of total precipitation falls in winter. There is a short season (March and April) when humidity is lower, with 82 - 84 mm monthly rainfall. The soil is quite rich in organic matter and calcium. A census was taken of all trees with diameter at breast height (DBH) ≥ 1 cm, and each tree was located by its coordinates. DBH and height were measured for each tree, and all individuals were tagged and identified (Godínez-Ibarra and López-Mata 2002).

The three evergreen species studied were: 18 trees of *Aphananthe monoica* (Hemsl.) Leroy (*Ulmaceae*) with DBH 1.9-116.2 cm and height 3.0 - 30.0 m, 18 trees of *Pleuranthodendron lindenii* (Turcz.) Sleu with DBH 2.9 - 23.3 cm and height 2.8 - 20.0 m (*Tiliaceae*), and 11 trees of *Psychotria costivenia* Griseb. (*Rubiaceae*) with DBH 2.9 - 10.1 cm and height 3.0 - 6 m. *Psychotria costivenia* is a shade-tolerant species characteristic of the understory, while *A. monoica* and *P. lindenii* are intermediate shade-tolerant species, typically dominant in late succession and distributed in the middle and upper strata (Yáñez-Espinosa *et al*. 2003).

Rainfall, air temperature (maximum, mean and minimum), and evaporation data were obtained from Misantla, the nearest meteorological station, 15 km from the study site and at the same elevation. Three thermohygrometer data loggers (*HOBO H8 Pro*; *Onset Computer Corp*., Pocasset, MA, USA) were positioned on tree branches 5, 15, and 25-m high in April 2000, to obtain air temperature and humidity data of the canopy strata in the study plot, and were unloaded using *BoxCar 3.6* (*Onset Computer Corp.*). Vapor pressure deficit was calculated using mean monthly temperatures and relative humidity. Soil samples (n = 24) were analyzed for pH, organic matter content, electrical conductivity, cation exchange capacity, and chemical composition (N, P, K, Ca, Mg, Na). Gravimetric soil moisture was taken in bimonthly samples from each 400 m^2.

A total of 47 trees of varying diameters and heights were selected. The geophytoelectrical current was measured bimonthly at the base of each selected tree using the method described by Rajda (1992). From May 2000 to September 2001, 10 repetitions N orientation were carried out. Measurements were made between 08:00 and 16:00. The effect of air temperature on the geophytoelectrical current (GPEC) was compensated by adjusting the increment ratio by 2.8 $\mu A\ ^{\circ}C^{-1}$ (Rajda 1992). DBH was measured at the same time using a diameter measuring tape on the painted reference mark applied at the time of the first measurement. The geophytoelectrical current per cm DBH (GPEDC) was calculated using the bimonthly geophytoelectrical current measurements.

Data were natural logarithm transformed prior to statistical analyses. Significant differences in GPEC and GPEDC among dates for each species were evaluated using analysis of variance (*ANOVA*). Differences between means were compared and separated by Tukey test ($P < 0.05$). A stepwise multiple regression analysis was performed between GPEDC as the dependent variable and the environmental variables as independent variables for the three species together. To detect collinearity of independent variables, a principal component analysis was performed (Belsley 1991), resulting in the inclusion of only the chosen variables. All statistical analyses were performed with *SAS* software version *6.04* (*SAS Institute Inc.*, USA 1989).

The three species showed two peaks of different magnitudes for the GPEC and GPEDC, occurring in January and July, and a minimum in May (Fig. 1). The *ANOVA* showed significant differences in GPEC among dates in *P. lindenii* ($F = 7.23$, $df = 8$, $P < 0.0001$, $n = 54$), and *P. costivenia* ($F = 26.81$, $df = 8$, $P < 0.0001$, $n = 36$), but no significant differences in *A. monoica* ($F = 2.37$, $df = 8$, $P < 0.25$, $n = 81$). The Tukey test confirmed that statistically significant differences exist in GPEC only between May and the other dates for the two species (Fig. 1*A*). The changes in GPEDC are similar, but the highest values were observed for *P. costivenia* (Fig. 1*B*). The *ANOVA* also showed significant differences in GPEDC among dates in *P. costivenia* ($F = 11.50$, $df = 8$, $P < 0.0001$, $n = 36$), but not in *A. monoica* ($F = 0.13$, $df = 8$, $P < 0.997$, $n = 81$), and *P. lindenii* ($F = 1.08$, $df = 8$, $P < 0.392$, $n = 54$). The Tukey test confirmed these statistically significant differences in GPEDC only between May and the other dates for *P. costivenia* (Fig. 1*B*).

Table 1 displays the correlations between the variables, unstandardized regression coefficients (*B*), standardized regression coefficients (β), and semipartial correlations (sr^2) and R^2. Only three of the independent variables contributed significantly to the prediction of GPEDC as logarithmically transformed - the log of maximum temperature scores (sr^2 = 0.92), log of air relative humidity scores (sr^2 = 0.005) and log of soil calcium content scores (sr^2 = 0.004). 93 % of the variability in GPEDC was predicted by the known scores in these three independent variables.

Each studied species showed different GPEC and GPEDC, as well as a different seasonal pattern than those reported for temperate species (Rajda 1986, 1992). In temperate species, minimum GPEC values occur during winter, rising steadily to reach a maximum in summer (though with a short one-month peak) and steadily decreasing to a minimum at the end of the year (Rajda 1992). A similar pattern can be observed in electrical resistance in temperate species, although inverted, due to the way in which it is measured (Davis *et al*. 1979). In the species studied, maximum GPEC and GPEDC values were observed in the winter for one month and in the summer for one month, with a slight decrease during the preceding and following months. Except for May 2000, month-to-month variation is not significant for the three species, unlike the considerable variation in GPEC for temperate species (Rajda 1992).

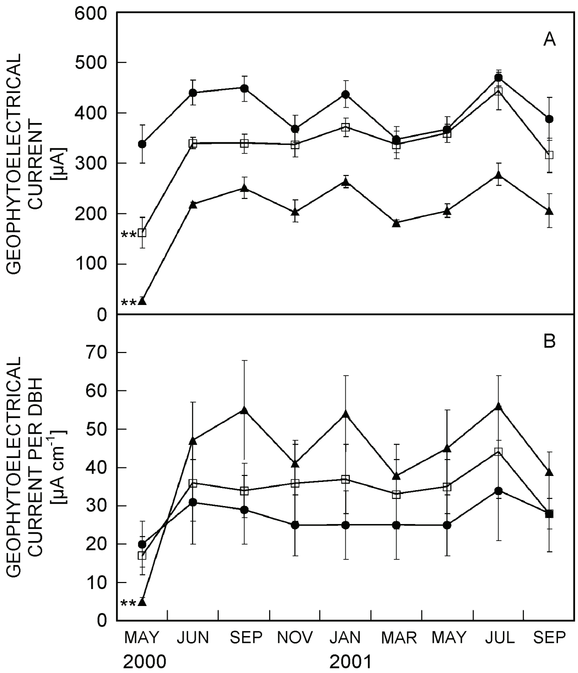

Fig. 1. Annual variation (means ± SE) in geophytoelectrical current, GPED (*A*) and geophytoelectrical current per cm of DBH, GPEDC (*B*) in the three species *A. monoica* - *circle*s, *P. lindenii* - *squares*, and *P. costivenia* - *triangles*. ** - significant differences at $P < 0.05$ (Tukey test).

Table 1. Stepwise multiple regression of environmental variables on GPEDC. ** - $P < 0.0001$.

Variables	GPEDC	Max. temp.	Relative humidity	*B*	β	sr^2
Max temperature	0.962			1.65**	1.69	0.925
Relative humidity	0.963	0.999		2.52**	3.38	0.005
Soil Ca	0.953	0.995	0.996	-0.98	-0.73	0.004
					$r^2 = 0.934$	

There are no studies of seasonal variation of GPEC or electrical resistance in tropical species. Electrical resistance as a measure of stem water content reported by Borchert (1994*a*,*b*) for the winter dry season in a tropical dry forest suggests that the decrease in stem water content in evergreen species is not great, and that a slight increase takes place during or after leaf fall. The GPEC pattern was similar for the three species studied, indicating seasonal behavior and only small decreases in stem water content. The occurrence of maximum GPEC values during winter and summer - when metabolic processes are most active, and minimum during the dry season - when metabolic processes are reduced, suggests a correlation with seasonal changes in water potentials (Davis *et al*. 1979).

This relationship between GPEDC and stem water content draws attention to the association between GPEDC and climatic and microclimatic variables, as they are related to moisture in the environment. The direct relationship between GPEDC and maximum temperature suggests a relationship with transpiration. Rajda (1986) demonstrated experimentally that an increase in electrical current is associated with an increase in transpiration. In fact, the low variation in GPEC may be due to the fact that seasonal adjustments in stomatal conductance in evergreen trees, in combination with seasonal moisture changes in the environment, led to a seasonal homeostasis of transpiration (Meinzer *et al.* 1993).

The direct relationship between air relative humidity and GPEDC suggests moisture availability in the environment. Prevailing environmental conditions in the study site enabled relative humidity to be maintained above 80 % year round. Rainfall is less in winter than in summer, but this is compensated by lower temperatures. The high relative water content of evergreen trees indicates the presence of available water that deciduous species do not have access to (Schulze *et al.* 1988). In some studies, evergreen trees have been observed to grow in sites with available ground water, indicating that seasonal precipitation is not the reason for variation in stem water content (Borchert 1994*b*). In the study site, however, relative humidity apparently had a considerable influence on regulating transpiration.

Rajda (1992) experimentally determined that an increase in the electrical current was associated with higher amounts of K, P, and Mn, and a reduction of excess amounts of Mg^{2+} and Ca^{2+} in the plant. Wargo *et al*. (2002) found that electrical resistance in *Acer saccharum* Marsh. was significantly correlated with soil pH and exchangeable Ca^{2+} and Mg^{2+}. The lowest values of electrical resistance and greatest root growth were seen in trees growing in locations with high soil cation availability, especially Ca^{2+} and Mg^{2+}. Moreover, the increase in electrical resistance during physiological dormancy periods indicates that low amounts of active vascular cambium activity and free water restrict ion movement and reduce ion concentration (Wisniewski *et al.* 1985). This could be the means by which the relationship between GPEDC and Ca^{2+} is associated with stem water content and vascular cambium activity.

The relationship with climatic variables suggests a close association between transpiration and GPEDC, though the leaves of each studied species displayed anatomical and morphological traits according to the particular sources of moisture in each forest stratum (Yáñez-Espinosa *et al*. 2003). However, it would be necessary to study further tropical species to be able to make generalizations about differences between tropical and temperate species.

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