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Drought Resistance of Mixed Pine-Oak Forest Species in the Sierra Madre Oriental, Mexico

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Introduction

Mixed pine-oak forests are widely distributed in the higher altitudes of the Eastern Sierra Madre and in the case of pine trees are ecologically and economically important in the region (Rzedowski, 1986). These forests are exposed to extreme climatic conditions of high temperatures and low precipitation distributed irregularly through the year. Moreover, climatic change makes the conditions for plant grow even more acute, and water availability is a limiting factor in these ecosystems (González et al., 2003). In addition, unsustainable management contributes to the acceleration of forest degradation and deforestation in great parts of the mountain chain Sierra Madre Oriental due to anthropogenic stresses like forest fires, agricultural, silvo-pastural and silvicultural activities (Cantú and González, 2002; Salinas and Treviño, 2002; González et al., 2005), and natural regeneration and reforestation are difficult. The response of ecosystems to such climatic and anthropogenic stresses will depend in part on the drought tolerance capabilities of the individual species (Tschaplinski et al., 1998). In order to develop and apply sustainable management or reforestation programs, detailed knowledge about the physical condition of tree species and their capacity to respond to a dynamic environment is an important precondition (Jurado et al., 1998). Under field conditions, water stress is more often limiting to plant growth than any other environmental variable and affects most physiological processes involved in plant growth (Kozlowski et al., 1991; Kramer and Boyer, 1995). The objectives of our study were to assess and quantify how seasonal plant water potentials (Ψ_w) and osmotic potentials (Ψ_s) are related to soil water availability and evaporative demand components in four tree species (*Acacia rigidula, Juniperus flaccida, Pinus pseudostrobus, and Quercus canbyi*).

Material and Methods

This research was carried out at the Experimental Forest Research Station (EF) of the Faculty of Forest Science, Autonomous University of Nuevo Leon (UANL) in the Sierra Madre Oriental (24º42'N; 99º51'W), located 15 km southeast of Iturbide in the state of Nuevo Leon, Mexico. The EF extends over an area of about 1035 ha and due to its protection status for about 20 years, it presents good characteristics for the study of undisturbed environmental processes. The mean annual air temperature is 13.9ºC and the average annual precipitation is 639 mm, and is concentrated from May to October. The dominant soils are rocky and comprise upper cretaceous lutite or siltstone (Cantú and González, 2002).

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Five individuals (from natural regeneration) of four tree species were randomly selected from a representative pine-oak forest for repetitive measurements of plant water potentials. All sampling trees were chosen within a 500 m^2 plot. The plant species were *Acacia rigidula* (Benth. Mimosaceae), *Juniperus flaccida* (Schlecht., Cupressaceae), *Pinus pseudostrobus* (Lindley, Pinaceae), and *Quercus canbyi* (Trel. Fagaceae). The leaf water potentials (Ψ_w, MPa) were determined twice a month from Jan-20 until Aug-17, 2006, and the osmotic potential (Ψ_s, MPa) was measured once a month during the same period. Plant water potentials (Ψ_w) were measured immediately after cutting the leaves or terminal twigs of each sample tree and monitored twice a day, at 6:00 h (Ψ_{wpd}) and 12:00 h (Ψ_{wmd}) according to the sampling date calendar. Measurements were made with a Scholander pressure chamber (Model 3005, Soil Moisture Equipment Corp., Santa Barbara, CA, USA) (Turner,1981). For determination of the Ψ_s, plant samples were taken with a hole puncher from leaves in the case of *Q.canbyi*. In the case of *J.flaccida*, *A.rigidula* and *P.pseudostrobus,* parts of terminal twigs or the pine needles were cut. Plant samples were collected at 6:00 a.m. (Ψ_{spd}) and 12:00 h (Ψ_{smd}) and immediately guarded in small tubes and shock frozen in liquid nitrogen to conserve them for later laboratorial analysis. Once in the laboratory, the osmotic potential was determined using a Wescor HR 33T (Wescor Inc., Logan, UT) automatic scanning dew point microvoltmeter (Wescor C-52) (Wilson et al., 1979).

Simultaneously, microclimatic data of air temperature (ºC) and relative humidity (%) was registered on an hourly basis by using thermo-hygrometer (HOBO® Pro Series Weatherproof Data Loggers) that were located directly in the sampling site between the sampling trees. Likewise, daily precipitation (mm) was obtained from self-emptying rain gauge (Onset® Data Logging Rain Gauge) installed in the same site. Vapor pressure deficit (VPD) was calculated on the basis of air temperature and relative air humidity (RH). On each sampling date, soil cores at different depths (layers) of 0-10, 20-30, 40-50, and 60-70 cm were collected using a soil sampling tube (Soil Moisture Equipment Corp.) for determining the gravimetric soil water content beneath the tree canopy.

Finally the data were analyzed statistically according to The R project for statistical computing (The R foundation for statistical computing version 2.2.1, 2005) and SPSS 13.0 for Windows.

Results and Discussion

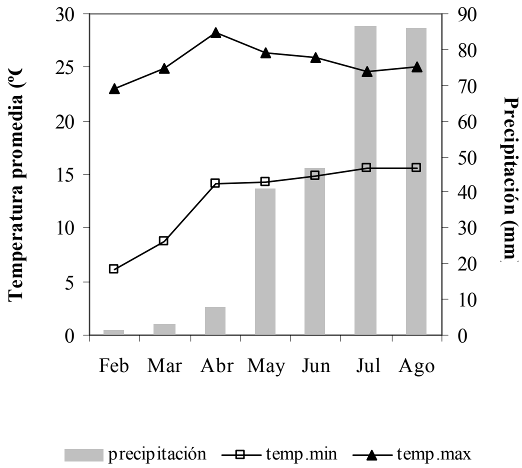


Figure 1: Total precipitation during the study period and trends of monthly minimum and maximum air temperatures.

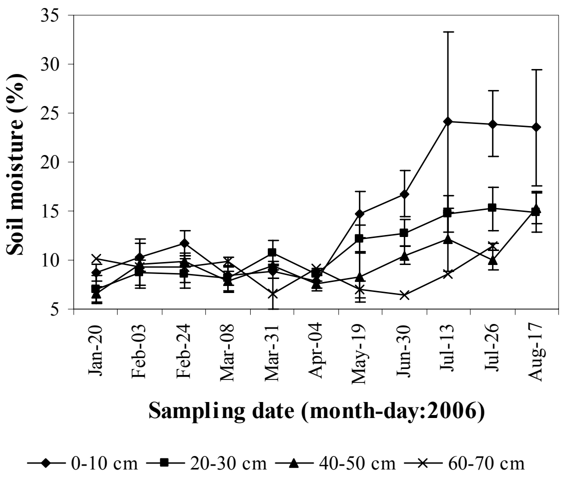
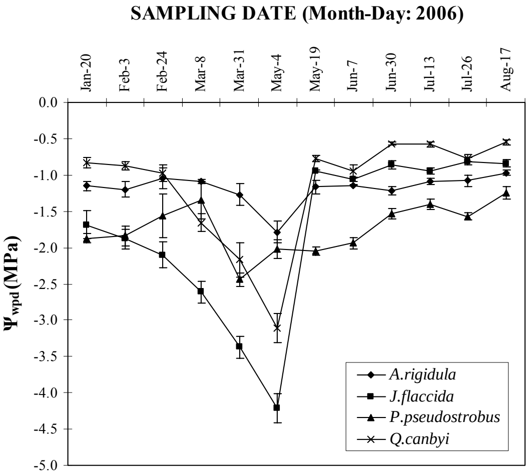


Figure 2. Soil moisture content at the study site.

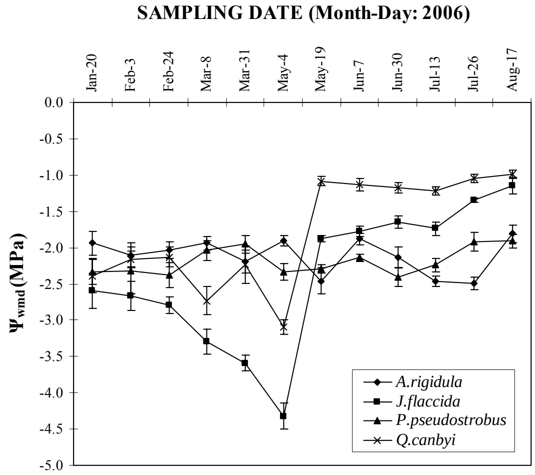
Trends of monthly minimum and maximum air temperatures as well as total precipitation are illustrated in Fig. 1. During the experimental period, minimum mean air temperatures ranged from 6.13ºC (February) to 15.61ºC (August). Maximum mean air temperatures in comparison ranged from 23.05ºC (February) to 26.30ºC (May). The total rainfall was 272.03 mm (Fig. 1).

With increasing air temperature, soil water content declined and increased again after the onset of the rainy season end of May. According to one-way ANOVA statistic analysis of differences among sampling dates in soil water content, soil water content was significantly different ($p<1.271e-11$) between different sampling dates. The ensuing TukeyHSD test revealed significant differences mainly between the dry months (Jan-20, Feb-3, Feb-24, Mar-8, Mar-31 and May-4) and the humid months (Jun-30, Jul-13, Jul-26 and Aug-17) (Fig. 2).

a)



b)



c)

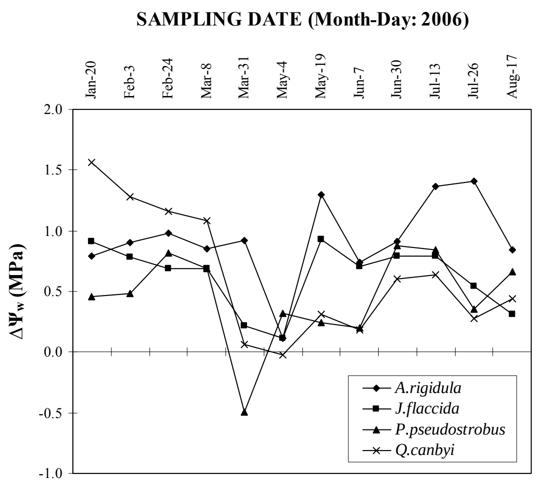


Figure 3: Water potential variations of four tree species in the course of the study a) predawn water potential (Ψ_{wpd}), b) midday water potential (Ψ_{wmd}), and c) diurnal variation in water potentials (Ψ_{wmd}- Ψ_{wpd}).

We found highly significant differences (Univariate Analysis of Variance) between the Ψ_w of different species as well as in the course of the study. All species showed high predawn and low midday values that declined progressively with increasing drought and soil-water loss. During the dry period, *J.flaccida* and *Q.canbyi* had the lowest Ψ_w (Fig.3) and Ψ_s (Fig.4) while *A.rigidula* maintained relatively high values. However, *J.flaccida* and *Q.canbyi* recovered high water potentials during the wet months indicating their capacity to overcome drought. *A.rigidula* had a wide range between predawn and midday Ψ_w during the dry season suggesting drought resistance.

The Ψ_w of *Q.canbyi* and *J.flaccida* were significantly correlated (according to Spearman) with environmental variables while the Ψ_w of *A.rigidula* and *P.pseudostrobus* not (Table 1). Significant correlations were mainly found with soil water content, explaining 32% *(Q.canbyi)* and 50% *(J.flaccida)* of temporal variation in predawn water potential (Ψ_{wpd}) (Linear Regression Analysis), and climatic variables that were directly related with water (RH, VPD, precipitation).

The Ψ_s had similar pattern or tendency as the Ψ_w (Fig.4). *A.rigidula* had highest values during the dry months, while *J.flaccida* and *Q.canbyi* reacted more dynamically to environmental changes. In comparison to the Ψ_w, Ψ_s were just correlated with climatic variables for *J.flaccida* and *Q.canbyi* (not shown).

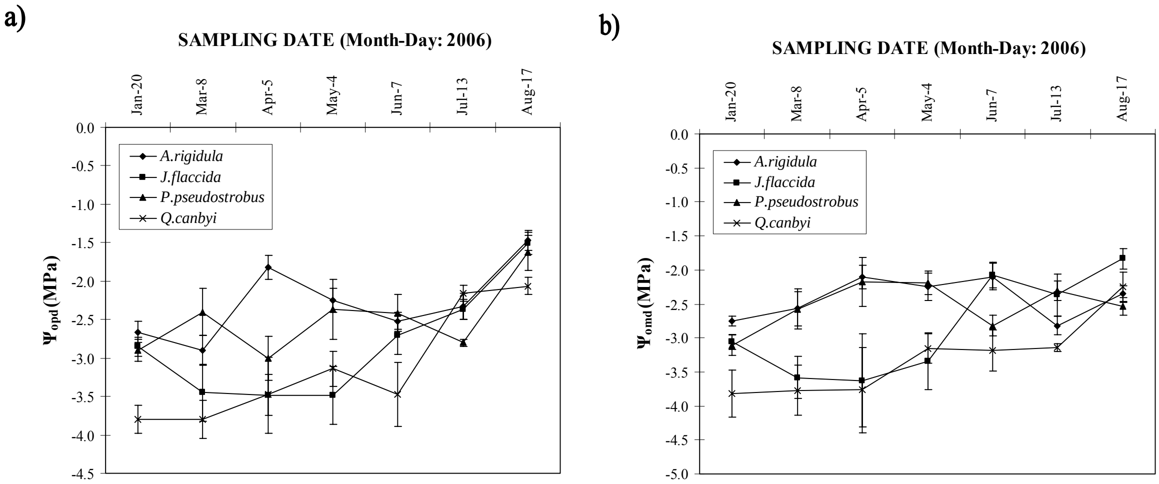


Figure 4: Osmotic potential variations of four tree species in the course of the study a) predawn osmotic potential (Ψ_{opd}), and b) midday osmotic potential (Ψ_{omd}).

Table 1: Spearman's correlations for leaf water potentials (Ψ_w) with environmental variables.

Environmental variable	Predawn leaf water potential (Ψwpd)				Midday leaf water potential (Ψwmd)			
	A. rigidula	*J. flaccida*	*P. pseudostr.*	*Q. canbyi*	*A. rigidula*	*J. flaccida*	*P. pseudostr.*	*Q. canbyi*
Soil water-content (0-70 cm)	0.48	0.74 **	0.47	0.77 **	-0.47	0.76 **	0.38	0.86 **
Air temperature	-0.12	0.44	0.05	0.44	0.25	0.49	0.03	0.50
Relative humidity	0.34	0.74 **	0.38	0.68 *	-0.04	0.79 **	0.46	0.69 *
Vapor pressure deficit	-0.50	-0.83 **	-0.47	-0.80 **	0.01	-0.90 ***	-0.24	-0.77 **
Precipitation	0.29	0.72 *	0.32	0.63 *	-0.21	0.75 **	0.40	0.64 *

Correlations are on a seasonal basis.
*<0.05, **<0.01, ***<0.001

Conclusions and Outlook

Finally, *Q.canbyi,* and *J.flaccida* had better capacity to react to environmental changes than any other species. Although, *A.rigidula* was the species that withstood best drought. Hence these species are suitable candidates for reforestation programs on dry sites in the Sierra Madre Oriental in Mexico. *P.pseudostrobus* in comparison is less competitive on xeric sites.

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