ACCURACY OF SOIL THERMOCOUPLE HYGROMETER MEASUREMENTS IN DESERT ECOSYSTEMS[1]

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The use of thermocouples in studies of soil and plant water relations began in the 1950's (Spanner 1951, Monteith and Owen 1958, Richards and Ogata 1958, Savage and Cass 1984). Initially, thermocouples were used only in laboratory studies because precise temperature control was thought to be essential for accurate measurements (Kramer 1972). Field applications began after Rawlins and Dalton (1967) and Wiebe et al. (1970) demonstrated that certain corrections eliminated the need for precise temperature control. With the advent of commercial availability, thermocouples have been widely used by plant ecologists (see Turner and Kramer 1980 for examples).

Despite their extensive use, many investigators are distrustful of data obtained with soil thermocouples. The prevalence of this distrust, although not expressed in the literature, is commonly expressed in discussions among scientists who have had field experience with thermocouples. We compared soil water potential data obtained with soil thermocouples to measurements of predawn xylem sap potential of desert shrubs (Scholander et al. 1965, Waring and Cleary 1967). The null hypothesis tested was that predawn xylem sap potentials would not differ significantly from soil water potential values measured with soil thermocouples in the dew point mode (hygrometers), because xylem sap potentials at that time are in equilibrium with rhizosphere water potential (Ritchie and Hinckley 1975).

Materials and Methods

The investigation was conducted at the Desert Long-Term Ecological Research Site on the New Mexico State University Ranch, 40 km north-northeast of Las Cruces, New Mexico. Measurements were made in control and irrigated experimental plots (two each), established in late May 1983 as part of a study of calcium carbonate deposition in arid ecosystems. The plots were located on the northeast-facing piedmont of Mt. Summerford in the Doña Ana Mountains. Each plot was 10 × 10 m and contained a 7 × 7 m area for measurement surrounded by a 1.5-m buffer zone. Plots were separated by 3-m pathways. Soils are Calciorthid and Typic Haplargid profiles consisting of coarse loamy texture derived from the gravelly alluvium of weathered quartz monzonite. A calcic horizon designated B_{2K} is present at 37 ± 8.8 cm (SD), $n = 11$. This layer is ≈ 20 cm thick and shows stage III carbonate morphology (Gile et al. 1966).

To determine soil water potential in the plots, five 6 cm diameter × 80 cm long polyvinyl chloride tubes (PVC), each containing a set of five ceramic-tipped Wescor thermocouple hygrometers (PCT-55-30-SF) were randomly located in each plot. Before burial, the hygrometers in each tube were calibrated with 0.05, 0.5, 1.3 and 1.5 mol/L solutions of NaCl. Each hygrometer was immersed for a minimum of 2 h in each solution and read with a Wescor HR-33T Dew Point microvoltmeter in the hygrometric (dew point) mode. After reading, each hygrometer was cleansed for a minimum of 2 h in distilled water and then air-dried before immersion in another solution. A linear regression between water potential and microvolts was formulated for each hygrometer (Wescor 1979). Coefficients of determination (r^2) for 147 of the 150 hygrometers ranged from 0.98 to 0.99. This protocol led to successful field measurements of soil water potential and to elimination of probes that would not have withstood field conditions. In June 1984, 1 yr after burial, >90% of the probes were still functional.

Holes for PVC tubes were dug with a post-hole digger to 70 cm depth. Along the vertical walls of these holes at 7, 21, 35, 50, and 70 cm depths, 10-cm long horizontal cavities were excavated. Hygrometer sensors protruding through sideports in the PVC tubes were then placed in the cavities and the cavities refilled with soil. The entire hole was then backfilled around the PVC tube. PVC tubes projected 10 cm above the soil surface, facilitating the connection of sensors to the dew point microvoltmeter.

Hygrometer sensors were installed horizontally to minimize diurnal variations in microvolt output (Merrill and Rawlins 1972). Positioning of the hygrometers at the various depths allowed for the measurement of water potential at equal 14-cm intervals in the soil above the carbonate layer (the portion of the rhizosphere containing the majority of roots), in (50 cm), and below (70 cm) the layer. Field measurements with the microvoltmeter were converted to water potential values utilizing the hygrometer-specific linear regressions. Mean soil water potential was calculated from the average of five depths in each of the tubes and subsequenntly averaged over the replicate tubes per plot type.

Larrea tridentata and *Gutierrezia sarothrae* were selected for measurement of predawn xylem sap potential because these species were the most important based on total number and biomass in the experimental plots
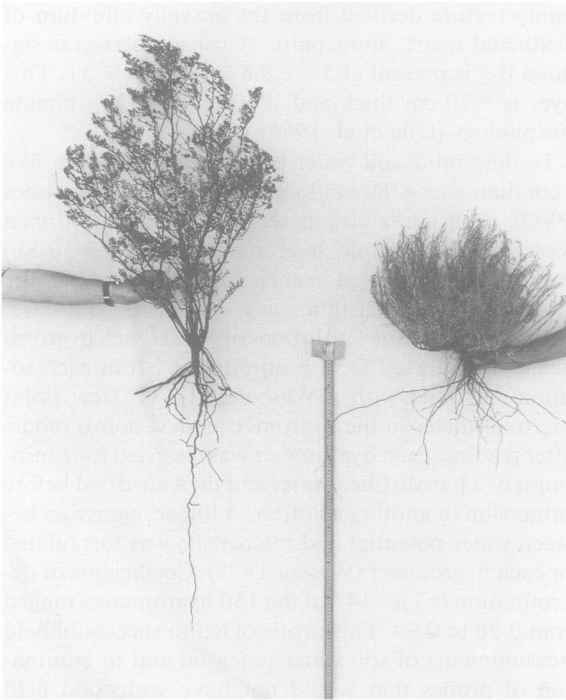
Fig. 1.   Excavated root systems of *Gutierrezia sarothrae* (right) and *Larrea tridentata*. Ruler in center is 1 m long.

(Schlesinger et al. 1987). They were also ideal because they typify two major perennial growth forms of the Chihuahuan Desert. *Larrea* is an evergreen shrub, 1–3 m in height, with small, resinous leaflets 6–10 mm long (Benson and Darrow 1981). *Gutierrezia* is a sub-shrub 0.2–0.6 m in height with chlorophyllous branches supporting narrow, linear leaves 1–4 cm long. Root excavations of three individuals of each species growing immediately adjacent to our experimental plots revealed differences in root habit (Fig. 1). The root system of *Larrea* consisted, for the most part, of many bark-covered roots 4–8 mm in diameter that extended vertically from the root-crown into the soil, sometimes growing into and through the caliche layer. A few roots also extended laterally > 1 m from the base of a plant. In contrast, many small 1 mm diameter lateral roots branched from the root-crown of *Gutierrezia* at depths ranging from 0–10 cm. Roots extended horizontally from the base of the plant to lengths of 1 m, and some of the larger lateral roots grew downward into, and in some cases through, the caliche layer.

Predawn xylem sap potentials (XSP) of *Larrea* and *Gutierrezia* were measured on terminal 15-cm shoots with a Scholander pressure bomb on 5, 17, and 20 July 1984. The xylem sap potentials of 6–10 shrubs of each species were measured on each sampling date in all four plots.
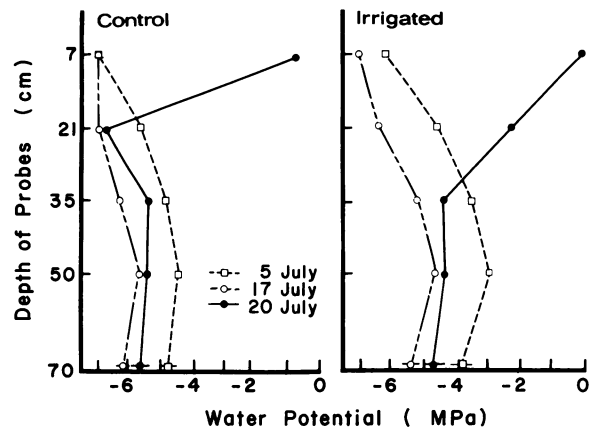

Fig. 2.   Soil water potential at five depths in control and irrigated plots. Horizontal bars denote average ±1 SE values of means for each curve.

Results and Discussion

An initial analysis of variance used replicate plots (as blocks), time (5, 17, or 20 July), treatment (control vs. irrigated), and method of measurement (soil water potential, *Larrea* XSP, or *Gutierrezia* XSP) as ordered main effects. There was no significant block effect, but all other main effects and their two-way interactions were significant. As a result, measurements from replicate plots of each type were combined in all further data analyses. In a subsequent one-way analysis of variance for each treatment and time, differences between methods were separated using the Scheffé test for multiple comparisons (Helwig and Council 1982).

On 5 July soil hygrometers showed higher water potentials with increasing depth in both control and irrigated plots (Fig. 2). The initial differences in soil water potential between control and irrigated plots were presumably the residual effect of an irrigation on 15 June. These differences were also seen in comparisons of xylem sap potential for *Larrea* and *Gutierrezia* between control and irrigated plots (Table 1). As the soils dried from 5 to 17 July, water potential decreased at all depths. These decreases, which resulted from evapotranspiration, caused a concomitant decrease in xylem sap potentials between 5 and 17 July. Immediately following a 1.3-cm rainfall on 18 July, readings on the soil hygrometers at the surface increased from ≈ −7.0 MPa to > −1.0 MPa in control plots, but there were no significant changes at the lower depths. Soil hygrometers at 7, 21, and 35 cm depths in irrigated plots responded to the composite effect of this rainfall and the 2 cm of irrigation that was applied on 19 July.

Xylem sap potential increased in both *Larrea* and *Gutierrezia* in control plots as a result of the 1.3-cm

TABLE 1.　Comparative values of predawn xylem sap potential of *Larrea* (LXSP) and *Gutierrezia* (GXSP) and soil psychrometer measurements (SP) in control and irrigated plots (MPa); n = 9–20. Data were treated with one-way analysis of variance followed by Scheffe's Test (α = .05). For each species, values within a plot type with a common superscript do not differ significantly.

Date		Control			Irrigated		
		LXSP	GXSP	SP	LXSP	GXSP	SP
5 July	$\bar{X}$	−5.40[a]	−5.01[b]	−5.37[ab]	−4.88[a]	−4.05[b]	−4.48[ab]
	SE	0.14	0.19	0.20	0.16	0.22	0.21
17 July	$\bar{X}$	−6.08[a]	−6.32[a]	−6.43[a]	−5.99[a]	−5.77[a]	−5.68[a]
	SE	0.18	0.21	0.16	0.20	0.25	0.22
20 July	$\bar{X}$	−4.28[a]	−2.89	−4.71[a]	−3.33[a]	−2.19	−3.17[a]
	SE	0.28	0.18	0.22	0.16	0.17	0.34

rainfall on 18 July. Following both rainfall and irrigation, soil water and xylem sap potentials in irrigated plots were higher than comparable values in control plots. In both cases xylem sap potential in *Gutierrezia* was significantly higher than that of *Larrea*, presumably as a result of more efficient uptake of moisture from the surface horizons by the shallow root system of *Gutierrezia*. Xylem sap potential of *Larrea* in irrigated plots (−3.33 MPa) was significantly higher than that in control plots (−4.28 MPa), reflecting deeper percolation of soil moisture in these plots as a result of rainfall and irrigation water.

Xylem sap potential and mean soil water potential over all depths are highly correlated for *Larrea* (r = 0.95, n = 6) in control and irrigated plots. The correlation is only slightly lower for *Gutierrezia* (r = 0.94, n = 6), despite the response of that species to light rainfalls that had little effect on soil water potential at lower depths. On 20 July, the xylem sap potential of *Gutierrezia* in control and irrigated plots was significantly different from the overall mean soil water potential, and was more closely correlated with the soil water potential of the uppermost soil layer (Fig. 2). All other comparisons suggest that as soil moisture is depleted, plants equilibrate with the average soil water potential, rather than with the highest water potential in the soil profile. This observation conforms to the laboratory results of Brunini and Thurtell (1982) and field results of Fahey and Young (1984).

Correlations between xylem sap potential and soil water potential have been reported for *Atriplex confertifolia* and *Eurotia lanata* (Moore and Caldwell 1972). Although Fahey and Young (1984) report a direct linear relation (r = 0.91) between these parameters in stands of *Pinus contorta*, the slope of the regression was only 0.58. As in our study, these authors found that predawn xylem sap potentials were in close agreement with the average soil water potential measured with hygrometers placed at several depths in the soil profile. Thus we conclude that with rigid calibration, soil thermocouple hygrometers are reliable and pro-

vide accurate data in arid environments, and that predawn xylem sap potential measurements are representative of soil water potentials.

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