Environmental and Experimental Botany, Vol. 30, No. 1, pp. 75–83, 1990
Printed in Great Britain.

0098-8472/90 \$3.00+0.00
Pergamon Press plc

A COMPARISON OF PRESSURE CHAMBER, LEAF-PRESS, AND CANOPY TEMPERATURE FOR FOUR SPECIES UNDER HUMID CONDITIONS

R. E. SOJKA,* E. J. SADLER,† C. R. CAMP† and F. B. ARNOLD‡

* USDA-Agricultural Research Service, Route 1, Box 186, Kimberly, ID 83341, U.S.A.,
† USDA-Agricultural Research Service, P.O. Box 3039, Florence, SC 29502, U.S.A. and
‡ USDA-Soil Conservation Service, 514 S. 23rd Ave, Bozeman, MT 59715-3963, U.S.A.

(*Received* 11 *January* 1989; *accepted in revised form* 22 *May* 1989)

SOJKA R. E., SADLER E. J., CAMP C. R. and ARNOLD F. B. *A comparison of pressure chamber, leaf-press, and canopy temperature for four species under humid conditions.* ENVIRONMENTAL AND EXPERIMENTAL BOTANY **30**, 75–83, 1990.—Numerous techniques are currently available for measurement of plant water status in field environments, including pressure chambers and indices based upon infrared-determined canopy temperatures. The Campbell–Brewster (J-14) leaf press has been promoted as a compact alternative to the pressure chamber for plant water potential determination. In-depth comparisons of the J-14 (Ψ_J) with the pressure chamber (Ψ_x) or with canopy temperatures (T_c) and crop water stress index (*CWSI*) have been limited, and an evaluation of the technique in a humid environment was needed. All three J-14 end points [exudation from cut (Ψ_{Jc}) or uncut leaf edges (Ψ_{Ju}) or darkening of interveinal areas (Ψ_{Jd})] were highly correlated among themselves for the four species studied. Correlations of J-14 end points with other stress indicators from unstable diurnal periods were poor. None of the water status indicators correlated well with leaf diffusive resistance. Our data showed a species-related reliability of the J-14. The J-14 produced r^2 values above 0.7 for soybean [*Glycine max.* (L.) Merr.] for all but comparisons with *CWSI* or T_c minus air temperature (ΔT), and for corn (*Zea mays* L.) for Ψ_x only. The J-14 did not perform well for tomato (*Lypersicum esculentum* Mill.) or rapeseed (*Brassica napus* L.), and is probably best regarded only as a relative indication of plant water status in the absence of calibration with other techniques. Failure of Ψ_x or J-14 to correlate well with *CWSI* underscores difficulty with *CWSI* measurement under humid conditions.

Key words: Hydraulic leaf press, J-14 leaf press, plant water potential, xylem pressure potential, pressure bomb, crop water stress index.

INTRODUCTION

DETERMINING plant water status in the field can be inconvenient because of technique or equipment limitations. The pressure chamber[23] has been widely used for field assessment of plant xylem pressure potential (Ψ_x) which is closely related to total plant water potential (Ψ) in the absence of significant osmotic potential (Ψ_π). Most pressure chambers are either excessively bulky or have inadequate gas capacity for numerous measurements. Psychrometric determination of Ψ[22] is very precise, but is poorly suited to field use because of the time required and sensitivity to environmental variation. A highly portable method which has been suggested and which requires little or no equipment maintenance and no material resupply is the Campbell–Brewster hydraulic leaf press.[2]

The Campbell–Brewster (J-14) press, however, has been slow to gain acceptance for several reasons. Only limited data comparing it in detail to established plant water status indicators other than the pressure chamber are available. The physical meaning of the J-14 end points remains uncertain. Published comparisons of the J-14 press have to date been only with the Scholander-type pressure chamber,[1,3,8–11,15,17–19,24,28] relative water content (relative turgidity) technique,[3,8,9,20] and thermocouple psychrometry.[8,18] Published comparisons of the J-14 end points with leaf temperature (T_c), leaf minus air temperature (ΔT), the derived crop water stress index (*CWSI*), or measurements of leaf diffusive resistance, leaf transpiration, or micrometeorologically-derived canopy parameters have not appeared.

The J-14 end points generally observed are: free exudation from either the cut or uncut leaf edge (Ψ_{Jc} or Ψ_{Ju}, respectively) or darkening of leaf interveinal areas (Ψ_{Jd}). Frequently, Ψ_{Jc} and Ψ_{Ju} are defined as exudation at or near a xylem element from either a cut or uncut edge. In the authors' experience, distinguishing between exudation at a xylem element or between xylem elements in the leaf lamina is difficult.

The majority of papers reporting a good relationship between Ψ_J and Ψ_x found that Ψ_J over-estimated Ψ_x, i.e. a more negative potential was measured for Ψ_x than for the corresponding value of Ψ_J.[1,8,11,17,18,28] Three factors may have contributed to this. One is the subtlety of the Ψ_J endpoint; Hicks *et al.*[10] over-estimated Ψ_x if the first exudation of sap was taken as the Ψ_J endpoint. A one-to-one relationship existed if Ψ_J was taken to be the pressure at which sap exuded from all leaf veins. Also, in none of the above Ψ_x vs Ψ_J comparisons did the authors report transporting leaves in plastic or wrapping leaves with moist gauze or with plastic during chamber pressurization as recommended by Gandar and Tanner[7] and Turner and Long[26] to combat the rapid rise in chamber temperature and vapor pressure deficit.[16,27] Grant *et al.*[8] also suggested that with the J-14, the xylem osmotic component is not measured, which upwardly biases Ψ_J by an amount that decreases as the plant progressively dries toward plasmolysis.

Other limitations of the J-14 have been noted. Good correlation of Ψ_J with Ψ_x and Ψ from pressure chamber and psychrometers, respectively have been limited to readings from stable (midday) periods[1,17] and in some species to partially stress-hardened plants.[28] Furthermore, Shayo-Ngowi and Campbell[24] caution that all J-14 end points include the pressure required to deform the tissue and increase the matrix potential to zero, and that these pressures alter matrix pore structure causing a measurement artifact, which can affect the end points in all but pre-frozen samples. Hunt *et al.*[11] may have seen evidence of this in their work. They found that with Ψ_J as the dependent variable, the *y* intercept increased and the slope decreased as specific leaf area (*SLA*) decreased. They concluded that leaves with lower *SLA* resist mechanical compression in the J-14 press, causing it to be less sensitive to differences in Ψ_x.

The objectives of this study were to compare Ψ_{Jc}, Ψ_{Ju}, and Ψ_{Jd} with one another, with the standard pressure chamber measurement of Ψ_x using wrapped leaf samples, and with the crop water stress index (*CWSI*) as developed by Jackson *et al.*[14] and Idso *et al.*[13] for four species in local irrigation studies. Unlike previous comparisons, these comparisons were conducted under the typically humid conditions prevailing in the study area (the southeastern U.S.A.).

MATERIALS AND METHODS

Ongoing field studies with irrigation treatments, providing a range of plant water status from non-stressed to moderately stressed, were monitored in Florence and Charleston, South Carolina. Corn (*Sea mays* L.), soybean [*Glycine max* (L.) Merr.], and rapeseed (*Brassica napus* L.) were grown on Norfolk loamy sand (fine-loamy, siliceous, thermic, Typic Paleudult) in Florence, and tomato (*Lypersicum esculentum* Mill.) was grown on Hockley loamy fine sand (fine-loamy, siliceous, thermic Plinthic Paleudult) in Charleston. Crops were grown using conventional cultural practices for each crop in the region, including in-row subsoiling to 0.45 m. Tomato was grown on 1.22-m staked rows. Soybean, corn, and rapeseed were grown on 0.76-m spaced rows. Rapeseed was in a twin-row configuration with 0.28 m between twin rows.

Xylem pressure potential (Ψ_x) was determined

Table 1. Slopes and intercepts of well-watered base-lines used in calculations. Data taken from Idso[12]

Crop	Scientific name	Intercept (°C)	Slope (°C/kPa)
Tomato	*Lypersicum esculentum* Mill.	2.86	−1.96
Soybean	*Glycine max* (L.) Merr.	1.44	−1.34
Rapeseed*	*Brassica napus* L.	1.94	−2.26
Corn	*Zea mays* L.	3.11	−1.97

* Idso[12] reported no data for rapeseed. Data for turnip (*B. rapa*) were used.

using a pressure chamber specially designed to allow rapid insertion and sealing and with a high chamber-mass to internal-volume ratio to minimize compression–decompression related temperature changes. Leaves were excised, immediately placed in plastic bags containing wet paper towels, and quickly inserted into the pressure chamber for pressurization. Two–three centimeters of excised petiole (or corn leaf) were left protruding from the plastic bag. With a constant pressure increase rate of 1300 kPa/min, total time from excision to decompression seldom exceeded 2 min. Pressure chamber end points were taken as the first free flow of sap from conductive tissue at leaf excision points. For rapeseed, soybean, and tomato chamber samples, excision was at the point of petiole attachment to the main stem, allowing entire compound leaves to be inserted into the pressure chamber. For corn, excision was at mid-leaf. All leaves selected were most-recently-matured, fully-expanded, sun-exposed leaves. For pressure chamber vs J-14 comparisons, matched pairs of leaves were selected from side-by-side plants (one for the chamber, one for the J-14).

The J-14 was pressurized at approximately double the chamber rate. This was because of the coarser control which prevented more gradual pressurization. Each J-14 leaf was excised from the plant with a sharp razor blade so that uncut or cut-edge exudation could be watched simultaneously. All three end points (Ψ_{Jc}, Ψ_{Ju}, Ψ_{Jd}) were noted on the same leaf sample. Each leaf was backed with white filter paper to facilitate detection of exudate.

Crop temperatures were obtained with an Everest model 110 Infrared thermometer using an emissivity setting of 0.98. It was aimed obliquely at the crop canopy taking care to include only foliage in the target area. Air temperatures were

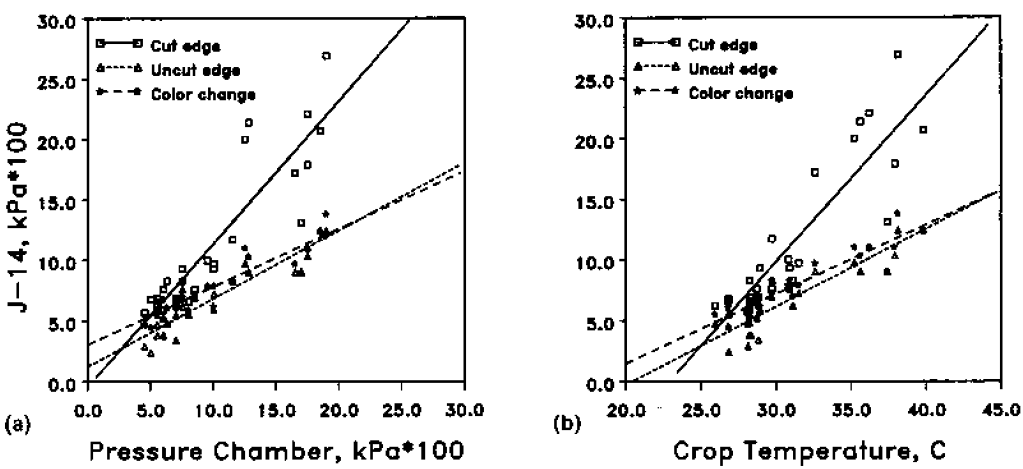

Fig. 1. (a) Comparison of J-14 press with pressure chamber for soybean. (b) J-14 press data plotted against crop temperature for soybean.

Table 2. Regression equations and coefficients of determination for relationships between measured plant water stress indicators for four species in kPa × 100 for Ψ and °C for T

Crop	Dep. var	Ind. var	No. of pairs	Slope	Intercept	r^2	Prob > F	Dep. Min	Dep. Max	Ind. Min	Ind. Max
Tomato	Ψ_{Ju}	Ψ_{Jc}	41	0.884	2.393	0.557	0.0001	3.4	9.0	2.1	6.6
	Ψ_{Ju}	Ψ_x	41	0.158	4.666	0.065	0.1063	3.4	9.0	4.7	11.9
	Ψ_{Ju}	T_c	41	0.177	1.657	0.176	0.0063	3.4	9.0	13.0	31.2
	Ψ_{Ju}	ΔT	41	0.255	5.715	0.171	0.0072	3.4	9.0	−7.1	6.6
	Ψ_{Jc}	Ψ_x	41	0.127	2.974	0.059	0.1249	2.1	6.6	4.7	11.9
	Ψ_{Jc}	T_c	41	0.127	0.920	0.128	0.0219	2.1	6.6	13.0	31.2
	Ψ_{Jc}	ΔT	41	0.169	3.842	0.106	0.0379	2.1	6.6	−7.1	6.6
	Ψ_{Jd}	Ψ_{Jc}	41	0.502	3.418	0.505	0.0001	4.0	6.9	2.1	6.6
	Ψ_{Jd}	Ψ_{Ju}	41	0.424	2.908	0.505	0.0001	4.0	6.9	3.4	9.0
	Ψ_{Jd}	Ψ_x	41	0.081	4.780	0.048	0.1688	4.0	6.9	4.7	11.9
	Ψ_{Jd}	T_c	41	0.080	3.481	0.102	0.0414	4.0	6.9	13.0	31.2
	Ψ_{Jd}	ΔT	41	0.138	5.310	0.141	0.0154	4.0	6.9	−7.1	6.6
Soybean	Ψ_{Ju}	Ψ_{Jc}	25	1.974	−2.094	0.814	0.0001	5.7	26.9	2.4	12.4
	Ψ_{Ju}	Ψ_x	25	1.179	−0.396	0.804	0.0001	5.7	26.9	4.5	19.0
	Ψ_{Ju}	T_c	25	1.375	−31.394	0.797	0.0001	5.7	26.9	25.9	39.8
	Ψ_{Ju}	ΔT	25	1.241	11.653	0.268	0.0081	5.7	26.9	−5.6	3.8
	Ψ_{Jc}	Ψ_x	25	0.559	1.253	0.866	0.0001	2.4	12.4	4.5	19.0
	Ψ_{Jc}	T_c	25	0.638	−13.031	0.823	0.0001	2.4	12.4	25.9	39.8
	Ψ_{Jc}	ΔT	25	0.392	6.974	0.128	0.0790	2.4	12.4	−5.6	3.8
	Ψ_{Jd}	Ψ_{Jc}	25	0.836	2.097	0.928	0.0001	4.5	13.8	2.4	12.4
	Ψ_{Jd}	Ψ_{Ju}	25	0.379	3.509	0.912	0.0001	4.5	13.8	5.7	26.9
	Ψ_{Jd}	Ψ_x	25	0.476	3.506	0.833	0.0001	4.5	13.8	4.5	19.0
	Ψ_{Jd}	T_c	25	0.568	−9.867	0.865	0.0001	4.5	13.8	25.9	39.8
	Ψ_{Jd}	ΔT	25	0.462	7.923	0.236	0.0139	4.5	13.8	−5.6	3.8
Rapeseed	Ψ_{Ju}	Ψ_{Jc}	30	0.805	2.713	0.493	0.0001	4.8	9.0	3.1	6.6
	Ψ_{Ju}	Ψ_x	30	0.388	3.682	0.269	0.0033	4.8	9.0	3.8	8.5
	Ψ_{Ju}	T_c	30	0.158	3.050	0.269	0.0033	4.8	9.0	12.9	23.9
	Ψ_{Ju}	ΔT	30	−0.048	6.289	0.004	0.7567	4.8	9.0	−1.9	3.5
	Ψ_{Jc}	Ψ_x	30	0.415	1.646	0.405	0.0002	3.1	6.6	3.8	8.5
	Ψ_{Jc}	T_c	30	0.157	1.200	0.353	0.0005	3.1	6.6	12.9	23.9
	Ψ_{Jc}	ΔT	30	−0.001	4.394	0.000	0.9933	3.1	6.6	−1.9	3.5
	Ψ_{Jd}	Ψ_{Jc}	30	0.780	2.828	0.443	0.0001	4.7	9.0	3.1	6.6
	Ψ_{Jd}	Ψ_{Ju}	30	0.946	0.340	0.858	0.0001	4.7	9.0	4.8	9.0
	Ψ_{Jd}	Ψ_x	30	0.340	3.998	0.199	0.0135	4.7	9.0	3.8	8.5
	Ψ_{Jd}	T_c	30	0.122	3.785	0.154	0.0322	4.7	9.0	12.9	23.9
	Ψ_{Jd}	ΔT	30	−0.284	6.276	0.001	0.8571	4.7	9.0	−1.9	3.5
Corn	Ψ_{Ju}	Ψ_{Jc}	41	1.278	3.001	0.657	0.0001	7.6	20.7	4.1	13.8
	Ψ_{Ju}	Ψ_x	41	0.789	2.405	0.499	0.0001	7.6	20.7	8.0	20.5
	Ψ_{Ju}	T_c	41	0.539	−3.464	0.400	0.0001	7.6	20.7	21.6	35.3
	Ψ_{Ju}	ΔT	41	1.062	13.701	0.166	0.0083	7.6	20.7	−4.4	0.0
	Ψ_{Jc}	Ψ_x	41	0.592	−0.169	0.699	0.0010	4.1	13.8	8.0	20.5
	Ψ_{Jc}	T_c	41	0.389	−4.146	0.519	0.0001	4.1	13.8	21.6	35.3
	Ψ_{Jc}	ΔT	41	0.599	7.931	0.131	0.0201	4.1	13.8	−4.4	0.0
	Ψ_{Jd}	Ψ_{Jc}	41	0.683	6.574	0.548	0.0001	8.3	14.8	4.1	13.8
	Ψ_{Jd}	Ψ_{Ju}	41	0.521	5.130	0.793	0.0001	8.3	14.8	7.6	20.7
	Ψ_{Jd}	Ψ_x	41	0.417	6.304	0.409	0.0001	8.3	14.8	8.0	20.5
	Ψ_{Jd}	T_c	41	0.310	2.509	0.386	0.0001	8.3	14.8	21.6	35.3
	Ψ_{Jd}	ΔT	41	0.651	12.449	0.182	0.0055	8.3	14.8	−4.4	0.0

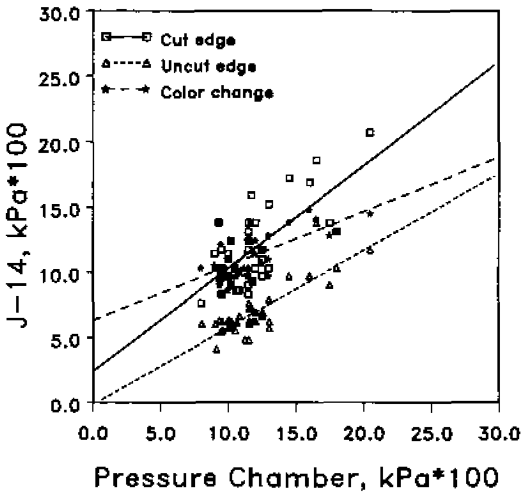

FIG. 2. Comparison of J-14 press with pressure chamber for corn.

determined from automated weather stations immediately adjacent to the plots. The Florence stations were described by SOJKA and PARSONS[25] and SADLER and CAMP.[21] The Charleston data were collected with commercial (CR21, Campbell Scientific, Logan, UT) data logger-based weather stations. For all but the rapeseed data, vapor pressures above the canopy (at 1 m height) were calculated from relative humidity measured with a Beckman Humi-Chek II precision hygrometer.

The *CWSI* was calculated using the empirical formulas derived by IDSO *et al.*[13] and summarized by CLAWSON *et al.*[5] Results were confirmed using the computer program of CARNEY and PINTER.[4] The equations used were as follows:

$$CWSI = (T_c - T_{c_l})/(T_{c_u} - T_{c_l})$$

where T_c is crop temperature (°C) and subscripts u and l indicate upper and lower limits, respectively.

$$T_{c_u} = T_a + a_0 + a_1 * (esa - esa'),$$

T_a is air temperature (°C), a_0 and a_1 are intercept (°C) and slope (°C/kPa) of the well-watered baseline (see Table 1 for values), *esa* is saturation vapor pressure at T_a (kPa), and *esa'* is saturation vapor pressure (kPa) at $(T_a + a_0)$. This last is an estimate of T_c at zero transpiration.

$$T_{c_l} = T_a + a_0 + a_1 * (esa - ea)$$

where *ea* is actual vapor pressure (kPa). The term $(esa - ea)$ is recognized as the vapor pressure deficit (VPD).

Upon completion of each plant water status determination, a record of T_a, T_c, ΔT, *RH* (relative humidity), *VPD*, Ψ_x, Ψ_{Jc}, Ψ_{Ju}, Ψ_{Jd}, and *CWSI* existed for correlation–regression analysis for the date and time. Regression analysis was accomplished using the PROC RSQUARE subroutine of SAS (SAS Institute, Cary, NC).

RESULTS AND DISCUSSION

A statistical summary of the relationship between physically measured parameters for all four crops is presented in Table 2. Soybean provided uniformly good correlations of J-14 parameters with all measured water status indicators except ΔT, which confirms and expands the findings of GRANT *et al.*[8] The relationships between Ψ_{Ju}, Ψ_{Jc}, Ψ_{Jd} and Ψ_x or T_c are shown in Figs 1a and 1b. In addition to the relationships between these parameters, it should be noted that the three J-14 end points for soybean are closely related. Under southeastern conditions, some problems

Table 3. Regression equations and coefficients of determination for relationships between Ψ_x values from unwrapped and wrapped samples for three species in a pressure chamber (unwrapped = dep. var.) in kPa × 100

Crop	No. of pairs	Slope	Intercept	r^2	Prob > F	Dep. Min	Dep. Max	Ind. Min	Ind. Max
Soybean	25	1.043	0.356	0.906	0.0001	4.5	22.5	4.5	19.0
Rapeseed	30	0.974	0.955	0.747	0.0001	4.5	10.7	3.8	8.5
Corn	11	0.831	3.348	0.700	0.0013	12.5	22.5	11.5	20.5

Table 4. Regression equations and coefficients of determination for relationships between CWSI *(dependent variable) and pressure chamber or J-14 measurements of plant water potential for four species in bars kPa* × 100 *for mid-day observations* (0900–1500 *hr*)

Crop	Ind. variable	No. of pairs	Slope	Intercept	r^2	Prob > *F*	*CWSI* min	*CWSI* max	Var. min	Var. max
Tomato	Ψ_x	16	0.172	−1.000	0.605	0.0004	−0.0	1.6	5.5	11.9
	Ψ_{Ju}	16	0.197	−0.743	0.238	0.0554	−0.0	1.6	5.0	9.0
	Ψ_{Jc}	16	0.112	−0.000	0.079	0.2917	−0.0	1.6	2.1	6.6
	Ψ_{Jd}	16	0.229	−0.753	0.141	0.1524	−0.0	1.6	4.0	6.9
Soybean	Ψ_x	25	0.074	−0.307	0.344	0.0020	−0.4	1.5	4.5	19.0
	Ψ_{Ju}	25	0.066	−0.319	0.472	0.0002	−0.4	1.5	5.7	26.9
	Ψ_{Jc}	25	0.121	−0.389	0.328	0.0028	−0.4	1.5	2.4	12.4
	Ψ_{Jd}	25	0.167	−0.870	0.472	0.0001	−0.4	1.5	4.5	13.8
Rapeseed	Ψ_x	26	0.002	0.556	0.000	0.9492	0.2	1.1	4.5	8.5
	Ψ_{Ju}	26	0.020	0.444	0.011	0.6175	0.2	1.1	4.8	9.0
	Ψ_{Jc}	26	0.040	0.394	0.032	0.3845	0.2	1.1	3.1	6.6
	Ψ_{Jd}	26	0.018	0.457	0.009	0.6437	0.2	1.1	4.7	9.0
Corn	Ψ_x	37	0.081	−1.165	0.498	0.0000	−0.9	0.2	8.0	20.5
	Ψ_{Ju}	37	0.049	−0.803	0.222	0.0033	−0.9	0.2	7.6	20.7
	Ψ_{Jc}	37	0.087	−0.813	0.292	0.0006	−0.9	0.2	4.1	13.8
	Ψ_{Jd}	37	0.085	−1.178	0.227	0.0029	−0.9	0.2	8.3	14.8

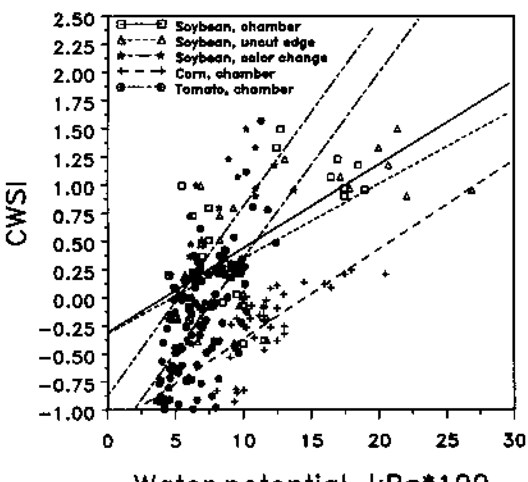

FIG. 3. Comparison of *CWSI* to water potential for soybean, corn, and tomato.

have been noted with ΔT determinations under fluctuating radiation. Despite efforts to minimize this, some haziness may have affected the ΔT determination in all four species.

Corn had moderately good correlations between Ψ_x and either Ψ_{Ju}, Ψ_{Jc}, or Ψ_{Jd} (Fig. 2). A good relationship was also reported for sorghum (*Sorghum bicolor* L. Moench) by HICKS *et al.*,[10] which has similar leaf structure and veination. The only comparison of the J-14 using corn previously reported was for matric potential determination.[24] As seen in Table 2, Ψ_{Jc} correlated measurably better with Ψ_x than did either Ψ_{Ju} or Ψ_{Jd}. Correlations between the J-14 end points were poorer than for soybean but did indicate they were strongly related.

Evaluations of the J-14 have not been reported for tomato or rapeseed. Table 2 suggests there is no acceptable relationship between the J-14 and any other traditionally measured indicator of stress for these two species. Indeed, the J-14 parameters are only moderately correlated among themselves in rapeseed and in tomato. By contrast, wrapped and unwrapped Ψ_x measurements for soybean, rapeseed, and corn are significantly correlated (Table 3). The wrapped Ψ_x determinations were a subset of Table 2. Data not presented were used to relate Ψ_x, Ψ_{Ju}, Ψ_{Jc}, and Ψ_{Jd}, to parallel leaf diffusive resistance of tomato and corn. No relationships were found. However, the number of mid-day data pairs were few and

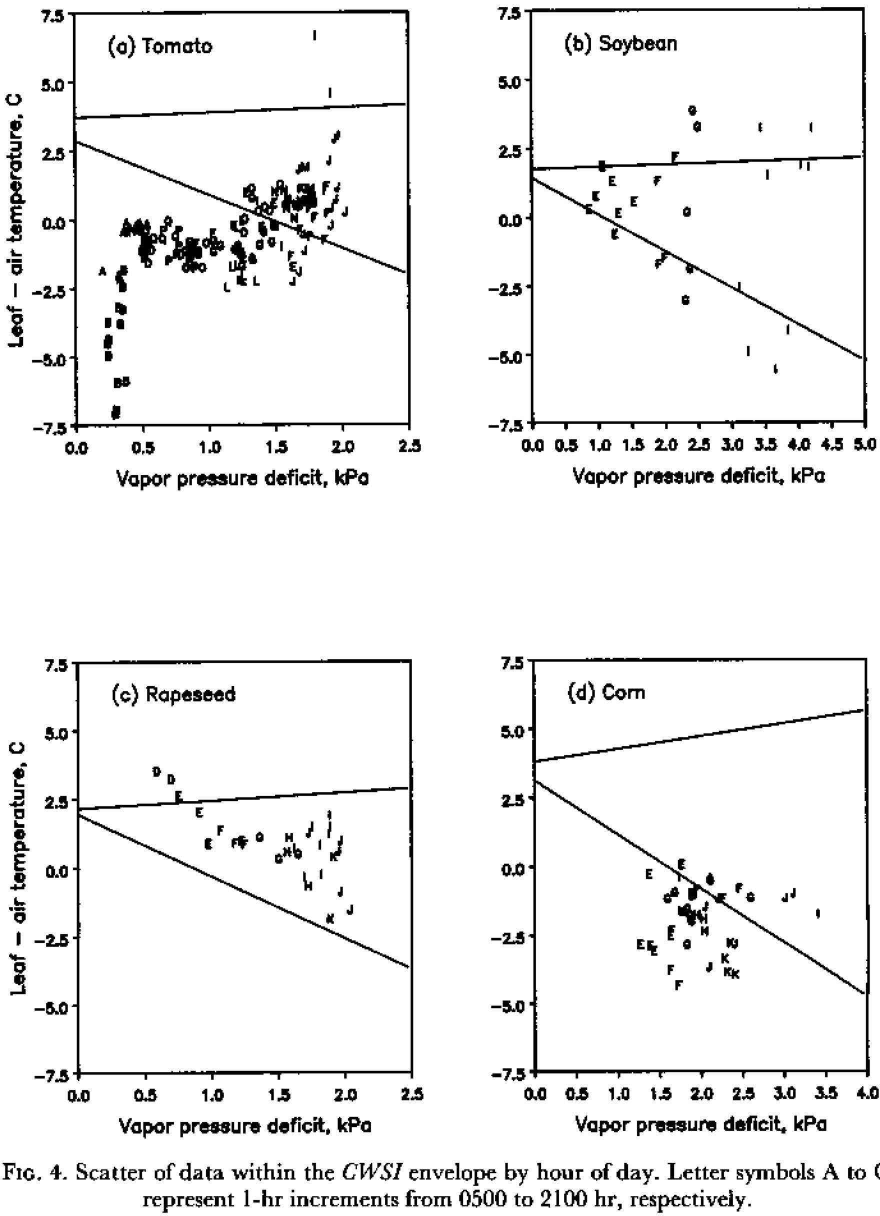

FIG. 4. Scatter of data within the *CWSI* envelope by hour of day. Letter symbols A to Q represent 1-hr increments from 0500 to 2100 hr, respectively.

they were from a narrow range of well-watered plant potentials with fluctuating radiation levels.

Previous investigators have shown that the relationship between J-14 parameters and other standard plant water stress indicators is diurnally affected.[10,17] The J-14 parameters apparently have different dynamics and therefore the ratio of J-14 parameters to other parameters changes until a mid-day plateau (a near-steady-state condition) is reached. To minimize variability it was also necessary in this study to limit comparison of Ψ_J to mid-day periods.

The crop water stress index (*CWSI*) was regressed on the four variables Ψ_x, Ψ_{Ju}, Ψ_{Jc}, and Ψ_{Jd}, for mid-day readings (0900–1500 hr) for all four crops (Table 4). Tomato showed the closest correlation of *CWSI* (with Ψ_x) and soybean and corn showed some correlation with *CWSI*; however, correlations were poor (r^2 below 0.5). Again the problem may in part relate to the limited plant water potential ranges. Figure 3 illustrates this with plots of *CWSI* vs Ψ_x for tomato, corn, and soybean. There have been indications that the *CWSI* may not perform well under humid conditions, particularly under variable radiation regimes, or where haziness limits maximum incoming radiation. Some indication of the difficulty associated with using the *CWSI* may be gained from Figs 4a, b, c, and d, in which measured ΔT values are plotted against corresponding *VPD* values with points coded for hour of day for the four crops and showing the calculated baselines. Several observations can be made from these data about use of the *CWSI* in humid regions. The range of *CWSI* observed indicates that the empirical form of the *CWSI* may need local calibration, since values considerably outside the range 0–1 are found. This can be seen from values outside the envelope of the upper and lower limits in Figs 4b and 4d, for soybean and corn. Most values outside the envelope for tomato are from early morning or late afternoon, and not within the 0900–1500 time period usually used for *CWSI* calculations. Values for rapeseed are mostly within the envelope. The data for soybean corroborate those of Evans and Sadler,[6] who found values ranging from about 2°C above to 2°C below the envelope, and found both a time-of-day and radiation dependence of *CWSI* for soybeans for the same soil series. Sojka and Parsons[25] and Evans and Sadler[6] reported a similar diurnal pattern. The current study lacks the time range to demonstrate the time-of-day dependence for soybean, though the range is similar. The trace for the tomato data is similar to the earlier soybean data, but lower in the envelope. The tomatoes were probably better watered than the soybeans.

Though the majority of published work with *CWSI* has used cloud-free conditions near mid-day, such conditions seldom exist during the growing season in the Southeast. The comparisons among crops shown by Idso[12] included sunlit and shaded baselines for five crops, for which the average effect of shading was to lower the baselines 3.8°C below that of the sunlit crops. If thin clouds or haze reduce irradiance, it is reasonable to assume some intermediate baseline applies. The dependence of these data on radiation could not be studied because all the weather stations integrated the irradiance, and the variability of irradiance precluded interpolation between hourly or half-hourly averages.

CONCLUSIONS

The reliability of the Campbell–Brewster J-14 press appears to be species-related, and was not acceptable for the tomato and rapeseed, reported here for the first time. The J-14 measurement of water status is at best a relative indicator and not necessarily an absolute measure of plant water status in the absence of precise species and environment related calibration. Our data confirm the inability to relate J-14 parameters to other water stress parameters during meteorologically dynamic diurnal periods. The J-14 performed well with soybean for all but comparisons with ΔT or *CWSI* and it performed well with corn only for comparison of Ψ_x. All three J-14 end points were highly correlated among themselves in soybean and corn and moderately so in tomato and rapeseed. The Ψ_J measurement generally over-estimated Ψ_x. The leaf press did not correlate well with the *CWSI* in any of the four species. Failure of *CWSI* to correlate highly with Ψ_x as well as the J-14 parameters underscores the difficulties with the *CWSI* under high humidity/limited-radiation regimes.

Disclaimer—Names of equipment manufacturers and suppliers are provided for the benefit of the reader and do not imply endorsement by the Department of Agriculture.

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