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ESTIMATION OF UPPER LIMIT CANOPY TO AIR TEMPERATURE DIFFERENTIAL FOR SUGARBEET USING INDIRECT MEASUREMENT OF TURGOR POTENTIAL[1]

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ABSTRACT

The possible error associated with dilution of cellular water by cell wall water in determination of osmotic potential of leaf expressed sap and frozen-thawed leaf tissues in sugarbeet (*Beta vulgaris* L.) was investigated. It was concluded that the measurement of osmotic potential in frozen-thawed leaf tissues is an acceptable measure of leaf osmotic potential and can be used along with a measure of leaf water potential to estimate leaf turgor potential (ψ_p). A linear relationship between canopy to air temperature differential, (T_c-T_a) and ψ_p can be established which results in estimation of upper limit canopy to air temperature differential, $(T_c-T_a)_{UL}$ at $\psi_p = 0$. This estimation of $(T_c-T_a)_{UL}$ is in agreement with those proposed by others and direct measurement.

تحقیقات کشاورزی ایران

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تخمین حد بالای تفاوت دمای پوشش سبز و هوا با استفاده از پتانسیل فشاری برگ چغندرقند

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<u>خلاصه</u>

خطای حاصله از رقیق شدن محتویات سلول های برگ چغندرقند توسط آب دیواره سلولی درحین اندازه‌گیری پتانسیل اسمزی درشیره سلولی وبافتهای یخگشا شده موردبررسی

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قرار گرفت. نتایج بدست آمده نشان داد که پتانسیل اسمزی حاصله از بافتهای یخ‌گشا شده
می‌تواند معیار صحیحی از پتانسیل اسمزی برگ باشد و تفاوت بین آن و پتانسیل آب برگ،
پتانسیل فشاری برگ را تعیین می‌کند. سرانجام یک رابطه خطی بین تفاوت دمای پوشش
سبز و هوا و پتانسیل فشاری برگ ارائه شد. وقتی که پتانسیل فشاری برگ صفر باشد از این
رابطه می‌توان حد بالای تفاوت دمای پوشش سبز و هوا را برای چغندرقند تخمین زد. حد
بالای تفاوت دمای پوشش سبز و هوا که از رابطه مذکور بدست آمد با آنچه که از روشهای دیگر
و یا از روش اندازه‌گیری مستقیم حاصل شده مشابهت دارد.

INTRODUCTION

A crop water stress index (CWSI) has been proposed for scheduling irrigation of crops (7, 8, 9). The necessary information to compute the CWSI may be obtained instantaneously and non-destructively by monitoring leaf temperature (T_l) or canopy temperature (T_c) using infrared thermometry and ambient wet- and dry-bulb temperatures. At any given vapor pressure deficit of the atmosphere (VPD), there is a theoretical upper and lower limit of leaf or canopy to air temperature differential (7). When a measure of foliage (canopy) temperature is made, the CWSI is calculated from the ratio of the difference between actual (T_c-T_a) and the lower limit of $(T_c-T_a)_{LL}$, over the difference between upper and lower limit of (T_c-T_a) at prevailing VPD conditions as follows:

$$CWSI = [(T_c-T_a) - (T_c-T_a)_{LL}]/[(T_c-T_a)_{UL} - (T_c-T_a)_{LL}] \qquad (1)$$

where $(T_c-T_a)_{UL}$ and $(T_c-T_a)_{LL}$ are the upper and lower limit of (T_c-T_a), respectively. Linear relationships between (T_c-T_a) and VPD have been established for a wide range of crop species and VPD conditions for well watered crop (5, 6, 7, 8). These relationships have been utilized for determining the lower limit of (T_c-T_a) or a "baseline" for a given crop (7, 8). The linear relationships have been extrapolated to the point of zero vapor pressure gradients from canopy to air and, thus empirically determining the upper limit of canopy to air temperature differential. However, according to the energy balance based discussion of $(T_c-T_a)_{UL}$ and $(T_c-T_a)_{LL}$ of Jackson *et al.* (9), the upper limit concept of Idso *et al.* (7, 8) might be questionable for many field conditions.

Initial estimates of $(T_c-T_a)_{UL}$ for soybean [*Glycine max* (L.) Merrill] and alfalfa (*Medicago sativa* L.) appeared to be relatively low (1 to 2°C at air temperatures of 10 to 4°C), (7, 8). Preliminary observations on $(T_c-T_a)_{UL}$ by O'Toole and Hatfield (11) for several crops gave values of 3 to 8°C. Jackson *et al.* (9) and Abdul-jabbar *et al.* (1) proposed 5 and 4°C for $(T_c-T_a)_{UL}$ for wheat (*Triticum aestivum* L.) and alfalfa, respectively. Jackson *et al.* (9) indicated that for a nontranspiring crop, the $(T_c-T_a)_{UL}$ can be expressed as:

$$(T_c-T_a)_{UL} = (r_a R_n)/(\rho C_p) \qquad (2)$$

where r_a is the aerodynamic resistance (S m^{-1}), ρ is the density of air (kg m^{-3}), C_p is the specific heat of air (J kg^{-1} $C^{\circ -1}$) and R_n is the net radiation (W m^{-2}). However, uncertainty will result in $(T_c-T_a)_{UL}$ by using estimated values of r_a and R_n (11). O'Toole and Hatfield (11) proposed a model to predict the corrected $(T_c-T_a)_{UL}$ of sorghum (*Sorghum bicolor* L.) by introducing a wind function. Errors in $(T_c-T_a)_{UL}$ will by definition cause errors in the CWSI.

Leaf turgidity is a physiological parameter which influences plant growth (14). A possible relationships between (T_c-T_a) and leaf turgor potential might be valuable in estimation of $(T_c-T_a)_{UL}$ by considering the point that zero turgor potential might be associated with nearly zero transpiration.

Therefore, this investigation was conducted to determine: (i) the possible error associated with dilution of cellular water by cell wall in determination of leaf osmotic potential of sugarbeet (*Beta Vulgaris* L.), (ii) the relationship between (T_l-T_a) and leaf turgor potential of sugarbeet, and (iii) $(T_c-T_a)_{UL}$ of sugarbeet.

MATERIALS AND METHODS

The experiment was conducted during 1986 in a one ha field of sugarbeet located on the experiment station farm, College of Agriculture, Shiraz University, Iran (29° 36' N 52° 32' E). The line source irrigation experiment was designed to study crop water stress index (CWSI) and irrigation scheduling relationships (10). The soil was a Calcixerollic Xerochrept silty clay. A local cultivar of sugarbeet was planted on May 3, 1986 in E-W oriented rows which were 60 cm apart and then thinned to 15-20 cm distance between seedlings on the row. The experiment consisted of four replications of six different amounts of irrigation, ranging from 9.1 to 55.9 cm. The irrigation treatment started after crop establishment.

Water and osmotic potentials of sugarbeet leaf discs were measured with a model C-52 Wescor sample chamber (Wescor Inc. S. Main, Logan, UT, 84321) coupled to a dewpoint microvoltmeter (Wescor HR-33-T)*. All measurements were taken from August 10 to 18, 1986 from different irrigation treatments, before and after irrigation. For each measurement, four fully expanded sunlit leaves were selected and excised from different plants from each irrigation treatment. The leaf samples were immediately placed in plastic bags and covered with moist cheesecloth. Leaf sampling was made from 12:00 to 12:30 h solar time. The leaf samples without petioles were cut almost along the midrib into tow halves. One half was used for ψ_1 and leaf osmotic potential measurements and the other half was used for measurement of leaf relative water content as described by Catsky (4).

The measurements of leaf water potential were made within 45-75 min of field collection. The half used for ψ_1 measurement was kept in a double layer plastic bag, placed in liquid nitrogen (-80°C) and stored in a freezer for osmotic

*The product name and the manufacturer's address are included for readers benefit and do not imply endorsement by Shiraz University over other equivalent equipments.

potential determination. The frozen leaf was thawed for about 30 min and osmotic potentials of small discs ($\psi_{\pi+t}$) were measured by the same procedure used for ψ_l determination. Furthermore, cell sap from the thawed leaf was extracted by squeezing between the jaws of a vise (13). Small filter paper discs were then saturated with the expressed cell sap and osmotic potential (ψ_π) was determined. The difference between leaf and osmotic potentials was used as an estimate of leaf turgor potential (ψ_p), assuming leaf matric potential to be zero (2, 16).

Leaf and canopy temperatures were obtained during the same period using a portable hand-held infrared thermometer (Micron 15 L) (17.5 to 14.0 μm band filter, 2° field of view) that was calibrated for use in high ambient air temperatures. The average leaf temperatures (T_l) were obtained by aiming the IR thermometer at four individual expanded leaves selected at random from the top of the canopy (the same leaves were used for water potential measurements). Average canopy temperatures (T_c) were taken with the radiometer pointed obliquely towards the crop (about 45 deg. from horizontal) and at right angles to the row direction and from all four cardinal directions, N, E, S, and W. At the beginning and end of each set of IR measurements, relative humidity was measured in the field with a dial gauge type psychrometer held at a shield of 1.2 m above the soil in a wooden shield. Furthermore, canopy temperatures and corresponding relative humidity and temperature of air were measured several times daily and for several days throughout the growing season.

RESULTS AND DISCUSSION

The inverse values of leaf water potential, leaf osmotic potential (measured from expressed sap) and frozen-thawed leaf osmotic potential as a function of leaf relative water content (RWC) are presented in Figs. 1, 2, and 3, respectively. The leaf osmotic potentials (MPa) measured on expressed sap, ψ_π,

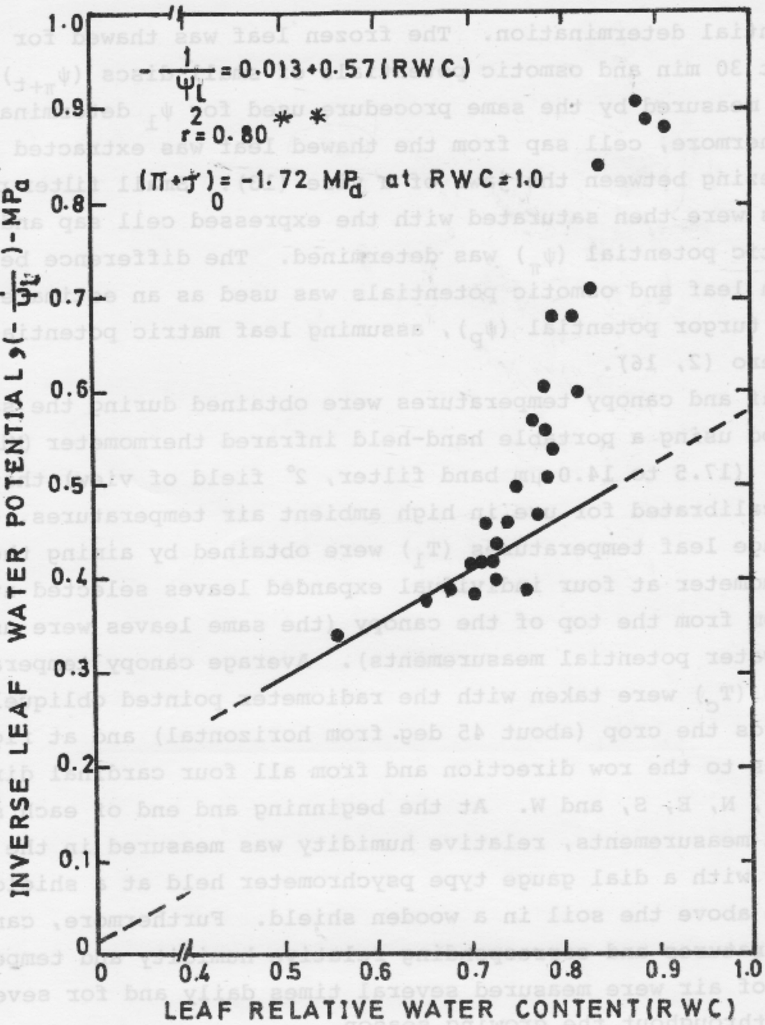

Fig. 1. The relationship between inverse leaf water potential (MPa^{-1}) and relative leaf water content (RWC) of sugarbeet.

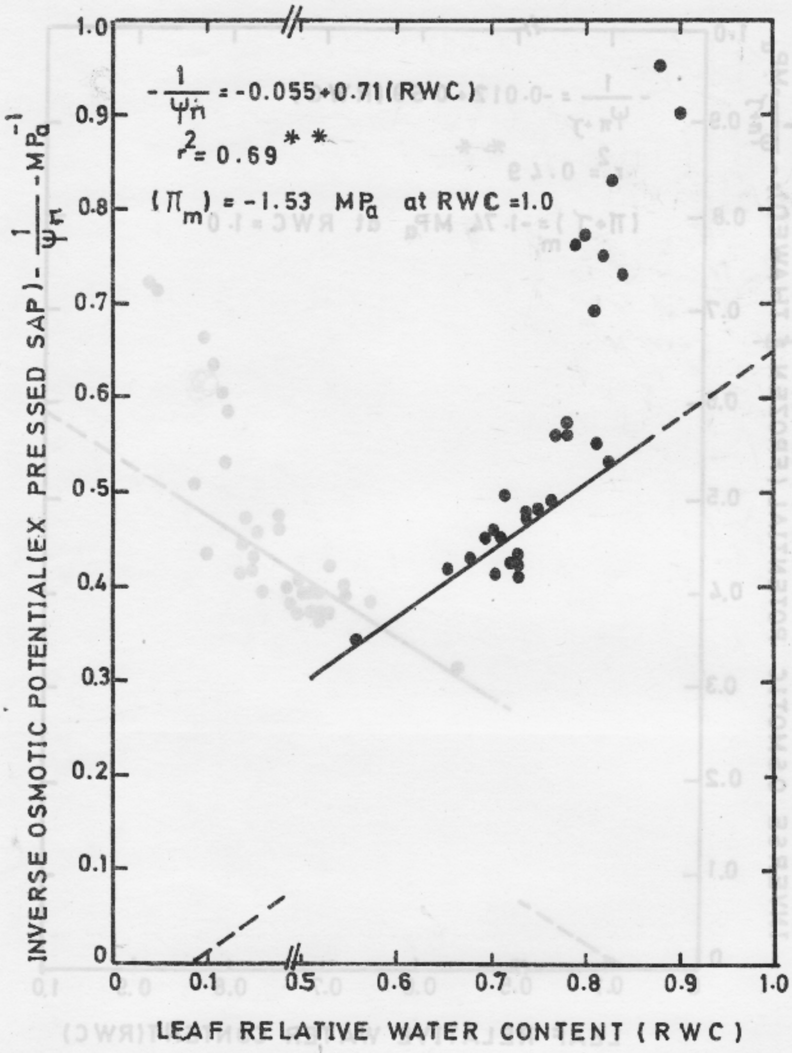

Fig. 2. The relationship between inverse osmotic potential of leaf expressed sap (MPa^{-1}) and relative water content (RWC) of sugarbeet.

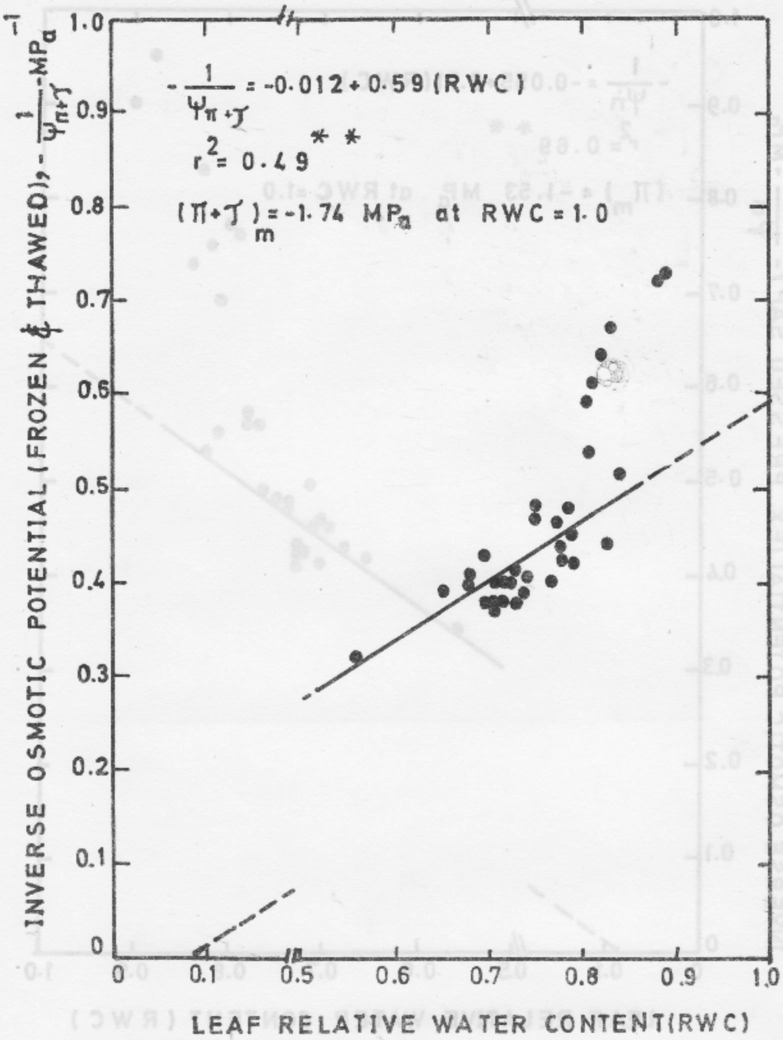

Fig. 3. The relationship between inverse osmotic potential of frozen-thawed leaf (MPa^{-1}) and relative leaf water content (RWC) of sugarbeet.

(or dilution error of 12%) could be considered as the correction factor and is similar to that used by other workers (3, 17).

The intercept value of inverse osmotic potential of frozen-thawed leaf at RWC = 1 (Fig. 3) was -1.74 MPa. The correction factor would be -1.74/-1.72 = 1.01 which would indicate that osmotic potential measurement in the frozen-thawed leaf could be used in leaf turgor potential determination ($\psi_p = \psi_l - \psi_{\pi+t}$) with apparently no significant error due to dilution of the cytoplasm by cell wall water.

Leaf turgor potentials ($\psi_p = \psi_l - \psi_{\pi+t}$) were calculated and the relationship between (T_l-T_a) and leaf turgor potential is shown in Fig. 5. The linear relationship is described by $(T_l-T_a) = 7.4 - 19.9\ \psi_p$ with R = 0.534 which is not very high but significant at P = 0.01. A $(T_l-T_a)_{UL}$ of 7.4°C is estimated from this equation as ψ_p approaches zero. It should be noted that $(T_c-T_a)_{UL}$ is used in CWSI calculations. On the other hand, a relationship between (T_c-T_a) and (T_l-T_a) can be obtained from equation:

$$(T_c-T_a) = 0.76\ (T_l-T_a) - 1.43$$

of Sepaskhah *et al.* (12). Thus using this equation, $(T_c-T_a)_{UL}$ is calculated to be 4.19°C.

The relationship between (T_c-T_a) and vapor pressure deficit (VPD) under well-watered conditions (lower limit equation) is shown in Fig. 6. The equation describing this relationship is

$$(T_c-T_a) = 2.81 - 0.26\ (VPD),\ R^2 = 0.93^{**}$$

Under calm wind conditions, the following equation proposed by O'Toole and Hatfield (11) can be used to estimate the $(T_c-T_a)_{UL}$:

$$(T_c-T_a)_{UL} = a + b\ |(VPG)| \qquad (3)$$

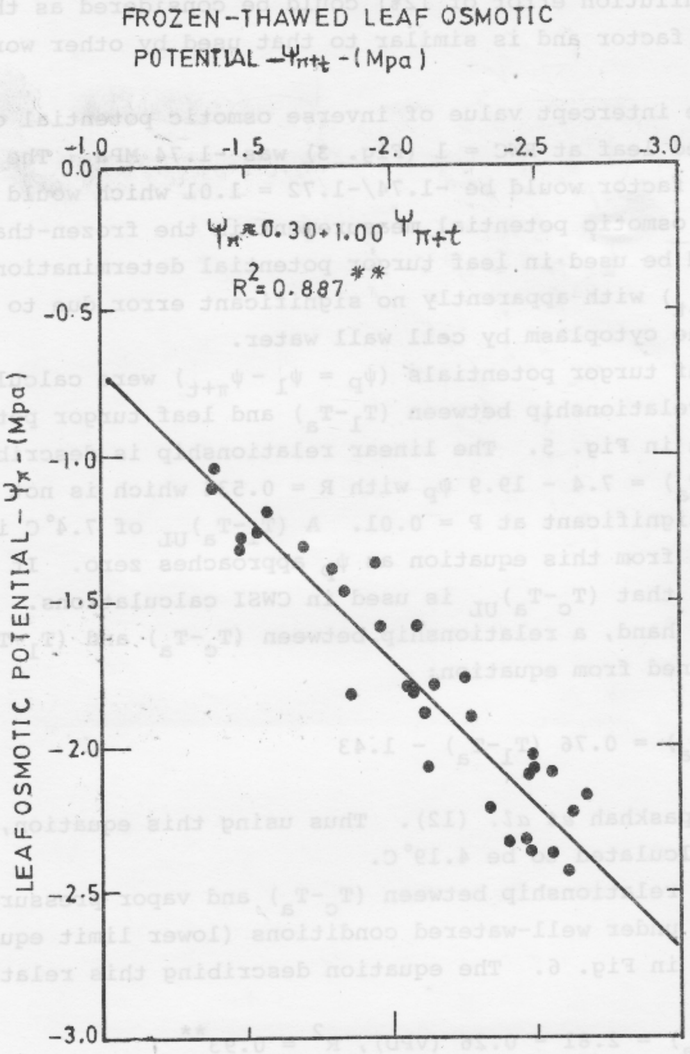

Fig. 4. The relationsip between osmotic potentials of leaf expressed sap (ψ_{π}) and frozen-thawed leaf ($\psi_{\pi+t}$), MPa of sugarbeet.

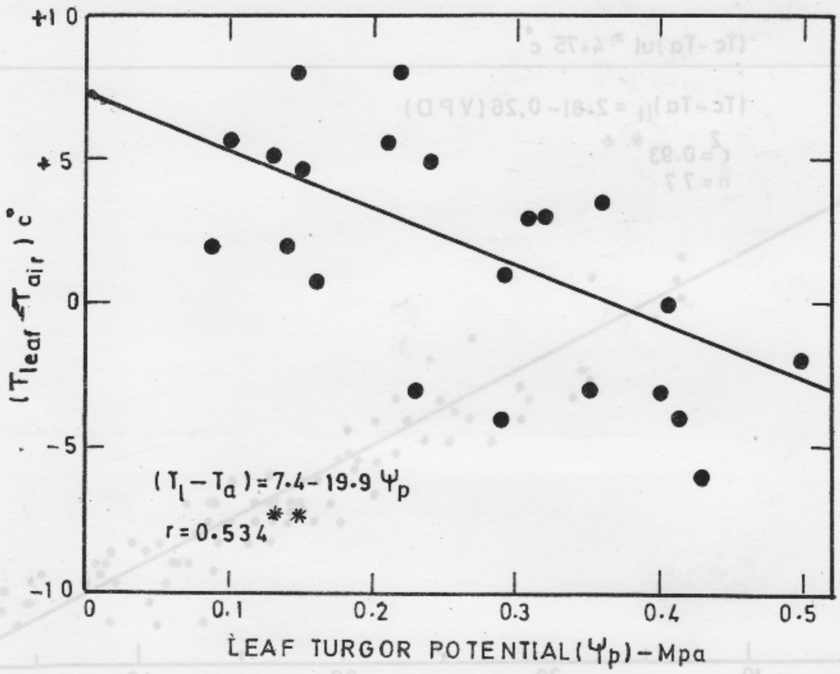

Fig. 5. The relationship between leaf and air temperatures difference $(T_l - T_a)$, °C and leaf turgor potential (MPa) of sugarbeet.

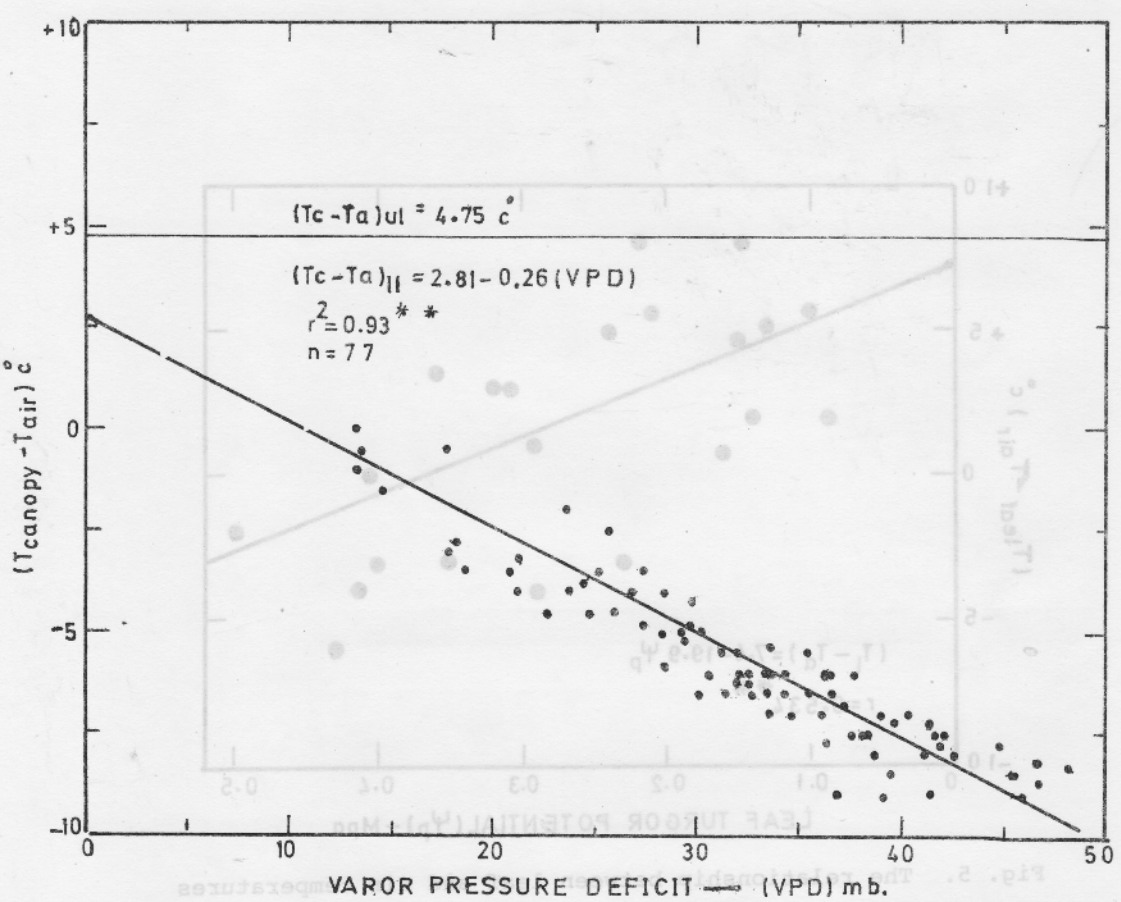

Fig. 6. The relationship between canopy and air temperatures difference (T_c-T_a), °C and vapor pressure deficit of air (VPD), mb of sugarbeet.

and from frozen-thawed leaf, $\psi_{\pi+t}$, were not equal as shown in Fig. 4. The linear relationship between the two methods of measurements was

$$\psi_{\pi} = 0.3 + 1.0\ \psi_{(\pi+t)} \text{ with } R^2 = 0.887^{**}$$

The difference between these measurements might be partially due to matric potential and/or errors in measuring expressed sap osmotic potential result from the dilution of the cytoplasm by cell wall water (15). Apparently this error did not occur in measuring the osmotic potential of frozen-thawed leaves. To ascertain this speculation, the linear relationships between inverse values of leaf water potential, osmotic potentials of expressed sap and osmotic potentials of frozen-thawed leaf and RWC were obtained by regression analysis. The values of line interception with abssica (RWC) could be a measure of error involved in measuring the osmotic potential of expressed sap (15) (Figs. 1-3).

A dilution error of 1.12 has been used to correct the measured osmotic potential of expressed sap (lowering the actual measured value) by several researchers (3, 17). Boyer and Potter (14) found an error of 11% in osmotic potential for intact frozen-thawed sunflower (*Helianthus annuus* L.) leaf tissue. Wenkert (17) observed errors of 16% and 11% in the expressed sap osmotic potential for field and greenhouse grown corn (*Zea mays* L.), respectively. Tyree (15) noted an error of 19% to 52% in the expressed sap osmotic potential of some woody plants.

In the present study, the procedure used by Wenkert (17) was employed to obtain the correction for sugarbeet leaves. The intercept value of leaf water potential at RWC = 1 (Fig. 1) could be considered as the correct osmotic potential (-1.72 MPa). The intercept value of inverse expressed sap osmotic potential at RWC = 1 (Fig. 2) could also be considered as the measured value of expressed sap osmotic potential (-1.53 MPa). The ratio of these values -1.72/-1.53 = 1.12

where a and b are the constants of the lower limit equation, and VPG (vapor pressure gradient) is calculated as follows:

$$VPG = e_c^* - e_a^*$$

where e_a^* and e_c^* are the saturation vapor pressure, mb, at air temperature (°C) and air temperature plus a (°C), respectively. The average maximum air temperature during the growing season was 31.6°C. The VPG was calculated to be 8.18 mb. Consequently, $(T_c-T_a)_{UL}$ was calculated as 4.94°C which is close to that obtained by approaching ψ_p to zero (4.19°C). Furthermore, the measured average value of $(T_c-T_a)_{UL}$ during the growing season was reported to be 4.75°C (10).

The estimation of $(T_c-T_a)_{UL}$ from equation (2) can be made by using the average values of calculated aerodynamic resistance of subarbeet 10.3 $S\,m^{-1}$ and net radiation of 0.74 cal cm^{-2} min^{-1} as found by Nazemossadat (10). Based on these values, the estimated $(T_c-T_a)_{UL}$ is 4.20°C which is the same as that obtained by approaching ψ_p to zero.

CONCLUSION

Osmotic potential measurement of the frozen-thawed leaf tissues of sugarbeet can be used in leaf turgor potential determination ($\psi_p = \psi_l - \psi_{\pi+t}$) apparently with no signficant error due to dilution of cytoplasm by cell wall water. The relation between ψ_p and (T_c-T_a) can be employed to estimate the $(T_c-T_a)_{UL}$ by equating the ψ_p to zero. The estimation of $(T_c-T_a)_{UL}$ obtained by this relationship is in agreement to those obtained by equations (2) and (3) and direct measurement.

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