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WATER STRESS OF SUGARBEET AS RELATED TO LEAF AND CANOPY TEMPERATURES AND TO LEAF WATER CONTENT[1]

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ABSTRACT

Preference of the sugarbeet (*Beta vulgaris* L.) canopy and leaf temperatures and possible use of leaf water contents in predicting the leaf water potential (Ψ_1) and crop water stress index $(CWSI)_1$ were investigated in Bajgah area of Fars Province, Iran. The Ψ_1 were equally sensitive to the leaf and canopy temperatures. The leaf-air temperature difference was more sensitive to changes in Ψ_1. Further inclusion of vapor pressure deficit (VPD) and $(CWSI)_1$ did not improve the prediction of Ψ_1. A linear relationship was established between Ψ_1 and $(CWSI)_1$. The appropriate value of $(CWSI)_1$ for sugarbeet irrigation scheduling as 0.15 could be comparable to Ψ_1 of -1.45MPa. The Ψ_1 and $(CWSI)_1$ of sugarbeet have been correlated with the leaf water contents both on fresh and dry wt. basis. The appropriate leaf water contents for irrigation scheduling could be 85.7% and 6.47 (ratio) on fresh and dry wt. basis, respectively.

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رابطه بین تنش آبی چغندرقند، دمای برگ، پوشش سبز و مقدار آب برگ

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خلاصه

ارجحیت دمای برگ بر دمای پوشش سبز و امکان استفاده از مقدار آب برگ چغندرقند در تخمین پتانسیل آب برگ و نمایه تنش آبی گیاهی در منطقه باجگاه از استان فارس مورد بررسی قرار گرفت. پتانسیل آب برگ چغندرقند بطور مساوی نسبت به دمای برگ و پوشش سبز حساس است

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نشان داده است. از طرف دیگر حساسیت تفاوت دمای برگ و هوا نسبت به تغییرات پتانسیل آب برگ بیشتر بود لذا پتانسیل آب برگ تنها با اندازه‌گیری تفاوت دمای برگ و هوا قابل تخمین بوده و با واردکردن عوامل دیگری از قبیل کمبود فشار بخار و نمایه تنش آبی گیاه در مدل، در تخمین پتانسیل آب برگ بهبودی حاصل نشد. همچنین رابطه خطی بین پتانسیل آب برگ و نمایه تنش آبی گیاهی ارائه شد. حد مناسب نمایه تنش آبی گیاهی برای برنامه‌بندی آبیاری چغندرقند (۰/۱۵) میتواند برابر ۱/۴۵- (MPa) پتانسیل آب برگ باشد. رابطه بین پتانسیل آب برگ و مقدار آب برگ چغندرقند براساس وزن تر و وزن خشک نیز ارائه شد. مقدار مناسب آب برگ برای برنامه‌بندی آبیاری چغندرقند میتواند برابر ۸۵/۷% (براساس وزن تر) و ۶/۴۷ (براساس وزن خشک) باشد.

INTRODUCTION

A quantitative estimate of plant water stress is a critical requirement for scheduling irrigation with higher efficiencies. Unfortunately, many of the methods for quantifying plant water potential are both labor intensive and tedius and especial equipments are needed. Furthermore, they are subject to considerable experimental and sampling errors (22). The direct measurement of plant water potential by pressure chamber is relatively simple and fast. However, the morphological peculiarity of sugarbeet petioles (unroundness and groovy) obscures the usage of pressure chamber for the leaf water potential measurements.

Different plant indicators have been proposed to schedule irrigation for higher irrigation efficiency (6, 7, 14, 15). The relationship between measured infrared (IR) canopy temperature and a moisture stress parameter which is termed the crop water stress index (CWSI) by Idso *et al.* (9) was well correlated with leaf water potential (Ψ_l) in alfalfa (*Medicago sativa* L.) (10) cotton (*Gossypium hirsutum* L.) (8, 19), sorghum (*Sorghum bicolor* L.) (5), and corn (*Zea mays* L.) (3). The major advantage which IR thermometry offers over conventional stress assessment techniques is the ease and rapidity with which plant temperature measurements can be made (12, 18).

Pinter and Reginato (19) reported a good correlation between xylem pressure potential of cotton leaves and CWSI, generated from radiant leaf temperature, air temperature and vapor pressure deficit. They concluded that physiological measure of plant stress could be bypassed and instead an optimum CWSI could be used as a mean for effective irrigation practices. Howell *et al.* (8) also concluded that for cotton fields the infrared thermometer offers a method of quickly assessing crop stress over large areas.

Plant water content also was used as an indicator for irrigation scheduling (13, 21). Longeneker and Lyerly (13) showed that petiole of cotton leaves had consistantly higher water content and reacted more uniformly than leaves during dry down periods. However, Reginato and Howe (21) compared the petiole water content of cotton with canopy temperature for irrigation scheduling, and concluded that the crop water stress index was a better indicator of plant water stress than was petiole water content.

The objectives of this study were: (i) to determine preference of the sugarbeet canopy or leaf temperature measurements for assessing crop water stress, (ii) to establish a relationship between CWSI and the water potential of sugarbeet leaf (Ψ_1), and (iii) to relate the water content of sugarbeet leaf to CWSI and Ψ_1.

MATERIALS AND METHODS

The experiment was conducted during 1986 in a one ha field of sugarbeet located on the experimental station farm, College of Agriculture, Shiraz University, 16 km north of Shiraz, 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 (16). The soil is a Calcixerollic Xerochrept silty clay. A local cultivar of sugarbeet (*Beta vulgaris* L.) was planted in E-W oriented rows which were 60 cm apart on May 3, 1986 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. The least and the most amounts were 9.1 and 55.9 cm per experimental period, respectively.

Water potential of sugarbeet leaf discs were measured with a model C-52 Wescor sample chamber (Wescor Inc. S. Main, Logan, UT, 84321)[†] coupled to a dew point microvoltmeter (Wescor HR-33-T). The measurements were taken from August 10 to 18, 1986 from different irrigation treatments, irregularly before or after an irrigation. At each day of measurement, four fully grown sunlit leaves were selected and cut from different plants from each irrigation treatment. The leaf samples were immediately placed in plastic bags and covered with a moist cheesecloth. The measurements of leaf water potential were made within 45-75 min of field collection. Leaf sampling was made from 12:00 to 12:30 h solar time. The leaf samples without petioles were halved from midrib. One half was used for Ψ_l measurement and the other half was used for leaf water content measurement. The leaf water content was determined by direct method as described by Catsky (2). The leaf water contents were calculated both as fresh wt. basis, %, [(leaf water/leaf fresh wt.) X 100] and dry wt. basis, ratio (leaf water/leaf dry wt.). Radiant 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 pass filter, 2° field of view) that was calibrated for use in high ambient air temperatures. The average leaf temperatures (T_l) were obtained 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 begin-

[†] The product name and the manufacturer address are included for readers benefit and do not imply endorsement by Shiraz University over other equivalent materials.

ning and end of each set of IR measurements, relative humidity was measured in the field with a dial gauge type psychrometer held at a height of 1.2 m above the soil in a wooden shield.

RESULTS AND DISCUSSION

The leaf and canopy temperatures and leaf water potentials for sugarbeets measured at 12:00 - 12:30 p.m. are presented in Fig. 1. The leaf and canopy temperatures increased as leaf water potential decreased. On clear days, a crop is subjected to high net radiation, air temperature and vapor pressure deficit, VPD (high evaporative demand) between 13:00 and 14:00 p.m. when partial stomatal closure may occur and transpiration may decrease when water extraction by roots is not adequate. The decrease in transpiration tends to increase leaf and canopy temperatures. A change in leaf water potential of -1.07 to -2.97 MPa, was associated with leaf temperatures ranging from 23 to 41°C, and canopy temperatures ranging from 23° to 38°C. It is suggested that scattering of the experimental data is at least partially due to the adjustments of the leaves to varying atmospheric conditions encountered during the study period (1). Scattering of the data also may have been caused by the different soil moisture conditions or irrigation treatments, and also due to the fact that measurements of leaf water potentials and leaf temperatures were made on different leaves (21).

Regression analysis of leaf water potential, and leaf and canopy temperatures are presented in Table 1. The linear fit to the data points was significant for both leaf and canopy temperatures, but the regression coefficients were not statistically different ($P > 0.05$). This result indicated that leaf water potentials were equally sensitive to the leaf and canopy temperatures.

To ascertain if the use of canopy and leaf-air temperature differences (ΔT) for sensing plant response to water stress

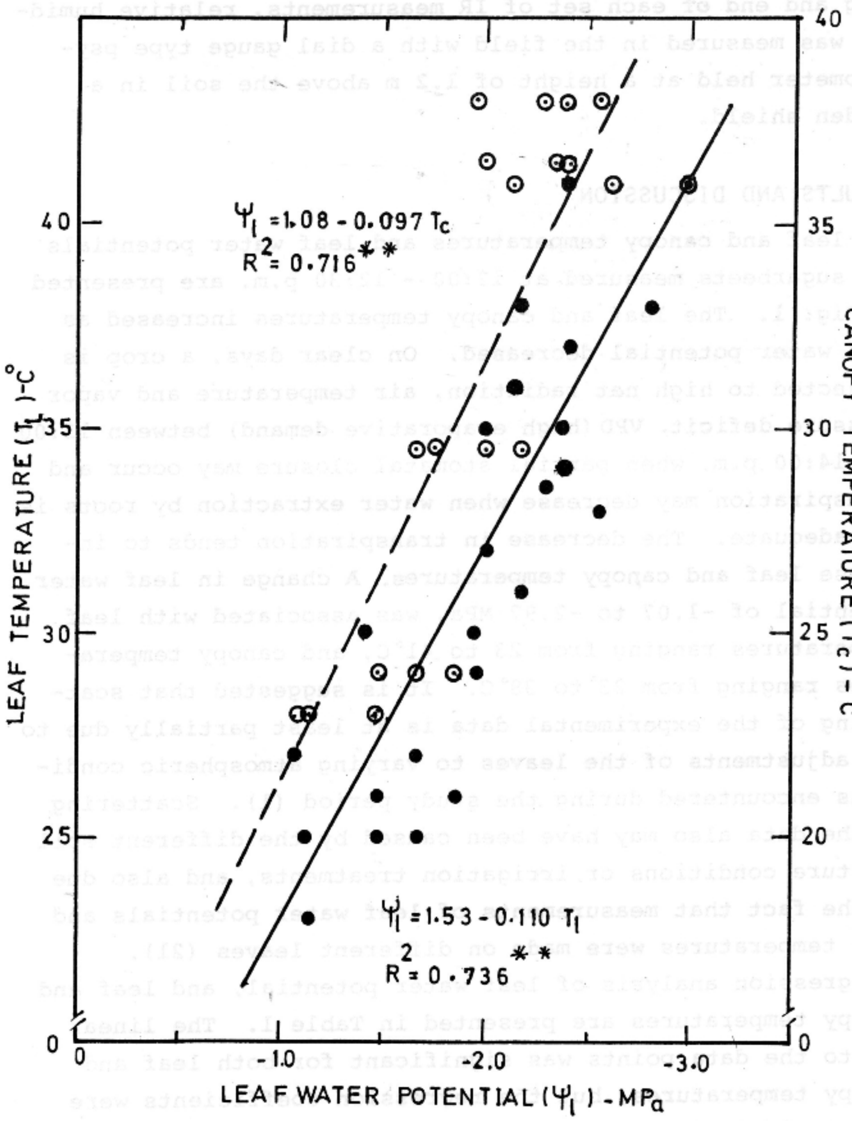

Fig. 1. Leaf and canopy temperatures versus leaf water potential of sugarbeet.

Table 1. Coefficient of determination (R^2), standard error and regression equations for relationships between leaf water potential of sugarbeets Ψ_l and T_l, T_c, (T_l-T_a) and (T_c-T_a).

Regression equation	R^2	Standard error
$\Psi_l = +1.53-0.110\ T_l$ [†]	0.736b [‡]	0.547
$\Psi_l = +1.08-0.097\ T_c$	0.716b	0.567
$\Psi_l = -1.86-0.125\ (T_l-T_a)$	0.882a	0.389
$\Psi_l = -2.10-0.164\ (T_c-T_a)$	0.622b	0.696

[†] Temperatures are reported in °C and Ψ_l in MPa.

[‡] R^2 values followed by the same letter are not significant at 5% level of probability.

is based on a sound physiological response or not the plot of ΔT for leaf and canopy temperatures against leaf water potentials were constructed (Fig. 2). Leaf water potentials were inversely related to the leaf and canopy-air temperature differences, ΔT. Similar results were reported for grain legumes by Pandey *et al.* (17). Regression analyses of leaf water potential and ΔT of leaf and canopy temperatures are presented in Table 1. The difference in linear regression equations was significant for the two relationships. Furthermore, the regression coefficients and coefficient of determination, R^2, were significantly higher for the leaf and air temperature difference, (T_l-T_a) as compared with (T_c-T_a). The more negative slope (Fig. 2) indicated that leaf-air temperature difference was more sensitive to changes in the leaf water potential, whereas, the canopy-air temperature difference with less negative slope was less sensitive. This might be explained partly by the fact that variation in leaf water potential is more associated with variation in

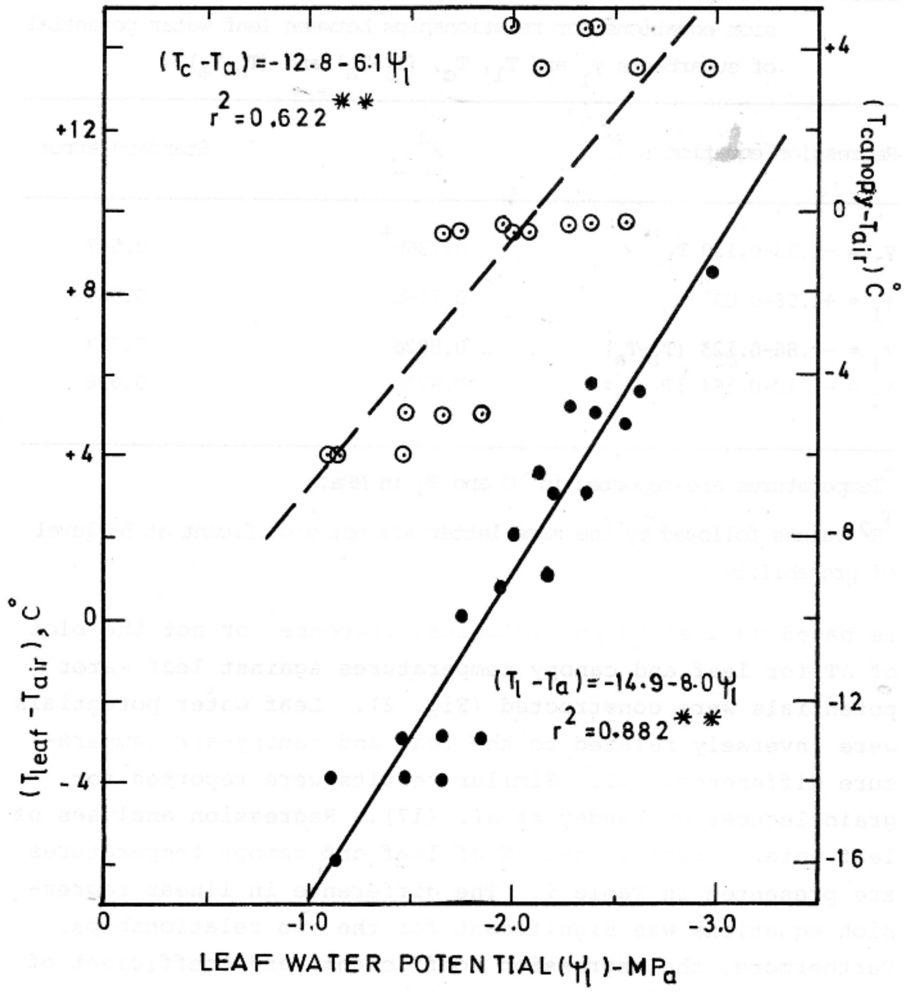

Fig. 2. Leaf and canopy temperature minus air temperature versus leaf water potential of sugargeet.

leaf temperature than canopy temperature. Pinter and Reginato (19) similarly reported a higher correlation between leaf xylem pressure potential and crop water stress index $(CWSI)_l$ based on leaf and air temperature differences than that of CWSI based on canopy and air temperature differences for cotton.

To determine whether IR thermometry would provide a reliable method for following changes in sugarbeet plant water status from one irrigation to the next and for all irrigation treatments, the T_l data were transformed into the CWSI parameter proposed by Idso *et al.* (9). The measurement period was from August 10 to 18 during which the CWSI varied from -0.05 to 1.19. This range exceeded the expected limits, mainly due to the variability around the base-line of $(T_{leaf}-T_{air})$ vs. VPD at non-stressed treatment, and to a lesser degree the empirical method by which the upper limit is determined.

The Ψ_l data for all treatments were paired with corresponding daily values of $(CWSI)_l$ and a simple linear relation between Ψ_l (MPa) and $(CWSI)_l$ was obtained (Fig. 3). The linear equation was $\Psi_l = -1.26-1.27(CWSI)_l$, with $R^2 = 0.881$ and SE = 0.391 which is comparable with the relationship between Ψ_l and $(T_{leaf}-T_{air})$, (Table 1). Similarly, simple linear relation between Ψ_l and $(CWSI)_l$ was reported by Howell *et al.* (8) for cotton. The leaf water potential presented in Fig. 3 represents a narrower range of values than those reported by Reginato (20) and Idso *et al.* (11), but they were similar to those reported by Howell *et al.* (8). The results of Nazemossadat (16) indicated that relative sugarbeet root yields of 80 and 0% have been obtained at CWSI of 0.15 and 1.00, respectively. Therefore, CWSI of 0.15 has been suggested as optimum level for irrigation scheduling for sugarbeet. According to Fig. 3, the corresponding leaf water potential to the relative root yields of 80 and 0% (or CWSI of 0.15 and 1.00) are -1.45 and -2.53 MPa.

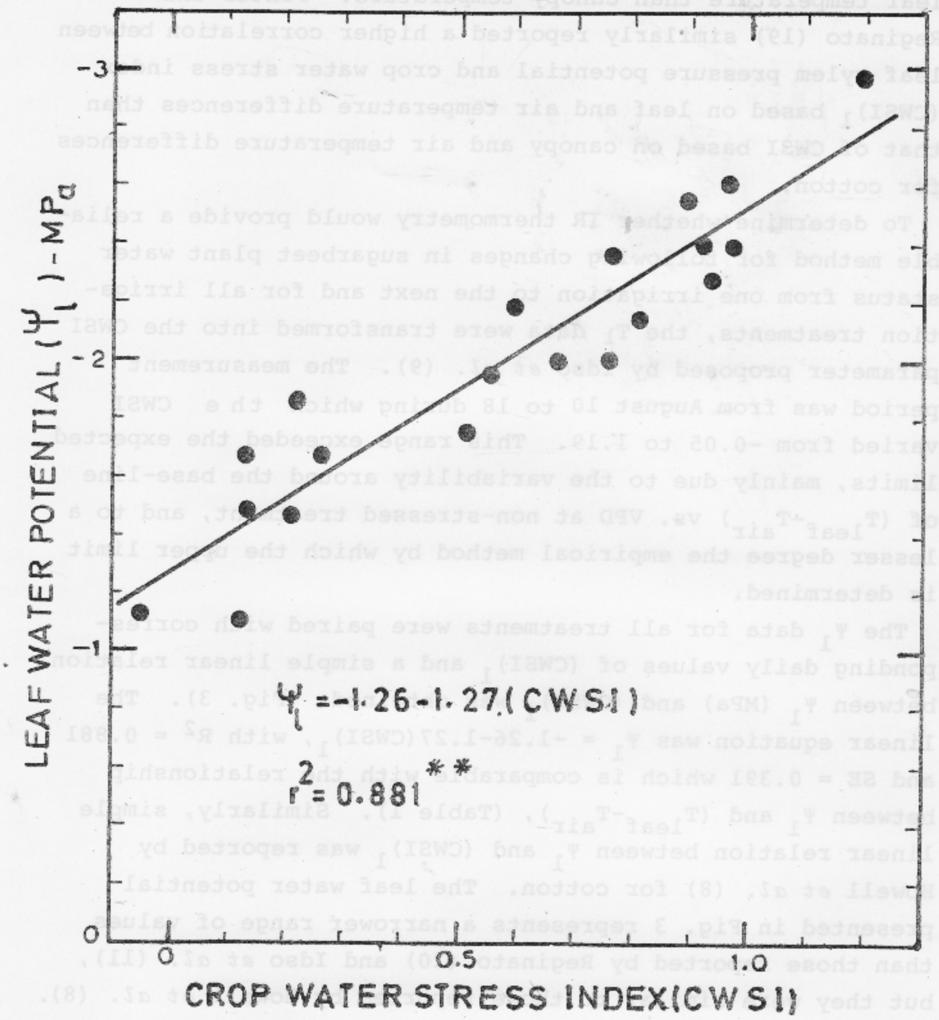

Fig. 3. The relationship between leaf water potential and crop water stress index (CWSI) for sugarbeet.

The CWSI ranges from 0.2 to 0.3 have been proposed for irrigation scheduling of cotton by Howell *et al.* (8) which corresponded to the leaf water potential range of -1.7 to -1.8 MPa.

The leaf water potentials (MPa) as a function of leaf water content (fresh wt. as % and dry wt. basis as ratio) are shown in Fig. 4. The linear model $\Psi_l = -13.35+0.139\theta_f$ with $R^2 = 0.894$ (significant at $P>0.01$) described the relationship for leaf water content on fresh wt. basis (%). The equation $\Psi_l = 1.97\ln\theta_d - 4.97$ with $R^2 = 0.888$ (significant at $P>0.01$) also described the relationship for leaf water content on dry wt. basis (ratio). These results indicated that similar relationships could be derived between the leaf water contents and CWSI. The relationships obtained by regression analysis are $\theta_f = 86.9-8.19\ (CWSI)_l$ with $R^2 = 0.830$ (significant at $P>0.01$), and $\ln\theta_d = 1.98-0.75\ (CWSI)_l$ with $R^2 = 0.824$ (significant at $P>0.01$). According to these equations, the corresponding leaf water contents on fresh and dry wt. basis for the relative root yields of 80% (or CWSI of 0.15) are 85.7% and 6.47 (ratio), respectively. These results show a prospect in use of leaf water content for irrigation scheduling of sugarbeet. It is certainly much easier to measure leaf water content than leaf water potential and leaf temperatures.

CONCLUSION

The leaf water potential (Ψ_l) of sugarbeet were equally sensitive to the leaf and canopy temperatures. The leaf-air temperature difference was more sensitive to changes in Ψ_l than canopy-air temperature difference. Inclusion of VPD and $(CWSI)_l$ did not improve the prediction of Ψ_l from ΔT_l values. A linear relationship was obtained between Ψ_l and $(CWSI)_l$. The appropriate value of $(CWSI)_l$ for sugarbeet irrigation scheduling or 0.15 is comparable to Ψ_l of -1.45 MPa. The Ψ_l and $(CWSI)_l$ of sugarbeet correlated with leaf

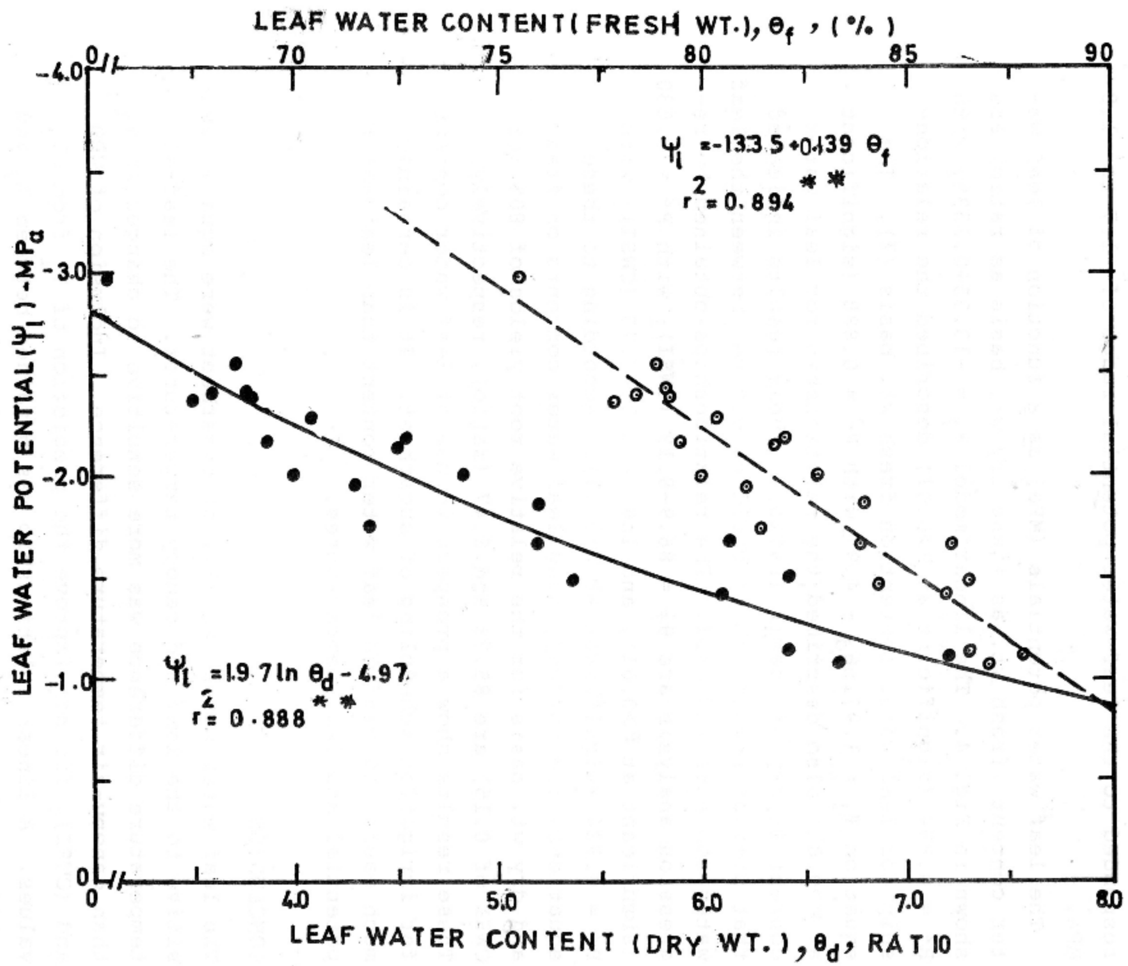

Fig. 4. The relationship between leaf water potential and leaf water contents of sugarbeet.

water contents both on fresh and dry wt. basis. The appropriate leaf water contents for irrigation scheduling could be 85.7% and 6.47 (ratio) on fresh and dry wt. basis, respectively. Further research is needed to confirm the use of leaf water content of sugarbeet in irrigation scheduling.

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