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DETERMINATION OF WATER STRESS INDEX IN SUNFLOWER

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SUMMARY

This study was conducted to quantify crop water stress index (CWSI) based on single leaf temperatures of sunflower and to determine if CWSI values were correlated with other measures of plant water stress. Plant were grown under furrow irrigation and subjected to five water treatments ranging from 100 to 0% (100, 75, 50, 25, 0%) replacement of evapotranspirational losses within 0.90 m soil profile. The yield and water use of fully irrigated sunflower were highest in both years. Trends in CWSI values were consistent with the soil water contents induced by deficit irrigations. An average CWSI of 0.59 before irrigation times produced maximum yield. An equation for calculating yield potential of sunflower was developed using the relationship between yield and seasonal mean CWSI. Moreover, statistically significant correlations were found between CWSI calculated from single leaf temperatures and stomatal resistance, leaf area index (LAI) and available water in the root zone.

Key words: **sunflower, crop water stress index (CWSI), stomatal resistance, leaf area index (LAI)**

INTRODUCTION

Irrigation management is generally based on measurement of soil water content or meteorological parameters for modeling or computing evapotranspiration. Irrigation management based upon crop water status should be more advantageous since crops respond to both the soil and aerial environment (Yazar *et al.*, 1999). Most methods used to quantify crop stress under field conditions have relied on point measurements. Plant stress measurements with hand-held infrared thermometers (IRT) have become increasingly popular after 1980. This technique is based on the fact that transpiration cools the leaf surface. As water becomes limiting, stomatal conductance and transpiration decrease and leaf temperature

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increases. A temperature measurement on individual leaves is a good indicator of plant stress (Reginato, 1983).

Plant stress under field conditions has been quantified by use of the crop water stress index (CWSI) and Idso *et al.* (1981) developed empirical linear relationships for canopy-air temperature difference (T_c-T_a) versus vapor pressure deficit (VPD) of the atmosphere for a crop transpiring at its potential rate. The lower limit (T_c-T_a) versus VPD represents the measured temperature difference when the crop is well watered (no stress). The upper limit (T_c-T_a) represents the temperature difference occurring when the crop transpiration rate approaches zero (maximum stress) (Reginato, 1983; Stegman and Soderland, 1992).

The CWSI has been shown to be closely related to available water in the root zone of a wheat crop (Jackson *et al.*, 1981) and to leaf diffusion resistance in cotton (Idso *et al.*, 1982). Nielsen and Anderson (1989) reported that statistically significant correlations were found between CWSI calculated from single-leaf temperatures and stomatal conductance, CO_2 exchange rate, leaf water potential, transpiration rate and percent available water in the active root zone for sunflower. Many researchers have used measurement of canopy temperature to avoid the influence of soil temperature. But situations exist in viewing partial canopies when it is not possible to avoid viewing the soil surface when making a canopy temperature measurements (e.g., small plants, low plant populations). An infrared thermometer with a narrow field of view can be used to measure a leaf temperature from an individual plant. Nielsen (1994) measured both leaf and canopy temperatures and concluded that CWSI could be used to schedule irrigation for sunflower.

Productivity response to water stress is different for each crop and this response is expected to vary with the climate. Therefore, the critical values of CWSI should be determined for a particular crop in different climates and soils to use in yield prediction and irrigation management. The objectives of this work were to 1) determine CWSI for sunflower based on single-leaf temperatures, and 2) determine correlations between CWSI and stomatal resistance, leaf area index, available water in the active root zone and sunflower seed yield.

MATERIALS AND METHODS

This study was conducted at the Viticulture Research Institute of Tekirdag, Turkey (40°59’N, 27°29’E, 4 m above sea level) during the 1999 and 2000 growing seasons. The climate in this region is semi-arid with annual precipitation averaging 575 mm and about 30% of this precipitation falls during the months of April through October. The soil type as this location is clay soil (44% clay, 30% silt and 26% sand) and the available water holding capacity in the top 0.90 m of the soil profile is approximately 131 mm. Irrigation water quality class was determined as C_2S_1.

The plots were arranged in a completely random design with three irrigation treatments in 1999 and five irrigation treatments in 2000 replicated three times. Irrigation was applied when approximately 50% of the available soil moisture was consumed in the active root zone of control treatment (T_1). The measured soil moisture of the T_1 treatment was used to initiate during the season. In treatments T_2, T_3 , T_4 and T_5, irrigation was applied at rates of 75, 50, 25 and 0% of T_1 on the same day, respectively. Only T_1, T_3 and T_5 treatments were investigated in the first year of the experiments. Sunflower seeds were planted on June 8, 1999 and May 17, 2000. Before planting, trifluralin was applied to control weeds at a 2 kg ha^{-1} rate. According to soil fertility analyses, 50 kg ha^{-1} N and 50 kg ha^{-1} P_2O_5 were applied to soil and incorporated by tillage. There were 50 plants in each plot (3.50 by 3.00 m) and plant spacing was 0.70 m between the rows and 0.30 m within the rows. There was a gap of 3 m between the plots. level furrows were set between the rows to ensure uniform water distribution. No runoff was allowed from the furrows by closing their ends. Irrigation water was applied with irrigation and total water to each plot was measured with a flow meter.

The soil water level was monitored in each plot by neutron probe (CPN, 503 DR Hydroprobe) in each 0.30 m soil layer during the growing season. To do this, aluminium access tubes were inserted at the depth of 1.20 m in the center of each plot. The neutron probe was calibrated at the beginning of the growing season for the experimental field by correlating probe readings as count ratios with gravimetric soil water samples taken at the time of access tube installation. The soil moisture content of the first 30 cm depth was measured by the gravimetric method since it was not possible to monitor by the neutron probe (Evett *et al.*, 1993). The measurements of soil water level were taken at 45, 75 and 105 cm. The amount of soil moisture in the 0.90 m depth in T_1 treatment was used to initiate irrigation and to determine the amount of irrigation water needed; the values within the 1.20 m depth were used to obtain the evapotranspiration of the crop (Doorenbos and Kassam, 1979). Evapotranspiration (ET) for ten-day periods was calculated using the water balance method (Heerman, 1985). The equation can be written as follows:

$$ET = P + I - D \pm \Delta W$$

where P is amount of precipitation (mm), I is the irrigation water applied (mm), D is the deep percolation and ΔW is variation in water content of the soil profile (mm). Since the amount of irrigation water was only sufficient to bring the water deficit to the field capacity, deep percolation was neglected. The soil water level measured at 9:00 AM daily in the T_1 and, if necessary, the plots were irrigated individually.

Leaf temperature (T_c) was determined using a hand-held infrared thermometer (Raynger ST8 model) with a 3° field view and equipped with 7-18 mm spectral band-pass filter. The infrared thermometer was operated with the emissivity adjustment set at 0.95. The IRT data collection was initiated on July 26, (DOY 207) in 1999 and on July 16, (DOY 197) in 2000. Leaf temperature was measured on a single, upper-canopy, fully sunlit leaf on 4 plants from four directions per plot and then averaged. The IRT was held as close to the leaf as possible without shading it (5-10 cm from the leaf). For each measurements the IRT was held above the plant leaf at angle of 20-30 degrees below the horizontal to minimize soil background in the field of view. The T_c dry and wet bulb temperature measurements were made from 1100 to 1400 at hourly intervals under clear skies. The dry and wet bulb temperatures were measured with an aspirated pyschrometer at a height of 2.0 m in the open area adjacent to the experimental plots from 1100 to 1400 at hourly intervals. The mean VPD was computed as a average of the calculated instantaneous VPD using the corresponding instantaneous wet and dry-bulb temperatures and the standard pyschrometer equation (Allen *et al.*, 1998). The VPD computations used a mean barometric pressure of 101.25 kPa for the Tekirdag, Turkey.

The crop water stress index (CWSI) values were calculated using the procedures of Idso *et al.* (1981). In this approach, the measured crop canopy temperatures were scaled to the minimum canopy temperature expected under no water stress and the maximum temperature under severe water stress. The non-stressed baselines for the canopy-air temperature difference (T_c-T_a) versus vapor pressure deficit (VPD) relationship were determined using data collected only in the control treatment (T_1). IRT measurements were made a day after irrigation. The upper (fully stressed) baseline was computed according to the procedures of Idso *et al.* (1981). To verify the upper baseline, the leaf temperatures of the fully stressed plants (in T_5 treatment) were determined several times during each season beginning on day 207 in 1999 and on day 197 in 2000.

Following the leaf temperature measurements with the IRT, a single, upper canopy, fully sunlit leaf of each of four plants in each plot was measured for leaf stomatal resistance with a portable porometer (Delta-T, AP4) and averaged to represent the value of this parameter for each plot.

Leaf area index (LAI) was determined at the end of each individual growth period as defined by Doorenbos and Kassam (1979) by cutting plants and measuring all the green leaves with a scanner using Flashe packing programme.

RESULTS AND DISCUSSION

The total number of irrigations, total amount of irrigation water, rainfall during whole growing periods and seasonal evapotranspiration for each treatment are given in Table 1. The number of irrigations and the amount of irrigation water in 1999 were lower than those in 2000 due to different growing season length, different climatic conditions and the total soil profile water content. The seasonal evapotranspiration in treatment T_1 was maximum in both years; suggesting that the irrigation water applied was adequate to meet the full crop water requirements. This treatment was used, therefore, to determine the non-stressed CWSI baseline. Other treatments underwent water deficits and gave lower seasonal ET. The lowest

ET occurred in treatment T_5 since there was no irrigation and maximum water deficit in the root zone. This treatment was used, therefore, to determine the fully stressed baseline.

Table 1: Total number of irrigations, total amount of irrigation water, rainfall and seasonal evapotranspiration

Year	Treatment	Number of irrigations	Irrigation water applied (mm)	Rainfall (mm)	Seasonal evapotranspiration (mm)
1999	T_1	8	560	50	762
	T_3	8	280		523
	T_5	-	-		305
2000	T_1	9	690	74	852
	T_2	9	517		670
	T_3	9	345		524
	T_4	9	172		393
	T_5	-	-		324

The upper and lower baselines for 1999 and 2000 were obtained from the data taken measurement period and are shown in Figures 1 and 2, respectively.

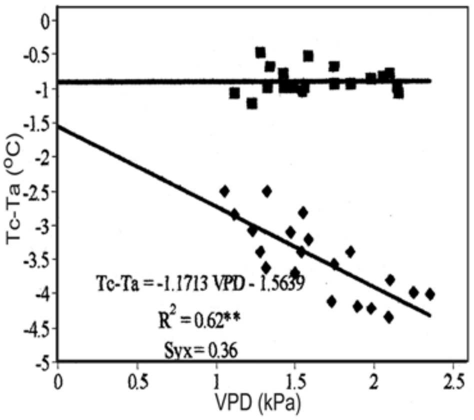

Figure 1: Leaf-air temperature differential (T_c-T_a) versus air vapor pressure deficit (VPD) for well watered and maximally stressed sunflower in 1999

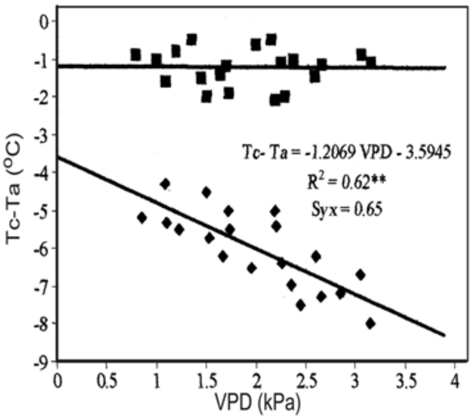

Figure 2: Leaf-air temperature differential (T_c-T_a) versus air vapor pressure deficit (VPD) for well watered and maximally stressed sunflower in 2000

The coefficients of determination (R^2) for the lower baselines were 0.62 in both years ($p<0.01$) and the standard errors of the estimate were 0.36 and 0.65, in 1999 and 2000, respectively. The lower baseline equations differed somewhat from each other. Several factors such as errors in determining relative humidity, IRT calibration, IRT aiming or field of view and microclimate factors (like clouds or wind) can affect the baseline relation. The upper baselines were similar for about -1°C in both years. There is a significant difference between the upper limits of sunflower in the present study and upper limits of the other crops reported by previous researches (Pinter *et al.*, 1983; Howell *et al.*, 1984; Irmak *et al.*, 2000). This result can be related to differences in heating and connective heat exchange due to leaf size, shape, color and orientation of sunflower.

The seasonal course of the CWSI values for the irrigation treatments studied in the years of 1999 and 2000 are shown in Figures 3 and 4, respectively.

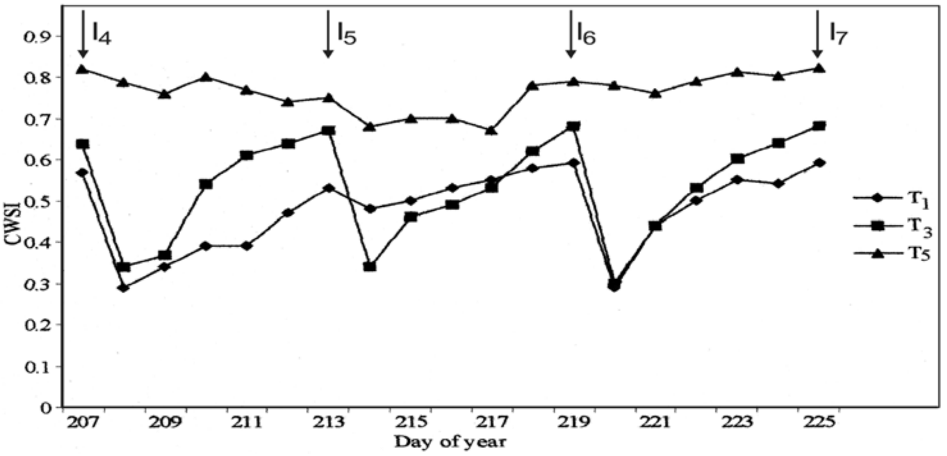

Figure 3: Seasonal trends in the CWSI for each treatment, 1999

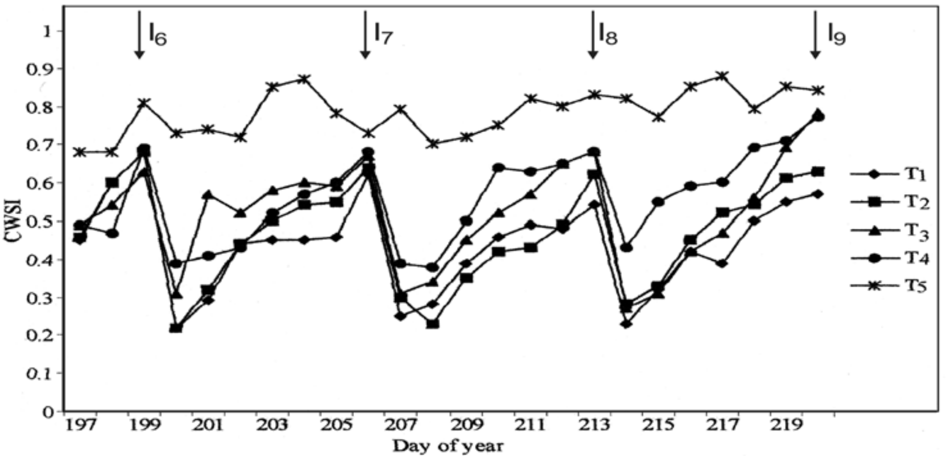

Figure 4: Seasonal trends in the CWSI for each treatment, 2000

In these figures, the arrows depict the days of irrigation. Following irrigation, water stress was usually relieved and CWSI declined accordingly, then increased steadily to a maximum value just prior to the next irrigation application as the soil water in the crop root zone was depleted. The CWSI values ranged from 0.29 to maximum values of 0.59 in T_1 treatment, to 0.68 in T_3 treatment, and to 0.82 in T_5

treatment plots in 1999. The maximum CWSI values in 2000 were 0.68, 0.68, 0.78, 0.77 and 0.88 in T_1, T_2, T_3, T_4 and T_5 treatments, respectively. Irrigations occurred when CWSI on the previous day reached an average value of 0.57 and 0.60 (avg. 0.59) in T_1 treatment, 0.67 and 0.69 (avg. 0.68) in T_3 treatment in the years of 1999 and 2000, respectively. The average CWSI values in 2000 were observed before irrigation times as 0.64, and 0.71 for T_2 and T_4, respectively. Irrigation resulted in more recovery from water stress in T_1, but recovery from water stress was smaller in the drier treatments. Soil water contents were consistent with CWSI values in that the lowest irrigation levels (T_5 and T_4) had the largest soil water depletion levels and CWSI values while the higher irrigation levels (T_1 and T_2) had the smallest soil water depletion levels and CWSI values. CWSI values in T_5 treatment approached a value of 0.85 and stayed near this value because of no irrigation.

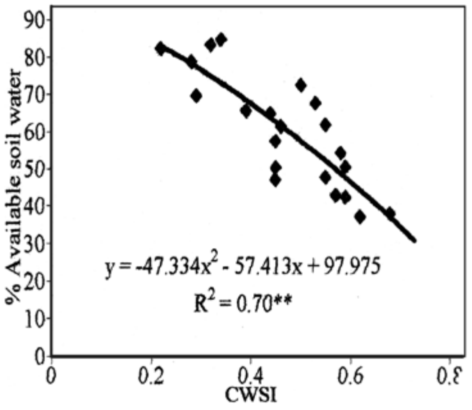

Figure 5: Relationship between CWSI and percent available soil water

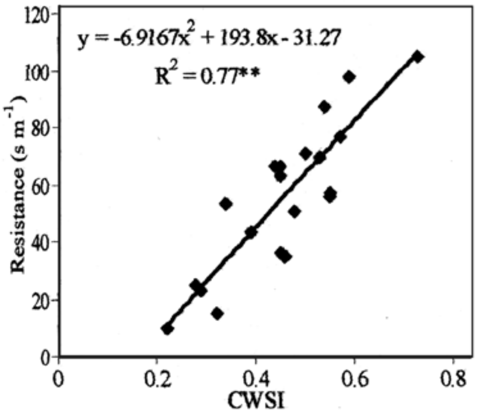

Figure 6: Relationships between CWSI and stomatal resistance

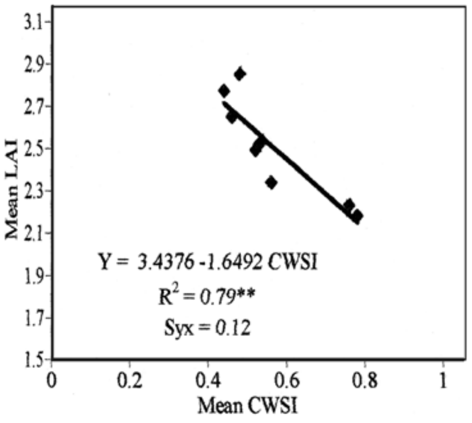

Figure 7: Mean LAI as related to seasonal average CWSI

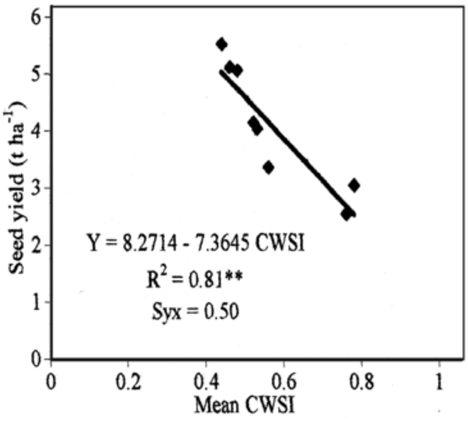

Figure 8: Seed yield as related to seasonal average CWSI

The relations among CWSI, soil water content and stomatal resistance for T_1 treatment in two years are shown in Figures 5 and 6, respectively. Quadratic regression curves of CWSI against soil water content and stomatal resistance were fitted to the data (Figures 5 and 6). Relationships were statistically significant at the level of $P<0.01$. The soil water content in the 0.90 m crop root zone declined while stomatal resistance increased with increasing CWSI for two years. As percent available soil water decreased, the stomata closed, transpiration rates declined, leaf temperatures increased and CWSI increased. Nilsen and Anderson (1989) reported similar results for sunflower.

Table 2: Leaf area index values for treatments

Year	Treatment	Individual growth period[1]			
		Early vegetative (1a)	Late vegetative (1b)	Flowering (2)	Yield formation (3)
1999	T_1	0.73	3.62	4.05	3.00
	T_3	0.67	2.78	3.74	2.88
	T_5	0.62	2.36	3.42	2.52
2000	T_1	0.52	3.61	4.05	2.89
	T_2	0.49	3.27	3.96	2.86
	T_3	0.49	3.21	3.60	2.64
	T_4	0.42	2.83	3.61	2.50
	T_5	0.38	2.61	3.31	2.41

[1] Sunflower growth periods were defined according to Doorenbos and Kassam (1979)

Leaf area index for each treatment was determined at the end of each individual growth period and listed in Table 2. LAI values increased with increasing amount of irrigation water. Since available soil water was the highest in T_1 treatment, the crop experienced less than the other treatments and vegetative growth occurred at the maximum level and consequently it gave the highest yield. The relationship between mean LAI and CWSI was linear ($P<0.01$) and LAI values decreased with increasing CWSI (Figure 7).

Table 3: Seasonal mean CWSI, mean CWSI before irrigation times, seed yield and mean LAI for different irrigation treatments

Year	Treatment	Seasonal mean CWSI	Mean CWSI before irrigation times	Seed yield ($t\ ha^{-1}$)	Mean LAI
1999	T_1	0.48	0.57	5.063 a**	2.85 a**
	T_3	0.53	0.67	4.027 b	2.52 ab
	T_5	0.76	-	2.544 c	2.23 b
2000	T_1	0.44	0.60	5.522 a**	2.77 a**
	T_2	0.46	0.64	5.118 a	2.65 ab
	T_3	0.52	0.69	4.142 b	2.49 ab
	T_4	0.56	0.71	3.359 bc	2.34 ab
	T_5	0.78	-	3.037 c	2.18 b

**Numbers followed by different letters indicate statistically significant differences at the level of 1% (Duncan's Multiple Range Test)

The mean CWSI values, mean CWSI before irrigations, mean LAI and total yields for different irrigation treatments in two years are presented in Table 3. Yield and mean LAI were significantly increased by irrigation level ($P<0.01$). The highest yield and LAI were measured for T_1 treatment in both years. The relationships between CWSI and yield were basically linear within the range of mean CWSI for two years (Figure 8). The seasonal mean CWSI for treatment in the highest yield group in two years ranged between 0.44 and 0.48. The linear equation $Y=8.2714-7.3645$ CWSI ($R^2=0.81$, $S_{yx}=0.50$ t ha^{-1}, $P<0.01$) can be used to predict the yield potential of sunflower. Predicting yield response to crop water stress is important in developing strategies and decision making for use by farmers and researchers for irrigation management under limited water conditions. The equation written above to predict the yield as a function of CWSI can be a useful tool to reach such goals.

The mean CWSI value before applying irrigation was 0.59 (average of 1999 and 2000). This CWSI value was consistent with the highest yield for sunflower in our study. However, we cannot conclude that this CWSI value should be used for timing of irrigations for sunflower since we did not test scheduling irrigation using CWSI.

CONCLUSIONS

The results showed that CWSI is an efficient technique to monitor and quantify water stress for sunflower. Significant relationships among CWSI, stomatal conductance and soil water content were determined. Based on these results an average CWSI of 0.59 before irrigation will produce maximum vegetative growth and yield. The yield in this study was directly correlated with mean CWSI values and the linear equation Y=8.2714-7.3645 CWSI can be used for yield prediction.

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DETERMINACIÓN DEL ÍNDICE DE ESTRÉS HÍDRICO PARA GIRASOL

RESUMEN

Esta labor se ha hecho para cuantificar el índice del estrés hídrico de las plantas agrícolas (IEHPA), a base de la temperatura de la hoja de girasol, tanto como para determinar si IEHPA se encuentra en correlación con otros parámetros del estrés hídrico de las plantas. Las plantas se cultivaban con el riego por surcos (por infiltración). El ensayo constaba de cinco variantes, que se diversificaban entre si por el porcentaje de pérdidas causadas por la evapotranspiración, que iban recompensándose en la capa del suelo hasta la profundidad de 0,90 m (100, 75, 50, 25 y 0%). En ambos años, el rendimiento y la utilización de agua, eran los mayores en girasoles con plena irrigación. Los valores de IEHPA estaban de conformidad con el contenido de humedad en el suelo, provenido de las irrigaciones deficitarias. El rendimiento máximo fue notado en el IEHPA promedio de 0,59 antes de irrigación. Mediante la relación entre el rendimiento y el IEHPA promedio de temporada, se ha hecho una ecuación para calcular el potencial para el rendimiento de girasol. Aparte de ello, se ha establecido una correlación, significativa desde el punto de vista de estadística, entre IEHPA calculado desde la temperatura de la hoja y la resistencia de los poros de la hoja, del índice de la superficie de la hoja (ILP) y el agua aprovechable en la zona de la raíz.

DÉTERMINATION DE L'INDEX DU STRESS DÛ AU MANQUE D'HUMIDITÉ POUR LE TOURNESOL

RÉSUMÉ

Le but de ce travail était de quantifier l'index du stress des plantes agricoles dû au manque d'humidité (ISPAMH) d'après la température des feuilles de tournesol et de déterminer si les valeurs ISPAMH se trouvaient en corrélation avec d'autres paramètres du stress dû au manque d'humidité des plantes. Les plantes ont été cultivées dans des sillons irrigués. L'expérience se composait de cinq variantes qui se différenciaient selon le pourcentage de pertes dues à l'évapotranspiration qui était compensée dans la couche de terre jusqu'à une profondeur de 0.90 m (100, 75, 50, 25, 0%). Pendant les deux années, le tournesol sous complète irrigation a eu un meilleur rendement et a fait une meilleure réutilisation de l'eau. Les tendances dans les valeurs de l'index de stress dû au manque d'humidité (ISPAMH) étaient en accord avec le contenu d'humidité dans le sol induit par un déficit d'irrigation. L'index moyen de 0.59 avant l'irrigation a produit un rendement maximal. À l'aide du rapport entre le rendement et l'index moyen saisonnier (ISPAMH) une équation a été établie pour calculer le potentiel du rendement du tournesol. De plus, une corrélation statistique significative a été constatée entre l'index (ISPAMH) calculé d'après la température de la feuille et la résistance des pores de la feuille, de l'index de la surface des feuilles (ISF) et de l'accessibilité de l'eau dans la zone de la racine.