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RELATIONSHIPS BETWEEN CROP WATER STRESS INDEX, EVAPOTRANSPIRATION AND YIELD OF SWEET LIME

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ABSTRACT

Increasing limitations on water supplies have forced growers to use drip irrigation systems. Therefore, irrigation management of higher water use efficiency is of prime interest. Sweet lime (*Citrus limetta* Swing.) was drip irrigated with water application rates based on 0.6, 0.75, 0.9 and 1.0 times pan evaporation rates in the first year and on 0.4, 0.6, 0.75 and 0.9 times pan evaporation rates in the second year. Crop water stress index (CWSI) values and fruit yields were measured in both years, while evapotranspiration was determined for the first year. Significant differences in seasonal average CWSI and fruit yields were obtained using the different irrigation treatments. Greatest yield was obtained using the 0.75 E_{pan} irrigation treatment which gave a seasonal average CWSI of near 0.1. Higher irrigation application rates resulted in lower CWSI, however, the fruit yield was not the highest due to the possible leaching of nutrients from the light soil of this study. The relative fruit yield decreased linearly with increasing CWSI at irrigation treatments of 0.75 (CWSI of about 0.1) to 0.4 E_{pan} (CWSI of about 0.5). The water use efficiency (fruit yield per unit of water) was highest for the 0.75 E_{pan} treatment. The CWSI was nearly equal to relative evapotranspiration reduction (1-ETa/ETp) and the relative yield reduction (1-Ya/Ym) was equal to 1.6 (1-ETa/ETp). It was found that sensitivity of sweet lime to irrigation water deficit was higher than that for citrus crops in general (medium-sensitive plants to water deficit). Therefore, sweet lime may be classified as a highly sensitive plant to water deficit.

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رابطه نمایه تنش آبی گیاه، تبخیرتعرق و محصول لیموشیرین

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چکیــده

افزایش محدودیت منابع آب، کشاورزان را وادار به استفاده از سیستم قطره‌ای نموده است. بنابراین، برای اینکه راندمان مصرف آب بالائی حاصل شود بایستی مدیریت آبیاری را مدنظر قرار داد.

آبیاری قطره‌ای لیموشیرین با مقادیر آب آبیاری براساس ۰/۶، ۰/۷۵، ۰/۹ و ۱/۰ برابر تبخیر از تشتک کلاس الف در سال اول و براساس ۰/۴، ۰/۶، ۰/۷۵ و ۰/۹ برابر تبخیر از تشتک کلاس الف در سال دوم انجام شد. نمایه تنش آبی گیاهان (CWSI) و محصول لیموشیرین در تیمارهای مختلف در سال های اول و دوم اندازه گیری شده ولی تبخیرتعرق تنها در سال اول تعیین گردید. متوسط فصلی CWSI و محصول لیموشیرین در تیمارهای مختلف متفاوت بود. بیشترین محصول در تیمار آبیاری ۰/۷۵ برابر تبخیر از تشتک بدست آمد که در آن متوسط فصلی CWSI حدود ۰/۱ بوده است. با افزایش میزان آب آبیاری، CWSI کاهش یافته ولی در بیشترین مقدار آب، حداکثر محصول بدست نیامد زیرا آب آبیاری زیاد ممکنست موجب شسته شدن موادغذایی در خاک سبک این آزمایش شده باشد. محصول نسبی با افزایش CWSI از حدود ۰/۱ در تیمار آبیاری ۰/۷۵ برابر تبخیر از تشتک تا حدود ۰/۵ در تیمار آبیاری ۰/۴ برابر تبخیر از تشتک با رابطه خطی کاهش یافت. بیشترین راندمان مصرف آب در تیمار ۰/۷۵ برابر تبخیر از تشتک بدست آمده است. مقدار CWSI تقریباً با کاهش نسبی تبخیر تعرق برابر بوده و همچنین کاهش نسبی محصول (I-Ya/Ym) برابر 1.6 (I-ETa/ETp) حاصل شده است. سرانجام، حساسیت لیموشیرین به کمبود آب بیشتر از انواع دیگر مرکبات بوده، لذا لیموشیرین را می‌توان گیاهی خیلی حساس به کمبود آب معرفی نمود.

INTRODUCTION

Production of sweet lime (*Citrus limetta* Swing.), a major fruit crop in the arid regions of Fars province (Iran), is dependent on irrigation water supplies and have forced growers to use drip irrigation system. Therefore, irrigation management for higher water use efficiency (yield per unit of water) is of prime interest.

Water deficit in crops, resulting in crop water stress, has a direct effect on evapotranspiration and yield. Water stress in plants can be quantified by the rate of actual evapotranspiration (ETa) in relation to the rate of maximum evapotranspiration (ETp). To evaluate the effect of plant water stress on yield reduction, it is necessary to derive the relationship between relative yield decrease (1-Ya/Ym) and relative evapotranspiration deficit (1-ETa/ETp) given by the empirically-derived yield response factor (Ky) (4):

$$(1-Ya/Ym) = Ky\ (1-ETa/ETp) \qquad [1]$$

in which Ya and Ym are the actual and maximum yields and ETa and ETp are the actual and maximum (or potential) evapotranspirations, respectively.

Crop water stress index (CWSI) studies and advances in infrared thermometry were also combined to form a simple technique for measuring crop water stress (7, 8, 11). CWSI is defined by Jackson *et al.* (8) as:

$$CWSI = 1-ETa/ETp \qquad [2]$$

in which ETa is the actual evapotranspiration and ETp is the maximum (or potential) evapotranspiration. The index was also quantified experimentally by Idso *et al.* (6) with canopy-air temperature differences (Tc-Ta) and vapor pressure deficit (VPD).

Estimated values of CWSI using the methods of Idso *et al.* (6) and Jackson *et al.* (8) were used to derive ETa/ETp for alfalfa by Abdul-Jabbar *et al.* (1). Both methods resulted in good estimate of the ETa/ETp.

The objectives of this study were to determine the CWSI values of sweet lime under high frequency irrigation, and to evaluate the relationships among yield, CWSI and relative evapotranspiration.

MATERIALS AND METHODS

The experiment was conducted at the Jahrom Soil and Water Research Station located 175 km SE of Shiraz (28°,30′ N. latitude, 53°,33′ E longitude, and 985 m above MSL) on gravelly loam soil with a field capacity and permanent wilting point of 0.32 and 0.1 cm^3/cm^3, respectively. The experimental period was two consecutive growing seasons starting in April 1987. It was conducted in a 14-year old sweet lime orchard. The sweet lime was grafted on lime (*Citrus limonum* Risso) with spacing of 6 by 6 m and irrigated with drip irrigation method.

Phosphorus and potassium were directly applied to soil in March as 137.5 kg ha^{-1} triple superphosphate and 97.3 kg ha^{-1} potassium sulfate, respectively. Nitrogen and iron were applied through chemigation as 100 kg ha^{-1} ammonium sulfate and 13.9 kg ha^{-1} iron chelate, respectively.

The climate is arid with an average annual rainfall of 317 mm, which mainly falls during the winter months (Nov.-March). The average monthly minimum temperature of the coldest month and the average monthly maximum temperatures of the warmest month are 0.2 and 40.9°C, respectively. The corresponding average monthly minimum and maximum relative humidities are 18.6% and 86.3%, respectively.

The experiment consisted of four irrigation treatments: 100, 90, 75 and 60% of class A pan evaporation (1.0 E_{pan}, 0.9 E_{pan}, 0.75 E_{pan} and 0.6 E_{pan}) during 1987, and 90, 75, 60 and 40% of class A pan evaporation (0.9 E_{pan}, 0.75 E_{pan}, 0.6 E_{pan} and 0.4 E_{pan}) during 1988. Irrigation treatments were changed in second year due to the fact that measured ET of treatments 1.0 E_{pan} and 0.9 E_{pan} were very close. Irrigation water was applied every other day through 4 l hr^{-1} emitters with 12 to 14 emitters per tree. The chemical analysis of the irrigation water indicated that it is suitable for drip irrigation (data not shown). The amount of applied water was measured by a water meter. Each irrigation treatment was replicated three times with four trees per replication. The treatment plots were separated by at least one row of trees in a citrus groove. The CWSI was measured on trees of these treatments.

Canopy temperature (Tc) was measured with an infrared thermometer with 7.5 to 14.0 micrometers band filter, and 2° field of view that was calibrated for use in high ambient temperature. The instrument was hand held at 2 m so that the tree was viewed from all cardinal directions, N, E, S and W at about 15 degrees above the horizontal plane, and two readings were taken from each direction. The instrument was pointed on parts of trees with about 90% of green cover. Vapor pressure deficit (VPD) was calculated from wet and dry bulb temperatures measured at a weather station located near the experimental site in the orchard. For CWSI measurements, canopy and air temperatures and VPD were measured weekly on the day between irrigations at 12:00-14:00. The CWSI was determined using the empirical method of Idso (6) and lower and upper base lines. The lower base line for sweet lime was reported as (Tc-Ta)=3.76-1.77 (VPD) and the upper base line value (Tc-Ta) was 5°C (12). (Tc-Ta) is the canopy to air temperature differential, °C, and VPD is the vapor pressure deficit of air, KPa.

The neutron scattering method was used to obtain soil water content at depths of 15, 25, 40, 55, 70, 85, 100 and 115 cm before and after irrigation. The results of these measurements then were used to estimate evapotranspiration rate (ETa, mm/d) using the following equation (9):

$$ETa = \{I + P - D + [\sum_{i=1}^{n} (\theta_1-\theta_2)\ \Delta S_i]\ \}/\Delta t \qquad [3]$$

where I is the amount of irrigation (mm), P is precipitation (mm), D is deep percolation (mm) out of the bottom of root zone, n is the number of layers, ΔS is the thickness of each soil layer (mm), θ_1 and θ_2 are volumetric soil water contents (cm^3/cm^3) after an irrigation and before the next irrigation, and Δt is the time interval between two consecutive measurements (d). The value of D was estimated by soil unsaturated hydraulic conductivity (K) equation through assumption of unit hydraulic gradient at bottom of root zone. The equation of K (mm/d) for the field soil is $(K)=2.42\times10^{-2}EXP(21.94\theta)$ (10). ETa determination for each irrigation treatment was made between once per month during winter to eight times per month during the rest of the growing season. By plotting ETa of different irrigation treatments versus time, the average monthly ETa rates were estimated.

Fruit yield was harvested at about mid-December in 1987 and 1988.

The total weight of fruits of each replication in all treatments was determined.

RESULTS AND DISCUSSION

Seasonal average and standard error values of CWSI for different irrigation treatments are given in Table 1. These averages are different for all irrigation treatments since their ranges (mean±SE) do not overlap. Fruit yields, total water applications and seasonal evapotranspiration values are also given in Table 1. The yield at irrigation treatment of 0.4 E_{pan} was the smallest (statistical ranges, mean±SE, do not overlap with other irrigation treatments) and the yield obtained of 0.75 E_{pan} was the greatest. Fruit yield was not greatest at the highest irrigation treatment. Maximum fruit yield was obtained at a CWSI value of 0.116 with an amount of irrigation water of 1842 mm. At this treatment (0.75 E_{pan}), maximum water use efficiency (26.8 kg fruit per mm of water) was obtained (Table 1). A similar value of CWSI (0.13) was reported for maximum yield of cotton under trickle irrigation by Fangmeier *et al.* (3).

Table 1 also summarizes annual ET for the 5 different irrigation treatments. Lower yield was obtained at higher ET at irrigation treatments of 1.0 and 0.9 E_{pan}. Maximum fruit yield was obtained at an ET value of 1551 mm. Further decrease in ET resulted in a decrease in fruit yield. The lower yield at the higher water application and ET (1.0 and 0.9 E_{pan}) could be attributed to leaching of nutrient from the root zone. However, at the lower water application (0.6 and 0.4 E_{pan}) water deficit resulted in higher CWSI values (3) and lower fruit yield (13).

Table 1. CWSI, yield, seasonal evapotranspiration, amount of irrigation and water use efficiency of sweet lime at different irrigation treatments (average of two years).

Irrigation treatment, fraction E_{pan}	CWSI	Fruit yield kg $tree^{-1}$	Seasonal ET mm	Irrigation water use mm	Water use efficiency kg mm^{-1}
1.00**	-0.005 (0.003)*	125.7 (6.1)	1692	2471	14.1
0.90	0.075 (0.007)	100.0 (29.8)	1633	2215	12.6
0.75	0.116 (0.015)	177.6 (52.8)	1551	1842	26.8
0.60	0.175 (0.008)	104.4 (33.0)	1448	1482	19.6
0.40**	0.435 (0.057)	49.0 (20.0)	nm	906	15.0

* The number in parantheses is standard error.
** Only one year data.
nm Not measured.

Relationships Between Ya/Ym, ET and CWSI

The ratios of fruit yield at different replications of irrigation treatments of 0.4, 0.6 and 0.75 E_{pan} with respect to maximum fruit yield at irrigation treatment of 0.75 E_{pan} were calculated (a total of 9 points). Then, they were related to the values of seasonal average CWSI at each replication of different irrigation treatments (0.4, 0.6 and 0.75 E_{pan}) by the following equation:

$$Ya/Ym = 0.92 - 1.6\ (CWSI) \qquad R^2=0.702 \qquad (P < 0.01) \qquad [4]$$

The results presented in Fig. 1 show the correlation between relative yield and CWSI at the irrigation treatments of 0.75 E_{pan} to 0.4 E_{pan}. These results show that the relative yield decreased with increase in CWSI from about 0.1 to 0.5 (data of CWSI smaller than 0.05 were not included). These results are similar to those of Howell *et al.* (5) and Fangmeier *et al.* (3) for cotton. These results suggested that the CWSI can be used for irrigation scheduling to minimize stress and increase yield.

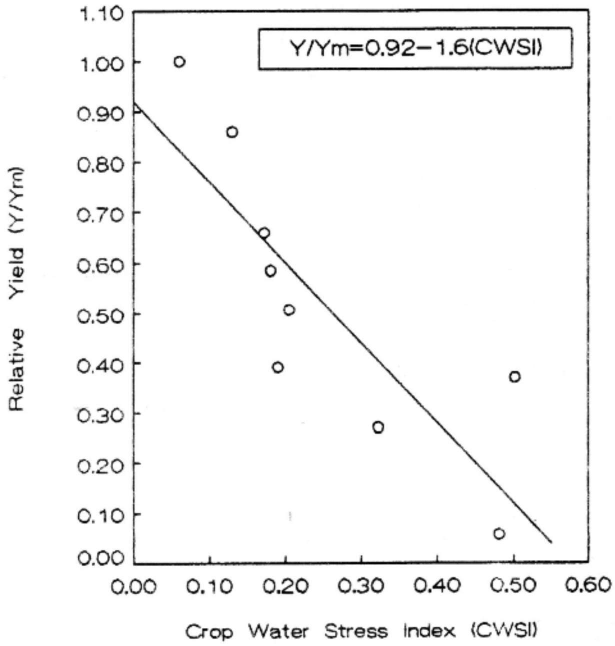

Fig. 1. Relative fruit yield vs crop water stress index (CWSI).

The ratios of monthly ETa at different irrigation treatments with respect to monthly ETa at irrigation treatment of 1.0 E_{pan} (ETp) were calculated. Linear relation between monthly average CWSI and ETa/ETp were then calculated as follows:

$$CWSI = 1.0 - 0.95\ (ETa/ETp) \qquad R^2=0.904 \qquad (P < 0.01) \quad [5]$$

The results are shown in Fig. 2. The energy balance procedure of Jackson *et al.* (8) (1-CWSI) is shown to be theoretically analogous to ETa/ETp. However, in equation [5] the value of (1-CWSI) is equal to 95% of ETa/ETp. This small deviation might be due to the fact that CWSI as estimated by Idso *et al.* (6) was empirically derived. However, the difference is small.

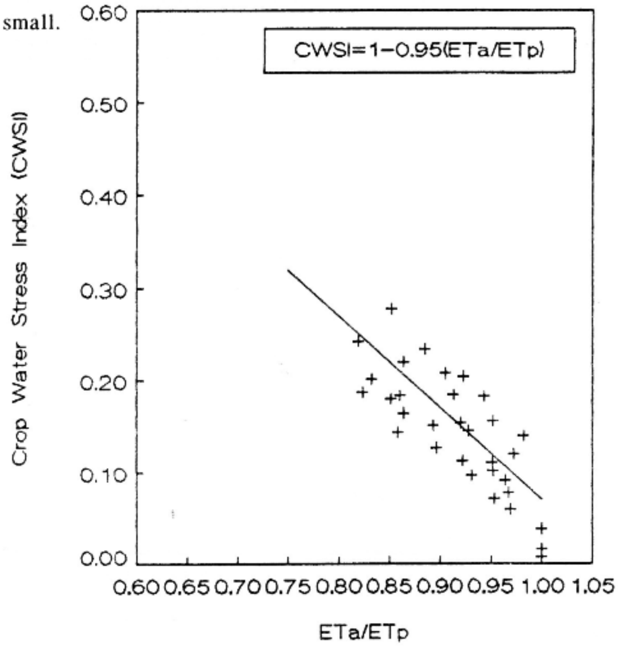

Fig. 2. Crop water stress index (CWSI) vs relative evapotranspiration (ETa/ETp).

By substitution of equation [4] in equation [5] the following equation is obtained:

$$(1\text{-}Ya/Ym) = 1.7 - 1.5\ (ETa/ETp) \qquad [6]$$

which can be approximated by:

$$(1\text{-}Ya/Ym) = 1.6\ (1\text{-}ETa/ETp) \qquad [7]$$

The coefficient, 1.6, in equation [7] is called yield-water response factor. Typically, the value of this coefficient has been reported as 1.1 to 1.3 for citrus crops, medium-sensitive plants to water deficit (2). It is shown that this coefficient for sweet lime is higher than that for citrus in general. Therefore, sweet lime may be classified as a highly sensitive plant to water deficit.

CONCLUSION

The fruit yield of sweet lime was shown to decrease under high frequency irrigation of greater than 0.75 E_{pan} corresponding to seasonal average CWSI value smaller than about 0.1. Furthermore, it was very sensitive to water deficit at lower water application and higher CWSI values. Water use efficiency was highest for water application of 0.75 E_{pan} and CWSI of about 0.1. The value of yield-water response factor was 1.6 which is greater than that of citrus crops in general (medium-sensitive plants to water deficit). Therefore, sweet lime may be classified as a highly sensitive plant to water deficit.

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