Agricultural Journal 2 (1): 31-37, 2007

Crop Water Stress Index and Water-Use Efficiency for Melon (*Cucumis melo L.*) on Different Irrigation Regimes

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Abstract: The main objective of this study was to optimize the irrigation requirements of a melon crop (*Cucumis melo* L.) cultivated in semi-arid climate conditions. The field experiment was conducted in four plots under different irrigation regimes. The effects of four water levels on melon crop were investigated during the growing season. The treatment designated as T1 (control treatment) received an irrigation rate of 75% of the cumulative class A pan evaporation applied through drip irrigation system. The treatments T2, T3 and T4 received 90, 80 and 70%, respectively, of the irrigation applied in treatment T1. The canopy temperature was monitored through an infrared thermometer and the soil moisture content with a neutron probe. Crop Water Stress Index (CWSI), Water-Use Efficiency (WUE) and melon yield were evaluated for all irrigation treatments. CWSI mean of 0.35 presented the maximum yield and can be used as a threshold value to start the irrigation in melon crop. The maximum total yield (30,380 kg ha^{-1}) occurred with a WUE of 55.37 kg $ha^{-1}mm^{-1}$ in treatment T2, while the minimum total yield (23,895 kg ha^{-1}) occurred with a WUE of 56.00 kg ha^{-1} mm^{-1} in treatment T4. The results indicated that a 30% reduction (treatments T4) in water total was sufficient to alter significantly the melon yield, though the WUE values was not significantly different ($p<0.05$). The linear regression between CWSI and melon yield was statistically significant ($p<0.05$) for all treatments and therefore can be used with reasonable accuracy for melon yield prediction, under the growing condition this experiment.

Key words: CWSI, melon yield, soil moisture content, canopy temperature

INTRODUCTION

Water resources in the semi-arid regions are limited for various activities including implantation and expansion of irrigated areas. The need for increasing agricultural production has motivated several investigations, principally with a view to optimize the available water resources. Low water-use efficiency and incorrect dimensioning of the irrigation system lead to the increase of the agricultural production costs. The crop production is strongly affected by the climatic conditions and soil available water.

The irrigation monitoring through different techniques has been used for determining the proper time and amount of water needed for crops[1-6]. Some earlier studies established the infrared thermometry as an appropriate tool for irrigation management of several agronomic crops[7-10]. For instance, irrigation scheduling for cotton using the difference between canopy (T_c) and air temperatures (T_a) was realized by Ehrler[11]. Indeed, some researches have studied the influence of clouds in the determination of the canopy temperature (T_c) of sorghum (*Sorgum bicolor*, L.) or evaluated the use of infrared thermometry in the irrigation management in wheat[12-14]. Furthermore, the relation between T_c and the physiological and phenological development of a corn crop was studied by (T_c-T_a) difference to schedule the irrigation requirements[15].

The crop water stress index (CWSI) also has been widely used to assess of crop water stress[16-20]. It was proposed a normalization of stress degree day (SDD) and created the CWSI[13], which is based on linear relation between (T_c-T_a) difference and the Vapor Pressure Deficit (VPD). This empirical approach has received much attention because it is simple and requires only canopy and air temperatures and relative humidity to be obtained[21]. Improving Crop Water-Use Efficiency (WUE) is essential because the lack of sufficient water resources

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is a serious problem in semi-arid regions. WUE relates the biomass production or the crop yield to amount of water applied or to crop evapotranspiration. Many studies have showed that CWSI is an important tool to improve water-use management in irrigated areas[22-24].

Northeast Brazil is a semi-arid region that presents favorable conditions for cultivating various crops, principally due to the abundant irradiance. This region has several restrictions on the availability of water resources becoming the irrigation an indispensable tool to assure the agricultural production. The melon crop is extensively cultivated in Brazil and Northeast region is the major producing area. A significant part of this production is exported to Europe and the USA, generating high profits and promoting the employment of manual labor in this region. Because it has great economical importance, melon crop has been many investigated in other regions of the world[25-27]. Thus, the main objective of this study was to evaluate the water use efficiency and the effect of different irrigations treatments on the melon yield grown under semi-arid climate conditions.

MATERIALS AND METHODS

Experimental site and climate: A field experiment was carried out on a commercial farm, located in Mossoró, RN, Brazil (latitude: 5°11'S; longitude: 37°o20'W; altitude: 18 m a.s.l.), during the period of October, 1998 to January, 1999. The region is characterized as semi-arid, weather is hot and dry and the rainy season is limited to the period of February to May. Mean annual rainfall and standard deviation are 672.5 mm and 312.7 mm, respectively, presenting a large spatial and temporal variability. The evaporation, wind speed and solar radiation present high annual rates. Air temperature is generally more than 26°C and in the months of November to January the mean daily air temperatures is around 29°C. Monthly mean of the some climatic variables during the experimental period are shows in Table 1. These variables were recorded at the meteorological station of the Escola Superior de Agricultura de Mossoró (ESAM) located 3 Km from the experimental site. The soil in the experimental area is classified as Equivalent Red Yellow Podzolic with clayed texture.

Crop management and experimental design: Melon seeds (*Cucumis melo* L.), cultivar Gold Mine, were planted on October 22, 1998 and the germination occurred three days after sowing (DAS). The flowering stage started on November 13, 1998 and the soil was completely covered by the crop on DAS 28. The fructification stage started on DAS 33 and the first harvest took place on December 21, 1999 (DAS 60). A total of 5 harvests were performed during experimental period on DAS 60, 63, 69, 76 and 83.

The experimental site was divided into four plots of equal area (8×100 m). Each plot contained 4 rows and each row had 100 m in length. The gap between the plants had 1 m, while the gap between the rows had 2 m. This experimental delineation resulted in a final plant density of 20 000 plants per hectare. Four different irrigation treatments, based on the cumulative class A pan evaporation (Epan) were employed by drip irrigation system. The irrigation treatment designated as T1 (control) received 0.75 Epan per irrigation. The irrigation treatments T2, T3 and T4 received water amounts of 90, 80 and 70% of T1, respectively. The total amounts of applied irrigation water in the treatments T1, T2, T3 and T4 were 609.6, 548.6, 487.7 and 426.7 mm, respectively. The fertilization was done daily and started on DAS 6 with NH_4NO_3, KNO_3, KCl, $CaNO_3$, K_2SO_4 and H_3PO_4, applied at a rate 100 kg ha^{-1}. The weed control was done manually on DAS 32 and 55.

Measurements: The canopy Temperature (T_c) was measured using an infrared thermometer (Model AG-42, Telatemp, Fullerton, CA, USA). This instrument has a resolution of 0.1°C, an accuracy of 0.5°C and a 5° angle of view, detecting electromagnetic radiation in the 8-14 μm wave bands. Maximum and minimum air temperatures, dry (T_a) and wet (T_w) bulb temperatures and net radiation (R_n) were recorded regularly during the crop growing season. The Vapor Pressure Deficit (VPD) was obtained from the wet and dry bulb temperatures and atmospheric pressure measurements obtained in a standard shelter located in the experimental site. In each irrigation treatment, T_a and R_n were recorded during the diurnal cycle at one-hour intervals. Mean values of (T_c-T_a) was obtained based on measurements recorded at 10:30 and 12:30 h. The net radiometer was located at 1.5 m above the ground in treatment T1.

Table 1: Mean values of air temperature (°C), relative humidity (%), sunshine duration (h), class A pan evaporation (mmd^{-1}) and total precipitation (mm) during the experiment period

Months	Air temperature	Relative humidity	Wind speed	Sunshine duration	Precipitation	Class A pan evaporation
October 1998	28.9	56.8	5.2	9.5	2.8	11.1
November 1998	29.5	56.3	5.0	9.5	-	13.3
December 1998	29.0	58.9	5.1	10.0	-	14.0
January 1999	28.0	65.6	3.9	9.0	65.0	7.0

Soil moisture content in the plots was monitored using a neutron probe (Troxler) with aluminum access tubes. The measurements were taken at 20, 40, 60, 80 and 100 cm. Volumetric soil moisture was measured at same depths by using the gravimetric method. The neutron probe observations were made three times a week in all the depths mentioned earlier. The Available Soil Moisture Content (ASMC) was obtained as the difference between the soil moisture content at the field capacity and the permanent wilting point.

Water stress index: The crop water deficit was monitored using the Crop Water Stress Index (CWSI). This index was computed using the method suggested by Idso *et al.*[13]:

$$\text{CWSI} = \frac{(T_c - T_a) - (T_c - T_a)_{LL}}{(T_c - T_a)_{UL} - (T_c - T_a)_{LL}} \tag{1}$$

where T_c (°C) is the canopy temperature, T_a (°C) the air temperature, $(T_c\text{-}T_a)_{LL}$ is lower limit of canopy-air temperature difference and $(T_c\text{-}T_a)_{UL}$ is upper limit of canopy-air temperature difference. The differences $(T_c\text{-}T_a)_{LL}$ was obtained from the linear regression for the crop under full irrigation (no water stress) and $(T_c\text{-}T_a)_{UL}$ when the crop is under maximum water stress condition. To calculate the CWSI it is necessary to obtain the lower baseline relating $(T_c\text{-}T_a)$ to VPD. The determination of the upper and lower baselines is crucial in the calculation of CWSI. The non-stressed baseline, $(T_c\text{-}T_a)$ versus VPD (lower limit) relationship was determined using data collected in treatment T1. On the other hand, the fully stressed baseline (upper limit) was computed according to the method provided by Idso *et al.*[13].

Water-use efficiency: Water-use efficiency (WUE) is defined as the crop yield per unit of water consumed as evapotranspiration (ET)[28]. Also, in some studies WUE is determined as the ratio of biomass yield to ET or as the sum of the harvest yield and the total dry biomass (shoot + roots) divided by the total amount of water used in irrigation. However, in this study WUE (kg $\text{ha}^{-1}\,\text{mm}^{-1}$) was adopted as defined in agronomy, which is the ratio between the crop yield (kg ha^{-1}) and the accumulated water applied (mm).

Statistical analysis: The experimental layout was a fully randomized block design, with four irrigation treatments and three replications. Analysis of Variance (ANOVA) was conducted to test the difference in melon yield among the four irrigation treatments using Tukey's test at $p<0.05$. Also the coefficients of determination (r^2) were evaluated statistically at 5% probability level with a t-test. The analyses were conducted using the ASSISTAT software[29].

RESULTS AND DISCUSSION

Water availability on plots: There was soil water depletion in treatments T1 and T2 starting on DAS 54. Soil water availability values declined from 12 cm on DAS 40 in treatment T3 and from 10 cm on DAS 31 in treatment T4 Fig. 1. These decreases were a consequence of the reduced irrigation water depths and also due to the increase in crop transpiration rate. The lowest irrigation level produced the largest soil water depletion which may be avoided by using higher irrigation levels. This is in agreement with results reported by Orta *et al.*[19].

The climatic conditions throughout the experimental period had a high evaporative demand. Mean net radiation and standard deviation was 541.14±173.77 Wm^{-2} and the mean sunshine duration was 9.5 h. On the other hand, mean monthly class A pan evaporation also was fairly high, which reached values of 14 mm per day in December 1998. Relative humidity ranged from 56.3 to 65.6% and mean monthly air temperature reached values higher than 29°C. The total rainfall during the experimental period was 67.8 mm and high rain events occurred at the end of the growing season, which is also the beginning of rainy period at the studied region Table 1.

Cumulative irrigation water in melon crop is presented in Fig. 2. The total water applied in the treatments T1, T2, T3 and T4 were 609.6, 548.6, 487.7 and 426.7 mm, respectively. All irrigation treatments started on same day after sowing (DAS) (October, 22) and ended on DAS 68 (December, 29).

Crop water stress index: The maximum difference between canopy and air temperature $(T_c\text{-}T_a)$ difference were obtained in treatment T4. Fig. 3 shows the lower

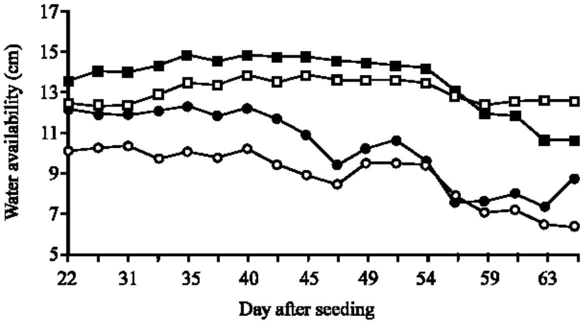

Fig. 1: Soil water availability for the treatments T1 (□), T2(■), T3 (●) end T4 (○) in melon crop

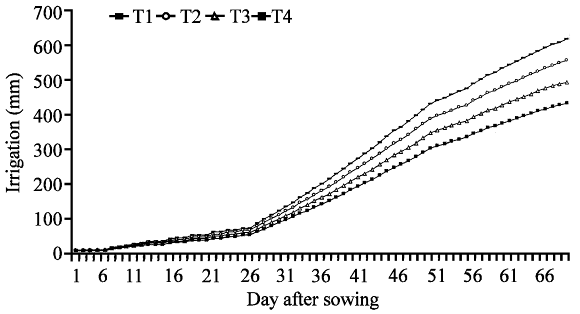

Fig. 2: Cumulative irrigation water applied in the irrigation treatments T1, T2, T3 and T4 in melon crop

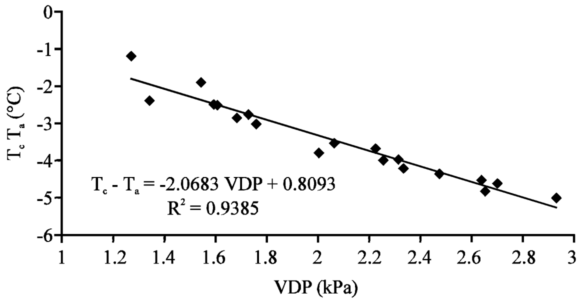

Fig. 3: Relationship between canopy-air temperature difference and vapor pressure deficit in a melon crop

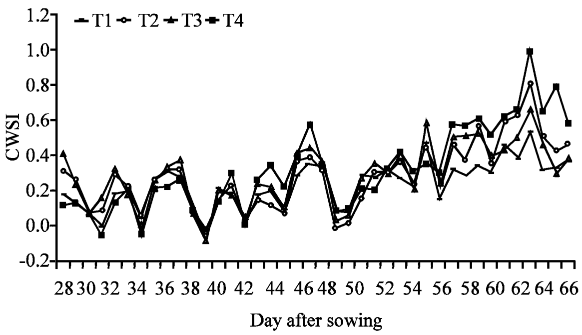

Fig. 4: Variation of CWSI as a function day after sowing for each irrigation treatment (T1, T2, T3 e T4) during experimental period

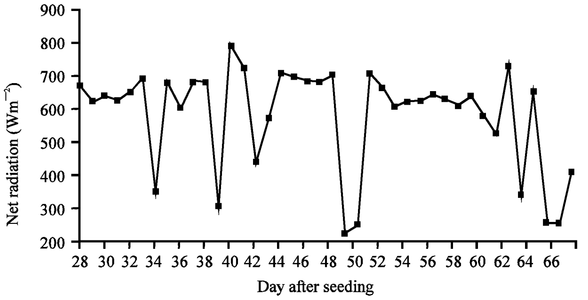

Fig. 5: Seasonal variation of net radiation during experimental period of a melon crop growing in a semi-arid environment

baseline, which resulted in a coefficient of determination of 0.93 and its slope indicated a decrease in (T_c-T_a) difference of 2.07°C for each kPa increase in VPD. According to Orta *et al.*[19] factors such as errors determining humidity relative, infrared thermometry calibration and climatic factors can affect baseline relationship. For alfalfa, Abdul-Jabbar *et al.*[30] obtained 4.0°C for the upper baseline, while Nielson[31] obtained a value of 3.5°C for a watermelon crop submitted to five different irrigation treatments.

Figure 4 shows an increasing trend in CWSI after the first half of the observational period. There is an abruptly increasing during the senescence stage in all treatments due to suppression of irrigation. This could not be attributed only to soil water status but also to variability in net radiation Fig. 5. Results also indicated that CWSI values oscillated around the value of 0.2, between DAS 28 and DAS 50.

Large differences were registered between the treatments T1 and T4, mainly after the suppression of the irrigations. The increase in CWSI values in this period are also associated to the increasing in soil evaporation and decreasing leaf area. Therefore, CWSI values presented higher values in all treatments during the senescence crop. Total melon yield and mean Water-Use Efficiency (WUE), as well as mean Crop Water Stress Index (CWSI) and total irrigation for different treatments in melon crop are given in Table 2. The mean CWSI in treatments T1, T2, T3 and T4 were 0.28, 0.35, 0.36 and 0.39, respectively.

The maximum and minimum yields were obtained on treatments T2 (30, 380 kg ha^{-1}) and T4 (23,895 kg ha^{-1}), respectively, whose difference is statistically significant at $p<0.05$ by Turkey's test. Melon yields on treatments T1 and T3 were 28,800 and 24,070 kg ha^{-1}, respectively. These values are not statistically significant ($p<0.05$) according to Turkey's test. Thus, except for treatment T1, the melon yield presented decreasing behavior with an increasing of irrigation amount. These results indicated that an increase of 10% in irrigation water content did not result in significant increase on melon yield. Similar result was obtained by Simsek *et al.*21 in a study with cucumber. The irrigation cost of the melon crop could be lowered using down to 10% of water normally applied in the region. Despite higher WUE the treatment T4 presented the smallest total yield (23,895 kg ha^{-1}).

Table 2: Total melon yield*, mean Water Use Efficiency (WUE), mean Crop Water Stress Index (CWSI) and total irrigation for different treatments in melon cro

Treatment	Yield (kg ha^{-1})	WUE (kg ha^{-1}mm^{-1})	Mean CWSI (SD)**	Irrigation (mm)
T1	28.800a	47.24	0.28±0.14	609.60
T2	30.380a	55.37	0.35±0.20	548.64
T3	24.070ab	49.36	0.36±0.18	487.68
T4	23.895b	56.00	0.39±0.25	426.72

* Values followed by the same letter within a column are not significantly different ($p<0.05$) according to Turkey's test, ** Standard deviation

Table 3: Mean of melon yield* (kg ha^{-1}), Water Use Efficiency (WUE) (kg ha^{-1}mm^{-1}) and crop water stress index (CWSI) to five harvest of melon crop under different irrigation treatments

		Harvest				
Treatments	Parameter	01(DAS 60)	02(DAS 63)	03(DAS 69)	04(DAS 76	05(DAS 83)
T1	Yield	10.670c	4.810b	3.770a	5.110a	4.440a
	WUE	19.84	8.48	6.18	8.38	7.28
	CWSI	0.19	0.37	0.39	0.41	0.46
T2	Yield	16.010a	6.480a	2.390c	3.450b	2.050c
	WUE	33.08	12.69	4.36	6.29	3.74
	CWSI	0.23	0.52	0.51	0.51	0.58
T3	Yield	12.360b	3.310d	3.530a	2.520c	2.350b
	WUE	28.73	7.29	7.24	5.17	4.82
	CWSI	0.25	0.43	0.44	0.48	0.55
T4	Yield	16.280a	3.955c	2.090d	680d	890d
	WUE	43.24	9.96	4.90	1.59	2.09
	CWSI	0.23	0.58	0.66	0.57	0.69

* Values followed by the same letter within a column are not significantly different ($p<0.05$) according to Turkey's test

The means values of yield. water-use efficiency and crop water stress index of melon crop in each harvest in all irrigation treatments are presented in Table 3. For each treatment. CWSI values ranged from minimum value (1st harvest) to maximum value (5th harvest), which were 0.190 and 0.465 in treatment T1, 0.216 and 0.583 in treatment T2, 0.246 and 0.547 in treatment T3 and 0.231 and 0.689 in treatment T4 Table 3. Jackson[18] observed that after irrigation, the CWSI values decreased and that in senescence stage could neither recover nor diminish the index value. Mean CWSI values for each treatment were obtained as the average of CWSI values for five harvests, while total yield and WUE were calculated as the sum of yield and WUE values for all harvest, respectively.

Mean values of melon yield to each harvest showed that highest yield (10,670 kg ha^{-1}) was obtained in treatment T2 and 1st harvest while that smallest yield (680 kg ha^{-1}) was obtained in treatment T4 and 4th harvest. For all levels of applied water the maximum yield was obtained in the 1st harvest. The treatments T1, T2, T3 and T4 had ratios of 37.06, 52.60, 51.35 and 68.81%, respectively, of mean yield of the 1st harvest.

The difference in mean yield was statistically significant at $p<0.05$ level among 1st harvest and others harvest in all treatments. However, differences between yields for all harvests and irrigation treatments were statistical significant at $p<0.05$ level, except in 1st harvest where the melon yield in treatments T2 and T4 did not change. The reason to obtain maximum yields in 1st harvest is to avoid injury in the fruits produced due heavy rain in the ending of growing season.

Relationship between melon yield and CWSI: A linear regression analysis was determined between melon yield and CWSI for all treatments Eq. 2-5. All coefficients of determination (r^2) are statistically significant at $p<0.05$ probability level according to t-test. From this study were obtained the following mathematical functions:

Treatment T1:

$$\text{Melon yield} = -24{,}392\ \text{CWSI} + 14{,}611\ (r^2 = 0.82) \quad (2)$$

Treatment T2:

$$\text{Melon yield} = -38{,}881\ \text{CWSI} + 24{,}293\ (r^2 = 0.92) \quad (3)$$

Treatment T3:

$$\text{Melon yield} = -35{,}760\ \text{CWSI} + 20{,}229\ (r^2 = 0.91) \quad (4)$$

Treatment T4:

$$\text{Melon yield} = -34{,}283\ \text{CWSI} + 23{,}535\ (r^2 = 0.92) \quad (5)$$

The above equations show that melon yield decrease with increasing in CWSI and the slope was largest on treatment T2. The coefficients of determination (r^2) between melon yield and CWSI were quite high for all treatments. Therefore, these equations can be used with reasonable accuracy for melon yield prediction. Results similar were reported by Orta *et al.*[19] in study conducted to determine CWSI to schedule irrigation in watermelon crop.

CONCLUSION

This study indicates that the highest irrigation level produces a decrease in WUE and did not result in the highest melon yield. Therefore, irrigation level provided on the basis of 0.75 Epan is not recommended for melon grown under field condition in Northeast of Brazil due an increase of production costs. The decrease of the irrigation amount affects significantly both melon yield and WUE only when the irrigation amount is less than that applied in treatment T2. The more effective irrigation water-use in melon crop was obtained with treatment T2, which presented a WUE of 55.37 kg ha^{-1} mm^{-1}. When the water level was decreasing the CWSI values increased because of the depletion of available soil water. Mean CWSI of 0.35 presented the maximum melon yield. This value suggests that it can be used as an appropriate threshold value to start irrigation for melon crop. The relationship between CWSI and yield showed high coefficients of determination and can be used for melon yield prediction, under the growing condition of this experiment. CWSI values had an increasing trend with a decreasing of irrigation level. Melon yield also showed the same behavior, except to maximum yield in the irrigation treatment T2. The maximum and minimum melon yield occurred when the irrigation was provided based on 90 and 70%, respectively, of the irrigation treatment normally applied in the region. The climatic variables affected both CWSI and WUE.

ACKNOWLEDGEMENTS

This research was supported in part by the Federal University of Campina Grande and The Agricultural Farm of São João. We also wish to thank the CNPq for the fellowship to the first and third authors.

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