J. Plant Production, Mansoura Univ., Vol. 8 (1): 83- 92, 2017

Effects of Pre-Harvest Deficit and Excess Irrigation Water on Vine Water Relations, Productivity and Quality of Crimson Seedless Table Grapes

El-Ansary, D. O.
Department of Pomology, Faculty of Agriculture (El-Shatby), University of Alexandria, 21545, Egypt
Corresponding author e-mail: diaa.elansary@alexu.edu.eg / diaaagri@hotmail.com / Tel.: +02-01000150804

ABSTRACT

This research investigated the effects of pre-harvest deficit and excess irrigation water on vine water relations, productivity and quality of Crimson Seedless table grapes. In 2011 and 2012 seasons, five irrigation regimes were imposed for seven weeks from veraison to harvest based on actual crop evapotranspiration (ETc): 80 % ETc (moderate deficit irrigation), 90 % ETc (slight deficit irrigation), 100 % ETc (standard control irrigation), 110 % ETc (slight excess irrigation) and 120 % ETc (moderate excess irrigation). Results showed that soil volumetric water content and midday leaf water potential responded to the irrigation treatments and there were very significant relationships among them. Vine yield was not influenced by irrigation treatments in 2011, but 80 % ETc irrigated vines had significantly lower yield (20.9 kg /vine) than control (23.6 kg/vine) in 2012. Pre-harvest water use efficiency (WUE) significantly decreased with increased irrigation level, while no variations were found in the seasonal WUE. 80 % ETc irrigated vines had the lowest significant berry diameter values as compared with control and other treatments in both seasons. Berry weight of 80 % ETc irrigated vines was only significantly lower than berries of 120 ETc treatment in 2011, but was lower than berries of 100 ETc, 110 ETC, and 120 ETc vines in 2012. Berry firmness was negatively affected by decreasing irrigation level as it was significantly lower in 80% ETc irrigated vines as compared with control and other treatments. Juice total soluble solids percent was significantly highest in deficit irrigation treatments as compared with control and excess irrigation treatments in both seasons, except for 90 % ETc treatment where it was not significantly different from control in 2012. Titratable acidity percent in juice decreased with decreasing irrigating level and was significantly lowest in 80 % ETc irrigated vines as compared with control and other treatments. TSS to Acid ratio in juice was significantly highest in 80 % ETc irrigation treatment, followed by 90% ETc and control treatments, and was lowest in excess irrigation treatments. Berry skin color characteristics data of lightness (L*), chroma (C*), and hue angle (h°) decreased with increasing irrigation level and were significantly lowest in deficit irrigation treatments as compared with excess irrigation treatments and control in both seasons, except for lightness values in 2011. Berry skin color index for red grapes (CIRG) increased significantly in deficit irrigation treatments, followed by control, and was lowest in excess irrigation treatments. It is concluded that 90 % ETc irrigation treatment maintained vine yield and had positive effects on berry commercial quality characteristics.

Keywords: grape, veraison, seasonal, soil volumetric water content, leaf water potential, water use efficiency, TSS to Acid ratio, skin color, color index for red grapes (CIRG).

INTRODUCTION

Table grape vineyards are expanding considerably in new reclaimed regions of Egypt with ultimate goal of export to European Union markets. Crimson Seedless (*Vitis vinifera* L.) is a late-maturing cultivar introduced in California in 1989, characterized by firm medium-sized berries having pleasant flavor and reddish-purple skin with light yellow flesh (Ramming *et al*., 1995). Inadequate and uneven red color development of berries are the main commercial quality problems of this cultivar in hot regions (Dokoozlian and Peacock, 2001) including Egypt. High temperature during berry ripening inhibits anthocyanin development resulting in a poor coloration for Crimson Seedless grapes (Cantin *et al*., 2007). Maintenance of soil water balance throughout the growing season by precise monitoring of vineyard climate determines grape crop quality (Tonietto and Carbonneau, 2004). Grape berry growth is characterized by a double sigmoid curve, and the beginning of second sigmoid phase is called veraison (Sadras and McCarthy, 2007), a stage that signals the beginning of ripening and is very responsive to irrigation regimes (El-Ansary *et al.,* 2005). On the one hand, there is a trade-off between crop yield and quality parameters for table grapes grown under deficit irrigation conditions (El-Ansary and Okamoto, 2008; Williams *et al.,* 2010; Conesa *et al*., 2014 and Pinillos *et al*., 2016). On the other hand, there are limited information on the responses of table grape crop yield and quality to excess irrigation water or water-logging conditions. Okamoto *et al*. (2004 a) worked on wild grape species (*Vitis coignetiae* Pulliat) and Kyoho (*V. vinifera* X *V. labrusca*) table grapes in Japan, and reported that treatments with water-logging and irrigation withholding conditions continuously for two weeks declined the rate of leaf photosynthesis and transpiration to almost zero. From field visits to several Crimson Seedless table grape vineyards along Alexandria-Cairo desert road, it is observed that most growers over irrigate their vineyards to ensure adequate water supply to their vines during ripening stage, meanwhile they are experiencing poor berry red color development and sugar accumulation. Therefore, this research work aimed at studying the effects of varying levels of water deficit or excess during berry ripening stage on soil and vine water relations, yield and commercial quality parameters of Crimson Seedless table grapes.

MATERIALS AND METHODS

- **Plant material, growing conditions and irrigation treatments:**

This experiment was conducted in 2011 and 2012 seasons in a commercial vineyard located in Bustan Extension area on 107 km at Alexandria – Cairo desert road. Seven-year-old own-rooted Crimson Seedless grapevines (*Vitis vinifera* L.) experimental plot was used in this experiment. Vines rows were oriented north south at spacing of 2 m between vines in each row and 3.5 m between rows with a planting density of 600 vines per faddan. Vineyard soil profile was homogeneous to depth of 120 cm, and soil texture was loamy sand (73.5, 16.3, and 10.2 %, sand, silt, and clay, respectively). At beginning of experiment, soil electrical conductivity (EC) was 0.82 dS/m and pH of 8.14. Irrigation was supplied from a water well with irrigation water EC of 0.68 and pH of 8.05. Soil field capacity (FC), permanent wilting point (PWP) and readily available water (RAW) values were 18.5 %, 8.1 % and 5.2 %, respectively. Soil physical analysis as well as analysis of salts and pH in soil and water were conducted at the Faculty of Agriculture of Alexandria University according to the methods described by Black *et al.* (1965) and Richards (1954). Grapevines were trained to a two-meter-high Spanish Parron horizontal trellising system and cane pruned to a level of 10 canes per vine with 12 nodes per each cane. Crop management was conducted according the commercial practices adapted in the area including: Pest management, Dormex spray at end of January to enhance bud break, fruit thinning by Gibberellic acid at beginning of flowering, and Ethephon spray at veraison to promote color development. Number of bunches per vine was adjusted in all experimental vines when berries reached 8 mm in diameter to approximately 42 bunch per vine. Starting at bud break, a weekly fertigation of a complete liquid fertilizer containing 60 ppm N was implemented, and its level was reduced to one third at beginning of veraison (El-Ansary and Okamoto, 2007). Each vine was irrigated by two drip irrigation lines having 0.5 m spaced drippers (4 liters per hour water discharge per dripper). Irrigation water amount and scheduling was implemented in 2011 and 2012 from data of actual crop evapotranspiration (ETc) calculated from equation of ETc = ETo x Kc (Allen *et al.*,1998), where ETo is reference crop evapotranspiration (Figure 1-A) and Kc is the FAO table grape crop factor (Figure 1-B). Weather ETo data were collected in 2011 and 2012 on a daily basis from the nearest weather station (WatchDog, Model 2900 ET, USA) located 12.5 km from the experimental area in Entlak region at Al-Esraa Wa Al-Miraag Extension Station, West Nubaria Rural Development Project, Ministry of Agriculture and Land Reclamation. Five irrigation regimes (Figure 2-A & 2-B for 2011 & 2012 seasons, respectively) were imposed on vines starting at grape berry veraison stage (13 June 2011 & 7 June 2012) and continued until crop harvesting (27 July 2011 & 20 July 2012). Irrigation treatments included: 80 % ETc (moderate deficit irrigation), 90 % ETc (slight deficit irrigation), 100 % ETc (standard control irrigation), 110 % ETc (slight excess irrigation) and 120 % ETc (moderate excess irrigation).

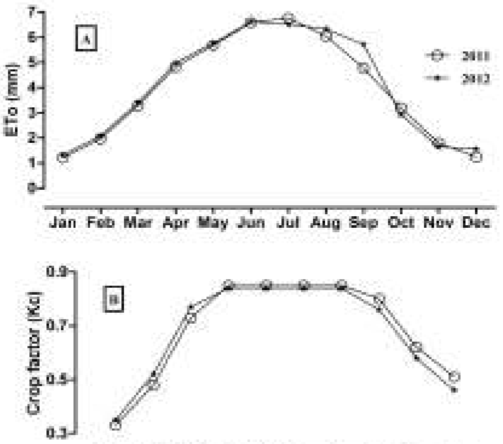

Figure 1. Monthly reference evapotranspiration (ETo) [A] and FAO table grapes crop factor (Kc) [B] data in 2011 and 2012 seasons.

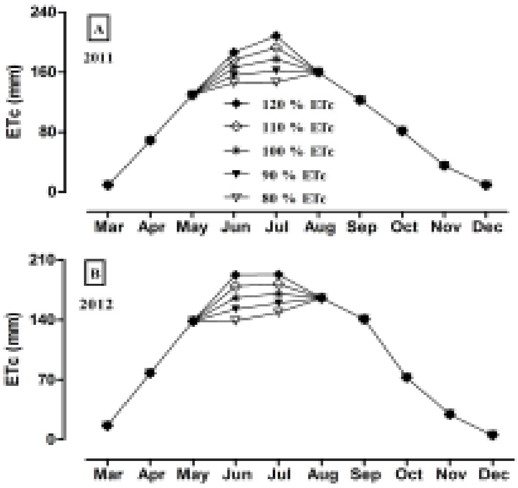

Figure 2. Crop evapotranspiration (ETc) data for irrigation treatments imposed on Crimson Seedless grapevines in 2011 (A) and 2012 (B) seasons.

- **Soil and vine water relations, sampling and analysis:**

Irrigation treatments were monitored and fine-tuned by weakly field measurements of soil and vine water status from veraison to harvest (7 measurements; day 1, 8, 15, 22, 29, 36 and 42). Soil water status was monitored by installing soil volumetric water content (SVWC) sensors (Decagon, 5TM, USA) connected to a data logger (Decagon, Em50, USA) at 40 cm soil depth of the active root-zone (one sensor to each treatment in one experimental block). Vine water status was monitored by measuring midday leaf water potential (Ψ_l) at 12 p.m. in 6 random leaves per treatment from the middle part of shoot by using plant moisture tensiometer (DIK-7003, Daiki Rika Kogyo Co., Ltd., Japan). All treated vines were harvested on 27 July 2011 and on 20 July 2012, and total yield (kg) for each experimental vine was recorded. Water use efficiency (WUE) expressed as the ratio of yield (kg) to applied irrigation (m^3) per vine was calculated by two methods based on pre-harvest applied irrigation (during treatments from veraison to harvest) and based on seasonal applied irrigation (total applied irrigation during the whole season). Ten representative bunches per vine replicate were selected for quality evaluation and all samples analysis procedures were conducted at the Department of Pomology, Faculty of Agriculture, Alexandria University. To measure berry quality parameters at harvest, the average of forty representative berries per replicate was recorded as one replicate per treatment. Berry diameter (mm) was measured by a digital caliper and berry weight (g) was recorded by a weighing balance. Berry firmness (Newton = N) was recorded by a penetrometer (Effegi, Italy) having a 3 mm tip size diameter. Berry juice total soluble solids (TSS) percent was measured by an automated temperature compensating refractometer (Atago ATC-1, Japan), and juice titratable acidity (TA) percent as tartaric acid equivalent was measured by diluting the juice with distilled water and titrating it with 0.1 N sodium hydroxide to the end point of phenolphthalein indicator. TSS to Acid ratio was also calculated. Four color characteristics for berry skin at harvest were evaluated by measuring the skin color with Minolta Color meter (CR-200, Japan) by using the CIELAB color system

(Commission Internationale de l'Eclairage translated as the International Commission on Illumination). Lightness (L*) represents black to white from 0 to 100, chroma (C*) represents the vividness or dullness of color, hue angle (h°) to distinguish the red, yellow, green and blue colors, and color index for red grapes (CIRG) ranging from yellow to dark violet with increasing values and is calculated by (180- h°) / (L* + C*).

- **Experimental design and statistical analysis:**

A randomized complete-block design (RCBD) was used in this experiment with total of 6 blocks. Five vines were assigned to each individual block as experimental units (one vine replicate per each irrigation treatment). Data analysis was performed by a one-factor (irrigation treatment) Analysis of Variance (ANOVA). Mean comparisons were conducted by following the procedures of the general linear model (GLM) of IBM SPSS Statistics Version 21 Software package by using the Posthoc Tukey test to examine differences among irrigation treatments, and significance was determined at p-value < 0.05. To model the relationships between irrigation treatments and obtained results as well as between different collected parameters, a further quadratic regression analysis was conducted by the same statistical software. Regression equation, effect size (r^2) and statistical significance at p-value 0.05, 0.01 or 0.001 were illustrated on each regression graph (Steel and Torrie, 1980).

RESULTS AND DISCUSSION

1) Soil and vine water relations:

From Figure 3-A & 3-B, it can be seen that soil volumetric water content (SVWC) responded to irrigation treatments during the experimental period from veraison to harvest. SVWC (%) for 100 % ETc (standard control irrigation) ranged from 13.9 to 15.6 and 13.8 to 15.8 in 2011 and 2012, respectively, during the 7 weeks of study. As for deficit irrigation treatments, SVWC (%) for 80 % ETc (moderate deficit) ranged from 11.7 to 13.4 and 12.2 to 14.7, and for 90 % ETc (slight deficit) ranged from 12.8 to 14.6 and 13.3 to 15.2, in 2011 and 2012, respectively. Whereas SVWC (%) for excess irrigation treatments ranged from 14.7 to 16.5 and 13.9 to 16.5 in 110 % ETc (slight excess) and from 15.9 to 17.2 and 15.7 to 17.0 for 120 % ETc (moderate excess), in 2011 and 2012, respectively. Results of regression relationship between applied irrigation (m^3/vine) and measured SVWC (%) illustrated in Figure 4-A & 4-B indicated that there was a very significant (p-value = 0.001) effect for irrigation treatments on SVWC as indicated from the high effect size values (r^2 = 0.86 & 0.64 in 2011 & 2012, respectively). Soil volumetric water contents measured by time domain reflectometry (TDR) as well as by neutron probe were directly related to imposed irrigation regimes (Edwards and Clingeleffer, 2013). Moreover, similar results for reduced and fluctuated SVWC under deficit irrigation were reported by Stevens *et al.* (2016), who found that SVWC reached 16.6, 17.4, 18.7 & 17.5 % in 2001, 2002, 2003 & 2014, respectively, when imposing 30 % irrigation cut-off. Mean midday leaf water potential (Ψ_l) data presented in Table 1 showed that Ψ_l (MPa) after one day of treatments, was -1.08 and -0.98 for 100% ETc treated vines in 2011 and 2012, respectively. Significant differences in Ψ_l among 100 % ETc vines and other deficient or excess irrigated vines became clearer with the progress of experimental period. As in the 2nd week, Ψ_l was highest in excess irrigated vines (-0.86 & -0.82 MPa for 110 ETc vines, and -0.82 & -0.74 MPa for 120 % ETc vines, in 2011 & 2012, respectively), followed by standard control irrigated vines (-1.22 & -1.03 MPa for 100 % ETc vines in 2011 & 2012, respectively), but was lowest in deficient irrigated vines (-1.41 & -1.22 MPa for 80 % ETc, and -1.20 & -1.30 MPa for 90 % ETc, in 2011 & 2012, respectively). In general, values of Ψ_l tended to decline with the progress of time in all irrigation treatments and reached the lowest values between day 36 and day 42 of experiment. In most measurements of Ψ_l during the 7 weeks for both seasons, there were no significant differences between excess irrigation treated vines (110 & 120 ETc), standard control irrigated vines differed significantly from all other treated vines, and there were significant differences between deficient irrigated vines (80 & 90 % ETc) as well as among them and most other treated vines. As shown in Figure 4-C & 4-D, there were very significant (p-value = 0.001) effect for applied irrigation (m^3/vine) treatments from veraison to harvest on vine Ψ_l in both seasons (r^2 = 0.76 & 0.77 in 2011 & 2012, respectively). Moreover, regression analysis results presented in Figure 4-E & 4-F revealed that, there was also a very significant ($p = 0.001$) positive relationship between SVWC and vine Ψ_l (r^2 = 0.76 & 0.53 in 2011 & 2012, respectively). Deficient irrigated grapevines had lower Ψ_l as compared with full irrigated vines (Johnson and Handley, 2000). Roots interact with drying soil by increasing abscisic acid and / or decreasing cyctokinin transport to leaves which consequently reduce leaf transpiration rate (Tardieu *et al.*, 1992 and Loveys *et al.*, 2000). This decline in Ψ_l under deficit irrigation conditions is increased with the progress of season in spite of any changes in soil moisture content due to increased leaf transpiration rate over the capacity of roots to supply water to shoots (Matthews *et al.*, 1987 and El-Ansary *et al.*, 2005). Furthermore, 17 % fall in SVWC and increased atmospheric vapor pressure deficit (VPD) led to increased vine water stress that can be confirmed by the reduced Ψ_l below -1.1 MPa above VPD of 3.2 kPa (Stevens *et al*, 2010).

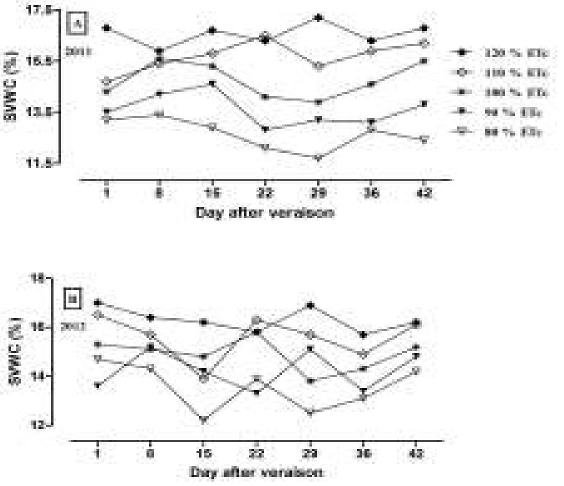

Figure 3. Soil volumetric water content (SVWC) as influenced by irrigation treatments applied from veraison to harvest on Crimson Seedless grapevines in 2011 (A) and 2012 (B) seasons.

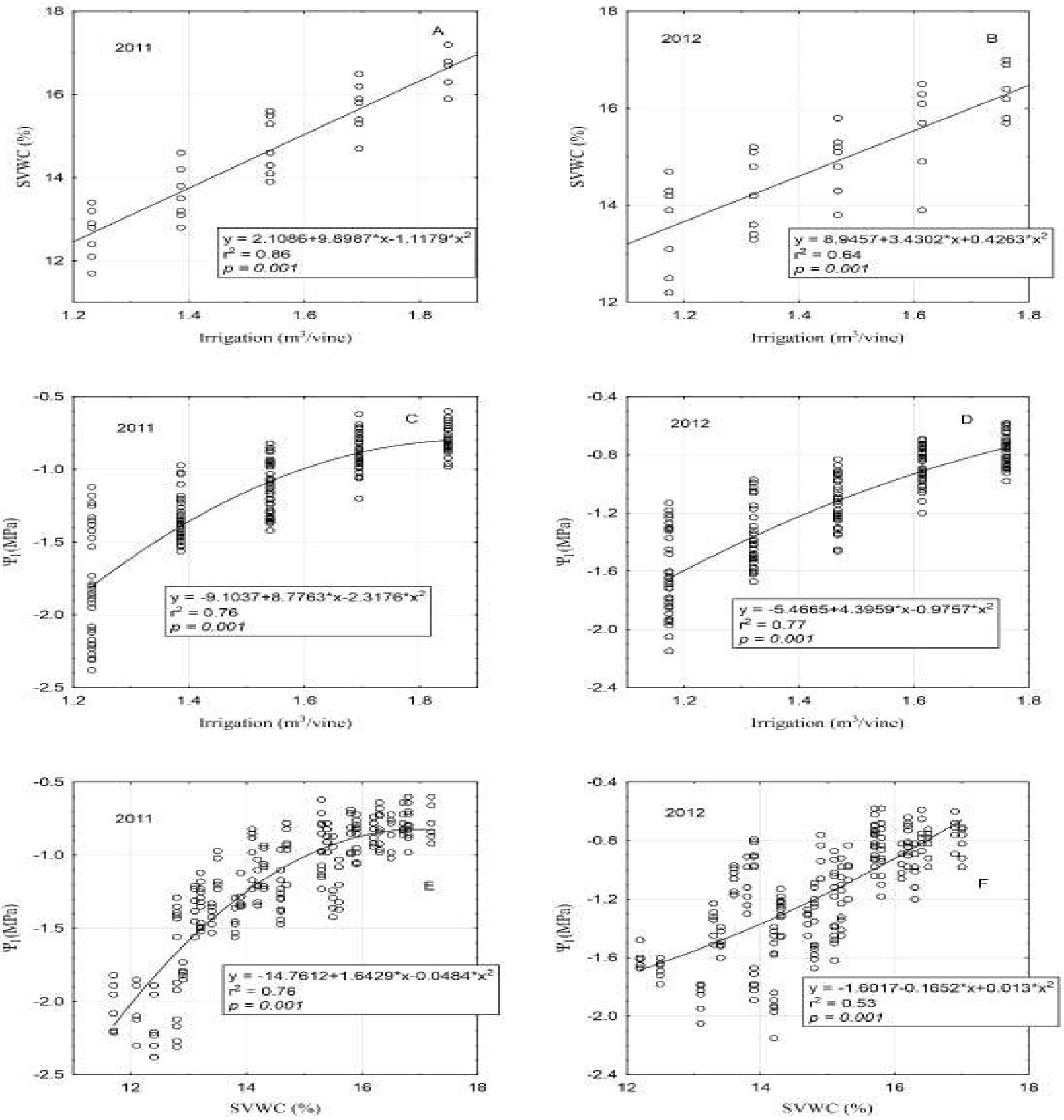

Figure 4. Regression analysis for vine water relations between applied irrigation water from veraison to harvest, soil volumetric water content (SVWC), and midday leaf water potential (Ψ_l) for Crimson Seedless grapes in 2011 and 2012 seasons.

Table 1. Vine midday leaf water potential Ψ_l (MPa) as influenced by deficit and excess irrigation water treatments from veraison to harvest for Crimson Seedless grapes in 2011 and 2012 seasons.

Treatment	Day after veraison						
	1	8	15	22	29	36	42
				2011			
80 % ETc	-1.23 ± 0.08 c[1]	-1.41 ± 0.08 c	-1.80 ± 0.04 d	-2.06 ± 0.17 c	-2.03 ± 0.16 c	-2.11 ± 0.18 d	-2.16 ± 0.20 c
90 % ETc	-1.10 ± 0.11 bc	-1.20 ± 0.12 b	-1.37 ± 0.08 c	-1.41 ± 0.09 b	-1.43 ± 0.10 b	-1.36 ± 0.13 c	-1.44 ± 0.10 b
100 % ETc	-1.08 ± 0.13 bc	-1.22 ± 0.14 b	-1.11 ± 0.09 b	-0.99 ± 0.17 a	-1.26 ± 0.11 b	-1.18 ± 0.13 bc	-1.19 ± 0.23 b
110 % ETc	-0.94 ± 0.15 ab	-0.86 ± 0.07 a	-0.84 ± 0.13 a	-0.85 ± 0.12 a	-0.79 ± 0.12 a	-0.94 ± 0.11 ab	-0.85 ± 0.08 a
120 % ETc	-0.86 ± 0.07 a	-0.82 ± 0.09 a	-0.78 ± 0.08 a	-0.83 ± 0.12 a	-0.78 ± 0.12 a	-0.81 ± 0.13 a	-0.73 ± 0.13 a
				2012			
80 % ETc	-1.35 ± 0.07 c	-1.22 ± 0.07 c	-1.60 ± 0.07 c	-1.78 ± 0.08 d	-1.68 ± 0.06 d	-1.87 ± 0.11 c	-1.95 ± 0.11 d
90 % ETc	-1.06 ± 0.08 b	-1.30 ± 0.14 c	-1.49 ± 0.08 c	-1.36 ± 0.10 c	-1.47 ± 0.09 c	-1.49 ± 0.08 b	-1.57 ± 0.06 c
100 % ETc	-0.98 ± 0.14 ab	-1.03 ± 0.12 b	-1.21 ± 0.09 b	-1.04 ± 0.10 b	-1.12 ± 0.15 b	-1.32 ± 0.11 b	-1.12 ± 0.16 b
110 % ETc	-0.83 ± 0.10 a	-0.82 ± 0.11 a	-0.89 ± 0.08 a	-1.00 ± 0.14 b	-0.84 ± 0.13 a	-0.86 ± 0.12 a	-0.95 ± 0.09 ab
120 % ETc	-0.82 ± 0.11 a	-0.74 ± 0.11 a	-0.80 ± 0.09 a	-0.74 ± 0.10 a	-0.72 ± 0.10 a	-0.72 ± 0.11 a	-0.80 ± 0.11 a

[1] **Mean ± standard deviation; means in columns followed by same letter are not significantly different by separation with Posthoc Tukey test at $p<0.05$.**

2) Yield and water use efficiency (yield/irrigation):

Data presented in Table 2 showed that vine yield (kg/vine) was not affected by the irrigation treatments in the first season, but in the second season only yield of 80 % ETc irrigated vines (20.90 kg /vine) was significantly lower than that of 100 % ETc irrigated control vines (23.63 kg/vine). Similarly, for the regression analysis between applied irrigation (m^3/vine) and vine yield (kg) illustrated in Figure 5-A & 5-B, there were no significant relationship in the first season ($p=0.20$, $r^2=0.11$), while it was significant in the second season ($p=0.01$, $r^2=0.32$). Prolonged deficit irrigation reduces vine crop yield due to effects on bunch number and / or bunch weight (Edwards and Clingeleffer, 2013). Stevens *et al.* (2010) reported that applying 30 % irrigation cut-off led to 17 % fall in SVWC and 31 % reduction in vine yield. In 2012 season, as applied irrigation water increased (Figure 5-B) up to 1.47 m^3/vine there was a positive corresponding increase in yield, however, with more increase in applied irrigation, yield line pattern was first flattened then declined. This indicates that Crimson Seedless grapes can be deficit irrigated, increasing water use efficiency and maximizing yield. Imposing severe deficit irrigation or excess irrigation reduces vine photosynthetic rate (Okamoto *et al.*, 2004 a) which negatively affects vine yield (Williams *et al.*, 2010). Pre-harvest water use efficiency (WUE) data calculated based on applied irrigation from veraison to harvest (Table 2) indicated that 80% ETc vines had the highest significant pre-harvest WUE value (17.72 & 17.80 in 2011 & 2012, respectively) as compared with control and other treatments except for 90% ETc vines in 2012. Pre-harvest WUE values decreased with increasing irrigation level as 110 & 120 ETc irrigated vines had the lowest significant pre-harvest WUE values in both seasons (13.47 & 14.19 for 110 ETc vines and 12.50 & 12.93 for 120 ETc vines, in 2011 & 2012, respectively). However, data of seasonal WUE calculated based on whole season applied irrigation water (Table 2) revealed that no significant differences were found among all irrigation treatments and control in both seasons. WUE is the balance between gained biomass (kg produced or mol of CO_2 assimilated) and water used (m^3 of irrigation water or mol of transpired water), and can be estimated at different levels of crop, plant or leaf (Morison *et al.*, 2008). On the one hand, results of increased pre-harvest WUE in deficient irrigated vines as compared with excess irrigated vines can be explained from previous research reporting that soil dryness modifies inorganic nutrient uptake by roots causing increases in xylem sap pH which reduces shoot growth and leaf stomatal apertures as a result of ABA concentration at the guard cell apoplast (Sauter *et al.*, 2001; Davies *et al.*, 2002 and Pellegrino *et al.*, 2005). Abscisic acid signal slightly reduces leaf photosynthetic rate but severely reduces transpiration rate leading to increased vine water use efficiency (Düring *et al.*, 1996 and El-Ansary and Okamoto, 2008). Increasing applied irrigation while maintaining yield resulted in lowering the pre-harvest WUE in excess irrigated vines. On the other hand, WUE in this research was compared by two different calculation methods reported in literature, at treatment-level (pre-harvest WUE), which is reported by many researches, and at whole season-level (seasonal WUE), which is scarce in literature, in order to identify whether there will be similar or different concluded results from both methods. Statistical analysis for seasonal WUE showed no variations among irrigation treatments and control as were found in pre-harvest WUE data. These results were due to the insignificant variations in seasonal irrigation quantities among treatments which were sums of 38 weeks of irrigation including the treatment period (7 weeks). Similarly, Tomas *et al.* (2012) comparing WUE at vine leaf-level and at whole vine-level in 8 different potted grape cultivars, reported that leaf WUE was not a reliable indicator to estimate vine WUE and that there were significant differences among cultivars. More research is needed to clarify optimum WUE calculation method as results can be also influenced by seasonal, agricultural and environmental conditions as well as by the current climate change scenarios, which suggests increases in water scarcity in near future (Flexas *et al.*, 2010 and Salazar-Parra *et al.*, 2012).

Table 2. Grapevine yield, applied irrigation and water use efficacy (WUE; yield/irrigation) as influenced by deficit and excess irrigation water treatments for Crimson Seedless grapes in 2011 and 2012 seasons.

Treatment	Yield (kg/vine)	Irrigation (m^3/vine) Pre-harvest	Irrigation (m^3/vine) Seasonal	WUE Pre-harvest	WUE Seasonal
			2011		
80 % ETc	21.84 ± 0.99 a[1]	1.23	5.44	17.72 ± 0.80 a	4.02 ± 0.18 a
90 % ETc	22.57 ± 1.45 a	1.39	5.59	16.28 ± 1.05 b	4.04 ± 0.26 a
100 % ETc	22.87 ± 1.26 a	1.54	5.74	14.84 ± 0.82 bc	3.98 ± 0.22 a
110 % ETc	22.83 ± 1.64 a	1.69	5.90	13.47 ± 0.97 cd	3.87 ± 0.28 a
120 % ETc	23.11 ± 0.99 a	1.85	6.05	12.50 ± 0.54 d	3.82 ± 0.16 a
			2012		
80 % ETc	20.90 ± 1.31 b	1.17	5.60	17.80 ± 1.12 a	3.73 ± 0.23 a
90 % ETc	22.03 ± 1.43 ab	1.32	5.74	16.68 ± 1.08 ab	3.84 ± 0.25 a
100 % ETc	23.63 ± 1.19 a	1.47	5.89	16.10 ± 0.81 b	4.01 ± 0.20 a
110 % ETc	22.92 ± 1.33 ab	1.61	6.04	14.19 ± 0.82 c	3.80 ± 0.22 a
120 % ETc	22.78 ± 1.54 ab	1.76	6.18	12.93 ± 0.88 c	3.68 ± 0.25 a

[1] **Mean ± standard deviation; means in columns followed by same letter are not significantly different by separation with Posthoc Tukey test at $p<0.05$.**

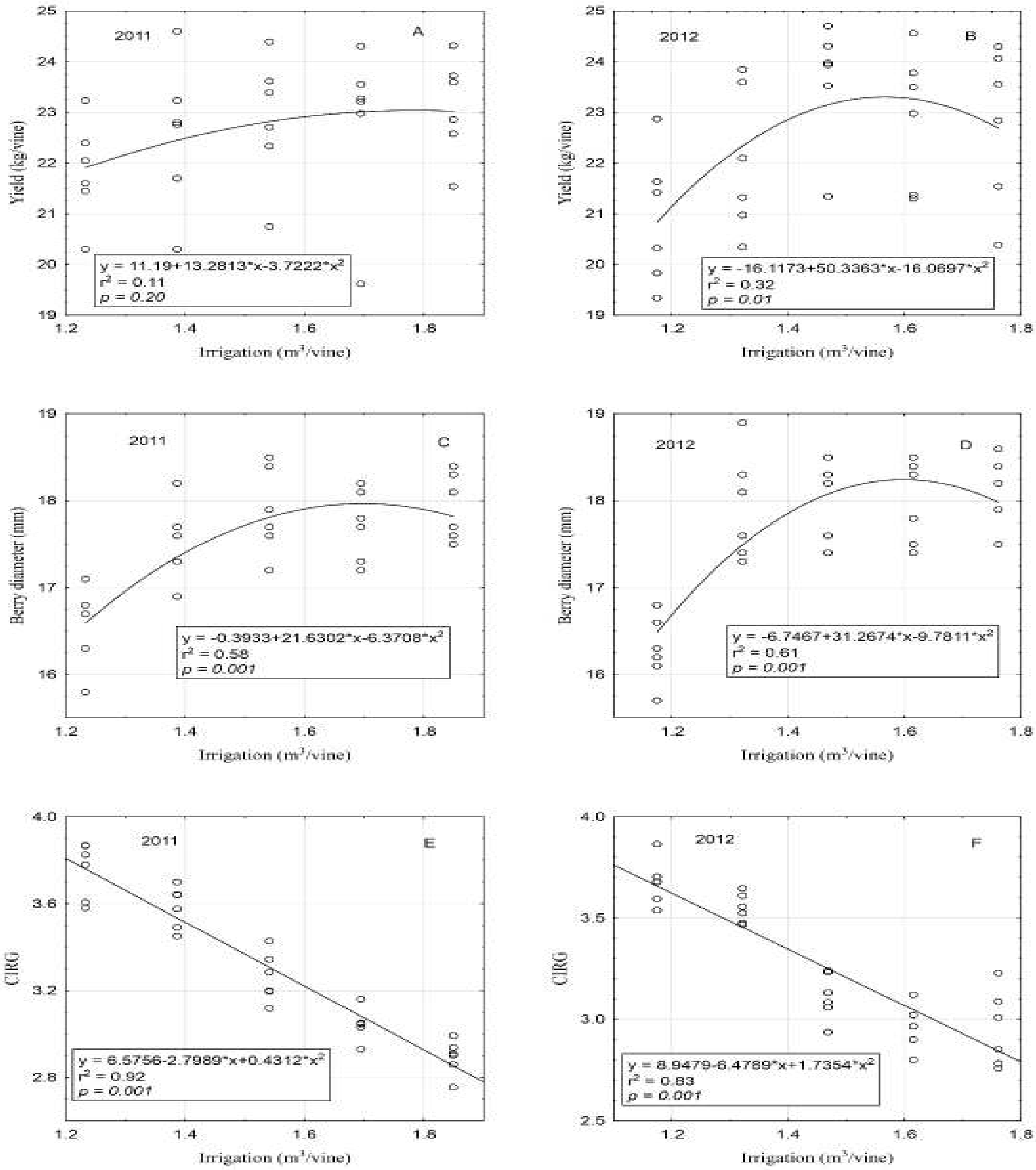

Figure 5. Regression analysis for relationships between applied irrigation water from veraison to harvest with vine yield (A & B), harvest berry diameter (C & D), and harvest berry skin CIRG (E & F) for Crimson Seedless grapes in 2011 and 2012 seasons.

3) Berry quality characteristics:

Berry diameter data presented in Table 3 indicated that only 80 % ETc irrigated vines had the lowest significant berry diameter values (16.5 & 16.28 mm in 2011 & 2012, respectively) as compared with control (17.88 & 17.93 mm in 2011 & 2012, respectively) and other treatments in both seasons. In addition, there was very significant (*p=0.001*) positive regression relationship between applied irrigation and berry diameter ($r^2 = 0.58$ & 0.61 in 2011 & 2012, respectively) as illustrated in Figure 5-C & 5-D. This pattern of best fit quadratic regression line between applied irrigation and berry diameter indicated that there was a significant almost linear relationship between them up to 1.54 and 1.47 m^3 applied irrigation water per vine in 2011 and 2012, respectively, but with greater applied irrigation the line was leveled then declined similar to previously reported water yield function in Figure 5-B. As for berry weight data (Table 3), berries of 80 % ETc irrigated vines were only significantly lower than berries of 120 ETc treatment in 2011, but was lower than berries of 100 ETc, 110 ETC, and 120 ETc vines in 2012. These results agree with those reported by Conesa *et al.* (2014) and Pinillos *et al.* (2016) working with regulated deficit irrigation on Crimson Seedless grapes, who reported that water deficit reduced berry growth and this effect was dependent on the level and period of deficit. Berry firmness (Table 3) was negatively influenced by decreasing applied irrigation level as it was significantly lower in 80% ETc irrigated vines (3.66 & 3.78 N in 2011 & 2012, respectively) as compared with control (4.36 & 4.81 N in 2011 & 2012, respectively) and other treated vines. Lower berry firmness in 80 % ETc treatment can be attributed to the advancement in maturation stage (El-Ansary *et al*., 2005 and Pinillos *et al*., 2016) and / or berry desiccation as a result of water stress (Reynolds and Naylor, 1994).Total soluble solids (TSS) data shown in Table 3 revealed that TSS values were significantly highest in berries of deficient irrigated vines (18.70 & 19.05 % for 80 % ETc, 18.52 & 18.05 % for 90 % ETc, in 2011 & 2012, respectively) as compared with control (17.07 & 17.27 % in 2011 & 2012, respectively) and excess irrigated vines in both seasons, except for 90 % ETc vines where TSS values were not significantly different from control vines in the second season. There were no significant differences in TSS between berries of control and excess irrigated vines, except for 110 % ETc irrigated vines in the second season where it was significantly lower than control. Previous work reported that reducing irrigation enhanced the accumulation of total soluble solids in grape berries (El-Ansary *et al*., 2005 & Stevens *et al*., 2016) due to reduced leaf growth and redirection of carbohydrates to berries with a concomitant concentration effect due to water loss from deficient berries (Reynolds and Naylor, 1994) and / or promotion of berry ripening by increased ABA signaling to berries (Okamoto *et al*., 2004 b). Titratable acidity (TA) percent decreased with decreasing irrigating level and was significantly lowest in berries of 80 % ETc irrigated vines (0.37 & 0.34 % in 2011 & 2012, respectively) as compared with control (0.72 & 0.64 % in 2011 & 2012, respectively) and all other treatments. These results are consistent with reports of El-Ansary *et al.* (2005) and El-Ansary and Okamoto (2007 & 2008). TSS to Acid ratio (Table 3) was significantly highest in berries of 80 % ETc irrigated vines (50.54 & 55.57 in 2011 & 2012, respectively), followed by 90 % ETc irrigated vines (31.06 & 29.35 in 2011 & 2012, respectively) and control vines (23.89 & 27.13 in 2011 & 2012, respectively), and was lowest in berries of excess irrigated vines. Increasing TSS while decreasing or maintaining acidity levels cause increase for TSS to Acid ratio. Berry skin color characteristics data presented in table 4 showed that lightness (L*) values decreased with increasing irrigation level and were significantly lowest in 80 % ETc irrigated vines (31.93 & 32.88 in 2011 & 2012, respectively) as compared with control (36.0 & 36.3 in 2011 & 2012, respectively) and excess irrigated vines. Also, skin chroma values were significantly lowest in deficit irrigated vines (9.5 & 9.6 for 80 % ETc and 9.5 & 9.7 for 90 % ETc, in 2011 & 2012 respectively) as compared with control (10.3 & 10.7 in 2011 & 2012, respectively) and excess irrigated vines. A similar trend was also for hue angle values (hº) as for example they were significantly lower in berries of 80 % ETc irrigated vines (24.5 & 23.8 in 2011 & 2012, respectively) as compared with control (29.3 & 33.8 in 2011 & 2012, respectively) and excess irrigated vines. Berry skin color index for red grapes (CIRG) increased significantly in deficient irrigated vines (3.8 & 3.7 for 80 % ETc and 3.6 & 3.6 for 90 % ETc, in 2011 & 2012, respectively), followed by control (3.3 & 3.1 in 2011 & 2012, respectively), and was lowest in excess irrigated vines (3.0 & 3.0 for 110 % ETc and 2.9 & 3.0 for 120 % ETc, in 2011 & 2012, respectively). Furthermore, Figure 5-E & 5-F indicated that there was a negative very significant relationship between applied irrigated and skin CIRG (r^2 = 0.92 & 0.83 in 2011 & 2012, respectively). As it can be seen from Figure 6, there were negative very significant relationships between skin CIRG and L*, C*, and hº. These data indicate that CIRG was a very practical sensitive index for red color development in Crimson Seedless berry skin as affected by irrigation regimes. These results are consistent with those of Pinillos *et al.* (2016) and Stevens *et al.* (2016), who reported enhancement of berry skin anthocyanin accumulation and decrease in skin color characteristics of L*, C*, and h° with an increase in CIRG as a result of imposing deficit irrigation. Increased anthocyanin accumulation in grape berry skin was attributed to activating the anthocyanin biosynthesis pathways as well as due to the concentrating effect as a result of reduced berry size under deficit irrigation conditions (Roby *et al*., 2004).

Table 3. Harvest grape berry diameter, weight and firmness, juice total soluble solids (TSS), titratable acidity (TA) and TSS to Acid ratio as affected by deficit and excess irrigation water treatments for Crimson Seedless grapes in 2011 and 2012 seasons.

Treatment	Berry diameter (mm)	Berry weight (g)	Berry firmness (N)	TSS (%)	TA (%)	TSS to Acid ratio
			2011			
80 % ETc	16.50 ± 0.46 b[1]	5.27 ± 0.14 b	3.66 ± 0.13 b	18.70 ± 0.23 a	0.37 ± 0.03 c	50.54 ± 3.45 a
90 % ETc	17.50 ± 0.44 a	5.45 ± 0.14 ab	4.05 ± 0.16 a	18.52 ± 0.31 a	0.60 ± 0.07 b	31.06 ± 3.12 b
100 % ETc	17.88 ± 0.50 a	5.38 ± 0.15 ab	4.36 ± 0.18 a	17.07 ± 0.39 b	0.72 ± 0.09 b	23.89 ± 2.86 c
110 % ETc	17.72 ± 0.41 a	5.45 ± 0.19 ab	4.32 ± 0.21 a	16.52 ± 0.69 b	0.93 ± 0.14 a	18.09 ± 3.24 d
120 % ETc	17.93 ± 0.38 a	5.52 ± 0.10 a	4.33 ± 0.29 a	16.60 ± 0.58 b	0.97 ± 0.08 a	17.29 ± 2.02 d
			2012			
80 % ETc	16.28 ± 0.39 b	5.13 ± 0.18 b	3.78 ± 0.10 c	19.05 ± 0.52 a	0.34 ± 0.02 c	55.57 ± 2.58 a
90 % ETc	17.93 ± 0.62 a	5.38 ± 0.17 ab	4.45 ± 0.21 b	18.05 ± 0.27 b	0.62 ± 0.07 b	29.35 ± 3.39 b
100 % ETc	17.93 ± 0.45 a	5.48 ± 0.17 a	4.81 ± 0.14 a	17.27 ± 0.39 bc	0.64 ± 0.07 b	27.13 ± 3.25 b
110 % ETc	17.98 ± 0.48 a	5.53 ± 0.12 a	4.71 ± 0.18 ab	16.18 ± 0.82 d	0.87 ± 0.10 a	18.82 ± 2.04 c
120 % ETc	18.13 ± 0.39 a	5.50 ± 0.15 a	4.74 ± 0.25 ab	16.35 ± 0.64 cd	0.99 ± 0.17 a	16.96 ± 2.84 c

[1] **Mean ± standard deviation; means in columns followed by same letter are not significantly different by separation with Posthoc Tukey test at *p<0.05*.**

Table 4. Harvest berry skin color characteristics as affected by deficit and excess irrigation water treatments for Crimson Seedless grapes in 2011 and 2012 seasons.

Treatment	Berry Skin color characteristics			
	L^*	C^*	h°	CIRG
		2011		
80 % ETc	31.93 ± 1.58 c[1]	9.52 ± 0.23 c	24.50 ± 2.35 c	3.76 ± 0.13 a
90 % ETc	33.98 ± 1.57 bc	9.48 ± 0.26 c	24.35 ± 1.21 c	3.58 ± 0.10 b
100 % ETc	36.00 ± 1.57 ab	10.25 ± 0.33 b	29.28 ± 1.14 b	3.26 ± 0.11 c
110 % ETc	35.38 ± 1.08 ab	11.60 ± 0.47 a	37.00 ± 3.46 a	3.04 ± 0.07 d
120 % ETc	36.83 ± 0.93 a	11.53 ± 0.58 a	40.17 ± 2.23 a	2.89 ± 0.08 d
		2012		
80 % ETc	32.88 ± 1.04 b	9.60 ± 0.25 c	23.83 ± 1.72 c	3.68 ± 0.11 a
90 % ETc	33.35 ± 1.16 b	9.68 ± 0.29 c	27.38 ± 1.25 c	3.55 ± 0.07 a
100 % ETc	36.32 ± 2.00 a	10.65 ± 0.62 b	33.83 ± 2.24 b	3.12 ± 0.11 b
110 % ETc	36.33 ± 1.61 a	11.52 ± 0.79 a	38.33 ± 2.16 a	2.96 ± 0.11 b
120 % ETc	36.35 ± 1.57 a	11.63 ± 0.37 a	38.50 ± 4.32 a	2.95 ± 0.19 b

[1] **Mean ± standard deviation; means in columns followed by same letter are not significantly different by separation with Posthoc Tukey test at *p<0.05*.**

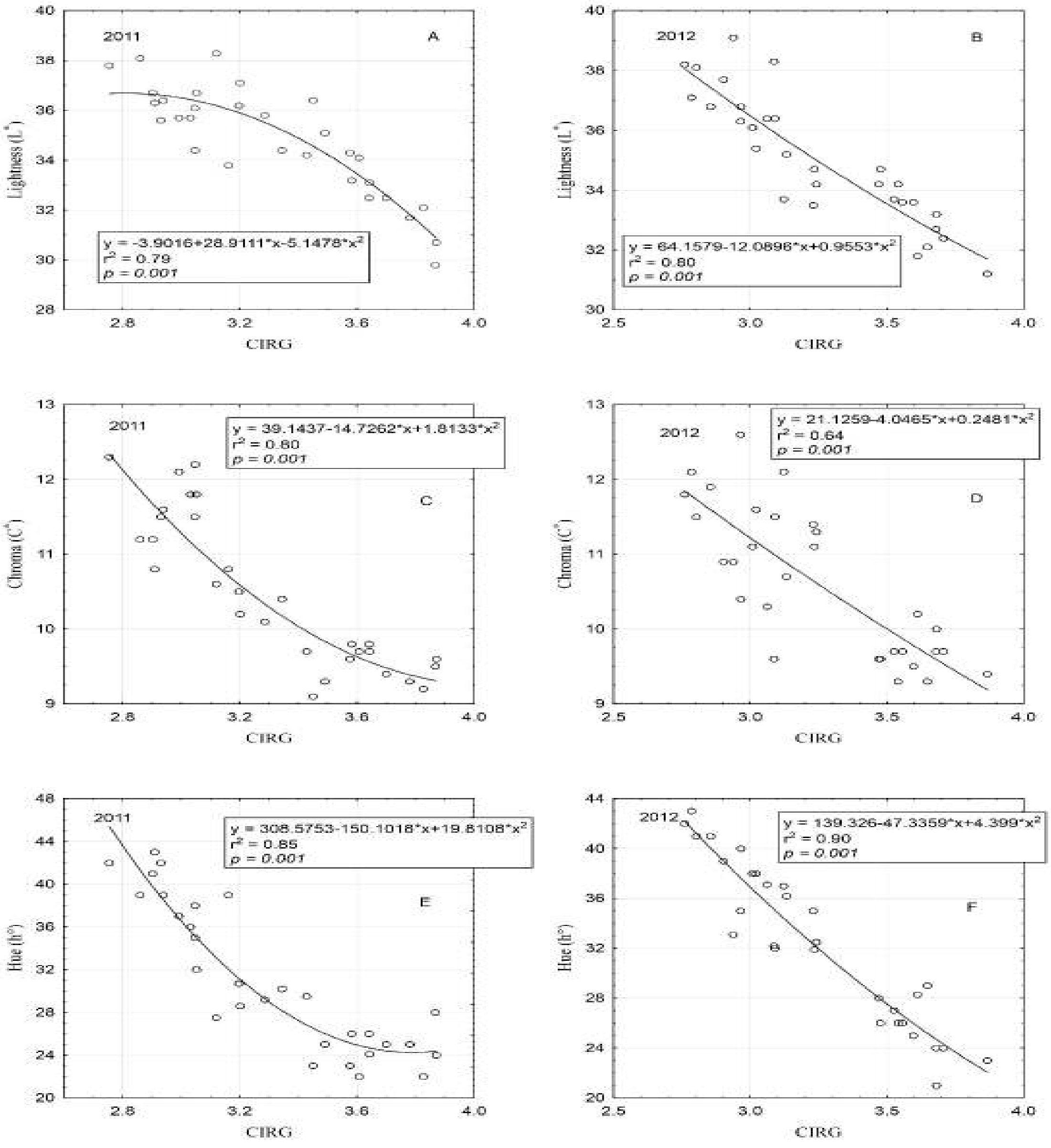

Figure 6. Regression analysis for relationships between harvest berry skin CIRG with harvest berry skin lightness (A & B), harvest berry skin chroma (C & D), and harvest berry skin hue (E & F) for Crimson Seedless grapes in 2011 and 2012 seasons.

CONCLUSION

Irrigation deficiency or excess affected Crimson Seedless crop yield and quality, moderate deficit irrigation reduced yield and some quality parameters, slight deficit irrigation maintained yield with beneficial effects on quality, no water deficit and excess irrigation water maintained yield but reduces some quality parameters. It is recommended under the conditions or this study to ripen Crimson Seedless table grapes under slight deficit irrigation to promote red color development and increase TSS to Acid ratio of berries.

REFERENCES

Black, C. A., D. D. Evans, J. L. White, L. E. Ensminger and F. E. Clark (1965). Methods of Soil Analysis. Part 1. Physical and Mineralogical Properties, Including of Statistics of Measurement and Sampling. American Society of Agronomy, Inc., Madison Publisher, Wisconsin, USA.

Cantin, C. M., M. W. Fidelibus and C. H. Crisosto (2007). Application of abscisic acid (ABA) at veraison advanced red color development and maintained postharvest quality of 'Crimson Seedless' grapes. Postharvest Biol. and Technol., 46: 237-241.

Conesa, M. R., J. M. de la Rosa, F. Artes-Hernandez, I. C. Dodd, R. Domingo and A. Perez-Pastor (2014). Long-term impact of deficit irrigation on the physical quality of berries in 'Crimson Seedless' table grapes. J. Sci. Food Agric., 95: 2510-2520.

Davies, W. J., S. Wilkinson and B. Loveys (2002). Stomatal control by chemical signalling and the exploitation of this mechanism to increase water use efficiency in agriculture. New Phytologist, 153: 449-460.

Dokoozlian, N. K. and W. L. Peacock (2001). Gibberellic acid applied at bloom reduces fruit set and improves size of 'Crimson Seedless' table grapes. HortScience, 36: 706-709.

Düring, H., P. R. Dry and B. R. Loveys (1996). Root signals affect water use efficiency and shoot growth. Acta Hort., 427: 2-14.

Edwards, E. J. and P. R. Clingeleffer (2013). Interseasonal effects of regulated deficit irrigation on growth, yield, water use, berry composition and wine attributes of Cabernet Sauvignon grapevines. Aust. J. Grape Wine Res., 19: 261-276.

El-Ansary, D. O. and G. Okamoto (2007). Vine water relations and quality of 'Muscat of Alexandria' table grapes subjected to partial root-zone drying and regulated deficit irrigation. J. Japan. Soc. Hort. Sci., 76: 13-19.

El-Ansary, D. O. and G. Okamoto (2008). Improving table grape quality with less irrigation water in Japan: partial root-zone drying versus regulated deficit irrigation. Acta Hort., 792: 265-271.

El-Ansary, D. O., S. Nakayama, K. Hirano and G. Okamoto (2005). Response of Muscat of Alexandria table grapes to post-veraison regulated deficit irrigation in Japan. Vitis, 44: 5-9.

Flexas, J., J. Galmes, A. Galle, J. Gulias, A. Pou, M. Ribas-Carbo, M. Tomas and H. Medrano (2010). Improving water use efficiency in grapevines: potential physiological targets for biotechnological improvement. Aust. J. Grape Wine Res., 16: 106-121.

Johnson, R. S. and D. F. Handley (2000). Using water stress to control vegetative growth and productivity of temperate fruit trees. HortScience, 35: 1048-1050.

Loveys, B. R., P. R. Dry, M. Stoll and M. G. McCarthy (2000). Using plant physiology to improve the water use efficiency of horticultural crops. Acta Hort., 537: 187-197.

Matthews, M. A., M. M. Anderson and H. R. Schultz (1987). Phenologic and growth responses to early and late season water deficits in Cabernet franc. Vitis, 26: 147-160.

Morison, J. I. L., N. R. Baker, P. M. Mullineaux and W. J. Davies (2008). Improving water use in crop production. Philosophical Transactions of the Royal Society of London Series B, 363: 639–658.

Okamoto, G., K. Ueki and T. Imai (2004 a). A comparative study of drought and excess-water tolerance in *Vitis coignetiae* and several table grapes grown in Japan. Scientific Reports of the Faculty of Agriculture, Okayama University, 93: 39-43.

Okamoto, G., T. Kuwamura and K. Hirano (2004 b). Effects of water deficit stress on leaf and berry ABA and berry ripening in Chardonnay grapevines (*Vitis vinifera*). Vitis, 43: 15-17.

Pellegrino A., E. Lebon, T. Simonneau and J. Wery (2005). Towards a simple indicator of water stress in grapevine (*Vitis vinifera* L.) based on the differential sensitivities of vegetative growth components. Aust. J. Grape Wine Res., 11: 306-315.

Pinillos, V., F. M. Chiamolera, J. F. Ortiz, J. J. Hueso and J. Cuevas (2016). Post-veraison regulated deficit irrigation in 'Crimson Seedless' table grape saves water and improves berry skin color. Agric. Water Manage., 165: 181-189.

Ramming, D. W., R. Tarailo and S. A. Badr (1995). 'Crimson Seedless': a new late-maturing, red seedless grape. HortScience, 30: 1473-1474.

Reynolds, A. G. and A. P. Naylor (1994). 'Pinot noir' and 'Riesling' grapevines respond to water stress duration and soil water-holding capacity. HortScience, 29: 1505-1510.

Richards, R. L., (ed.) (1954). Diagnosis and Improvement of Saline and Alkali Soils. Agriculture Handbook No. 60, U.S. Gov. Printing Office, Washington, USA.

Roby, G., J. F. Harbertson, D. A. Adams and M. A. Matthews (2004). Berry size and vine water deficits as factors in winegrape composition: Anthocyanins and tannins. Aust. J. Grape Wine Res., 10: 100-107.

Sadras, V. O. and M. G. McCarthy (2007). Quantifying the dynamics of sugar concentration in berries of Vitis vinifera cv. Shiraz: a novel approach based on allometric analysis. Aust. J. Grape Wine Res., 13: 66-71.

Salazar-Parra, C., J. Aguirreolea, M. Sanchez-Diaz, J. J. Irigoyen and F. Morales (2012). Photosynthetic response of Tempranillo grapevine to climate change scenarios. Annals of Applied Biology, 161: 227-292.

Sauter, A., W. J. Davies and W. Hartung (2001). The long-distance abscisic acid signal in the droughted plant: the fate of the hormone on its way from root to shoot. J. Exp. Botany, 52: 1991-1997.

Steel, R. G. D. and J. H. Torrie (1980). Principal and Procedures of Statistics. 2nd edition, McGraw-Hill Book Company, New York, USA.

Stevens, R. M., J. M. Pech, J. Taylor, P. Clingeleffer, R. R. Walker and P. R. Nicholas (2016). Effects of irrigation and rootstock on *Vitis vinifera* (L.) cv. Shiraz berry composition and shrivel, and wine composition and wine score. Aust. J. Grape Wine Res., 22: 124-136.

Stevens, R. M., J. M. Pech, M. R. Gibberd, R. R. Walker and P. R. Nicholas (2010). Reduced irrigation and rootstock effects on vegetative growth, yield and its components, and leaf physiological responses of Shiraz. Aust. J. Grape Wine Res., 16: 413–425.

Tardieu, F., J. Zhang, N. Katerji, O. Bethenod, S. Palmer and W. J. Davies (1992). Xylem ABA controls the stomatal conductance of field grown maize subjected to soil compaction or drying soil. Plant Cell Environ., 15: 193-197.

Tomas, M., H. Medrano, A. Pou, J. M. Escalona, S. Martorell, M. Ribas-Carbo and J. Flexas (2012). Water-use efficiency in grapevine cultivars grown under controlled conditions: effects of water stress at the leaf and whole-plant level. Aust. J. Grape Wine Res., 18: 164-172.

Tonietto, J. and A. Carbonneau (2004). A multicriteria climatic classification system for grape-growing regions worldwide. Agricultural and Forest Meteorology, 124: 81-97.

Williams, L. E., D. W. Grimes and C. J. Phene (2010). The effects of applied water at various fractions of measured evapotranspiration on reproductive growth and water productivity of 'Thompson Seedless' grapevines. Irrig. Sci., 28: 233–243.

تأثيرات نقص و زيادة ماء الري قبل الحصاد على العلاقات المائية للشجيرة والإنتاجية وجودة ثمار عنب المائدة كريمسون سيدلس

ضياء أسامة الأنصاري
قسم الفاكهة – كلية الزراعة (الشاطبي) – جامعة الاسكندرية – الاسكندرية – 21545 - مصر
الباحث المتصل: diaa.elansary@alexu.edu.eg / diaaagri@hotmail.com / Tel.: +02-01000150804

إهتم هذا البحث بدراسة تأثيرات نقص وزيادة ماء الري قبل الحصاد على العلاقات المائية للشجيرة والإنتاجية وجودة ثمار عنب المائدة كريمسون سيدلس. ولقد تم في موسمي 2011 و 2012 م تطبيق 5 معاملات ري لمدة 7 أسابيع بداية من مرحلة نزول الماء في الحبة وحتى الحصاد وذلك بناءً على البخر نتح الفعلي للمحصول: 80 ٪ من بخر نتح المحصول (نقص ري متوسط)، 90 ٪ من بخر نتح المحصول (نقص ري خفيف)، 100 ٪ من بخر نتح المحصول (ري قياسي مرجعي)، 110 ٪ من بخر نتح المحصول (زيادة ري خفيفة) و 120 ٪ من بخر نتح المحصول (زيادة ري متوسطة). أظهرت النتائج أن بيانات المحتوى المائي للتربة على أساس الحجم والجهد المائي بالأوراق وقت الظهيرة قد أستجابت لمعاملات الري وكانت هناك علاقات معنوية جداً بينهم. ولم يتأثر المحصول بمعاملات الري في الموسم الأول بينما قل المحصول معنوياً في معاملة 80 ٪ من بخر نتح المحصول (20,9 كجم / شجيرة) بالمقارنة بالشجيرات المرجعية (23,6 كجم / شجيرة) في الموسم الثاني. وقلت معنوياً كفاءة إستخدام الماء قبل الحصاد بزيادة مستوى الري، بينما لم توجد أي إختلافات في كفاءة إستخدام الماء موسمياً. وكان قطر الحبة في معاملة 80 ٪ من بخر نتح المحصول الأقل معنوياً بالمقارنة بالمعاملة المرجعية وباقي المعاملات في الموسمين. كذلك فإن وزن الحبة في معاملة 80 ٪ من بخر نتح المحصول كان فقط أقل معنوياً من ذلك في معاملة 120 ٪ من بخر نتح المحصول في 2011، بينما كان أقل من ذلك في معاملات 100 ٪ و 110 ٪ و 120 ٪ من بخر نتح المحصول في 2012. وقد تأثرت صلابة الحبة سلبياً بقلة مستوى الري حيث كانت الأقل معنوياً في معاملة 80 ٪ من بخر نتح المحصول بالمقارنة بالمعاملة المرجعية والمعاملات الأخرى. أما النسبة المئوية للمواد الصلبة الذائبة الكلية في العصير فكانت الأعلى معنوياً في معاملتي نقص الري وذلك بالمقارنة بالمعاملة المرجعية ومعاملات زيادة الري في الموسمين، بإستثناء معاملة 90 ٪ من بخر نتح المحصول والتي لم تختلف فيها معنوياً عن المعاملة المرجعية في 2012. وإنخفضت النسبة المئوية للحموضة في العصير بإنخفاض مستوى الري وكانت الأقل معنوياً في شجيرات معاملة 80 ٪ من بخر نتح المحصول وذلك بالمقارنة بالمعاملة المرجعية وباقي المعاملات. هذا وكانت نسبة المواد الصلبة الذائبة الكلية إلى الحموضة في العصير الأعلى معنوياً في معاملة 80 ٪ من بخر نتح المحصول، ويليها معاملتي 90 ٪ و 100 ٪ من بخر نتح المحصول، وكانت الأقل في معاملتي 110 ٪ و120 ٪ من بخر نتح المحصول. وقلت قيم خصائص لون جلد الحبة L* و C* و h° بزيادة مستويات الري وكانت الأقل معنوياً في معاملتي نقص الري وذلك بالمقارنة بمعاملات زيادة الري والمعاملة الكنترول في الموسمين، بإستثناء قيم L* في 2011. وزادت معنوياً قيم دليل لون العنب الأحمر (CIRG) لجلد الحبة في معاملتي نقص الري، وتلاها المعاملة المرجعية، وكانت الأقل في معاملتي زيادة الري. هذا وخلصت الدراسة إلى أن معاملة ري 90 ٪ من بخر نتح المحصول حافظت على محصول الشجيرة وكان لها تأثيرات إيجابية على خصائص الجودة التجارية للحبات.