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ABSCISIC ACID AND IRRIGATION LEVELS EFFECTS ON MORPHOLOGICAL CHARACTERISTICS OF STRAWBERRY

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ABSTRACT
The high value of strawberries creates potential for high rates of employment and farm income in Turkey. Optimizing water application and effective cultivation practices are of considerable importance in improving strawberry yield. In this study, the effects of four different irrigation regimes and Abscisic Acid application (ABA use and control) effects on the leaf area, plant dry matter and crown number of strawberry (*Fragaria × ananassa* cv. Rubygem) were evaluated under Spanish type high tunnels conditions. ABA was applied three times starting from March to May via foliar application as 20 μmol L^{-1}. From the initiation of the treatment to the end of the trial, a total of 552, 447, 342 and 237 mm of water were applied to treatments IR125, IR100, IR75 and IR50 respectively. The IR50 treatment caused a significant decline in morphological parameters, indicating that the amount of irrigation water did not meet the plant water requirement. The increased amount of irrigation water increased the leaf area, dry matter and the crown number significantly. Furthermore, the ABA application increased the leaf area by 15%, the plant dry matter 12% and crown number by 8%. Under water stress conditions (IR50), ABA significantly increased growth rate as well as increasing leaf area, plant dry matter and the crown number by 13%, 12% and 11%, respectively, when compared to the control plot. Consequently, in the protected cultivation, the IR125 irrigation level and the ABA application enhanced vegetative growth and in turn the total marketable fruit yield and its components.

Keywords: *Leaf area, Dry matter, Class A pan, High tunnel, Rubygem.*

INTRODUCTION
Water scarcity depresses the crop production that occurs a major constraint in providing the food demand worldwide. Approximately 45% of the world agricultural areas are exposed to incessant water shortage, where 38% of the world population lives (Bot et al., 2000). Nowadays, almost 18% of the global farmland

is under irrigation as well as up to 40% of the global food supply is produced from this area (Somerville and Briscoe, 2001; Hussain *et al*., 2012). Therefore, to enhance the efficiency of water in irrigated agriculture, optimal strategies should be developed to avoid the risk of future water supply shortages. Thus, advanced crop drought resistance applications and using optimal irrigation scheduling appears as a significant concern in agricultural production, mainly on water-sensitive crops. Even though it's high sensitivity to water stress, strawberry has a commercial value in Turkey due to the raised market demand. Turkey is the leading country in the strawberry production of Europe by 400.167 metric tons in 2017 (TUIK, 2019). In this regard, water stress research and the investigation of various agricultural practices have gained popularity in the study of strawberries. Limited irrigation is generally associated with the reduction of morphological parameters and thus negatively affects the strawberry yield (Liu et al., 2007; Giné Bordonaba and Terry, 2010).

In this context, the crucial object in agricultural applications and research is how to struggle the water stress, within the environmentally and economically sustainable procedures. Although the extensive use of irrigation in strawberries, their specific water requirements are uncertain (Lozano *et al*., 2016). In the earlier studies, a wide range of irrigation water applications have been reported, but they differ depending on the cultivar, production method, climate and water requirement calculations (Hancock, 1999; Lozano *et al*., 2016). In this way, variations in irrigation water use suggest that locally conducted trials are required to develop the irrigation management in specific regions and cultural systems (Kirschbaum *et al*., 2004). Furthermore, exogenous applications to crops are vital to improve the yield and quality under stress conditions. Abscisic acid (ABA) is one of the major exogenous applicants, which is a plant growth regulator and an osmotic protector that increases the degree of tolerance of the plants against water stress (Heschel and Hausmann, 2001; Wang *et al*., 2003). Plant physiological processes, growth, development, productivity, and responses to abiotic stresses are also affected by ABA applications. Moreover, ABA application effects were remarkable in terms of some morpho-physiological parameters under water stress conditions (Hussain *et al*., 2012). The effect of ABA on growth responses of strawberry under drought stress conditions has not yet been well studied. Therefore, in this sense, this trial is focused on the effect of foliar spray of ABA on plant morphological parameters of strawberry which induces the yield under various irrigation regimes.

MATERIALS AND METHODS

The experiment was executed inside the high tunnel at the Cukurova University experimental farm (latitude: 36^o 59`N, longitude 35$^o$ 27`E, 20 m above sea level). A typical Mediterranean climate prevails in the experimental area, with cool, rainy winters and hot, dry summers. The soils at the site have been classified as Xerofluvents of the Entisol order with heavy clay texture. The bulk density for the top 0.3 m is 1.6 g cm^{-1} and the pH is 7.6. The water content at field capacity and permanent wilting point are 36% and 16%, respectively. The strawberry (*Fragaria*

× *ananassa* Duch.) cultivar 'Rubygem', of short day type, earliness, good taste and aroma, was planted on September 22 (referred to as 0 days after planting (DAP)) 2017 and cropping continued until June 11, 2018. The frigo plant material was used. The high tunnel was made of a steel frame covered by 0.1 mm thick transparent polyethylene (PE) film, with a center height at 2.50 m and 0.8 m at the open sides (40 m long and 6.5 m wide). To monitor temperature and humidity, climate station was placed in the center of the high tunnel 2 m above soil surface. The area inside the tunnel was heated solely by solar radiation.

The strawberries were planted in trapezoidal raised beds measuring 0.70 m at the base, 0.50 m at the top, with a height of 0.30 m, and a 0.30 m distance between each bed. Each were covered with a 0.05 mm thick, two-sided polyethylene mulch cover, having a grey upper side and black under side, (in accordance with conventional cultural practices in the area) with surface drip irrigation installed down the center. Strawberries were planted in two rows, 0.3 m apart, with plants set 30 cm apart, to an equivalent plant density of 6.65 plants m^{-2}. Each tunnel had four beds. After planting, sufficient water was applied until the plants were well developed. Fertilizer was applied uniformly to each treatment by drip irrigation and foliar application of agricultural pesticides served to control foliar and fruit diseases.

The trial was implemented as a 4×2 factorial scheme of irrigation levels and Abscisic Acid use, in a split-plot design with 4 replicates (blocks) combined over six periods, totaling 32 plots. Applications (ABA use and control) were designed over the main plot and different irrigation regimes were arranged as the sub plots. Furthermore, approximately six months after planting, three times starting from March to May via foliar application, 20 µmol L^{-1} Absisic Acid was applied (March 07, April 05, May 08, 2018). The four irrigation treatments were designated IR50, IR75, IR100, and IR125, where the water quantities applied were 0.5, 0.75, 1.00 and 1.25 times of the pan evaporation (Epan). Epan value was determined using the US Weather Service Class A pan, with a standard 120.7 cm diameter and 25 cm depth, and placed over the crop canopy in the center of the high tunnel. Four irrigation treatments were established in four beds of four, 10 m by 4 m plots, with 266 plants per plot. The irrigation amount was calculated as reflected at Kapur et. al. (2018). From the initiation of the treatment to the end of the trial, a total of 552, 447, 342 and 237 mm of water were applied to treatments IR125, IR100, IR75 and IR50 respectively.

In order to evaluate the morphological responses of strawberry, the samples were taken in May which is the active harvest period. Evaluation of the leaf area (LA), above ground dry matter (DM), crown number (CN), was conducted to characterize the vegetative growth of strawberry under various applications. Leaf area was measured with a leaf area meter (model 3050A; Li-Cor Lincoln, NE, USA). To obtain a value for the dry matter of the crop, the above-ground tissue was dried in an oven at 70 °C until the dry-weight was maintained. The same plants were used to determine the crown number. The obtained data were analyzed with the statistical program JMP version 5.0.1 (SAS Institute Inc., Cary, NC, USA).

ANOVA was calculated to determine the effects of irrigation regime and bio-stimulant on the observed parameters, combined over six periods. A Least Significant Difference test was performed to examine the differences among groups. Comparisons that yielded $P \leq 0.05$ were considered statistically significant. Additionally, using JMP 5.0.1., the multivariate method was used to determine the correlation among all the obtained results, with $P \leq 0.05$.

RESULTS AND DISCUSSION

The responses of strawberry plants to different treatments are presented in Table 1. The measured parameters, LA, DM and CN, ranked similarly. The IR50 treatment caused a significant decline in morphological parameters, indicating that the irrigation amount did not meet the plant water requirement. The higher amounts of irrigation water produced plants with more leaf area and dry matter development. Diminishing growth rate is one of the earliest responses of plants to water deficit. Similarly, reductions in LA and DM have been noted under water stress conditions previously (Liu *et al*., 2007; Grant *et al*., 2010; Grant *et al*., 2012; Ghaderi *et al*., 2015). According to our results, 75 cm^2 LA, 0.06 CN and 0.7 g DM increased per plant for a water level of about 10 mm rise. Leaf area enhancement assesses light interception and is a major parameter in determining plant productivity (Gifford *et al*., 1984; Koester *et al*., 2014). Therefore increased leaf area increased the yield of strawberry in this study (yield data were not shown). Our results are in accordance with that of Yuan et al. (2004), that plant leaves and above-ground biomass with total berry yields all increased when the amount of irrigation water increase.
The effect of the ABA was significant in LA, while CN and DM were not significantly increased. The average values of the parameters increased by 15%, 12% and 8% for LA, DM and CN respectively. The irrigation level and ABA interaction insignificantly affected the LA DM and CN. Under water stress conditions (IR50), ABA significantly increased growth rate as well as increasing LA, CN and DM by 13%, 11% and 12%, respectively, when compared to the control plot. Previous works have found that exogenous applicants both promote plant growth and enhance abiotic stress tolerance (Battacharyya *et al*., 2015). Similar to our results, application of the salicylic acid resulted in increasing the leaf number in strawberry under water stress conditions and drought stress reduced dry matter in strawberry cultivars. Under water limited conditions, application of the salicylic acid increased dry matter, irrespective of the cultivar (Ghaderi *et al*., 2015). Moreover, ABA is known to play an important role in enhancing plant water use efficiency under environmental stress (Jamalian *et al*, 2013). Therefore, ABA is recommended to act as a suitable solute that manages the osmotic potential in the cells (Arshi *et al*., 2005; Caballero *et al*., 2005; Bartels and Sunkar, 2006) and considered to undertake a major role in the protection mechanisms of stressed cells. According to Serraj and Sinclair (2002), osmotic adjustment is the main physiological response to maintain the growth of crops under water stress conditions. Furthermore, the growth and development of vegetation is controlled by phytohormones, like ABA, and gibberellic acid that effect plant growth by

regulating the growth activity, thus explaining the improved growth of strawberry determined in the present study (Khan *et al.*, 2009). It is possible that exogenous application increased the leaf area, and improved light interception, thereby heightening the photosynthetic rate and increasing plant productivity (Koester *et al.*, 2014). However, aforetime, the cost of producing ABA was too high to support its application as a plant growth regulator, but in these days ABA production methods have been improved and application in cash crops could be advised (Cantin *et al.*, 2007; Ferrara *et al.*, 2013). The irrigation and ABA application interactions do not significantly differ, probably due to a major variability in the applications. LA, CN and DM change between 1737-4351 cm^2, 3-5.3 and 45.3-72.2 g, respectively.

Table 1. Effects of irrigation regimes and ABA on morphological parameters of strawberry

Leaf Area (cm^2)					
Application	Irrigation Regime				Ave. App.
	IR50	IR75	IR100	IR125	
Control	1737	2710	3603	4088	3035 B
ABA	1956	3658	3960	4351	3481 A
Ave. Irrigation	1846C	3184B	3781AB	4220A	
LSDirr***=624.3		LSDapp**=441.4		LSDirrxapp= N. S.	
Crown Number					
Application	IR50	IR75	IR100	IR125	Ave. App.
Control	3.0	3.6	4.6	5.0	4.0
ABA	3.3	4.0	4.3	5.3	4.3
Ave. Irrigation	3.2C	3.8BC	4.5AB	5.2A	
LSDirr***=0.78		LSDapp= N. S.		LSDirrxapp= N. S.	
Dry Matter (g)					
Application	IR50	IR75	IR100	IR125	Ave. App.
Control	45.3	48.7	63.7	64.9	55.7
ABA	50.9	55.8	70.0	72.2	62.2
Ave. Irrigation	48.1B	52.2B	66.9A	68.6A	
LSDirr***= 11.8		LSDapp= N.S.		LSDirrxapp= N. S.	

[1]Differences between the means were showed with different letters.
[2] N. S.: Not Significant, ***: $p < 0.01$; **: $p < 0.05$.

CONCLUSIONS

The appropriate and efficient use of drip irrigation systems is significant regarding reduced growth and yield both caused by excess and inadequate irrigation bound to water stress. The effects of different irrigation water applications based on the Class A pan evaporation on strawberry growth were studied in a high tunnel drip irrigation experiment. The leaf area, crown number, dry matter all increased with the increasing amount of irrigation water from IR50 to IR125. The optimal amount of irrigation water is about 552 mm and the optimal crop pan factor is about 1.25

for strawberry growth inside the high tunnel under the Mediterranean environment conditions. Applying water by drip irrigation in relation to the amount of water evaporated from a standard Class A pan is a suitable, simple and low cost method. Thus, strawberries grown inside the high tunnel could be irrigated using a pan factor of 1.25 as a guideline for irrigation during the full vegetation period. Furthermore, the ability of the exogenous compatible solutes, such as ABA, to counteract the water stress effects in strawberry (*Fragaria × ananassa* Duch. cv. Rubygem) was investigated. However, the economic evaluation of the applications cost is important for the final decision.

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