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THE INFLUENCE OF WATER DEFICIT ON VEGETATIVE GROWTH, PHYSIOLOGY, FRUIT YIELD AND QUALITY IN EGGPLANTS

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Summary. The effects of water deficit on plant growth, physiology and dry matter accumulation in the eggplant (*Solanum melongena L.* cv., Teorem F1) grown in pot were studied under out door conditions. Water stress was imposed by irrigating the plants with 80%, 60% and 40% of water needed to reach pot capacity (PC) in the soil. Control plants were irrigated 100% of PC. Water deficits increased leaf temperature up to 3-4 ^{o}C compared to the control. The water stress resulted in significant decreases in chlorophyll content, electrolyte leakage (EL), leaf relative water content (LRWC) and vegetative growth. Severe water stress (40% of PC) reduced plant height by 46%, stem diameter by 51%, total dry weight by 43% and relative leaf expansion rate (RLER) by up to 75%. The root to shoot ratio was 2.1 times higher in water-stressed plants, showing that water stress in eggplants alters the pattern of dry matter distribution favoring the roots. Plants grown under high water stress had less fruit yield and quality than those in the control treatment. Water deficit also inhibited the uptake of nitrogen, phosphorus and potassium within the plant. The decrease in fruit yield, quality and plant growth induced by water deficit was a consequence of a reduction in both RLER and transpiration.

Key words: eggplant, water deficit, transpiration, plant growth

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Abbreviations: PC – pot capacity, LRWC – leaf relative water content, RLER – relative leaf expansion rate, EL – electrolyte leakage

Introduction

The reduction in growth, yield and quality by water stress has been well documented (Fischer 1980; Kriedemann and Barrs 1981), although different physiological processes have been put forward to account for this reduction in different species. The onset of stress may initially cause a loss of cell turgor which in turn reduces gas exchange and leaf elongation since both are turgor-dependent processes. The result is a decrease in growth rate since this is a function of transpiration rate and leaf area (Chartzoulakis et al., 1993). Evapotranspiration (ET) has been positively correlated with yield of many crops since it is a direct measure of crop water loss. Thus, there has been a growing use of ET data for irrigation scheduling studies. Water stress causes a decrease in transpiration, an increase in foliage temperature and closure of stomata (Tan and Buttery 1982).

Although there have been many studies on the effects of water deficit on yield, comparatively few have addressed the relationship among yield, vegetative growth, and physiological responses to different irrigation regimes, especially in eggplant under semi-arid conditions. The objects of this study was to study the effect of water deficit on plant growth, canopy temperature, nutrient uptake and physiology (chlorophyll concentration and membrane permeability) of eggplants.

Material and Methods

Plant culture and treatments

The experiment was conducted under field conditions in Sanliurfa (Turkey) from the middle of March to the end of July, 2001 with the eggplant (*Solanum melongena* L. cv., Teorem F1). Average daily maximum and minimum temperatures were 39 °C and 17 °C, respectively. Three seeds of eggplant were sown directly in plastic pots containing 8 kg of air dried soil containing manure and sand mixture and after germination, they were thinned to one plant per pot and then plants were grown for further 16 weeks. The containers were covered with black plastic to exclude light from the roots and to prevent evaporation.

Treatments were: (1) control (C): 100% of PC, (2) WS_1: 80% of PC, (3) WS_2: 60% of PC, and (4) WS_3: 40% of PC. Control plants were irrigated to pot capacity (100% PC). Soil water potential was monitored using a tensiometer at 15 cm depth. As soon as soil water potential reached – 10 kPa, these plants were watered to pot

capacity. Water-stressed plants received 80% (80% PC), 60% (60% PC), and 40% (40% PC) of the applied amount of water to the control plant. Before initiating treatments, plants were irrigated to the pot capacity for one week in order to improve root development.

Soil in the pot was the mixture of sand, loamy clay, and manure (1:2:0.5). The pH and electrical conductivity (EC) of the mixture were 7.1 and 0.48 $dS.m^{-1}$, respectively. The pot capacity was 25.5% gravimetrically. N, P and K were applied at the rates of 300, 200 and 250 mg kg^{-1} to the soil for all treatments in granular form. Nitrogen as ammonium sulfate and P and K as mono potassium phosphate were applied in three equal split dressings prior to planting, at flowering and fruit set. N was surface applied and P and K were banded into the soil.

Each treatment was replicated four times in a randomized block design and each replicate included 6 plants (i.e., 24 plants per treatment). Excess water drained through holes in the bases of the containers. In order to determine the influence of water deficit on the leaf growth, two plants per treatment were randomly selected. The area of each leaf was measured with a portable leaf area meter (AM100, Eijkelkamp, The Netherlands) daily. The relative leaf expansion rate (RLER) then was calculated by the formula:

$$RLER = LA_2 - LA_1/LA_2/T_2\text{-}T_1$$

Where LA_1, LA_2 are the initial and final leaf areas and T_1, T_2 are the times of the two measurements.

Crop canopy temperatures were measured weekly with an infrared thermometer (Teletempt Model AG-42). Measurements were made when stress was considered to be maximal (13:00–15:00 h). Fruits were harvested weekly from the middle of June to the end of July for 6 weeks. The values for the fruit yields are the means of the fruit yield of 6 plants per replicate and given in kg per plant. Plant height and diameter were measured at the final harvest.

Chlorophyll concentration

Two plants per replicate were used for chlorophyll determination. Fresh tissue was sampled from the youngest fully expanded leaf (1 g), extracted with 90% acetone and read using a UV/Visible Spectrophotometer (Bausch & Lomb, Belgium) at 663, 645 and 750 nm wavelengths. Absorbance at 750 nm was subtracted from absorbance at the other two wavelengths to correct for any turbidity in solution before chlorophyll concentrations were calculated using the formulae given by Strain and Svec (1966).

$$\text{Chl. } a \text{ (mg.ml}^{-1}) = 11.64\times(A663) - 2.16\times(A645)$$
$$\text{Chl. } b \text{ (mg.ml}^{-1}) = 20.97\times(A645) - 3.94\times(A663)$$

where (A663) and (A645) represents absorbance values read at 663 and 645 nm wavelengths, respectively.

Transpiration

The most reliable method of measuring plant transpiration is to monitor plant weight loss over a given time interval once evaporative losses have been prevented. This method (gravimetric) is easily adapted for potted plants. Transpiration was calculated based on a water balance approach since volumes of water applied to the root zone and drained from the pots were known. There was no rainfall during the experiment. As there were plastic covers on the tops of the containers, evaporation was negligible. In order to determine transpiration, each container was weighed using a portable weighing scale with an accuracy of ±5 g. The weekly transpiration measurements were started in the beginning of April until the end of May 15. Then, daily transpiration measurements (eight times on a daily basis) were made between 15 May and 15 June.

Electrolyte leakage

Electrolyte leakage was used to assess membrane permeability. Electrolyte leakage was measured using an electrical conductivity meter. The procedure used was based on Lutts et al. (1995). Two randomly chosen plants per replicate were used and two tissue samples per plant were taken from the second leaf below the shoot apex and the second leaf above the base to represent developing and mature leaves, respectively, and cut into 1 cm segments. Leaf samples were then placed in individual stoppered vials containing 10 mL of distilled water after three washes with distilled water to remove surface contamination. The samples were incubated at room temperature (ca. 25ºC) on a shaker (100 rpm) for 24 h. Electrical conductivity (EC) of the bathing solution (EC1) was determined after incubation. Samples were then placed in an autoclave at 120ºC for 20 min and EC was determined a second time (EC2) after cooling the bathing solutions to room temperature. Electrolyte leakage was calculated as EC1/EC2 and expressed as percent.

Leaf relative water content

Leaf relative water content (LRWC) was calculated based on the methods of Yamasaki and Dillenburg (1999). Leaves were always collected from mid section of runners in order to minimize age effects. Individual leaves were first removed from stem and then weighed to obtain fresh mass (FM) at the harvest stage. In order to determine the turgid mass (TM), leaves were floated in distilled water inside a closed petri dish. During the imbibition period, leaf samples were weighed periodically, after gently wiping the water from the leaf surface with tissue paper. At the end of the imbibition period, leaf samples were placed in a pre-heated oven at 80 °C for 48 h, in order to obtain dry mass (DM). All mass measurements were made using an analytical scale, with precision of 0.0001 g. Values of FM, TM and DM were used to calculate LRWC using the following equation:

$$\mathrm{LRWC}(\%) = [(\mathrm{FM}-\mathrm{DM})/(\mathrm{TM}-\mathrm{DM})]\times 100$$

Chemical analysis and dry weight determinations

Three randomly selected plants per replicate were divided into leaves, stems and roots, and dried in an oven at 70ºC for two days to determine dry weights and elemental concentrations. Leaves from the same plants were used for chemical analysis. Leaves were washed in detergent solution to remove any dust on leaf surfaces, soaked in 0.5 M HCl for 20 s, followed by 3 to 4 rinses in distilled water and then dried at 70 °C for 48 h to constant weight. The dried leaves were ground to powder using a pestle and mortar and stored in polyethylene bottles. Ground samples (ca. 0.5 g per replicate) were ashed at 550 °C for 6 hours. The white ash was taken up in 2 M hot HCl, filtered into a 50 mL volumetric flask and made up to 50 mL with distilled water. Potassium (K) and phosphorus (P) were determined in these sample solutions. P was analyzed by a vanadate-molybdate method using a UV/visible spectrophotometer (Bausch & Lomb, Belgium) and K was analyzed using a Flame photometer (Corning 400, UK). Total N was determined in samples of 0.1 g dry weight using the Kjeldahl method (Chapman and Pratt 1982).

A Statview ANOVA program was used for statistical analyses of the data. Means were separated by Duncan's multiple range test ($P \leq 0.01$).

Results

Dry matter production and total chlorophyll content were used to assess the effects of water stress on plant growth. The water deficit reduced the growth of each plant component (Table 1). Plant height, stem diameter and dry weights of water-stressed plants were smaller than the equivalent component in the well-watered plants. At 40% PC treatment (WS_3), plant height and stem diameter were reduced by 46% and 51% compared to the control, respectively. Water stress treatments reduced both dry matter and chlorophyll content in the plants. Total plant dry weight was reduced by 27–43% under severe water stress (WS_2 and WS_3). Total chlorophyll content in WS_3 treatment was reduced by 55% compared to C treatment (Table 2).

The water stress treatment (WS_2 and WS_3) resulted in significant (at $P \leq 0.01$) increases in electrolyte leakage compared to C treatment (Table 2). Electrolyte leakage was slightly higher in mature than in developing leaves.

Fruit yield was reduced by up to 68% in the water stressed plants (WS_2 and WS_3) compared with unstressed (C) plants (Table 3). There were also significant reductions in fruit height, diameter and weight under water stress and these reductions were the highest in the WS_3 treatment. These results show that the reduction in fruit weight, diameter and height under stress conditions may be considered as the main reason for the reduction in fruit yield.

Water stress also significantly ($P \leq 0.01$) reduced macroelement concentrations in the leaves (Table 4). The well-watered plants showed higher nutrient concentrations than the water-stressed plants.

Table 1. Effects of different soil moisture levels on dry matter and vegetative growth of eggplants grown in pots

Treatments	Shoot[a] DW, (g plant^{-1})	Root[a] DW, (g plant^{-1})	Whole plant[a] DW, (g plant^{-1})	Root/shoot[a]	Plant[a] height, (cm)	Stem[a] diameter, (mm)
C	40.4 a (100)	7.5 a (100)	47.9 a (100)	0.19 c (100)	78.5 a (100)	14.6 a (100)
WS_1	38.5 b (95)	6.8 b (91)	45.3 b (95)	0.18 c (105)	71.1 a (91)	13.2 a (90)
WS_2	27.4 c (68)	7.6 a (101)	35.0 c (73)	0.28 b (147)	60.5 b (77)	11.4 b (78)
WS_3	19.6 d (48)	7.8 a (104)	27.4 d (57)	0.40 a (211)	42.3 c (54)	7.1 c (49)

Within each column, the same letter indicates no significant differences among treatments (P<0.01). Values in parentheses show percentages relative to the control (i.e., the control=100). C – Control; WS_1 – 80% of PC; WS_2 – 60% of PC; WS_3 – 40% of PC;
[a] Means of four replicates of 3 plants

Table 2**.** Chlorophyll content, electrolyte leakage and leaf relative water content (RLWC) of eggplants grown in pots under different irrigation treatments

Treatments	Chlorophyll content[a] (mg.kg^{-1} fresh weight)			Electrolyte leakage[a] (%)		RLWC (%)
	Chl a	Chl b	Chl a+b	D.L	M.L	
C	1007 a (100)	716 a (100)	1723 a (100)	8.5 c	10.1 c	96 a
WS_1	968 b (96)	685 b (96)	1653 b (96)	12.6 c	15.2 c	90 b
WS_2	725 c (72)	430 c (60)	1155 c (67)	19.9 b	22.7 b	84 c
WS_3	494 d (49)	290 d (40)	784 d (45)	42.6 a	45.2 a	66 d

Within each column, the same letter indicates no significant difference among treatments (P<0.01). Values in parentheses indicate percentages relative to the control (i.e., the control=100). C – Control; WS_1 – 80% of PC; WS_2 – 60% of PC; WS_3 – 40% of PC;
[a] Means of four replicates of 2 plants

Soil moisture levels in the root zone were determined using tensiometer readings. Whenever soil tension reached to –10 kPa level, irrigation was started. The volume

Table 3. Effects of different soil moisture levels on fruit yield and quality of eggplants grown in pots

Treatments	Fruit yield[a] (kg.plant^{-1})	Fruit[a] height (cm)	Fruit[a] diameter (cm)	Fruit[a] weight (g)
C	2.8 a (100)	20.4 (100)	6.5 (100)	255 (100)
WS_1	2.1 b (75)	17.5 (86)	6.1 (94)	195 (76)
WS_2	1.45 c (52)	15.6 (76)	5.2 (80)	140 (55)
WS_3	0.95 d (34)	10.4 (51)	2.1 (32)	95 (37)

Within each column, the same letter indicates no significant differences among treatments (P<0.01). Values in parentheses show percentages relative to the control (i.e., the control=100). C – Control; WS_1 – 80% of PC; WS_2 – 60% of PC; WS_3 – 40% of PC;
[a] Means of four replicates of 6 plants

Table 4. Nutrient concentrations in mature leaves of eggplants grown in pots under different irrigation treatments.

Treatments	Elements[a]		
	N	P	K
C	4.54 a	0.60 a	3.98 a
WS_1	3.87 b	0.41 b	3.17 b
WS_2	3.23 c	0.30 c	2.72 c
WS_3	2.59 d	0.14 d	2.05 d

Within each column, the same letter indicates no significant difference among treatments (P<0.01). C: Control; WS_1 – 80% of PC; WS_2 – 60% of PC; WS_3 – 40% of PC;
[a] Means of four replicates of 3 plants

of water applied to the root zone of plants ranged from 75 mL to 1350 mL per container each day depending on plant growth and climatic conditions. Transpiration rate for the stressed and control treatments is shown in Fig. 1. Transpiration rate was the highest in the control treatment due to well-watered conditions and production of the highest leaf area. Transpiration rate gradually decreased with increasing the incidence of water stress. In general, transpiration rate was highest in the mid day for C and WS_1 treatments. However, for WS_2 and WS_3 treatments, the highest transpiration rate reached the peak point earlier. Transpiration rate in stressed plants (WS_2 and WS_3)

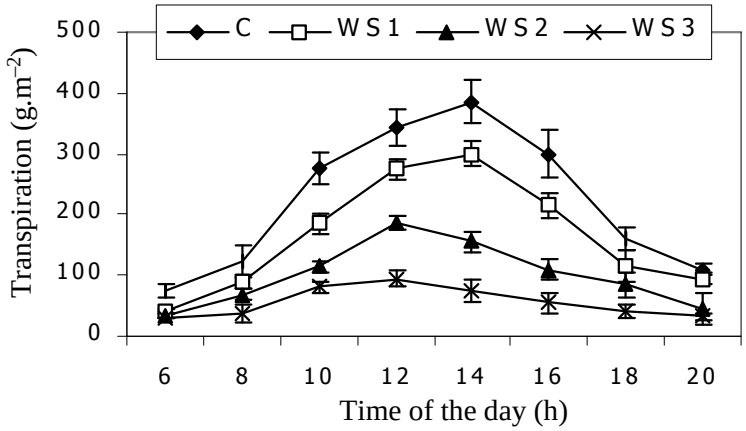

Figure 1. Changes in transpiration rate for well-watered and stressed plants. Vertical bars represent standard errors of the means of four replications.

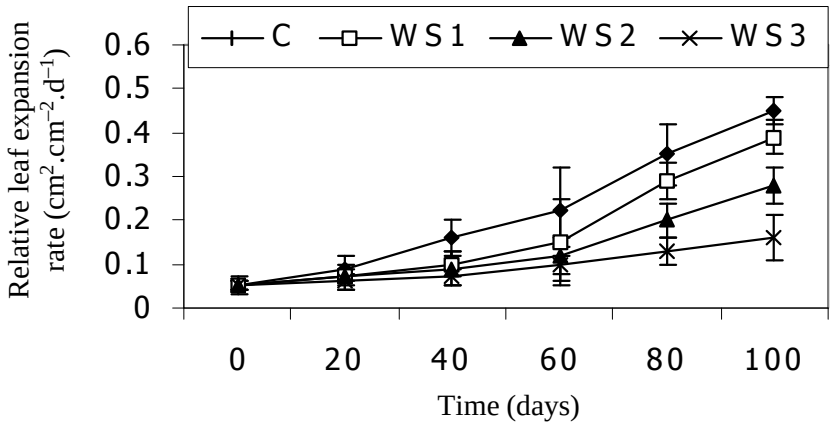

Figure 2. Daily relative leaf expansion rate (RLER) of eggplants in well-watered and stressed plants. Vertical bars represent standard errors of the means of four replications.

mainly remained low throughout the day. The RLER reduced significantly under water stress conditions (WS_2 and WS_3). The RLER of C treatment was almost 4 times higher than WS_3 treatment (Fig. 2). Seasonal averages of canopy temperature and canopy temperature minus air temperature (T_c–T_a) were calculated from 10 April to 20 June (Fig. 3 and 4). The plants receiving most frequent irrigation (C treatment) had the lowest crop canopy temperatures and T_c–T_a values. The extreme T_c–T_a differences ranged from –3.2 °C for the plants receiving most frequent irrigation (C) to a maximum value of +3.6 °C for the plants receiving 40% of PC (WS_3).

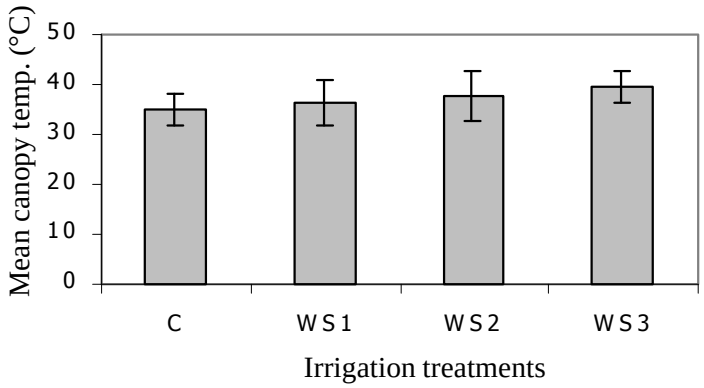

Figure 3. Average canopy temperature as affected by various irrigation treatments. Vertical bars represent standard errors of the means of four replications.

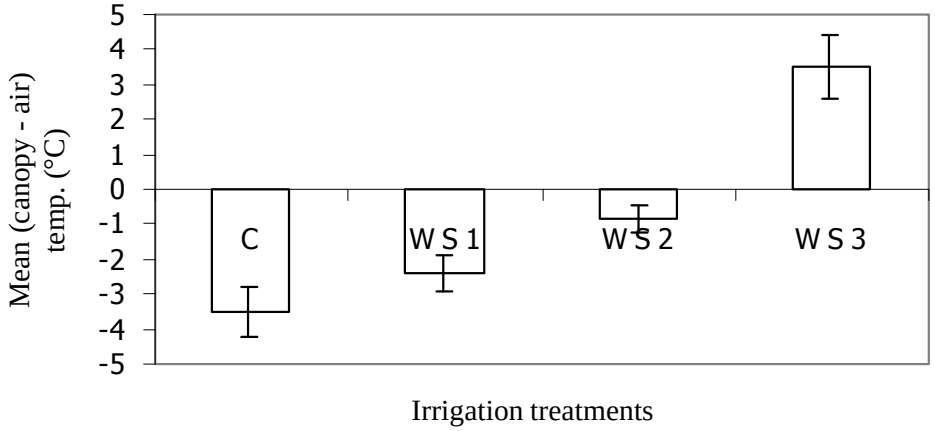

Figure 4. Average canopy minus air temperature as affected by various irrigation treatments. Vertical bars represent standard errors of the means of four replications.

Discussion

Soil water content either directly or indirectly influences plant growth as well as transpiration rate, since they are mainly turgor-dependent processes. At the onset of stress extension growth and leaf expansion are first affected, followed by a decrease in rates of transpiration due to partial stomatal closure potentially. There were significant reductions in dry matter and chlorophyll content at high water stress compared to the control (C). These results are in agreement with the findings of Bradford and Hsiao (1982) and Chartzoulakis et al. (1993). The adverse effect of water stress on chloro-

phyll concentration has previously been shown for young peach trees by Steinberg et al. (1990).

Our results showed that water stress in the container grown eggplants produced a very significant reduction in both dry biomass and total chlorophyll content. Chartzoulakis et al. (1993) reported similar effects of water stress on dry matter in Kiwifruit. It is well known that as soil water availability is limited, plant growth is usually decreased. This was previously considered to be due to turgor loss in expanded cells. More recent studies, however, have shown that stem and leaf growth may be inhibited at low water potential despite complete maintenance of turgor in the growing regions as a result of osmotic adjustment. This suggests that the growth inhibition may be metabolically regulated possibly serving an adaptive role by restricting the development of transpiring leaf area in the water-stressed plants (Sharp 1996).

In our experiment, root growth was less inhibited than shoot growth under water stress (Table 1). This observation is in agreement with studies conducted by Kirnak et al. (2001) who reported that some roots continue to elongate at low soil water potentials that completely inhibited shoot growth.

Seasonal mean canopy temperatures of the plants receiving less water (WS_2 and WS_3) were almost 3.6°C higher than the C and WS_1 plants. The trend in canopy temperature and T_c–T_a values are an indicator of the plant water stress. Besides, it should be noted that canopy temperature is dependent on climatic parameters and internal plant water status. High crop canopy temperature in water-stressed plants may also be related to decreased transpiration rate and LRWC values. There seems to be a positive link between yield and transpiration rate. This is in agreement with the findings of Tan (1993) in tomato. Important increases in crop yield might be possible if irrigation water was applied at the most appropriate time to prevent excessive and nutrient leaching. In order to improve irrigation efficiency, it is necessary to adjust the water application rate based on crop ET.

There were significant reductions in fruit yield in the water-stressed plants compared to unstressed (C) plants. A number of other workers have reported similar effects of water stress on fruit yield and/or biomass reduction for a range of other agricultural and horticultural crops including sorghum (Chaudhuri and Kanemasu, 1982), tomato (Rudich et al., 1977; Tan, 1988), peach (Tan and Buttery, 1982) and strawberry (Kirnak et al. 2001).

Another parameter affected by water stress in our experiments is the electrolyte leakage. The WS_2 and WS_3 treatments induced significant increases in electrolyte leakage compared to the control (C). We suggest that the increase in electrolyte leakage that we have demonstrated under water stress is at least partly due to the combined effects of both reduced water uptake and chlorophyll concentration. Kirnak et al. (2001); Dhindsa et al. (1981); Chen et al. (1991) have linked increased electrolyte leakage to reductions in chlorophyll concentrations (due to leaf senescence) while

Premachandra et al. (1992); McDonald and Archbold (1998) have shown that reductions in water use affect electrolyte leakage.

The leaf concentrations of N, P and K were the highest in the control plants. The concentrations of these elements decreased with increasing the incidence of water stress (Table 4). These findings are in partial agreement with Schier and McQuattie (2000) who showed that K and P concentrations in the leaves of pitch pine were decreased by water stress. Furthermore, in our previous work with strawberry, concentrations of N, P and K were decreased by water stress (Kirnak et al. 2001). This is probably due to less availability of these elements to the plant under water stress condition.

Conclusion

Overall, from the results of this experiment, it can be concluded that water stress significantly decreases leaf chlorophyll concentrations, plant growth, fruit yield but increases membrane permeability in eggplant grown to the fruiting stage. The severe water stress treatment (WS_3) reduses the fruit yield by 66% compared to control treatment (C). High water stress can lower nutrient levels in the leaves. The growth reduction of eggplant, cv. Teorem F1, associated with water stress, appears to be a consequence of a number of different effects of water stress on transpiration, RLER, RLWC, EL and chlorophyll content. The WS_2 and WS_3 treatments reduce plant dry matter by 27% and 43%, respectively.

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