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WATER STRESS AFFECTS GROWTH AND YIELD OF CONTAINER GROWN TOMATO (*Lycopersicon esculentum Mill*) PLANTS

I. C. Sibomana, J. N. Aguyoh* & A. M. Opiyo
Department of Crops, Horticulture and Soils, Egerton University, P.O.BOX 536 NJORO
*Corresponding author: nyamori2001@yahoo.com

ABSTRACT
A study to quantify the effects of water stress on the growth and yield of tomatoes was carried out at Egerton University, Horticultural Research and Teaching Field between 2009 and 2010. Tomato "Money Maker" was subjected to four soil moisture threshold levels of 100%PC, 80%PC 60%PC and 40%PC under randomized complete block design with four replications. Five weeks old tomato seedlings were transplanted into 10-litre pots put under polyethylene covered tunnels. The measurements taken to quantify the effects of water stress on the crop include flower abortion (%), crop yield, fruit equatorial diameter, plant height, stem diameter, internode length, stomata conductance, leaf relative water content (LRWC) and leaf chlorophyll contents. Water stress resulted in significant decreases in chlorophyll content, leaf relative water content (LRWC) and vegetative growth. Severe water stress (40% of PC) reduced the plant height by 24%, stem diameter by 18% and chlorophyll concentration by 32% compared to the control. The highest yield reduction of 69% was observed in the most stressed plants. The decrease in plant growth and yield as a result of water stress can be attributed to the effects water has on the physiology of the crop.

KEYWORDS: Water stress, *Lycopersicon esculentum,* soil moisture levels, pot capacity, crop yield, relative leaf water ratio, stomata conductance

INTRODUCTION

Tomato (*Lycopersicon esculentum Mill.*) is an herbaceous plant and a member of the solanaceae family that includes eggplant, peppers, Irish potato and tobacco (Dobson *et al.,* 2002). Fresh tomatoes and other processed tomato products make a significant contribution to human nutrition owing to the concentration and availability of several nutrients in these products and to their widespread consumption. Tissues of most herbaceous vegetables have about 90% in their vacuoles. Water deficits and insufficient water are the main limiting factors affecting worldwide crop production (Nuruddin, 2001). Plants growing under suboptimal water levels are associated with slow growth and, in severe cases, dieback of stems, such plants are more susceptible to disease and less tolerant of insect feeding (Wilson, 2009). In crops, water stress has been associated with reduced yields and possible crop failure. The effects of water stress however vary between plant species. As the plant undergoes water stress, the water pressure inside the leaves decreases and the plant wilts. The main consequence of moisture stress is decreased growth and development caused by reduced photosynthesis, a process in which plants combine water, carbon dioxide and light to make carbohydrates for energy. Chemical limitations due to reductions in critical photosynthetic components such as water can negatively impact plant growth. The ability to recognize early symptoms of water stress is crucial to maintaining the growth of plants; the most common symptom is wilting (Bauder, 2009). Tomato plants need a controlled supply of water throughout the growing period for optimal quality and higher yield. Tomatoes are very sensitive to water deficits during and immediately after transplanting, at flowering and during fruit development (Nuruddin, 2001). According to Shamsul *et al.* (2008), the water stress at earlier stage of growth (20 day stage) is more inhibitory compared to the later stage (30 day stage). Photosynthetic response to drought is a highly complex in plants. Water deficit inhibits photosynthesis by causing stomatal closure and metabolic damage. Stomata of the leaves that are slightly deficient in water opened more slowly in light and close more quickly in the dark (Nuruddin, 2001). Soil moisture stress reduces leaf water potential which in turn may reduce transpiration (Shibairo *et al.*, 1998). Kirnak *et al.* (2001) have found that water stress results in significant decreases in chlorophyll content, electrolyte leakage, leaf relative water content and vegetative growth; and plants grown under high water stress have less fruit yield and quality. Tomato plants tend to grow a denser root system at soil water potentials which are slightly less than field capacity (Nuruddin, 2001). Tomato plants subjected to different levels of water stress under field conditions (Nyabundi and Hsiao, 2009) had inhibited vegetative growth but enhanced fruit development.

MATERIALS & METHODS

Field experiment to test the effects of water stress on growth and yield of tomato was done in Horticulture Research and Teaching Farm, in Egerton University for two seasons in 2009 and 2010. The farm lies at a latitude of 0^o23'S, longitude 35^o35'E and an altitude of 2238 m. The experimental site receives minimum annual rainfall of 907 mm, and average temperature of 26.4^oC (max) and

7.8^{o}C (min) (Wambua, 2008). Seeds of tomato (Money maker) were purchased from Kenya Seed Company and tested for viability before planting in the nurseries. Five (5) weeks old tomato seedlings were then transplanted into 10 liter pots**.** These pots were filled with 10 kg of air dried soil (a mixture of sand, top soil and manure at the ratio of 2:4:1). The transplanted tomato seedlings were water daily for 14 days before initiating water treatments in order to improve root development. Six pots with one seedling each were randomly assigned to each of the four levels of water until harvesting. The containers were covered with black plastic to prevent evaporation. The pots were put on top of a plastic paper to avoid direct contact with the soil surface. The amount of water to be added was determined based on the percentage of pot water capacity. Treatments included: WS_1 (100% of PC) or control (3000 ml), while stress was achieved by applying 80% (80% of PC), 60% (60% of PC) and 40% (40% of PC) of the amount of water applied to the control plant. The treatments were arranged in a randomized complete block design (RCBD) under polyethylene covered structures

Parameters & Data collection

Growth parameters measured included: Plant height (cm) from the ground to the tip of the plant; Stem diameter (mm) was measured 10 cm from the ground and internode lengths (cm), measured between the trusses. Gravimetric method was applied in monitoring plant transpiration. Possible water loss from the soil surface was reduced to minimal by covering the pot surfaces with black polyethylene. Plants were weighed before any water application was applied to give the weight loss over a period of time. According to Kirnak *et al*. (2001), the gravimetric method is an appropriate way of measuring transpiration in potted plants since the volumes of water applied to the root zone and the volumes of water drained from the pots are known. Transpiration rates were calculated based on a water balance approach. The transpiration was measured by weighing each container using a portable weighing scale with an accuracy of ±5 g. The measurements were taken from April to June 2010 and from July to September 2010.

Relative water content (RWC) is the appropriate measure of plant water status in terms of the physiological consequence of cellular water deficit. The leaf relative water content (LRWC) was calculated based on the methods of Yamasaki and Dillenburg (1999). The leaves were picked from the mid-section of branches. A leaf sample was made up of four leaves, collected from the same branch, and then weighed to obtain the fresh mass (FM). The turgid mass (TM) was recorded when the same leaves were floated in distilled water inside a closed Petri-dish for 24 hours and after gently wiping the water from the leaf surface with tissue paper. After the imbibition period, the dry mass (DM) was taken after the leaf samples were placed in a pre-heated oven at 80^{o}C for 48 h. All mass measurements were made using an analytical scale, with precision of 0.001 g. Values of FM, TM, and DM were used to calculate LRWC, using the equation: LRWC (%) = [(FM – DM)/(TM – DM)] x 100

Two fully mature leaves from each of the two selected plants per treatment were random picked for measurements of stomatal conductance (mmol/m^{2}s) using the Leaf porometer at every water application time. Since light is responsible for stomatal opening, measurements were taken on a clear part of the day. Chlorophyll measurements were done on two fully opened leaves from each of the two tagged plants using SPUD (Minolta SPAD 502 chlorophyll meter). Spud measures chlorophyll content through remote sensing without destruction of leaf tissue. The SPUD Chlorophyll content of each treatment was gotten by averaging all the readings from each plant.

The effects of water stress on the crop yield was measured through estimation of abortion rate, number of fruits, fruit diameter, weight of fruits per plant and the consequent weight per hectare. The number of flowers /truss/plant was recorded and tagged to help in the determination of the flower abortion rate. Abortion (%) was based on the formation of flower buds and fruit primodia. Abortion rate (%) = TFB-FRP /TFB. Where, TFB-Total number of flower buds formed and TFR-Total number of fruit primodia. Fruits were harvested at mature green stage, counted and weighed. Equatorial diameter of the fruits was measured from a sample of 5 fruits from each treatment at every harvest. The data collected were subjected to Analysis of Variance (ANOVA) using SAS version 9.2. Significant means were separated using the Duncan Multiple Range Test (DMRT) at $\alpha \leq 0.05$.

RESULTS

Growth parameters

Changes in the plant height stem diameter and internodes length were used to study the effects of water deficit stress on the growth of tomato plants. The data were pooled for each parameter before the statistical analysis was carried out due to lack of significant differences between the two trials. The highly stressed plants (40% PC) were shorter by 22% compared to the tomato plants from the control treatment at 90 DAP. For internode length and diameter, plants that received more 60% PC and above had longer internodes (up to 36%) compared to those that received 40% (Table 1)

TABLE 1: Height, stem diameter and internode length of tomato as influenced soil moisture levels

Water Level (%Pot Capacity)	Height (cm)	Stem Diameter (mm)	Internode Length (cm)
100	83.8a	10.0a	19.4a
80	84.7a	9.5ab	18.0ab
60	80.6a	9.4ab	16.6ab
40	65.1b	8.9b	12.5b

*Means with the same letter(s) within a column are not significantly different at $P \leq 0.05$

Physiological parameters

Our results show that water stress affected chlorophyll content, stomatal conductance, Leaf Relative Water Ratio (LRWC) and transpiration rate of the pot grown tomato (Table 2).

Chlorophyll content

In this study, soil moisture deficit influenced the chlorophyll content of tomato plants. Total chlorophyll concentration of plants that received 40% PC was lower by 32% compared to those subjected to 100% PC of water.

Stomata conductance

Well watered plants had generally higher stomata conductance of 228 mmol/m^{2}s compared to the plants grown under 40%PC that had low stomatal conductance of 94 mmol/m^{2}s**.**

Leaf Relative Water Content (LRWC)

It estimates the current water content of the sampled leaf tissue relative the maximal water content it can hold at full turgidity. Leaf Relative Water Content (LRWC (%) = [(FM–DM)/(TM–DM)] x100) of the tested plant leaves were dependent on the pot water levels. There was a consistent reduction (y = 93.78-4.84x; R^2 = 88%) of the LRWC (%) with the decrease in the amount of water available in the pots. The leaf relative water content was reduced by 24.7% in the most stressed plants (40% PC) compared to the control (100% of PC)

TABLE 2: Effect of water application levels on selected physiological parameters of tomato

Water levels	Chlorophyll	Stomata conductance	RLWC^z
(%Pot Capacity)	(Spud readings)	(mmol/m^{2}s)	(%)
100	61.45a*	227.50^{x}a	87.73a
80	52.08ab	157.63bc	84.56ab
60	51.65ab	202.38ab	79.90ab
40	41.85b	94.00c	66.18c

*Means followed by the same letter within a column indicate no significant differences in the treatments (P<0.05). ^{z}LRWC is Leaf Relative Water Content

Transpiration rate

There was a reduction in transpiration by 46% in the most stressed plants (40% of PC) compared to the control (Figure 1). The highest rate of transpiration was observed in plants that received 100% PC

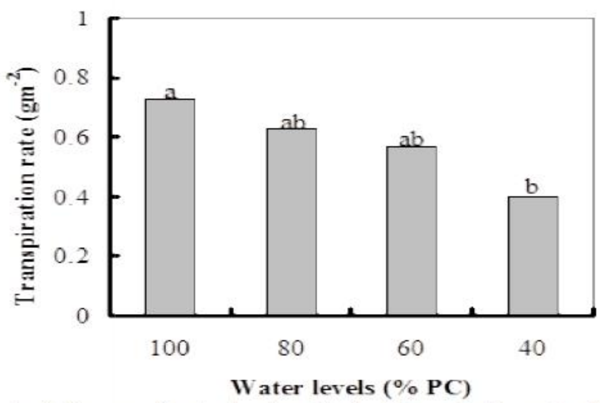

Fig. 1. Influence of water level on the leaf transpiration rate of tomato

Yield parameters

The results obtained show that soil moisture deficit had an effect on abortion rate, fruit diameter, number of fruits per plant and yield per hectare

Flower abortion

The results confirm significant differences in flower abortion among the treatments. The highest percentage (22%) of flowers that aborted was recorded in the most stressed plants (40% of PC) compared to the control (100% of PC) in the 3rd and 4th trusses (Table 3). The number of flower buds that failed to form fruit premodia increased with a decrease in water levels (R^2=82%) (Fig. 2).

TABLE 3: Flower abortion (%) of tomato as influenced by trusses distance under different soil moisture levels

	Number of trusses			
Water Levels (%PC)	1	2	3	4
100(Control)	5.05a*	3.57a	6.65b	9.73b
80	3.95a	5.92a	5.45b	5.99b
60	3.45a	6.16a	2.78b	13.56b
40	3.57a	8.66a	19.38a	43.83a

*Means with the same letter(s) within a column are not significantly different at P ≤ 0.05

%PC-Percentage of water added to a pot relative to the control (100%)

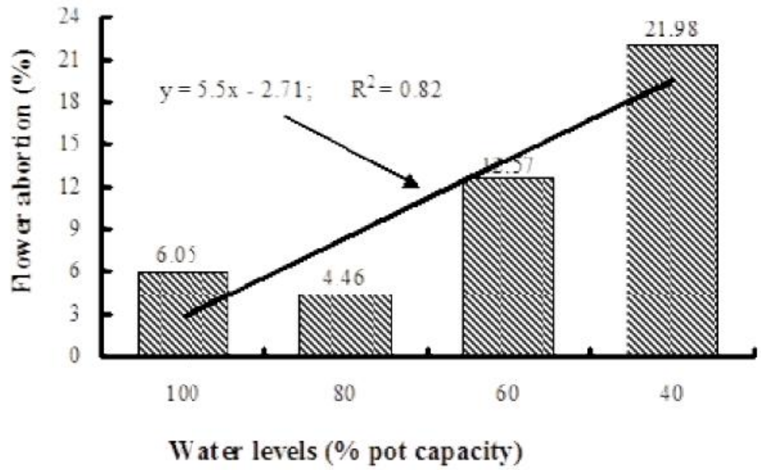

FIGURE 1: Flower abortion (%) as influenced by water levels (%PC)

Fruit number and diameter: Significant differences were noted between the treatments regarding the number of fruits per plant and average fruit diameter in both trials. Number of fruits per plant was reduced by between 25 to 34%, while the average equatorial diameter of the fruits subjected to the highest water stress was 11.5% to 19% lower compared to the control (Table 4)

TABLE 4: Influence of different soil moisture levels on the fruit number and diameter (Trial 1 and Trial 2**)**

	Trial 1		Trial 2	
Water Levels	Fruits/plant	Dia. (mm)	Fruits/plant	Dia. (mm)
100% PC(Control)	46.03a	31.29ab	48.0a	33.4a
80% PC	41.3ab	33.38ab	41.8a	33.0ab
60% PC	37.5ab	32.25a	43.5a	30.5b
40% PC	34.5b	27.66c	31.3b	27.0c

*Means with the same letter(s) within a column are not significantly different at P ≤ 0.05
%PC-Percentage of water added to a pot relative to the control (100%)

Total yield per hectare

There was a general reduction in the yield as the stressed level increased. In both trials, the lowest yield was obtained in the most stressed plants compared to the control. While the highest fruit yield of 69.5 t/ha was observed in plants subjected to 100% PC in the 2nd trial, the most stressed plants on the same trial only produced 25 t/ha of the tomato fruits (Fig. 3).

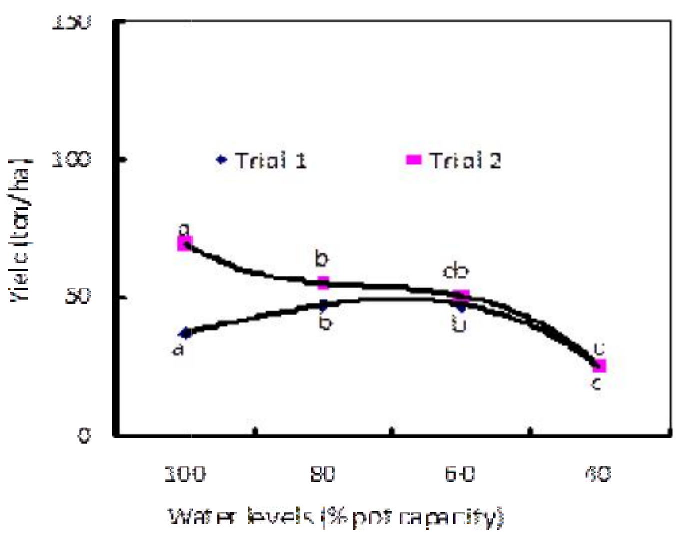

FIGURE 2: Influence of different soil moisture levels on the fruit yield (ton/ha)

DISCUSSION

In this research there was a significant reduction in height and diameter of plants subjected to high water stress. Results from this study are similar to those found by Kinark *et al.* (2001) where plant height and stem diameter of water stressed plants were smaller than the equivalent component in the well-watered plants. Similar effects of water stress were also observed on dry matter in Kiwifruit (Chartzoulakis *et al.*, 1993) and muskmelon (Zeng *et al.*, 2008). Bradford and Hsiao (1982) and other investigators have shown that stem and plant growth may be inhibited at low water potential despite complete maintenance of turgor in the growing regions as a result of osmotic adjustment. Klepper *et al*. (1971) indicates that the stem diameter changes reflect changes in stem tissue hydration. On the other hand, well watered plants had an increase in internode length compared to the moderate and severe stressed plants, for it is well known that as soil water availability becomes limited, plant growth is usually decreased. It was reported that when tomato plants are subjected to different levels of water stress under field conditions, vegetative growth is inhibited (Nyabundi and Hsiao, 1989). However, Kamrun, *et al.* (2011) observed no difference in the height of tomato plants subjected to different water levels. The authors attributed the lack of response to the fact that when water becomes available after a short period of stress, growth is very rapid such that there will be no net observable reduction in the tomato plants subjected to different water stress. In one of the plant physiology investigation, a 40% reduction in the transpiration rate of wilted plants tomato plants was reported compared to the control with a smaller reduction in transpiration rate when a substantial part of the tomato root system (75%) is subjected to moisture stress (Sharp, 1996). It is also possible 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). However, Kirnak *et al.,* (2001) attributed the observed decreases in rates of transpiration to partial stomatal closure caused by water stress.

Several changes in plant growth and developmental processes are often observed in plants that are slow water stress overtime (Taiz and Zeiger, 1998). Our results concur with the previous findings reported by Nuruddin *et al*. (2003) that photosynthesis and transpiration are inhibited immediately after receiving the water stress, but gradually recover under continuous stress treatment. El Jaafari (2000) reported that water deficit exert a negative effect on relative water content, thus the ability of the plant to survive severe water deficits depends on its ability to restrict water loss through the leaf epidermis after the stomata have attained minimum aperture. It should be kept in mind that the more water is absorbed during imbibitions, the greater the turgid mass and the smaller the corresponding value of relative water content. The first two initial trusses had no flower abortion irrespective of the amount of soil moisture. However, as the truss distance increased, the amount of flower abortion also increased. For example, the 4th truss had 78% abortion in the most stressed plants compared to the control. When abortion (%) was compared among the water treatments, the most stressed plants aborted 50% of the flowers formed, which was 72% more compared to the control (100% PC) (Fig 2). The high percent abortion observed in severe stressed plants may be explained by the fact that as the water stress increases, the number of ovules per floret decreases. It is widely reported that irrigation deficit in the 1st growth period reduces the number of flowers leading to a decrease in the number of fruits and in the marketable yield. Our results are in agreement with the findings of Turner (1993) who stipulated that water stress increased floret abortion and premature death of whole flower heads. Both fruit diameter and yield of tomato were also affected by water stress. Birhanu and Tilahun (2010) reported a decreased number and sizes of tomato fruits from plants subjected to moisture stress. The same observation of water stress on tomato yield parameters was also reported by Zotarelli *et al.,* (2009). In this research, general growth and yield of tomato plants subjected to severe water stress were significantly reduced compared to the well watered plants. It is possible that at 40 % PC the plant tissues did not get enough water for optimum physiological functioning.

CONCLUSION

The response of tomato plant to different water stress levels can be used for optimization and sustainability of tomato production in areas where water sources are limited or expensive

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