Research Application Summary

Growth and physiological changes of tomato as influenced by soil moisture levels

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Abstract

Tomato (*Lycopersicon esculentum* Mill.), as in most fruit vegetables, is often exposed to stresses either imposed by other organisms (biotic) or arising from imbalance of environmental factors (abiotic). Water management is a key factor that can influence tomato production since the crop is affected by both deficit and surplus irrigation water. Bringing the optimum irrigation water to the crop might reduce field losses during production. The effect of five different soil moisture levels (40, 55, 65, 80 and 100% (control)) was studied in tomato cv Money Maker planted in pots under greenhouse conditions. The 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 decrease in plant growth as a result of water stress could be attributed to reduction in the transpiration rate that was observed.

Key words: *Lycopersicon esculentum*, pot capacity, soil moisture levels, water stress

Résumé

La tomate (*Lycopersicon esculentum* Mill.), Comme dans la plupart des légumes fruits, est souvent exposée à des contraintes, soit imposées par d’autres organismes (biotiques) ou découlant d’un déséquilibre des facteurs environnementaux (abiotiques). La gestion de l’eau est un facteur clé qui peut influencer la production de tomates au moment où la récolte est affectée par le déficit et l’excédent d’eau d’irrigation. E apportant l’eau d’irrigation optimale à la récolte, cela peut réduire les pertes sur le terrain pendant la production. L’effet de cinq différents niveaux d’humidité du sol (40, 55, 65, 80 et 100% (de contrôle)) a été étudié chez la tomate cv Money Maker plantées dans des pots en serre. Le stress hydrique a entraîné une diminution significative de la teneur en chlorophylle, la teneur des feuilles en eau relative (LRWC) et la croissance végétative. Le stress hydrique sévère (40% des PC) réduit la hauteur de la plante de 24%, le diamètre de la tige de 18% et la concentration en chlorophylle de 32% par rapport au contrôle. La diminution de la croissance des plantes en raison du stress hydrique pourrait être attribuée à la réduction du taux de transpiration qui a été observée.

Mots clés: *Lycopersicon esculentum*, la capacité de pot, les niveaux d'humidité du sol, le stress hydrique

Background

Tomato (*Lycopersicon esculentum* Mill.) is an herbaceous plant and a member of the solanaceae family that includes crops such as eggplant, peppers, Solanum 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. Composition tables show that ripe tomato contains 93-95% water and low levels of solid matter (Wikipedia, 2008). Tissues of most of the herbaceous vegetables have about 90% in their vacuoles.

Water deficits and insufficient water are the main limiting factors affecting crop production worldwide (Nuruddin, 2001). Water stress, which is caused by insufficient soil moisture, is among the chief causes of poor growth or poor health in plants. It is responsible for slow growth and, in severe cases, dieback of stems. It also makes plants more susceptible to disease and less tolerant of insect feeding (Wilson, 2009).Plant water stress resulting from insufficient soil moisture can have major impacts on plant growth and development. In crops, plant water stress has been associated with reduced yields and crop failure. 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. Photosynthesis is the 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.

Literature Summary

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 (Doorenbos and Kassam, 1979; Nuruddin, 2001).

According to Samshul *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).Vegetable seeds require water to germinate. Tomato seeds need a suitable amount of water and adequate supply of oxygen just after the germination has started (Nuruddin, 2001). A study conducted on tomato line Apedice to determine the effects of water stress (induced by 10% and 20% PEG-6000) on the growth reported that seedling growth responses were dependent on the genotype and the severity of the stress applied (Shtereva *et al.,* 1999).

Photosynthetic response to drought is highly complex. 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 closed more quickly in the dark (Nuruddin, 2001). Stomatal closure is the main cause for transpiration decline as water stress develops and is generally the dominant mechanism in restricting transpiration rates in mesophytes during development of water stress.Soil moisture stress reduces leaf water potential which and in turn may reduce transpiration (Shibairo *et al.,* 1998). Kirnak *et al.* (2001) found that water stress resulted in significant decrease in chlorophyll content, electrolyte leakage, leaf relative water content and vegetative growth; and plants grown under high water stress had less fruit yield and quality. On the other hand excessive water (waterlogged) adversely affects shoot growth by restricting internodal elongation, leaf initiation and expansion by inducing epinasty of leaf and petiole, leaf senescence, leaf chlorosis, and leaf abscission. In flooded tomato plants the stem base often swells. The most common type of root response in flood conditions is the development of adventitious roots on the stem above the soil and usually in the flood zone. 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.

Study Description

The study was conducted at the Egerton University Research and Teaching Field. The trial was conducted from February to July 2010. Egerton is located at approximately latitude 0°23' south, longitude 35° 35' East and at an elevation of 2238 m above sea level (Kassilly, 2002). The area receives a moderate mean rainfall of 1012mm. The average temperature during the research period ranged from 7ºC (min) to 22ºC (max). Greenhouse temperatures ranged from11ºC to 35ºC (max).

Four seeds of tomato were sown directly in plastic pots containing 10kg of dried soil. The seedlings were thinned to one per pot two weeks after germination. The pots were covered with black plastic to exclude light from the roots and to prevent evaporation. The water treatments were: (1) control (C): 100% of PC, (2) WL_2: 80% of PC, (3) WL_3: 65% of PC, (4) WL_4: 55% of PC, and (5) WL_5: 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, the plants were watered to pot capacity. Water-stressed plants received 80% (80% PC), 65% (65% PC), 55% (55% 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 of the mixture was 6.8. Nitrogen was applied as Diammonium Phosphate (18%N) at planting and as Calcium Ammonium Nitrate (26%N) in two splits, four weeks after planting and at the flowering, but before fruit set. Each treatment was replicated four times in a randomized block design with six plants per replicate to allow for destructive sampling. Excess water was 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 parameters recorded were: Plant heights, chlorophyll concentration, stem diameter and Leaf relative water content (LRWC). Leaves from two plants were randomly picked for the determination of chlorophyll content and stomatal conductance per plot. The SPUD (Minolta SPAD 502 chlorophyll meter) was used to measure chlorophyll content of a tagged leaf (Four leaves on the second node from the top). The instrument measures chlorophyll content through remote sensing without destruction of leaf tissue. Using the readings from the chlorophyll meter (SPUD), chlorophyll content of each plot was obtained by averaging the readings from the two plants.

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 biweekly measurements were taken from April to June 30, 2010.

Similarly, fully mature leaves from two plants per treaments were picked at random and used in taking biweekly measurements of stomatal conductance ($mmol/m^2s$) using the leaf porometer from April 30th 2010 to June 30th 2010. Measurements were taken from the four fully expanded leaves on the 2nd node from the top. 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 the 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 0.0001g. Values of FM, TM and DM were used to calculate LRWC using the following equation: LRWC (%) = [(FM–DM)/(TM–DM)] x 100.

This was a two-factor factorial experiment with 4 replications in a Randomized Complete Block Design (RBCD). All data collected were be subjected to analysis of variance using SAS 2002 and means that were significantly different according to the F test were then separated by Duncan’s multiple range test at Pd”0.05.

Research Application

Changes in stem diameter, plant height and chlorophyll content were used to study the effects of water stress on the growth of tomato. Plant height of the most stressed plants was reduced by 24% compared to the control (Fig. 1). The smallest stem diameter of plants was observed in those that received the least amount of water. The average diameter of these plants was 18% lower than those of the control (Fig. 2). The amount of

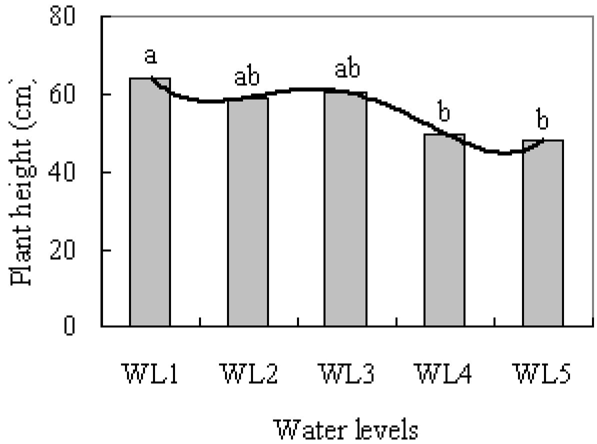

Figure 1. **Percent change in the height of tomato as affected by the soil moisture level.**

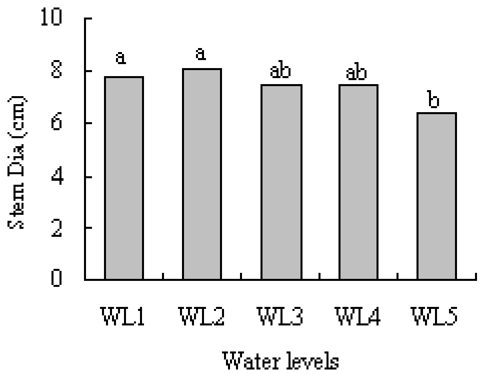

Figure 2. **Influence of water level on the stem diameter of tomato.**

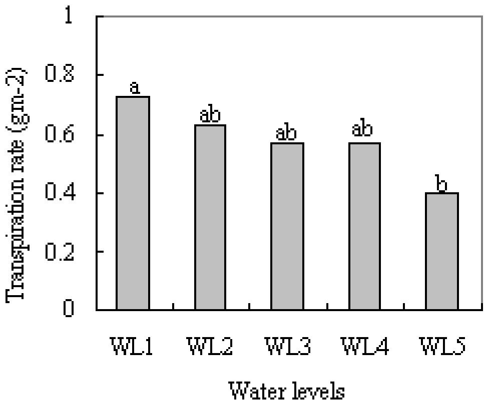

Figure 3. **Influence of water level on the leaf transpiration of tomato.**

moisture in the soil within the root zone of tomato was determined using tensiometer readings. Water was added whenever soil tension reached to –10 kPa level. The volume of water applied to the root zone of plants was dependent on the plant growth stage, humidity and air temperature within the green house. However, the amount ranged from 100 to 850 Ml per container. Transpiration rates for the different treatments are shown in Figure 3. Transpiration rate was highest in the control ports (100%PC) which received optimal amount of water throughout the plant growth. Transpiration rate of the most stressed plants was 32% lower compared to the control (Fig. 3).Water stress also affected chlorophyll concentration, stomatal conductance (STC) and Leaf Relative Water Content. Total chlorophyll concentration of plants that received 40% of pot capacity was lower by 32% compared to those subjected to 100PC of water. Well watered plants had generally a higher stomata conductance relative to plants that received 40% of the pot capacity. 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; R2 = 88%) of the LRWC (%) with the decrease in the amount of water available in the pots (Table 1).

Table 1. Effect of water application levels on selected physiological parameters of tomato.

Water levels$_y$	Chlorophyll (Spud readings)	STC (mmol/m^{2}s)	RLWC (%)
Control	61.45a^z	227.50^{x}a	87.73a
WL$_2$	52.08ab	157.63ab	84.56ab
WL$_3$	51.65ab	202.38ab	79.90c
WL$_4$	46.75ab	110.13b	78.35c
WL$_5$	41.85b	94.00b	66.18c

Key: ^{z}Means followed by the same letter within a column indicate no significant differences in the treatments (P<0.05).

^{y}The treatments were given in relation to the amount of water in the pots: Control=100% PC). WL$_2$ – 80% of PC; WL$_3$– 65% of PC; WL$_4$ – 55% of PC; WL$_5$ – 40% of PC, STC –Stomatal Conductance, LRWC-Leaf Relative Water Content

Many researchers have linked physiological changes in plants either directly or indirectly to soil water content. Plant growth and transpiration rates have been closely linked to water availability since both are turgor-dependent processes. It is well known that as soil water availability is reduced, plant growth is usually decreased. Soil water stress reduces leaf water potential and this has been associated with reduced transpiration (Kramer, 1983; Shibairo *et al.*, 1998). 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. Changes in the leaf size and transpiration rate are more visible at the start of water stress due to stomatal closure. In this research, there were significant reductions in the growth of potato plants, both in width (stem diameter and height) as well as chlorophyll content at high water stress compared to the plants at 100%PC. The reduction in shoot growth (Figs. 1 and 2 and Table 1) that we observed is in agreement with those reported by Kirnak *et al.* (2001). The author observed 41% and 51% in height and stem diameter of eggplants subjected to 40% of PC compared to the control. According to Kirnak *et al.* (2001) the inhibition of shoot growth at low soil water content could be attributed to reduced root elongation and its inability to extract the limited water at low soil water potential. These results are also in agreement with those reported by Bradford and Hsiao (1982) and Chartzoulakis *et al.* (1993). Steinberg *et al.* (1990) reported reduction of chlorophyll concentration in peach trees subjected to different levels of water stress. Our results showed that water stress in the container grown tomatoes produced a very significant reduction (32%) in total chlorophyll content. 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).

Recommendation

Based on the results of this study, reduced chlorophyll content and plant growth are directly related to soil water availability. Severe water stress reduced the plant height by 24% and chlorophyll concentration by 32% compared to the control. Changes in the stomatal conductance as a result of water stress affected transpiration rate and the overall performance of the tomato crop. From the results, it can be recommended that for optimum growth of tomato plants, soil water should be maintained at between 80% to 100% of the field capacity

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