Some Effects of Soil and Ambient Air Temperature Differences on Tomato Growth[1]

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Abstract

An experimental laboratory study was designed to evaluate the effect of temperature difference combinations on the growth response of tomato seedlings. Growth indices were changes in stem diameter, root-mass length, and stem height. The stem diameter was continuously monitored with a specially designed electronic micrometer.

An endogenous cyclic pattern of change in stem diameter was noted as a function of the light and dark intervals. Increases in root temperatures up to 35°Centigrade (95° Fahrenheit) for periods of approximately four days had at least temporary beneficial effects on growth. However, further increases in root temperature were deleterious to growth, particularly root development.

Introduction

One of the most troublesome environmental problems in the United States is thermal pollution in water. It is readily apparent, due to the importance of temperature on metabolic and respiratory processes of living organisms, that release of large volumes of heated water to waterways and lakes can be an upsetting influence on natural life cycles. Heated waste water, because of its low grade temperature condition, has little industrial value and controls are both costly and complicated. Mechanical cooling towers and cooling ponds are the most common methods of controlling waste heat output but both are rather inefficient with little capital return accruing to their use. A possible alternative would be to find beneficial uses of the heated waste water.

One proposed solution is to use the heated water for irrigation and environmental control of crops. However, depending on the means of application of this water to plants, relatively large temperature gradients between plant tops and the root systems could exist.

The purpose of the reported study was to evaluate some of the effects of soil and ambient air temperature differences on the growth response of tomato seedlings which might occur as a result of using thermally polluted water as the source of water for irrigation (1).

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Literature

Plant growth may be defined as cell multiplication with or without an increase in volume or an increase in volume without cell multiplication. In the reported study only non-destructive measurements of volume were used as indices of plant growth. Measurement of stem diameter was after Splinter (5) who reported on the design of an electronic micrometer using a linear variable differential transformer to give continuous monitoring of plant stem diameter. Using this device, he also showed a high correlation coefficient between stem diameter and total leaf area for plant species exhibiting apical dominance.

The effect of temperature gradients between plant tops and their root systems has been previously investigated (4) but more so in recent years (3, 6) because of the possibility of thermally polluted soil water and because of improvements in instrumentation and experimental control. Currently, Boersma from Oregon State University is studying the effects of heating soil under field conditions by using buried electrical cables to simulate irrigating with thermally polluted water (2).

Equipment and Procedure

Three-week old tomato seedlings (Heinz 1350) were "transplanted" from a gravel to a mist culture. Transplanting was accomplished by securing a plant stem in the top side of a root environmental chamber with a cork and floral putty so that the root system would extend into the chamber. The root environmental chamber was in turn contained within a larger growth chamber as shown in Figure 1.

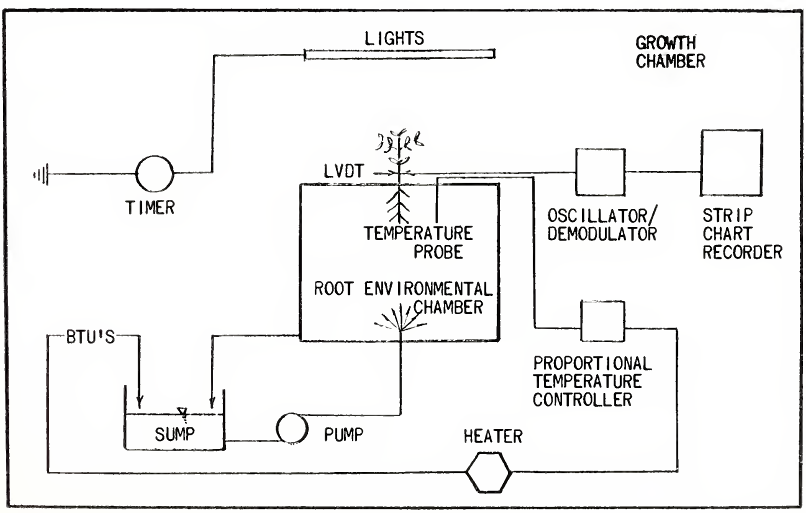

FIGURE 1. *Experimental setup showing the root environmental chamber within the larger growth chamber.*

Nine different root-top temperature combinations were used. Ambient air temperatures of 20 and 25°C were combined with 5°C increments of "soil" temperatures ranging from that of the ambient air to 40°C.

In the root environmental chamber, the plant roots were continuously sprayed with modified Hoagland's #1 nutrient solution. The temperature of the solution was controlled by a temperature probe, a proportional temperature controller, and a heater to ±0.25°C once equilibrium conditions were established. The root environmental chamber, which was transparent, was covered to provide a darkened space for root growth.

In the growth chamber, the air temperature was controlled at either 20 or 25°C ± 0.3°C, the relative humidity at 70 ± 2%, and the light intensity at 1200 ± 100 ft-c. The day was divided into 16-hour continuous light and 8-hour continuous dark periods.

The growth response of the tomato seedlings was evaluated from changes in stem diameter which were continuously monitored with an electronic micrometer and from changes in root-mass length and stem height over the time period for each experiment. Each experiment lasted approximately 4 days. For any one experiment only the stem diameter of one tomato plant was measured. The equipment used to measure stem diameter consisted of an LVDT (linear variable differential transformer) head assembly, an oscillator/demodulator (Automatic Timing & Controls, Inc., Series 6101E) and a potentiometric strip chart recorder. This equipment is schematically represented in Figure 1 and the LVDT head assembly in position for monitoring change in stem diameter is shown in Figure 2.

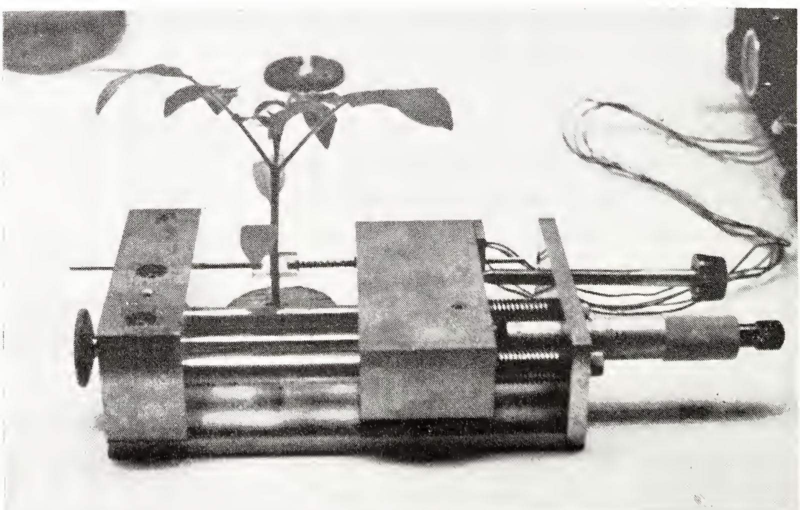

FIGURE 2. *LVDT head assembly positioned for monitoring change in stem diameter of a tomato plant.*

The LVDT (ATC No. 6233A) was enclosed in a precisely machined central housing. The head assembly was constructed of non-magnetic stainless steel and Plexiglas to prevent stray electrical current interference with the LVDT. A micrometer head (Starret Co. T263RL) was used to provide precise mechanical positioning of the LVDT armature in the center or null position of the coil.

The LVDT head assembly provided a non-destructive means of measuring stem diameter. The only back pressure, considered negligible, was caused by a small coil spring which was used to keep the LVDT in constant contact with the plant stem. When operating, the oscillator/demodulator was used to excite the LVDT primary coil, amplify the a-c output with phase sensitivity and convert it to a d-c signal suitable for direct readout on the strip chart recorder. The readout was thus directly proportional to the differential transformer armature displacement. Readings of 10^{-3} mm were considered accurate without readout interpolation.

Results and Discussion

The growth response of a tomato plant with leaf temperatures of 20 and 25°C, respectively, and root temperatures ranging from 20 to 40°C are shown in Figures 3 and 4. These curves were smoothed through many data points which also exhibited diurnal fluctuations. At a 40°C root temperature for both leaf temperatures, increases in stem diameter did not occur after 72 hours. Prior to this time, the roots of

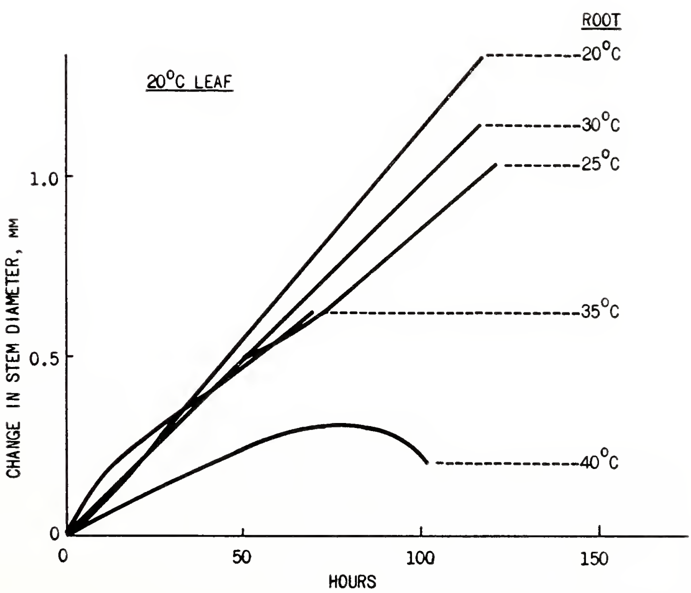

FIGURE 3. *Growth response of tomato plants with 20°C leaf temperature and root temperatures ranging from 20 to 40°C.*

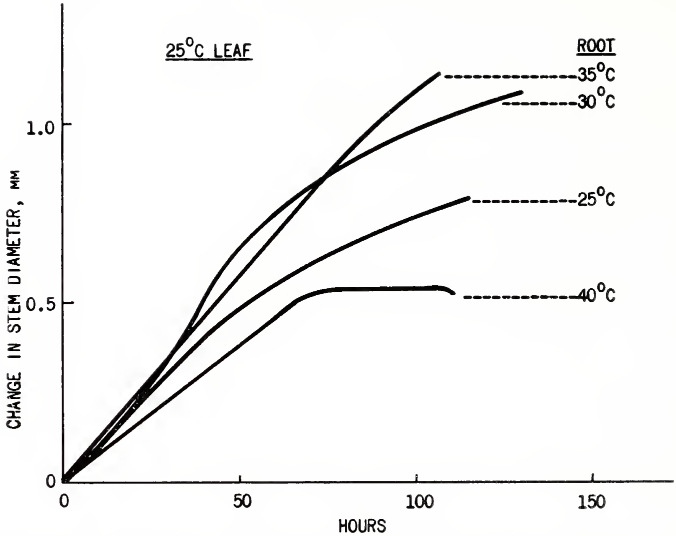

FIGURE 4. *Growth response of tomato plants with 25°C leaf temperature and root temperatures ranging from 25 to 40°C.*

the tomato plants showed little secondary root growth and were much darker in color than had been observed with any of the lower root temperatures. However, little visual damage to the leaf and stem portions of the plants was noted up to 72 hours but by 96 hours severe wilting and obvious death had occurred.

For all root temperatures less than 40°C, the stem diameter increased throughout the length of the experiment for both leaf temperatures. Trends if any between these root temperatures were not discernible for a given leaf temperature. However, increases in stem diameter were more linear for the 20°C than for the 25°C temperature during this stage of plant growth.

Effects of root temperature on the growth rate of tomato plants as measured by stem and root-mass lengths are shown in Figures 5 and 6. Both the stem and root-mass lengths are the average of three tomato plants for any one experiment. The maximum growth rate as measured by stem length occurred at a 30°C root temperature for both the 20 and 25°C leaf temperatures. The growth rate for the 25°C leaf temperature, however, was about double that of the 20°C leaf temperature. The maximum growth rate as measured by root-mass length occurred when the root temperature was 5°C higher than the leaf temperature. The 25°C leaf temperature condition produced about 1.5 times the growth rate of the 20°C leaf temperature when root-mass length was used as the growth index. The optimum temperatures for obtaining maximum stem and root-mass growth in these experiments were 25°C leaf and 30°C root temperatures.

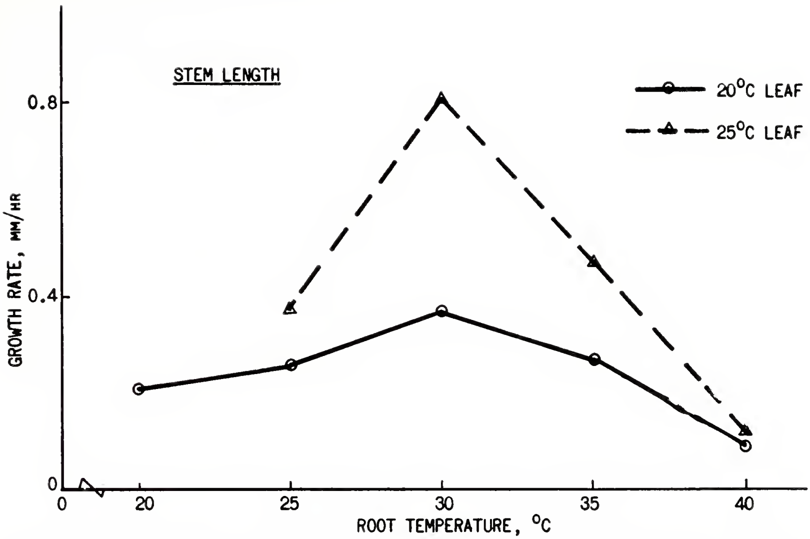

FIGURE 5. *Effect of root temperature on the growth rate of tomato plants as measured by stem length.*

In all experiments, the diameter of the plant stem changed with respect to the light and dark periods. Figure 7 is an expanded example of the diurnal growth response of a tomato plant with 20°C leaf and 20°C root temperatures. The growth rate based on change in stem

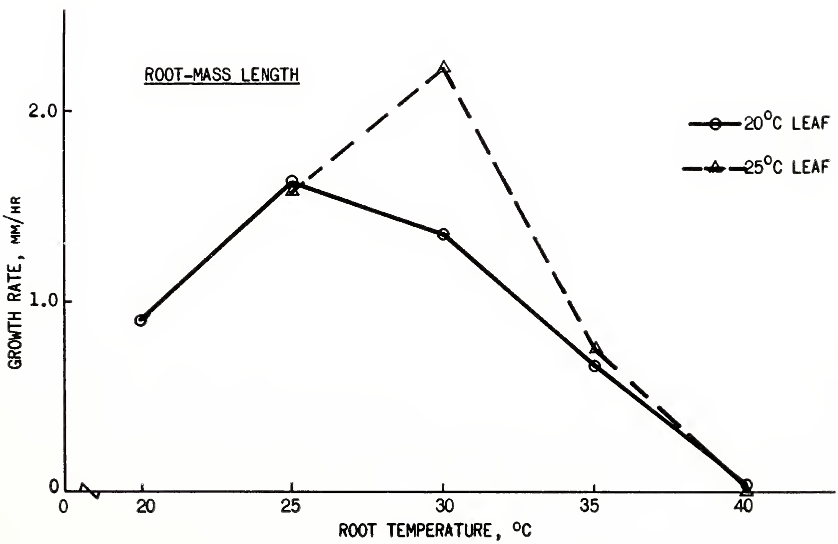

FIGURE 6. *Effect of root temperature on the growth rate of tomato plants as measured by root-mass length.*

diameter tended to decrease over the latter portions of both the light and dark intervals. This condition may have been caused by "fatigue" during the light periods and consumption of photosynthetic products during the dark periods. A rapid increase in stem diameter always occurred shortly after the climate chamber was darkened. This rapid increase in growth was probably caused by a change in the water regime within the plant. Turgor pressures tended to increase rapidly because of the closing of the stomata in the absence of light and because of the probable cooling of the leaves which would cause the energy available for transpiration to decrease.

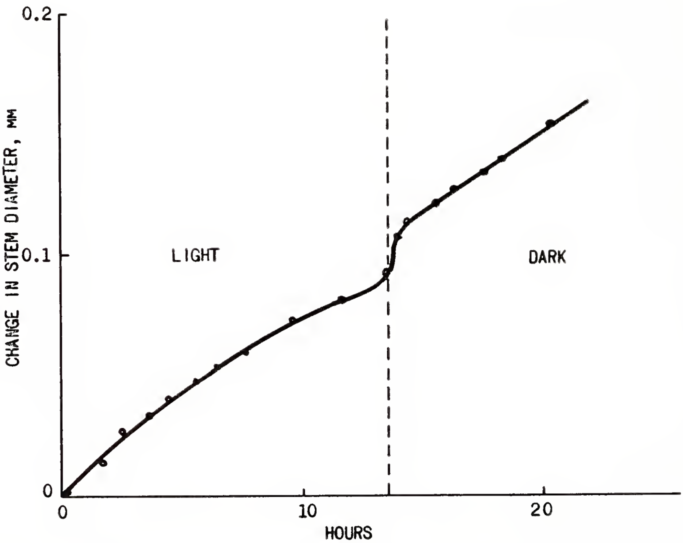

FIGURE 7. *Diurnal growth response of a tomato plant with 20°C leaf and 20°C root temperatures.*

Conclusions

Based on this study, the optimum temperatures for this stage of tomato plant development appear to be 25°C (77°F) leaf and 30°C (86°F) root temperatures. At these temperatures, the rate of growth as measured by increases in stem length and root-mass length was maximum. The rate of growth as measured by increases in stem diameter, although not always maximum under these temperature conditions, was always high. A continuation of these optimal conditions might be expected to result in maximum fruiting but this is only conjectural.

The LVDT head assembly provided a versatile and highly precise means of measuring changes in stem diameter in a non-destructive manner. Its precision was illustrated in the manner by which it was able to measure the small cyclical changes occurring between light and dark periods.

At 40°C (104°F) root temperature, the tomato plants died. The deleterious effect of this temperature was quickly noticed by the condition of the root system but approximately 3 days passed before it became noticeable from measurements of stem diameter. For lower temperatures, growth trends as measured by changes in stem diameter were not discernible. At this particular stage of tomato plant growth, measurement of changes in stem diameter should be coordinated with other growth indices and visual inspection to give much information concerning overall plant response. However, each type of measurement can yield useful information about certain physiological responses of the plant.

Heated waste water usually varies anywhere from 25 (77°F) to 50°C (122°F). Over the first half of this temperature range, direct application of the heated waste water to the soil would probably give beneficial growth results. However, over the last half of this temperature range, some cooling of the water should be accomplished during the application process. Under these conditions, sprinkler irrigation should be considered because the spray drops tend toward equilibrium with the wet-bulb temperature. The major objection to the use of heated waste water by tomato plants or for that matter any plant is not whether it can be beneficially used—it can—but the fact that it may be largely a consumptive use. Over-irrigation and the collection of return flow for reuse could reduce the percentage of applied water lost to consumptive use, however.

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