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THE EFFECT OF ROOT ZONE TEMPERATURE ON NUTRIENT UPTAKE OF TOMATO

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ABSTRACT: Tomato (*Lycopersicon esculentum* cv. Burpee 'Big Boy Hybrid') was grown in a growth chamber under six root zone temperature treatments: 10, 15.6, 21.1, 26.7, 32.2, and 37.8 °C with four replications per treatment. Ambient air temperature was 21.1 °C. The experiment was repeated three times and the treatments were completely randomized. All treatments received the same nutrient concentrations. Nutrient uptake for each element generally peaked at 26.7 °C. Uptake of all mineral elements was significantly different with each temperature treatment except for B, Fe, and Mo which did not respond to temperature.

Root and shoot dry weight, rate of shoot growth, plant height, and water use also peaked at 25 °C. Optimal temperature appears to be approximately 25 °C for uptake of the majority of mineral elements and all plant growth responses measured.

INTRODUCTION

The uptake and translocation of essential nutrients, root growth and development, and root-cell differentiation of plants is directly influenced by temperature of the root zone (Cooper, 1973). As such, the root zone temperature should be an important parameter influencing the uptake of nutrients by different crop species. This could be especially true when studying nutrient uptake under various mulch treatments given the effect a mulch has on ameliorating soil temperature. Soil temperature of the root zone can vary considerably under a bare surface, plastic mulch, or straw mulch (Rosenberg et al., 1983). Although plant growth and development are quite different in soil and nutrient solutions, the relevancy of comparing uptake in nutrient solutions as compared to soil has been well established (Wild et al., 1987).

Several studies have been performed on the effect of soil temperature on nutrient uptake. However, the majority of these studies have concentrated primarily on nitrate or ammonium nutrition as affected by root zone temperature (Neumann et al., 1980 and 1985, Kharitonashvili et al., 1986). There have been few studies investigating the effect of root zone temperature on uptake of essential nutrients. These include the uptake of iron by banana (Lahav and Turner, 1984), nutrient uptake by wheat (Whitfield and Smika, 1971), calcium uptake and translocation by sorghum (Murtadha et al., 1989), and nutrient uptake by barley (Schwartz et al., 1987).

The study by Schwartz was unique in that it examined nutrient uptake as affected by zinc and phosphorus competition as well as by soil temperature. During the experiment the mean uptake rates of Ca, Mn, Cu, Fe, and Zn were the same or higher at 10 °C as at 20 °C. Clarkson et al. (1986) grew perennial ryegrass from seed for 49 days, decrementally lowering solution temperature from 20 to 5 °C for acclimatization and then changing it to 3, 5, 7, 9, 11, 13, 17, or 25 °C, with an air temperature of 25/15 °C day/night. The net uptake of N from solution (maintained at 10 μM NH_4NO_3) during the subsequent experimental 14+ day period increased 6 fold between 3 and 25 °C. The percentage of N taken up as ammonium was inversely related to root temperature, decreasing from 93% at 3 °C to 65% at 25 °C. MacDuff et al. (1987) in a very similar experiment with oilseed rape (Brassica napus L. cv. Bien venu) discovered that N uptake increased 3 fold from 3 to 13 °C but above 13 °C showed no further increase.

Research by Lahav (1984) revealed that the temperature for maximal Fe uptake in banana was not reached even though temperature regimes included day/night temperatures of 17/10, 21/14, 25/18, 29/22, 33/26, 37/30 °C. The increase in temperature from 17/10 to 37/30 resulted in a 3-fold increase in Fe uptake. Setter and Greenway (1988) discovered that during periods of long term growth at low soil temperatures, the relative growth rates of rice shoots were reduced and chlorosis developed. There were cultivar differences, which were consistent with field observations.

In a previous study by Tindall et al. (1988-unpublished) focusing on the root distribution and growth of tomato under plastic and straw mulches, the average soil temperature was 25 and 36 °C under the straw and plastic mulches, respectively. In that study, yield and plant dry weight were much lower with plastic mulch than with straw mulch. There were no visible deficiency symptoms with either mulch. Soil analysis showed no deficiency of major elements. However, plants grown under the plastic mulch showed a stunted, spindly appearance.

This experiment was conducted to determine the effect of various root zone temperature regimes on nutrient uptake and growth of tomato while maintaining ambient air temperature constant.

MATERIALS AND METHODS

Tomato was grown in a growth chamber under six root zone temperature treatments: 10, 15.6, 21.1, 26.7, 32.2, and 37.8 °C consisting of four replications of each treatment. An ambient air temperature was maintained at 21.1 °C. Root zone temperatures were maintained in all treatments within 1 °C. The experiment was repeated on three successive dates and completely randomized. Results presented are averages of the three replications.

Seedlings were germinated and when approximately 8 cm in height were placed into 3 L solution culture pots. Each pot contained an air supply and the 26.7, 32.2, and 37.8 °C treatments contained a 50 watt aquarium heater (Therma Flo "PC"). Prior to placing plant roots in the solutions all heaters were calibrated over a three week period and maintained temperature within 1 °C of that desired. Solution temperatures were monitored daily during the experiment. The 10 and 15.6 °C treatments were placed in cooling baths to maintain temperature below ambient air (21.1 °C). The 21.1 °C treatment used no heaters as it was the ambient temperature of the chamber. After placing plants in the pots, they were acclimatized to the chamber for two weeks at 21.1 °C root zone/ambient air in a 1/4 strength Hoagland solution. After acclimatization, temperature treatments were initiated and full strength Hoagland solution applied (Table 1). Growth chamber day/night temperature was 21.1 °C during the course of the experiment. Light intensity in the chamber remained constant at 390 $\mu E\ m^{-2}\ s^{-2}$ with a light/dark period of 14/10 hours.

Solution samples were taken at the end of each week before and after the nutrient solution was changed to determine nutrient uptake. Samples were analyzed on a simultaneous plasma emission spectrometer (Thermo Jarrell Ash Model 9000 Inductively Coupled Argon Plasma 'ICAP'):P, K, Mg, Zn, Mn, Mo, Fe, Cu, and B. Nitrate and NH_4^+ were analyzed on an Flow Injection Analyzer (LACHAT, Instruments). Plant height and water uptake were measured daily and solution pH was monitored every other day. Daily measurements for water use and plant height were analyzed by the repeated measures method after Cole et al. (1966) and Pendergast and Littell (1988). After 2 weeks, above solution plant parts were harvested and plant stems and leaves were dried, ground, and ashed for tissue analysis. Plant roots were dried and weights recorded.

RESULTS AND DISCUSSION

Macro nutrient Uptake

Uptake amounts at the different temperature regimes varied for each macro nutrient but in general, peaked at 25 °C (Figure 1). There was a significant quadratic response for NO_3^-, NH_4^+, K, Mg, P, and Ca for each temperature treatment (Table 2).

The uptake of N in this experiment agrees with that of Clarkson (1986) but not with that of MacDuff et

Table 1. Composition of Modified Hoagland Solution

Nutrient	Source	Concentration of ions in solution (mole m^{-3})	
Ammonium	$(NH_4)_2SO_4$	1.785	
Nitrate	$Ca(NO_3)_2 \cdot 4H_2O$	5.360	
Potassium	KH_2PO_4	0.908	2.661
	K_2SO_4	1.753	
Calcium	$Ca(NO_3)_2 \cdot 4H_2O$	2.680	
Magnesium	$MgSO_4 \cdot 7H_2O$	1.234	
Phosphate	KH_2PO_4	0.807	
Sulphate	$(NH_4)_2SO_4$	0.893	
	K_2SO_4	0.877	
	$MgSO_4 \cdot 7H_2O$	1.234	3.045
	$ZnSO_4 \cdot 7H_2O$	0.015	
	$CuSO_4 \cdot 7H_2O$	0.016	
Fe	FeNaEDTA	0.168	
Zinc	$ZnSO_4 \cdot 7H_2O$	0.015	
Copper	$CuSO_4 \cdot 5H_2O$	0.016	
Manganese	$MnCl_2 \cdot 4H_2O$	0.018	
Molybdenum	MoO_3	0.010	
Boron	H_2BO_3	0.093	

pH of solution = 5.8 ± .03

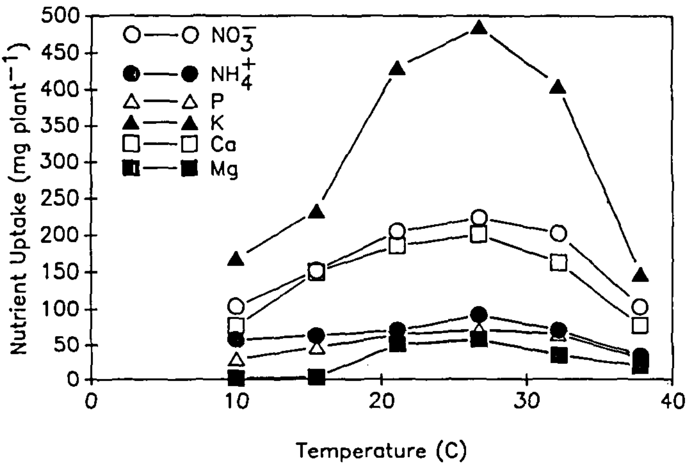

Figure 1: Uptake of macro-nutrients for tomato (1990)

al. (1987). The experiment of Clarkson (1986) using perennial ryegrass showed a decrease in NH_4^+ uptake as a percentage of total N uptake as temperature increased while that of MacDuff et al. (1987) using oilseed rape showed an increase of 3-fold up to 13 °C but no increase after that. This experiment showed that while NH_4^+ uptake decreases in proportion to NO_3^- as temperature increased up to 25 °C, it is compared to total N since NO_3^- is taken up more readily as temperature increases. Absolute uptake in mg plant^{-1}, increased as temperature increased up to 26.7 °C. The difference in our results compared to those of McDuff et al. (1987) for N may be that our peak temperature for uptake was higher than the highest temperature used by MacDuff et al. (1987) or that it is simply due to plant species difference. The maximum temperature in the experiments by Clarkson (1986) and MacDuff et al. (1987) was approximately 20 °C. This temperature is

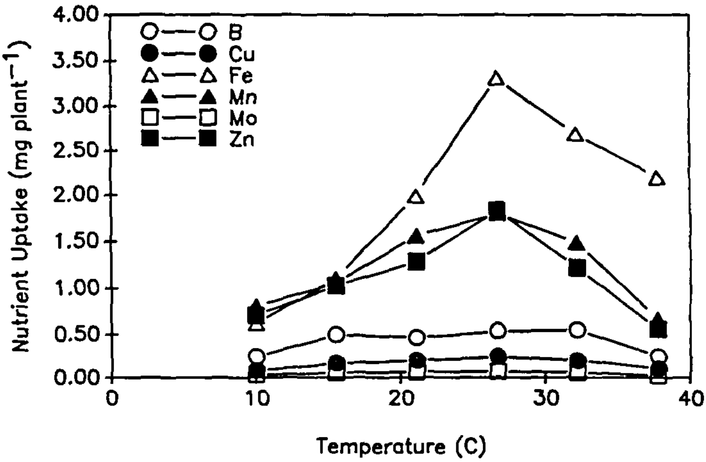

Figure 2: Uptake of micro-nutrients for tomato (1990)

too low to approximate what may be taking place under summer field conditions in the upper 2-5 cm of soil where a majority of roots exist, especially under irrigated conditions. In either case, uptake of both N forms increased with temperature in this experiment and then decreased for NO_3^- and NH_4^+ after 26.7 and 32.2 °C, respectively.

Micro nutrient Uptake

Micro nutrient uptake is given in Figure 2. Uptake of Cu, Mn, and Zn also showed a significant quadratic response for all temperature treatments (Table 2). Uptake of B, Fe, and Mo was not significantly affected by temperature. The response of Fe does not agree with that of Lahav (1984) in which the maximal uptake was not reached despite increases in

Table 2. Equations and Optimal Temperatures for Nutrient Uptake

Mineral Element	Equation	Optimal Temperature (C)
NO_3^-	$y = -71.3379^{**} + 11.0882(T)^{**} - 0.2249(T)^{2**}$	24.65
NH_4^+	$y = -11.3561^{**} + 2.6490(T)^{**} - 0.0554(T)^{2**}$	23.91
P	$y = -19.9064^{**} + 2.8402(T)^{**} - 0.0565(T)^{2**}$	25.11
K	$y = -107.1449^{**} + 15.7151(T)^{**} - 0.3286(T)^{2**}$	23.91
Ca	$y = -31.5754^{*} + 4.9857(T)^{**} - 0.0983(T)^{2**}$	25.35
Mg	$y = -8.8004^{*} + 1.4800(T)^{**} - 0.0303(T)^{2**}$	24.42
B	$y = -0.0079 + 0.0098(T) - 0.0001(T)^{2}$	
Cu	$y = -0.2188^{*} + 0.0289(T)^{**} - 0.0006(T)^{2**}$	24.08
Fe	$y = 0.8131 - 0.0073(T) + 0.0006(T)^{2}$	
Mn	$y = -0.5958^{**} + 0.0838(T)^{**} - 0.0017(T)^{2**}$	24.64
Mo	$y = -0.0249 + 0.0242(T) - 0.0005(T)^{2}$	
Zn	$y = -0.2369^{**} + 0.0285(T)^{**} - 0.0005(T)^{2**}$	28.50

* Significant at the 0.05 level.
** Significant at the 0.01 level.

temperature. The uptake of Fe (although not significant and the most impressive visually) in this instance follows the same pattern as the other essential micro nutrients.

Schwartz (1987) using barley reported that uptake of Ca, Mn, Cu, and Zn was the same at root zone temperatures of 10 °C as at 20 °C while MacDuff et al. (1987) reported that all macro nutrient uptake increased as temperature increased up to 13 °C but

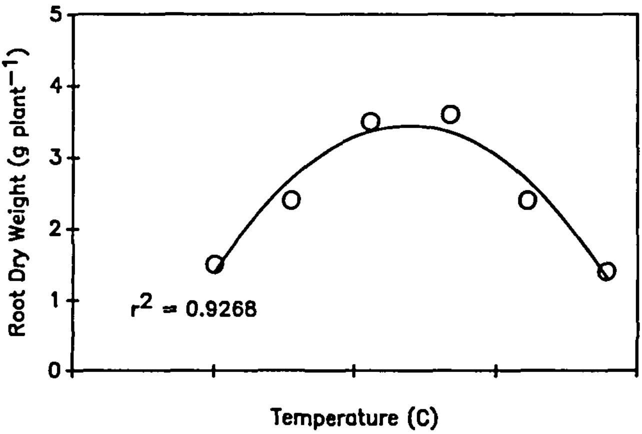

Figure 3: Root dry weight as influenced by temperature

showed no increase after that. The results of this experiment for Zn agree with that of Schwartz (1987). However, for the majority of macro and micro nutrients, this experiment showed a trend in increased uptake from 10 to 26.7 °C, with a steady decrease in uptake for all nutrients at higher temperatures.

As previously mentioned, the differences between this experiment and those of Clarkson (1986), Schwartz et al. (1987), and MacDuff et al. (1987) may be due to plant species differences, initial method and length of acclimatization, day length, the physiological growth stage of the plant when treatment was initialized, or the frequency of changing the nutrient solutions. In addition, Schwartz (1987) created a competition effect between Zn and P by increasing levels of Zn in solution which may have had an effect on overall uptake of other major ions.

Plant Growth:

Roots: Root dry weight increased significantly with temperature until 26.7 °C and then steadily decreased

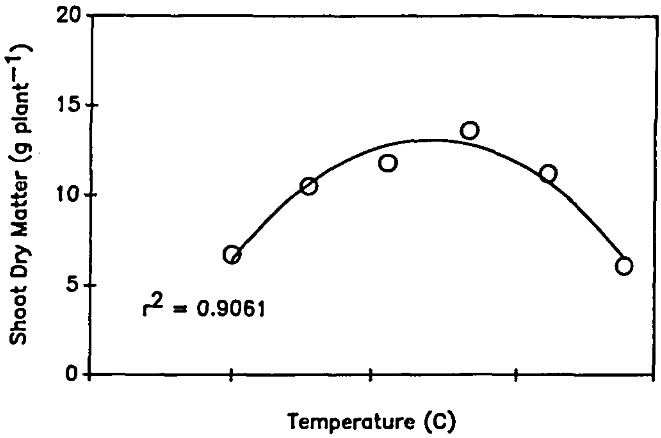

Figure 4: Shoot dry matter as influenced by temperature

(Figure 3 and Table 2). Upon visual inspection, roots at 10 °C showed poor elongation with somewhat larger diameter roots, but had a small number of roots. At 15.5 °C, roots were slightly more elongated but had considerably more density. There was little visible difference between roots at 21.1 and 26.7 °C both being very dense with good elongation. In the 32.2 °C treatment, density was approximately the same as in the two lower temperature treatments but with one-half the elongation. Roots at 37.8 °C were similar in density and elongation to 10 °C but were very fine with very little branching and a dark color.

Shoots: Shoot dry weight followed the same pattern as the roots with a significant quadratic response to temperature (Figure 4 and Table 3). Shoot elongation was similar at intermediate temperatures but sharply reduced at 10 and 37.8 °C. Both of these treatments had visible N and Mg deficiency symptoms. Growth under

Table 3. Optimal Temperatures for Tomato Growth and Water Use

	Equation	Optimal Temperature (C)
Plant Height	$y = -20.00^{**} + 5.2866(T)^{**} - 0.10347(T)^{2**}$	25.55
Water Use	$y = -2188.0^{**} + 303.92(T)^{**} - 5.9429(T)^{2**}$	25.57
Shoot Dry Weight	$y = -6.6151^{**} + 1.6451(T)^{**} - 0.03433(T)^{2**}$	23.96
Root Dry Weight	$y = -2.8112^{**} + 0.5253(T)^{**} - 0.01014(T)^{2**}$	25.90

**Significant at the 0.01 level.

both treatments appeared spindly and stunted with the lower leaves of the 37.8 °C treatment showing rapid senescense. This was possibly due to a change in root physiology with temperature and thus a subsequent decrease in water and nutrient uptake.

Plant Height:

The height of the plants at the conclusion of the experiment was significantly affected by temperature as well (Figure 5 and Table 3). This was most likely due to the effects of temperature on physiological (enzymatic) factors of plant growth and on nutrient uptake.

Water Uptake:

Total water use over time also showed a significant quadratic response to temperature (Figure 6 and Table 3). This was evident as the experiment progressed with the 10, 15.5, and 37.8 °C treatments

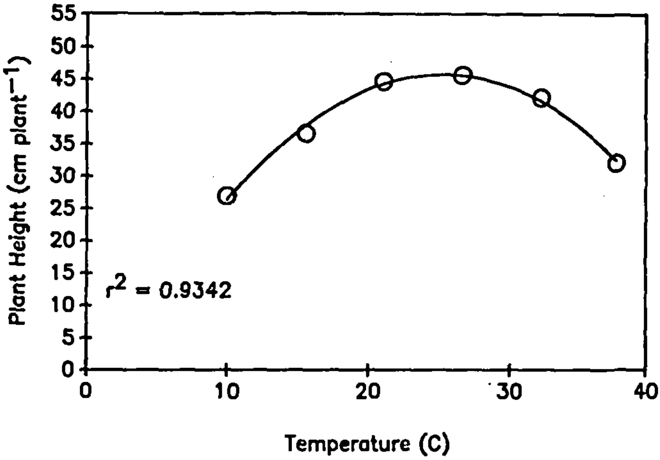

Figure 5: Plant height as influenced by temperature

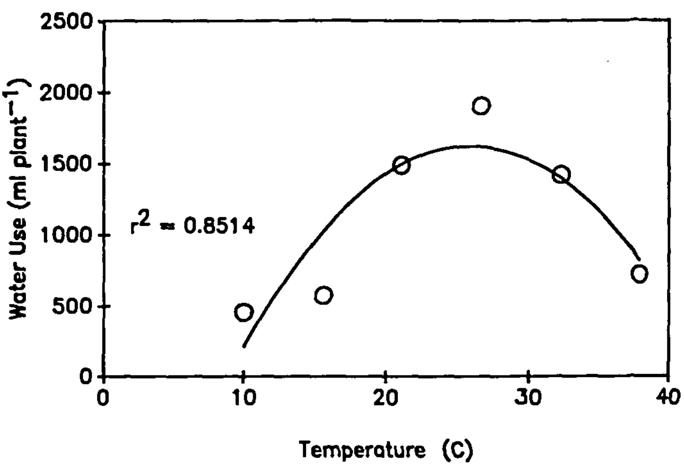

Figure 6: Total water use as influenced by temperature

Table 4. Tissue Analysis

	Temperature (C)					
	10.0	15.5	21.1	26.7	32.2	37.8
Element*	%					
N (Total)	2.41b	3.72a	4.01a	4.39a	4.07b	2.05b
P	0.44b	0.44b	0.55a	0.52a	0.58a	0.48b
K	2.51b	2.21b	3.66a	3.55a	3.61a	2.41b
Ca	1.15	1.42	1.58	1.47	1.45	1.26
Mg	0.03c	0.03c	0.43a	0.42a	0.44a	0.31b
	ppm					
B	35.8b	46.6a	39.2a	39.0a	48.8a	40.0a
Cu	12.3b	22.5a	14.0a	14.4a	17.4a	17.5a
Fe	92.0	104.1	186.2	203.2	98.9	123.7
Mn	120.6	100.0	132.5	131.3	132.4	108.5
Mo	5.1	5.2	5.6	5.1	5.2	4.3
Zn	105.6a	97.1a	109.2a	133.8a	108.8a	90.9b

Means within same letter not significantly different.

using visibly less water than the others. This correlates well with the findings of Cooper (1973) on the effects of soil temperature on plant growth which shows less water use at lower temperatures.

Optimal Temperature:

Using regression analysis the optimal temperature for plant growth, water use, and root response appears to be between 21.1 and 26.7 °C (Table 3). The fact that the optimum temperature for root growth is higher than that for shoot growth may indicate that the plant partitions more photosynthate to the roots under mild heat stress.

Tissue Analysis:

Analysis of the plant tissue (Table 4) showed sufficient or high levels of P, Ca, B, Cu, Fe, Mn, Mo, and Zn at all temperature treatments according to Wolf et al. (1989). Low levels of N were found in the 10 and 37.8 °C treatments while all other treatments had sufficient levels. This corresponds well with the visual symptoms noticed for these treatments and overall appearance. Both K and Mg had significantly lower levels at the 10, 15.5, and 37.8 °C treatments which also correlates with visual deficiency symptoms.

Analysis showed that P and K was significantly lower at 10, 15.5, and 37.8 °C than at the other treatments although P was at sufficient levels. Tissue content of Fe, Mn, and Mo showed no difference among treatments while Zn was significantly lower at 37.8 °C but not deficient. Although not deficient, B and Cu were significantly lower at 10 °C.

CONCLUSIONS

Nutrient uptake by tomato was optimal for most macro and micro nutrients when root zone temperature was approximately 25 °C. Uptake of most macro and micro nutrients was reduced at lower temperatures (<25 °C) and higher temperatures (>25 °C). Uptake of B, Fe, and Mo was unaffected by temperature. Uptake of all other elements was significantly different at each temperature with uptake peaking at about 25 °C. Root and shoot growth were also optimal at approximately 25 °C.

Temperatures <20 °C and >30 °C probably greatly impair the plants' ability to absorb nutrients and take up water, not only due to the effects of temperature on root growth but also due to the effect of temperature on the plants ability to actually absorb nutrients.

Since temperature impacts the physiology of roots (Gregory 1988), thus affecting ion absorption, this may result in either a visible deficiency symptom or perhaps a hidden hunger. This study implies that modification of soil temperatures by mulching, irrigation, or other means to approach an optimal temperature of approximately 25 °C would allow maximum nutrient uptake and result in the best plant growth and yield of tomato.

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