TOMATO SEED GERMINATION AND PLANT GROWTH IN RELATION TO SOIL TEMPERATURES AND PHOSPHORUS LEVELS

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The major source of tomato plants for the north and east United States and south Canada is south Georgia and north Florida. Very often tomato plants are of certification size (4) when cold weather conditions still prevail in the northern tomato producing areas or, on the other hand, plants may still be too small when northern growers are ready for transplanting. In order to develop a heat unit system to more accurately determine proper seeding time in reference to harvest date, a study was made of the effects of soil temperatures on rate of seed germination and plant growth at different P levels.

A large number of investigators have studied the effects of P levels and/or root temperatures on the growth of tomato seedlings (2, 7, 9, 11, 13, 18, 19, 20). Locascio and Warren (9) and Cannell, *et al* (2) reported that P levels and root temperatures interacted to alter dry matter yield; 244 and 450 ppm of P (soil basis) were the highest treatments respectively. However, others (7, 11, 20) did not find a significant effect from the interaction of P levels and root temperatures on dry weight yield, P uptake or P composition although the effects of P levels and root temperatures were significant. In those experiments, the fact that the P fertilizer was banded below the seed instead of thoroughly mixed with the soil probably contributed to the nonsignificance of the interaction. The percent increase in tomato growth, as measured by weight, due to increased P levels is generally found to be large at lower root temperatures (7, 9, 20). This information would indicate that sufficient levels of P at one root temperature can easily be insufficient at another temperature.

As would be expected, the P concentration in the plant material generally increases with increasing P levels in the soil and increasing root temperatures (2, 7, 9, 11, 13, 20). Lingle and Davis (7) reported an 85% increase in P concentration in tomato tissue from a high P treatment at 60 to 65°F. and less increase at higher root temperatures. Shtrausberg (13) showed that the P concentration in leaves 19 days after starting the experiment was 2.5 times more at 68°F. than 54°F.

Different researchers have reported on the optimum and base temperature for tomato growth and the importance of root temperature to growth. Went (17) reported that the growth rate of tomatoes was determined by the temperature at the plant tops and that root temperatures contributed little to growth rate. Only when plants were grown under sub-optimum conditions did root temperatures substantially affect growth rate. In a detailed review on effects of temperature on plant growth, Went (18) reported that most of the tomato plant growth occurs at night. In young tomato plants, the optimum night air temperature was reported to be above 77°F. and with older plants below 68°F.

The optimum root temperature for maximum tomato plant growth also has been studied by using excised plant parts and by using the entire plant. White (19) found that the optimum growth temperature for excised tomato roots was 86°F. In experiments employing whole plants, optimum growth as measured by fresh and dry weight of tomato shoots was found to be at root temperatures of 70-85°F. (7). Cannell, *et al*, (2) found maximum growth at 68°F, when tomato plants were grown to a later stage of maturity.

Heat units for predicting plant development and growth are in widespread use throughout the world. Most systems are based upon some temperature below which growth or development does not occur and above which growth rates are linear with temperature. Arnold (1) concluded that some researchers have used base temperatures which are too high. It is known that growth rates are not usually linear over large temperature ranges and, in addition, heat and/or energy requirements are not constant in effect through the growth cycle (6). Valli (16) has proposed a development index for peanuts which is based entirely on an accumulation of available solar energy in Langley units ($cal/cm^2/min$). With this index it was possible to predict maturity, plus or minus two days, for six different varieties of peanuts with planting dates spread over three months.

Materials and Methods

Two experiments were conducted successively in six 172-gallon coolers, each containing a thermostatically controlled heating and refrigeration unit. The water in each tank was continuously circulated with a pump to insure uniform water temperature. In the first experiment the water was controlled at 45°, 55°, 65°, 75°, 85°, and 95° F. while in the second experiment the water temperature was controlled at 55°, 65°, 75°, 85°, 95° and 105° F. The tanks were housed in a greenhouse where the air temperature ranged from 80-95°F. daytime to 60-70°F. night time.

A Tifton loamy sand soil, fumigated with methyl bromide and very low in available P and K, was used in both experiments. Two thousand grams of air-dried soil were placed into 6-inch plastic pots with a small hole in the bottom. The plastic pots were set into one gallon porcelain jars with moist sand packed between the plastic pot and the porcelain jar. A small glass tube was placed inside the sand in order to remove excess water at the bottom of the plastic pot.

In the first experiment, super phosphate treatments were at 25, 50, and 100 ppm of P on a soil basis. Nitrogen and potassium were applied at the uniform rate of 100 ppm each. Since the initial root growth of the tomato is of the taproot type and the penetration is about an inch at the time the cotyledons emerge (8, 10), nutrients were applied in a band 1 inch beneath the soil surface or ½ inch beneath the seed. The treatments were replicated 4 times. Each pot was seeded with 25 clay-coated Campbell 146 tomato seeds of 92% germination. The percent seed germination was determined every week and only 4 plants were allowed to grow beyond the cotyledon stage. Plant height was measured for growth response 35 days after seeding after which plants, cut off at the ground level, were oven-dried at 158°F. Plant material was digested and phosphorus was measured by the procedure of Toth, *et al* (15).

The second experiment was conducted similarly except the phosphorus levels were increased to 50, 100 and 200 ppm of P. Plants were grown at soil temperatures of 85° for 10 days after seeding, at which time they were thinned to 4 per pot and grown at the indicated constant root temperatures for 24 days.

Results and Discussion

Low soil temperature resulted not only in reduced germination but also in delayed germination as illustrated in Table 1. Even at temperature of 75° to 95°F., a large percentage of the seed germinated 2 or more weeks after seeding. The very slow and low germination at the optimum temperature indicates that the rate of emergence may be the major factor contributing to nonuniformity of tomato growth in commercial fields. After 35 days from seeding, no germination had occurred at 45°F. Under tomato plant production conditions, lack of uniform growth necessitates successive harvests of plants from the same field on more than one occasion.

The plants growing at the lower root temperature were stunted and dark green with purple discoloration of the stems and bottoms of leaves while plants growing at 75° to 95°F. were luxurious with normal green color.

Tomato growth responses, as indicated by plant height, to P and root temperatures are presented in Tables 2 and 3. Maximum plant height was found at 85°F. in both experiments, with reduced growth at higher temperatures. In the second study the P-temperature interactions were significant. When stem diameter was used as an index of growth, the maximum was also observed at root temperature of 85°F. After 35 days from seeding, stem diameters were 0.088, 0.165, 0.203, 0.254, 0.225, and 0.155 inches for temperatures of 55° to 105° by 10° increments, respectively.

Root temperatures had a marked effect on the dry weight of shoots (Tables 2 and 4). Growth was usually depressed at temperatures 10°F. above or below the optimum root temperature of 85°F. The higher P levels did not overcome the stunting effect of the lowest and highest root temperature. The highest P level reduced the total dry weight at 95° F. in one study.

The analysis of dried shoots for the first experiment showed that the percent P increased from 0.52 to 0.73 from the lowest to highest P treatment. In the second experiment the percent P in the dry shoots increased with both the P levels and higher root temperatures (Table 5). The total P in the shoots varied with both root temperature and P level (Table 6). At 55°F. the P content nearly doubled from the lowest to the highest P level. Even at the highest P level, however, the percent P in the shoots was markedly reduced at root temperatures of less than 85°F. A very high P content in the tomato seed-

Table 1. Percent tomato seed germination with time as affected by soil temperature 1/

Soil temperature (°F)	Weeks after seeding				
	1	2	3	4	5
55	0^{a}	1^{a}	21^{abc}	39^{cd}	49^{de}
65	0^{a}	39^{cd}	53^{def}	58^{defg}	62^{efgh}
75	16^{ab}	65^{efghi}	75^{fghi}	79^{ghi}	81^{ghi}
85	24^{bc}	60^{defgh}	70^{efghi}	79^{ghi}	82^{hi}
95	22^{abc}	59^{defg}	74^{fghi}	82^{hi}	85^{i}

1/ Any two treatment means having the same letter are not different at the 5% level.

ling may be beneficial by enabling the plant to regenerate its new root system more rapidly immediately after transplanting. Tiessen and Carolus (14) have reported that both soluble N and soluble P were markedly lowered in plant tissue following transplanting because they were utilized in new root formation.

In attempting to predict growth rates of tomato plants on the basis of this experiment, it is first necessary to break down development into

Table 2. Tomato plant height and dry weight as affected by root temperature 1/

	Root temperature (°F)				
	55	65	75	85	95
Plant height (inches)	1.7^{a}	3.5^{b}	3.5^{b}	6.0^{d}	5.1^{c}
Dry weight (mg)	41^{a}	335^{ab}	435^{b}	995^{d}	777^{c}

1/ Five weeks after seeding.
Any two treatment means having the same letter are not different at the 5% level.

Table 3. Tomato plant height in inches as affected by phosphorus levels and root temperature 1/

P Level (ppm)	Root temperature (°F) 55	65	75	85	95	105
50	2.6[a]	3.9[b]	4.5[b]	7.8[e]	6.8[d]	4.0[b]
100	2.6a	4.5[b]	6.1[c]	7.9[e]	6.3[cd]	4.1[b]
200	2.3[a]	4.0[b]	6.0[c]	7.6[e]	5.9[c]	3.9[b]

1/ 34 days after seeding.
Last 24 days at indicated constant root temperature.
Any two treatment means having the same letter are not different at the 5% level.

two phases: germination to emergence; and emergence to maturity, or maximum desired growth. In the first phase soil temperatures are the paramount factor with air temperature and insolation secondary, if at all important. In this experiment, soil temperature is considered the major variable affecting germination and pre-emergence growth.

An accumulation of daily mean soil temperatures above 45 degrees (at 45 degrees no germination occurred) shows that heat unit requirements for germination increase to 75°F. drop sharply at 85°F., and increase again at 95°F. showing a depressing effect of higher temperatures (Table 7).

Table 4. Dry weight (in mg) of 4 tomato plant tops as affected by phosphorus levels and root temperature 1/

P Level (ppm)	Root temperature (°F) 55	65	75	85	95	105
50	417[a]	935[abc]	1208[abcde]	3678[h]	3560[h]	1027[abcd]
100	456[ab]	1531[cdef]	2333[fg]	3846[h]	2982[gh]	1341[bcde]
200	331[a]	1020[abcd]	2080[ef]	3239[h]	1791[def]	1083[abcde]

1/ 34 days after seeding.
Last 24 days at indicated constant root temperature.
Any two treatment means having the same letter are not different at the 5% level.

Table 5. Percent phosphorus in tomato shoots as affected by phosphorus levels and root temperature 1/

P Level (ppm)	Root temperature (°F)					
	55	65	75	85	95	105
50	0.30[a]	0.41[abc]	0.55[def]	0.51[cde]	0.47[bcd]	0.55[def]
100	0.39[ab]	0.40[abc]	0.60[efg]	0.59[efg]	0.63[fg]	0.68[fg]
200	0.55[def]	0.55[def]	0.69[g]	0.82[h]	0.82[h]	0.83[h]

1/ 34 days after seeding.
Last 24 days at indicated constant root temperature
Any two treatment means having the same letter are not different at the 5% level.

For growth from emergence to 35 days after seeding, the methods of computing heat units proposed by Gilmore and Rogers (5) for corn and Mills (12) for peanuts are used. Briefly, the method assumes that no appreciable growth takes place below a lower cardinal temperature and that temperatures above a certain upper cardinal temperature reduce or stop growth. Using these corrections, effective heat units are computed as follows:

$$EHU = \frac{T_{max} + T_{1c} + \Delta T_{1c}}{2} - T_{1c} - \Delta T_{oc}$$

T_{max} = Maximum Temperature

T_{1c} = Lower Cardinal

T_{oc} = Optimum

$\Delta T_{1c} = T_{min} - T_{1c}$ (for positive values only) (if negative =0)

T_{min} = Minimum Temperature

$\Delta T_{oc} = T_{max} - T_{oc}$

Examination of these data suggest a lower cardinal temperature of 55°F. and an optimum cardinal value of 85°F.

Using these values, EHU's were computed from emergence to termination of the experiment at 35 days after seeding. Because of the variation in germination these growth periods ranged from 32 days at soil temperatures of 95°F. to 21 days at 55°F. All plants were subject to the same environmental conditions above the soil, the only variable being time from emergence to termination. Table 8 shows an accumulation of 707 EHU's at the time of maximum stem diameter, dry weight and height.

The root temperatures of 75°F. to 95°F. are comparable to existing soil temperatures in the field during April 10 to June 1 in South Georgia. Under field conditions during this period soil temperatures at the one inch level averaged 80°F. with a mean maximum of 91°F. and a mean minimum of 69°F. for the seven day period following seeding. During this period the air temperatures at the twelve inch level averaged 72°F. Temperatures at the one inch soil level frequently exceeded 100°F. until vegetative growth provided shading of the soil. The effect of shading is shown by the soil temperatures during the sixth week after seeding. Air temperatures at the twelve inch level averaged 75°F. during this period while the mean minimum and mean maximum soil temperature at the one inch level were 72° and 85°F., respectively. The shading effect was also apparent at the four inch soil level in which the temperature averaged 60°F. during the first week after seeding and 56°F. during the sixth week after seeding.

Summary and Conclusions

Low soil temperatures delayed *germination* and reduced germination percentages. No ger-

Table 6. Total phosphorus (in mg) in tomato shoots as affected by phosphorus levels and root temperature 1/

P Level (ppm)	Root temperature (°F)					
	55	65	75	85	95	105
50	1.27a	3.71ab	6.53bc	18.16ef	16.46def	5.46abc
100	1.68a	4.95abc	14.01de	22.53gh	18.65fg	8.64c
200	1.81a	5.66abc	13.64d	25.84h	14.70def	9.00c

1/ 34 days after seeding
Last 24 days at indicated constant root temperature
Any two treatment means having the same letter are not different at the 5% level.

mination was observed 35 days after seeding at a soil temperature of 45°F. The very slow rate of seedling emergence may be the major factor contributing to nonuniformity of tomato growth in commercial fields. An accumulation of growing degree days from a base of 45°F. using daily mean soil temperatures indicates a mean soil temperature of 85°F. is the most efficient temperature. Maximum plant heights and stem diameters were observed with root temperatures of 85°F. Growth was usually depressed at 10°F. above and below this value. One experiment showed increased content of P with both increased P and increased temperatures. At 55°F. the percent P was nearly doubled from the lowest to the highest P level. The percentage P was

Table 7. Heat units for germination computed from mean daily soil temperatures using a base of 45° F.

Soil temperature	Daily heat units	Days to germination	Total heat units
55°	10	14	140
65°	20	9	180
75°	30	7	210
85°	40	4	160
95°	50	4	200

Table 8. Accumulated effective heat units from emergence to termination computed with lower cardinal temperature 55°F. and optimum temperature 85° F.

EHU	Stem diameter (inches)	Plant height (inches)	Dry weight (mg)
734	.225	5.1	777
707	.254	6.0	995
617	.203	3.5*	435
598	.165	3.5	335
580	.088	1.7	41

* Plant height measurements were not as precise as other growth measurements.

markedly reduced in the shoots at root temperatures less than 85°F. Effective heat unit computations using a lower cardinal temperature of 55°F. and an optimum temperature of 85°F. best fit the data. These data indicate that an accumulation of about 760 EHU's would be necessary to produce an 8 inch plant.

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