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Influence of Soil Temperature in Greenhouse Tomato Production[1]

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Abstract. **An increase in soil temperature from 14.0 to 21.8°C increased total yield of greenhouse tomatoes (*Lycopersicon esculentum* L. cv. Vendor) by 47% in the spring under warm air temperature conditions, but a rise in soil temperature from 13.8 to 20.5° increased tomato yield by only 5% in the fall. Under plastic tunnel conditions (low air temperature), heating soil increased total yields by 36% in the spring and 42% in the fall.**

Increase in energy costs has greatly endangered the survival of the North American greenhouse vegetable industry in recent years. The ensuing rise of production costs has narrowed the profit margin. The situation is even worse in Quebec (latitude 47°N) because of more rigourous climatic conditions and also the common use of single unit greenhouses. Several authors have reported that increases in soil temperature may enhance plant growth (1, 2, 4) and increase yield in various species (3, 5, 8). In England, Jones and coworkers (7) showed with greenhouse tomatoes that night air temperature could be reduced and production maintained when the root system was kept warm. Under their conditions, energy needs were decreased by 20 to 30%. Studies in Ontario (6) showed that warming the soil increased tomato yield by 15 to 20% under normal growing conditions. When night air temperature was reduced and the soil heated, energy consumption was lowered by 33 to 50% and productivity levels were maintained.

Previous experiments conducted by the authors (5) showed that soil temperature influences tomato plant growth and development. Soil warming caused an increase in shoot growth as measured by plant height and shoot dry weight and a reduction in the development of the root system. The higher water content of the shoot and the greater mineral content of the plants maintained at higher root temperature were attributed to more efficient root systems.

The objective of this work was to determine the effect of warming the soil in both spring and fall crops of greenhouse tomatoes grown under 2 different greenhouse environments: normal and reduced air temperature regime.

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'Vendor' and 'Ohio MR-13' tomatoes were planted at a spacing of 5.5 or 11 plants/m^2. Crops were grown at a normal air temperature regime of 20 to 22°C during the day and 15 to 17° at night in a Cornell 21 greenhouse (29 × 6.6m) covered with a double layer of polyethylene. Treatments were: 1) an increase in soil temperature, and 2) normal soil. Soil temperature of the heated plots was maintained at 20.5° by circulating hot air from a standard oil burner through tile drainage pipes buried 38 cm deep and 68 cm apart. For the spring crop, tomato plants, seeded on Feb. 11, 1980, and transplanted at a density of 11 plants/m^2 on April 1, were distributed amont 10 heated and 2 nonheated plots of 40 plants. Plants were pruned to a single stem and were topped after the development of 2 leaves over the second or third cluster. Fertilization and other cultural practices were as described in the Quebec greenhouse vegetable recommendations booklet (9). Harvesting started on June 12 and ended on July 14, 1980. Fruits were harvested at maturity and graded according to their weight and appearance. Number 1 fruits weighed more than 91 g and were defect-free.

In the fall, 6-week-old tomato plants were transplanted at the above density (11 plants/m^2) on August 14 in 10 heated (20.5°C) and 10 nonheated plots containing 40 plants topped after the development of the second cluster. Harvesting period extended from Oct. 26 to Nov. 23, 1980.

In an adjacent quonset greenhouse (29 × 7 m) covered with a single film of polyethylene and in which air temperature was not allowed to drop below 5°C to avoid freezing, soil warming was achieved by circulating 38° water in a network of 2-cm plastic pipes located 38 cm deep and 38 cm apart. Soil temperature in heated plots was maintained at 23.9°. This greenhouse simulated conditions of plastic tunnels without heating or ventilation systems. For the spring crop 'Vendor' tomatoes were seeded at 3 different dates (March 10, 17, and 27) and transplanted on April 24, May 1, and May 5 in 6 heated and 6 nonheated plots of 45 plants. Population density was 11 plants/m^2. Plants were trained to a single stem and limited to the first 2 clusters. Harvesting started on July 11 and ended on August 18. For the fall crop, 'Vendor' and 'Ohio MR-13' tomatoes were seeded on June 27 and transplanted on August 14, in 20 heated and 20 nonheated plots of 18 plants at a density of 5.5 plants/m^2. Plants were topped after the development of the third cluster. The harvest period extended from October 16 to November 14.

The data was analyzed as a split plot design. Since the same trends were obtained for both cultivars, 'Vendor' and 'Ohio MR-13', and for all 3 dates of transplanting, data were pooled for each of the soil temperature treatments.

The effects of an increase in soil temperature on the productivity of spring and fall tomatoes grown under normal air temperature are presented in Table 1. In the spring, a rise in soil temperature increased total yield by 47% compared to only 5% for the fall crop. In the spring, soil temperature of the unheated plots was low (10°) at the beginning of the experiment and increased during the growing season. In the fall, soil temperature of the unheated plots was high (16°) at planting and decreased with time. Average seasonal temperature was 13.8° for the unheated plots. Low soil temperature caused more detrimental effects on vegetative growth in the spring, and consequently lower yields were obtained. In the fall, low light intensity obscured the effect of soil temperature. The proportion of number 1 fruit increased by 70% in the spring and 27% in the fall. An increase in soil temperature not only increased total yield but also improved fruit quality. In the fall, the number of fruits rejected in the heated plots because of gray mold disease was reduced by 60% compared to the unheated plots. Fig. 1 illustrates the cumulative yield for the various treatments. Although ripe fruits were observed first in the nonheated plots, fruits ripened more rapidly with an increase in soil temperature.

The influence of soil temperature on tomato yields grown under low air temperature conditions is presented in Table 2. In the spring, with an increase in soil temperature, total yield was increased by 36% compared to 47% under the normal air temperature regime as cited above. However, in the fall, increases in number 1 fruit weight and total yield were much higher (54 and 42%, re-

Table 1. Effect of soil temperature on the yield of greenhouse tomato grown under normal air temperature conditions.

Season	Soil temp[z] (°C)	No. 1 fruit size (g/fruit)	Yield No. 1 fruit (kg/m^2)	Total yield (kg/m^2)
Spring	14.0	146	6.2	8.7
	21.8	164*	10.5	12.8*
Fall	13.8	167	5.6	7.6
	20.5	168	7.1**	8.0

[z]Avg. seasonal temp.
*,**Significantly higher than paired comparison at 10% (+) or 1% (**) level.

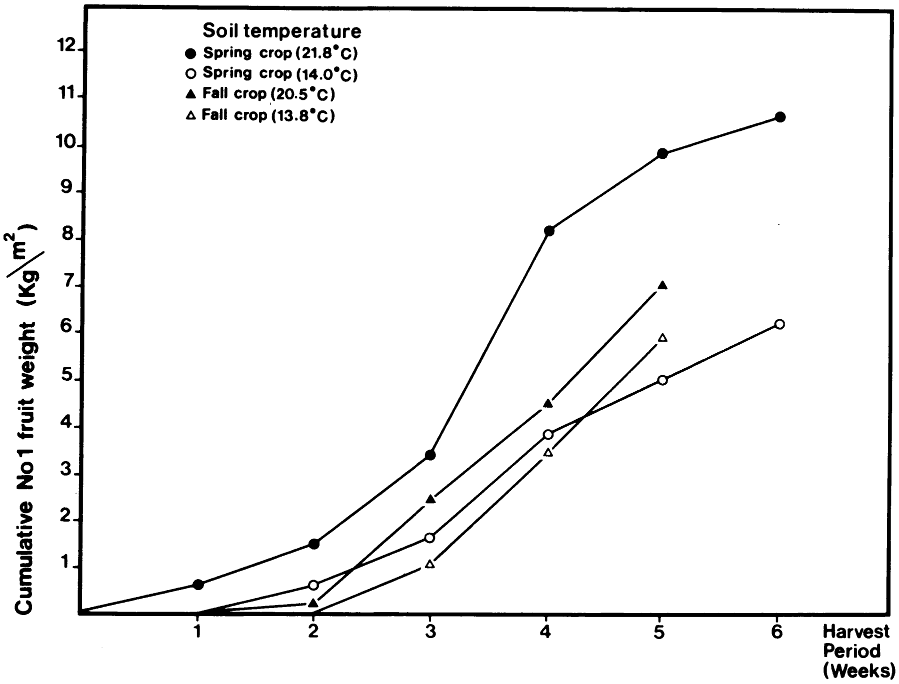

Fig. 1. Influence of soil temperature on the cumulative yield of tomato number 1 fruit weight grown under normal air temperature conditions.

spectively) with an increase in soil temperature. These large differences resulted from small yields obtained in the unheated plots and a 66% reduction in the number of fruits affected by gray mold in the heated parcels.

Warming the soil was shown to improve the productivity of greenhouse tomato. Our experiments have clearly demonstrated that an increase in soil temperature had a greater influence in the spring than in the fall when light intensity was not the limiting factor and soil temperature was lower. In the fall, warming the soil had an important effect only under low air temperature conditions.

The use of plastic tunnels for the production of tomato has been limited because of low yield and a lack of earliness as compared to the field crop. With an increase in soil temperature, it was possible to obtain yields as high as under normal greenhouse conditions and with sufficient earliness to command high prices. Moreover, under these low air temperature conditions, energy cost has been estimated to be only 20 to 25% of a conventional greenhouse. These data on effect of soil temperature in conventional greenhouse raise the possibility of growing 3 short crops of tomato a year using high density planting of 2 or 3 cluster plants. Such a low canopy could easily be covered with thermal blankets and allow additional energy savings. More work is needed to determine the profitability of these new cultural practices.

Table 2. Effect of soil temperature on the yield of greenhouse tomato grown under reduced air temperature conditions in a plastic tunnel.

Season	Soil temp[z] (°C)	No. 1 fruit size (g/fruit)	Yield No. 1 fruit (kg/m²)	Total yield (kg/m²)
Spring	13.8	162	8.7	10.0
	23.9	175*	12.2*	13.6*
Fall	13.0	161	2.5	5.2
	22.0	158	3.9*	7.4**

[z]Avg seasonal temp.

*,**Significantly higher than paired comparison at 10% (*) or 1% (**) level.

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Water-soluble Calcium in Ca-efficient and Ca-inefficient Tomato Strains[1]

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Abstract. **Seedlings of 5 strains of tomato (*Lycopersicon* spp.) were grown in low-Ca nutrient solutions in a greenhouse for 4 weeks in order to determine whether Ca-efficient and inefficient strains differed in concentrations of water-soluble Ca. Aqueous extracts from dried tissues of efficient strains were lower in percent of Ca and in electrical conductivity than were extracts from inefficient strains. Efficient strains may suffer less than inefficient strains from precipitation or displacement of Ca from functional sites in tissues by other ions.**

Calcium appears in many forms in plants, ranging from water soluble to insoluble. The soluble portion occurs in the cytoplasm as ionic Ca or as relatively soluble Ca salts, and the less soluble forms include Ca in cell walls, Ca associated with enzymes, and relatively insoluble Ca salts. Researchers have estimated the occurrence of the various forms of Ca by using analysis of juice (3), extraction with water, salt solutions, or acids (6), and microscopic identification of Ca oxalate crystals (9). These methods are often imprecise, and Ferguson et al. (7) believe that Ca oxalate is the only cellular fraction that currently can be measured reliably. They argue that mea-

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