Using Forced Air Heat to Warm the Soil

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The common techniques used to heat the soil, such as buried tubing heated with circulating hot water or buried electric heating cables, are a substantial and expensive modification of the typical greenhouse. Additional heating and control systems are required. Such methods are unlikely to be used by growers if there is only marginal benefit in terms of increased yield. Here, we describe a simpler method for heating soil that makes use of the forced hot air furnace that is used to heat the greenhouse air. The only modification to the greenhouse was burial of air ducts underneath raised beds of soil.

Experiments were conducted in a greenhouse at Malerba's Farm in Norwich CT. The greenhouse area was 30 x 96 ft, covered with a double layer of 6-mil polyethylene film supported by steel hoops at 4-ft spacing. It was heated by a 90 kilowatt oil-fired, forced-air furnace located in the south-west corner of the house. The furnace was activated by a thermostat if the air in the greenhouse cooled below 61F. Fans for horizontal air flow helped maintain a uniform air temperature throughout the greenhouse. The soil was heated by blowing air from the furnace through buried air ducts (Figure 1). First, two 96-ft lengths of 4-in diameter, black polyethylene, corrugated drainage tubing were buried 1 ft deep and 2 ft apart centered under the location of raised beds. The ends of the tubing were vertical and 2 ft were extended into the air. Then soil was formed into raised beds, 0.5 ft high x 4 ft wide, that were covered with black polyethylene film. The beds were arranged along the north-south axis of the house and separated by 2-ft wide aisles. Unheated beds for comparison had no drain pipe. The furnace had three outlet ducts, two of which were directed into the air. One duct was attached to 1-ft diameter polyethylene-film tubing which served as a manifold for distribution of forced hot air to the drainage tubing in the soil. The amount of heat going through the soil could be reduced if necessary by constriction of this manifold. The air going through the soil was exhausted from the drainage tubing into the north end of the greenhouse.

This soil heating system was tested in two years. Seedlings of the tomato cultivars ‘Jetstar’ (Harris Moran, Rochester NY), ‘Buffalo’ and ‘Caruso’ (Stokes, Buffalo NY) were germinated and grown for 7 to 8 weeks before transplant into the raised beds in the production greenhouse. Plants were pruned to a single stem and supported by string. The rows were watered by drip irrigation with a complete nutrient solution (Peters 15-16-17 N-P_2O_5-K_2O) at a concentration that was increased from 50 ppm N shortly after planting to 200 ppm during fruit production. Each raised bed was planted with one cultivar of tomato. The plants were set into the raised beds in two rows spaced 2-ft apart and separated by 2-ft within the row. Four raised beds were used for the experiment. The two beds on the east were heated and the beds on the west were not. In each year, two cultivars were grown in both a heated and an unheated bed. Fruit was picked at two to four day intervals and weighed. The highest quality (number one) fruit were selected and weighed.

Soil temperatures were measured at 8:00 am, daily for the first two weeks, then at weekly intervals. A thermometer was inserted to a depth of 4 inches in the center of the raised bed. Heated and unheated beds were measured at two locations, half way between the mid point and the end of the bed, in the north section away from the furnace, and in the south section, near the furnace. Maximum and minimum air temperatures were also recorded. The soil temperature was 59F at planting on 21 March 1992. The soil in the south section of heated beds, near the furnace, warmed to 66F in one day and 68F in one week. The soil in the north section of the heated beds, away from the furnace, was about 5F cooler. The soil in the unheated beds remained at 59F for the week after planting. In April, the soil in the south section of the heated beds averaged 68F, and it was 2 to 3F cooler in the north section. The unheated beds were 61F in the first week and 63F for the rest of April. In May, the heated beds cooled from 68 to 66F, because the furnace was used much less for heating, while the unheated beds averaged 64F.

The soil temperature was 50F when heating commenced on 12 March 1993. At planting, on 17 March and for the next 10 days, the heated beds were 70F in the south section and 66F in the north section. The unheated beds warmed to 59F during this period. The end of March was warm and cloudy, and the furnace was used less for heat. Consequently, the soil in the heated beds cooled to 64F. In April, the soil in the south section of the heated beds averaged 72F, and it was a degree cooler in the north section. The south section of the unheated beds warmed from 60 to 64F during April. The north section was 2 to 3F cooler. Minimum air temperatures were nominally 61F but cooled to 57F on some nights in March. Maximum air temperatures, which were as low as 70F in mid March, tended to increase to 86F in May and 95F in June.

In 1992, heating the soil increased the total yield of tomatoes. The heated beds were more productive than the unheated beds throughout the season, resulting in a 16% greater overall yield. Ripe fruit was picked from plants in the heated beds 3 days earlier than unheated beds. 'Jetstar' yielded more than 'Buffalo' throughout the 1992 season, and continued producing in August when 'Buffalo' declined. Heating the soil increased yields of both 'Jetstar' and 'Buffalo', but for 'Jetstar' this increase was small until mid July. The difference in yield between heated and unheated beds was greater in the south section of the greenhouse, near the furnace, than in the north section. Although, heated beds produced more high quality tomatoes than did unheated beds, the weight fraction of number one fruit was not increased significantly. The early production of 'Buffalo' had higher quality tomatoes than 'Jetstar'.

In 1993, heating the soil increased the early yield as well as the total yield, but it did not advance ripening of the first fruit. Production from the heated beds by 30 June was 14% greater than that from the unheated beds. There was no difference in production between heated and unheated heated beds in July, so the differences in total yield reflected the differences in early production. 'Caruso' yielded more than 'Buffalo' over the 1993 season and heating the soil increased yield of 'Caruso' more than 'Buffalo'. The south sections yielded more than the north sections. In 1993, the tomatoes of both cultivars grown in the heated beds were of better quality than those from unheated beds. Over the season, 82 w/w% of tomatoes picked from the heated beds were rated number ones, compared to 72 w/w% from the unheated beds.

These results showed that blowing hot air from a forced-air furnace through buried air ducts could quickly heat the soil within the root zone. However, there were two drawbacks of this method that would not occur in a system that heated the air and soil independently. During a period of warm weather in 1993, the furnace was idle at a time when heating the soil would have been beneficial. Due to the one-way flow of air, the soil near the furnace was warmed more than that at the other end of the greenhouse. Despite these drawbacks, this method increased the yield of tomatoes in trials in two years.

Costs were low for this method of heating the soil. The material costs for the air duct, at $0.25 per ft, would be $250 for a 25 x 96 ft house. With a tractor to make furrows, the installation can be completed in a few hours. Soil heating would increase energy cost due to a greater loss of heat from the soil through the perimeter of the house. Perimeter insulation was not used in this study. It would reduce heat loss from the soil, and help raise the soil temperature, with or without soil heating. However, far more energy is used to heat the air in a greenhouse than to heat the soil, so the increased energy costs for soil heating would be a small fraction of the total.

The increase in yield due to heating the root zone warrants its use in greenhouse tomato production in the northeast US. When planted in March, the ambient temperature of the soil was sufficiently cool to limit tomato production. In other experiments with successive plantings, soil temperatures did not seem to limit greenhouse tomato production in Connecticut after mid April (Gent, 1991; Gent and Malerba 1994). Thus, there may be little benefit to heating the soil for tomatoes transplanted later than in the present study. Sub-surface heating may also have less effect in bag and trough culture or with the nutrient film technique, because in these situations the temperature of the root medium follows that of the air more closely than the temperature of the soil mass under the greenhouse. Conversely, root zone heating has been found to increase yield in unheated or minimally heated greenhouses more than in heated houses (Moss, 1983; Cholette and Lord, 1989).

In conclusion, blowing hot air from a forced-air furnace through ducts beneath raised beds heated the soil rapidly. This method of heating the soil resulted in greater yields and a higher quality of greenhouse tomatoes than if the soil was not heated.

References

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Figure 1. Schematic diagram of a greenhouse with soil heating using a forced-air furnace