Season Extension for Tomato Production Using High Tunnels

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Abstract

As part of a multi-year project funded by the New Jersey Agricultural Experiment Station, two high tunnels were constructed according to the Penn State high tunnel design with some minor modifications. These included an improved design of the end wall construction, automated roll-up side vents used for ventilation. During the spring and summer of 2003, a tomato crop was grown with the same treatments in both tunnels. The treatments included two commercial tomato varieties (*Lycopersicon esculentum*, cv. SunBright and SunShine), grown in: 1) a tunnel with either manual or automatic roll-up side vents, and 2) beds covered with colored mulches (bare, red, green, and black). The plants were irrigated with a drip irrigation system that was manually operated based on soil tensiometer readings. The tunnels were instrumented with dataloggers that recorded: 1) inside and outside temperature, relative humidity, and photosynthetically active radiation, and 2) inside and outside soil temperature. Results of this first trial indicated an average final accumulated production of 5.4 kg of marketable tomatoes per plant for a crop grown between May 5 and August 29 (approximately 7.9 kg per m^2). Minimal difference in final accumulated production occurred between the manual and automatic roll-up side vents, two varieties, or differently colored plastic mulches.

INTRODUCTION

Tomato production was ranked first in total value ($27,962,000) in 2003 among vegetables grown for the fresh market in New Jersey (New Jersey Agricultural Statistics Service). In that year, a total of 1,255 ha were harvested, resulting in an average production value of $22,280 per ha. However, total growing area has steadily declined over the last five years while income per ha has increased only slightly. To consumers all along the East Coast, the Jersey tomato has enjoyed the reputation as a premium product. In New Jersey, tomatoes are grown by a large variety of producers, from small farm marketers to large wholesale producers. In order for the Jersey tomato to remain competitive, efforts must be undertaken to improve production practices, profitability, and post harvest handling. To that end, a multi-year research project was started to address these issues by investigating the merits of high tunnels for commercial tomato production. Two high tunnels have been installed on Cook Campus in New Brunswick. Two commercial tomato varieties are being grown and their yields compared. A modest amount of automation has been introduced in order to investigate potential labor saving strategies, while keeping the installation costs to a minimum. The tunnels were instrumented so that environmental conditions inside and outside the tunnels can be studied, compared, and evaluated for optimum ventilation control strategies.

Tunnel Design

Two 5.2 by 11 m tunnels were constructed according to the Penn State high tunnel design (Center for Plasticulture, 2003; Lamont et al., 2002). These high tunnels are classified as temporary agricultural structures because no concrete footings were used to anchor the foundation posts. In fact, the foundation posts were hammered into the ground allowing for relatively easy removal. The hoops were bolted to the anchor posts making for easy installation with two people. These tunnels are called high tunnels because it is possible to stand up straight almost throughout the tunnels without touching the cover material or the structural elements. This design allows for large hinged doors in the end walls that, when opened, enable a small tractor to drive straight through during soil and growing bed preparation. The relatively tall (1.5-1.8 m) vertical sidewalls were installed as roll-up sidewalls allowing for sufficient cross ventilation during crop production. Often such roll-up sidewalls are operated manually because there is no electricity on site to operate an electric motor, or because of the costs involved with installing motorized sidewalls. The roof of the high tunnels has a sufficiently steep angle (approximately 26.5 degree) for most snow accumulation to slide off. Unless motorized sidewalls are used, only a reliable water source is needed at the site to grow a crop. A standby heater may be needed to prevent frost damage very early or late in the growing season. A single layer (0.15 mm) of 4-year polyethylene greenhouse film was used to cover the tunnels. The film had anti-condensate and infrared blocking features, to prevent condensation drips and reduce the heat gain during the day as well as reduce the heat loss at night.

End Walls

The end walls were made of three different sections: 1) a permanently installed triangular shaped section covering the top part of the end walls, 2) a large rectangular shaped section that is hinged from the top section, and 3) two curved sections filling the space between the large hinged door and the sidewalls (Fig. 1). A regular access door was framed as part of one of the large hinged doors. The different end wall sections were covered with a single layer of the same polyethylene film used to cover the rest of the tunnel (Fig. 2). In order to easily attach the polyethylene covering film, the entire end wall was framed in wood using 2 by 4 (3.8 by 8.9 cm) framing studs. Where the wood came in contact with the soil, pressure treated wood was used. In order to increase the strength of the wooden end wall frame, all wood on wood connections were lapped, glued and screwed. Curved sections of the end wall frames were made out of 1.9 cm thick pressure treated plywood, that when doubled up were the same thickness as the other framing elements. Where needed, the wooden end wall frame was bolted to the outside metal framing bow. The polyethylene covering film can be attached to the frame of the end walls with wooden lathe, or with extruded aluminum profiles that secure the film with a stainless steel wire profile.

During soil and growing bed preparation, the large hinged doors were placed in a horizontal position by placing a temporary support underneath the bottom of the doors. In addition, the curved sections to the left and right of the hinged door were removed to allow easy access for the tractor and soil tillage equipment.

Sidewalls

The sidewalls of the high tunnels can be rolled up to allow for cross ventilation when the inside temperature rises above a target set point temperature. Typically, such sidewalls are operated manually: opened in the morning and closed in the evening. The polyethylene film covering the sidewalls was rolled around a metal pipe extending the entire length of the tunnel. Once the desired opening was reached, the pipe was secured in place by sticking another pipe through a T-section attached at the end of the roll-up pipe.

In order to reduce the labor involved in operating the sidewalls and in an attempt to improve the temperature control inside the tunnels, two of the six tunnels constructed for this project were outfitted with motorized roll-up mechanisms. These automatic systems contained the following components: 1) a motor controller that uses temperature measurements to engage an electric switch that operates the tube motors, 2) a tube motor for each roll-up side that is attached to the end of the roll-up pipe, 3) extruded half-pipe segments that formed the roll-up pipe and that were secured at the bottom of each polyethylene film roll-up side, 4) a special aluminum extrusion attached to the baseboard at the bottom of the side opening (this extrusion holds the roll-up pipe firmly in place when the sides are closed), and 5) some additional hardware needed to guide the tube motor during operation. Finally, a rope webbing was installed outside each side vent to prevent them from moving around during high wind conditions.

Instrumentation

Each of the high tunnels was outfitted with aspirated temperature (T-type thermocouple) and relative humidity sensors (Vaisala, Model Humitter 50U) to measure aerial conditions. A quantum sensor was placed in each tunnel just above the top of the crop canopy to measure light (photosynthetically active radiation, PAR) intensities. A temperature sensor (T-type thermocouple) was placed in the soil of each of the four growing beds in each tunnel. Tensiometers (Irrometer, Model R) were installed in each tunnel to measure the soil moisture tension. Outside conditions (air temperature and relative humidity, light intensity, and soil temperature were also measured. Except for the tensiometers, all sensors were connected to a programmable data logger (Campbell Scientific, Inc., Model 21X) to record one-minute averages.

Tomato Production

Prior to transplant, the soil in the high tunnels was tilled and an herbicide was applied to reduce weed growth during the early stages of crop growth. Immediately thereafter, the beds were formed and the plastic mulch and irrigation drip tape (underneath the mulch) were installed. The tomato seedlings were transplanted into the tunnels on May 5, 2003. The first harvest occurred on July 2, the final harvest on August 29, 2003. Two tomato cultivars were planted: ‘SunBright’ and ‘SunShine.’ In each tunnel, four beds were prepared. The distance between the beds was approximately 1.1 m, while each bed was approximately 53 cm wide. In each bed, the distance between the plants was 46 cm. This resulted in a plant spacing of approximately 1.48 plants per m^2. Each of the four beds randomly received a different mulch treatment: one of the beds was left uncovered, while the remaining three beds were covered with a red, green, or black colored plastic mulch, respectively. Each bed was divided in two sections of equal length, and each section was randomly planted with one of the two cultivars. A guard plant was planted at the end of each bed and in between the two different cultivars. The plants were irrigated based on tensiometer readings by supplying tap water through drip tape. When necessary, a liquid fertilizer solution was injected into the irrigation water. As the plants grew, stakes and strings were used to keep the plants growing in an upright direction and to support the weight of the tomatoes. The plants were scouted weekly to check for insect infestations and sprayed with a pesticide when necessary.

RESULTS AND DISCUSSION

Price estimates based on prices paid and the amount of labor required to build the high tunnels for this project are presented in Table 1. Note that the motorized roll-up mechanism almost doubled the price. However, the particular system installed used various extruded aluminum profiles that were more expensive as compared with alternative components. Note that the cost of the motorized system is virtually the same for larger tunnels, further reducing the price per square meter of growing area. Also note that significant labor savings can be realized by using an automated ventilation system, as well as potentially better temperature control.

The average PAR transmission during the experiment for both the manually and the automatically vented tunnel was 74%, with a standard deviation of ±2%. During the experiment, an average daily light integral of 25.6 mol m^{-2} d^{-1} was measured inside the tunnels at the top of the plant canopy.

The tomato harvest data are shown in Figure 3. Through August 29, a total of 771 kg of marketable fruit was harvested from 144 plants in the two tunnels (approximately 5.4 kg per plant or 7.9 kg per m^2 of growing area). When comparing the final accumulated harvest data, there appeared to be minimal difference in production between 1) the manual and automatic roll-up sides, 2) the two different varieties, and 3) the different colored mulches. The cultivar ‘SunShine’ appeared to be an earlier variety as compared with ‘SunBright.’

Figure 4 shows the (aspirated) daily average air temperatures inside the manually and the automatically vented tunnels as well as the outside temperature. Early in the growing period, the daily average air temperature was higher inside compared to outside the tunnels (Fig. 4). Minimal difference was observed between the two ventilation systems. Note that no environmental data were collected between May 5 (planting) and May 24.

Figure 5 shows the daily average soil temperature inside the manually and the automatically vented tunnels as well as the outside soil temperature. The sensors were positioned 15 cm below the soil surface and the inside soil temperatures shown in Figure 5 for each tunnel were the average temperatures calculated from sensors placed underneath the black, green, and red mulch. Minimal difference was observed between the two ventilation systems. Note that the daily average soil temperature in both tunnels remained higher than the outside soil temperature for a significant portion of the growing period.

Figures 6 and 7 illustrated 15-minute averages of the air and soil temperatures as well as the sunlight (PAR) intensity for the period June 1-4, 2003. The figures illustrate the effect of sunlight intensity on air and soil temperatures. The differences in temperatures measured inside the manually and automatically vented houses can be explained by the timing (usually twice daily) and the extent (usually opened a certain amount in the morning and fully closed late in the afternoon) of the adjustments made to the manually vented tunnel.

ACKNOWLEDGEMENTS

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Literature Cited

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Tables

Table 1. Price estimates for the various components of the two types of high tunnel used for this project (5.2 by 11 m). Note that this table does not include price estimates for freight, bringing water and electricity to the site, nor price estimates for growing a crop (e.g., irrigation, fertigation, mulch film, soil and growing bed preparation, seedlings, crop scouting and pest management, labor for crop maintenance and harvesting).

Component	Price (manual roll-up)	Price (motorized roll-up)
High tunnel frame	$ 770	$ 650
Lumber	$ 260	$ 260
Hardware	$ 400	$ 400
Polyethylene covering film	$ 145	$ 145
Roll-up sides	included	$ 2,545
Construction labor ($15/hr)	$ 1,200	$ 1,440
Total	$ 2,775	$ 5,440

Figures

Fig. 1. High tunnel under construction showing a completely framed end wall.

Fig. 2. High tunnel covered with a single layer of plastic and vented with roll-up sides.

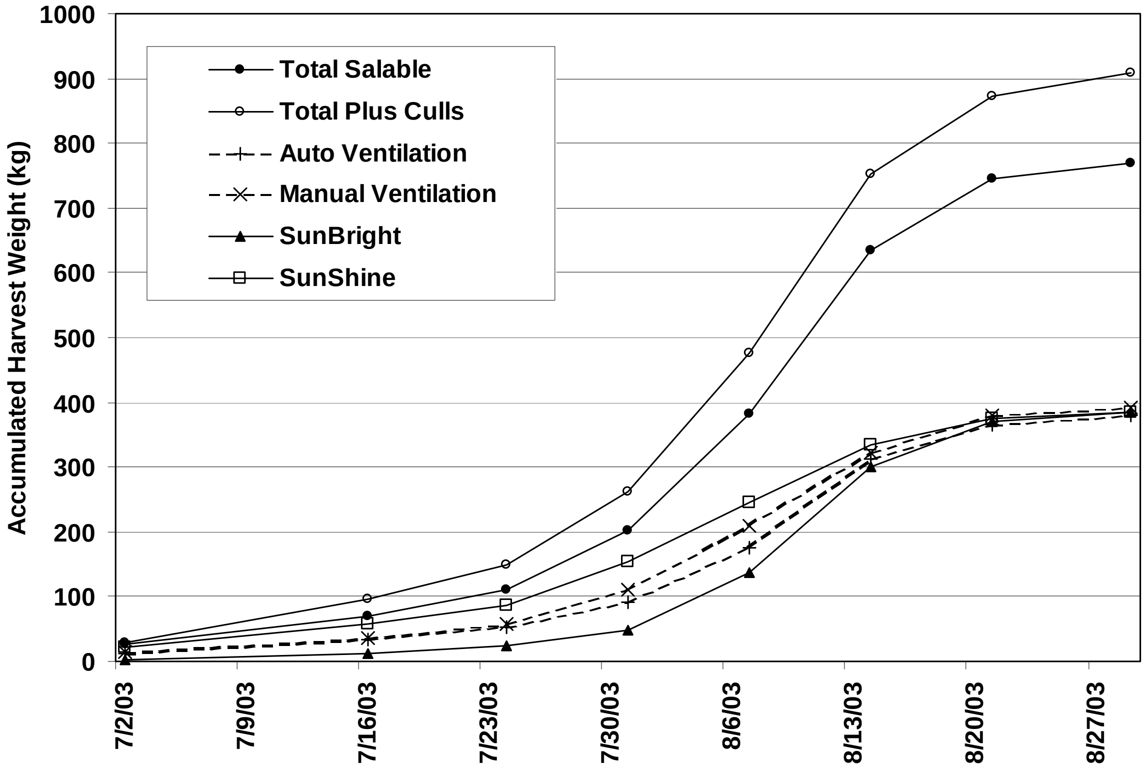

Fig. 3. Accumulated harvest weights (from 144 plants).

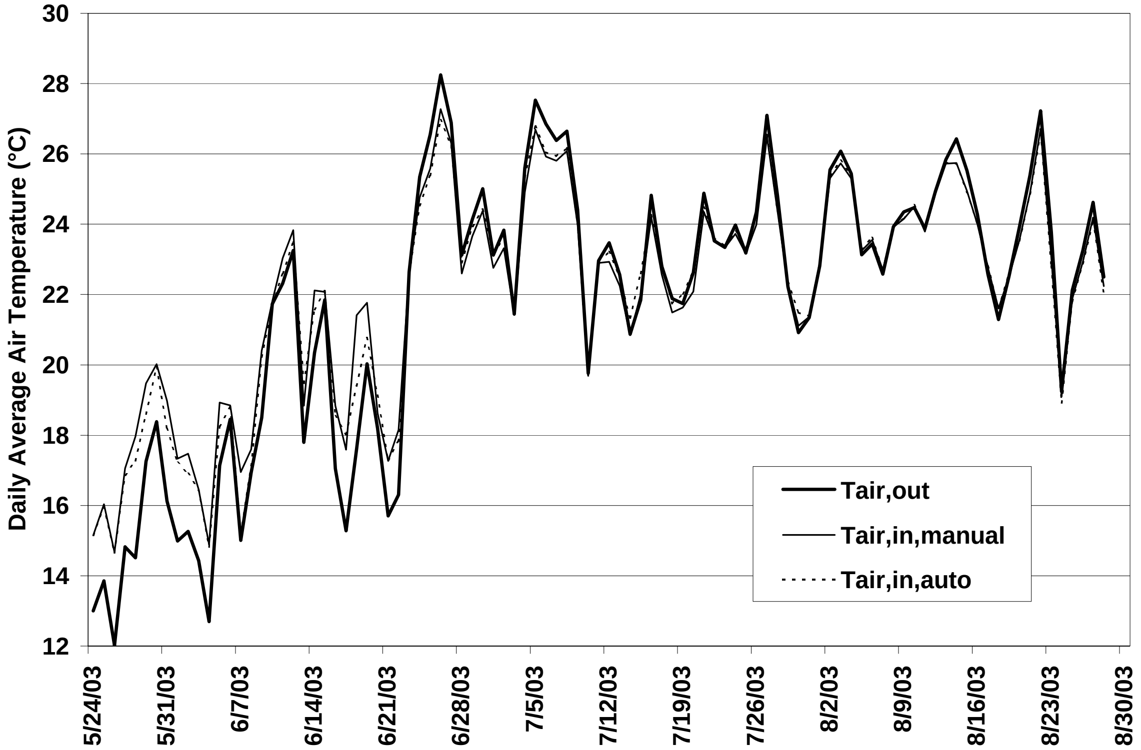

Fig. 4. Measured daily average air temperatures outside and inside the high tunnels.

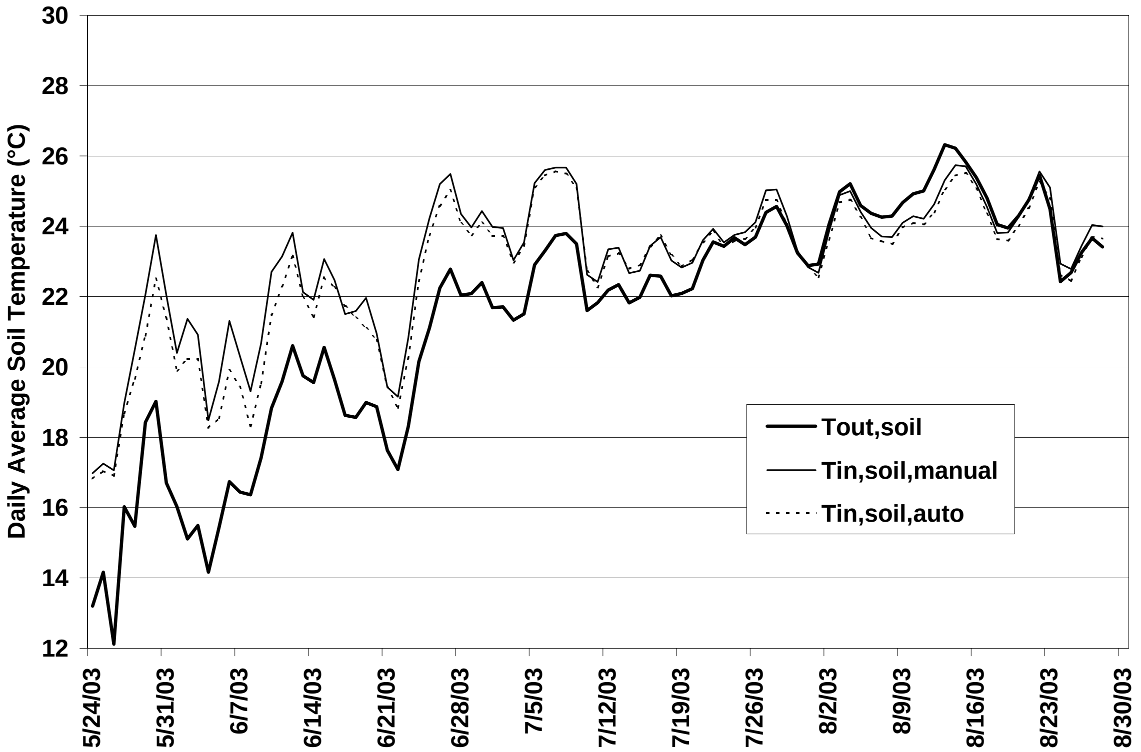

Fig. 5. Measured daily average soil temperatures outside and inside the high tunnels.

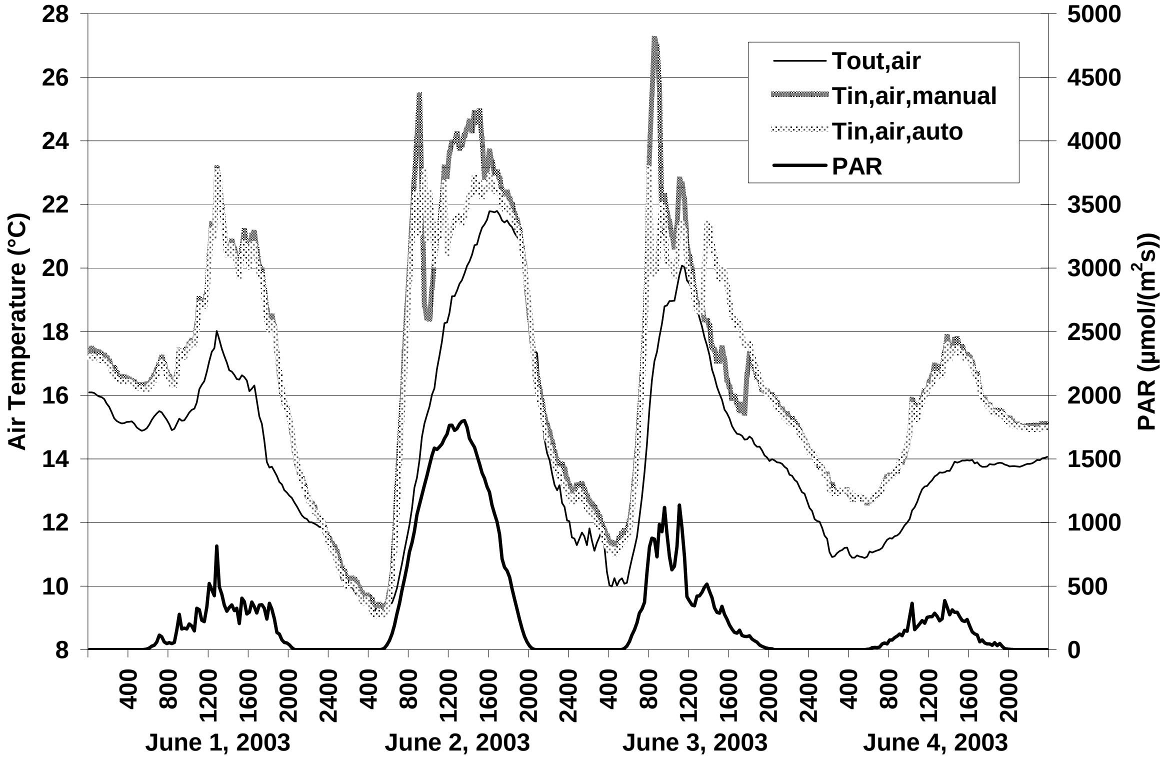

Fig. 6. Measured air temperatures and outside light intensity (PAR) for June 1-4, 2003.

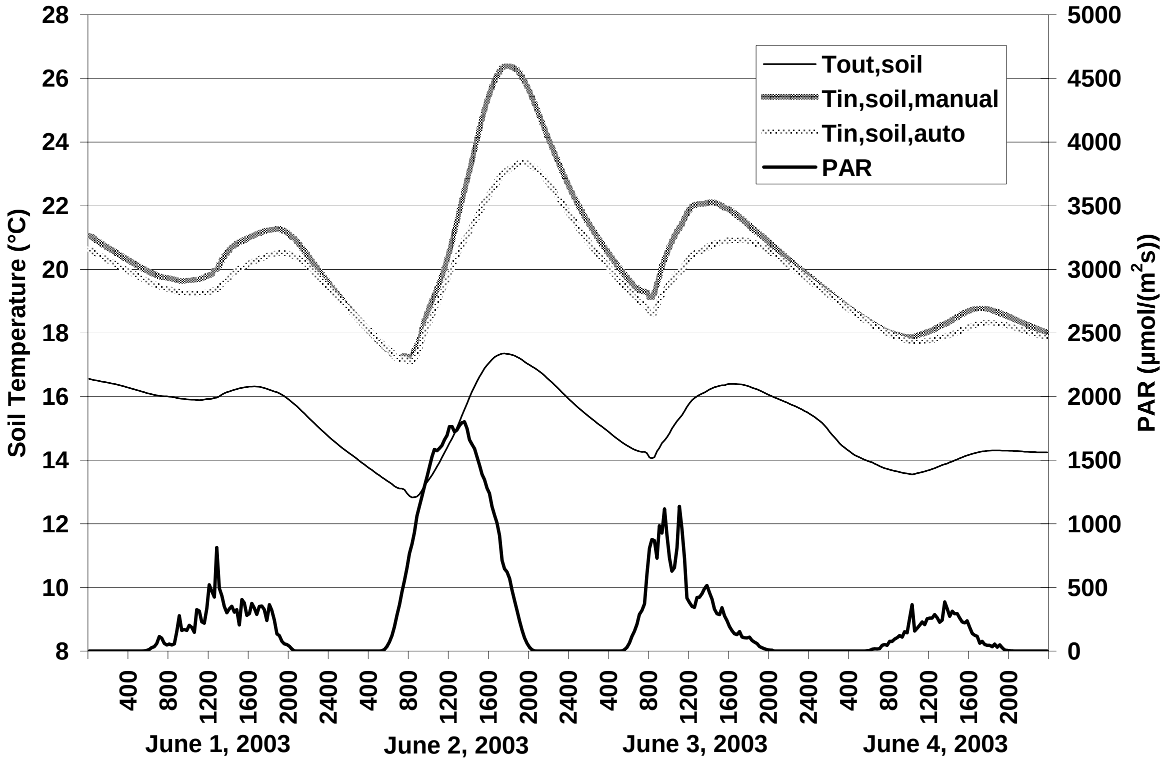

Fig. 7. Measured soil temperatures and outside light intensity (PAR) for June 1-4, 2003.