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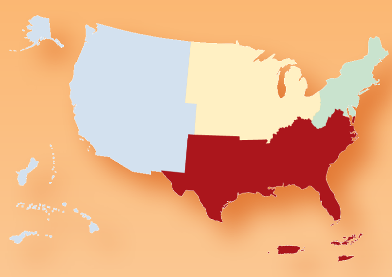

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# Organic Heirloom Tomato Production in High Tunnel and Open Field Systems

## Project Summary

Organic heirloom tomatoes are a high-value product with a growing demand but there are many challenges to successful cultivation. High tunnel systems may help farmers supply a growing regional market for high-value horticultural crops and take advantage of the lengthy, sub-tropical growing season (USDA hardiness zone 7b-8a) in eastern North Carolina. For this reason, a replicated, systems-level comparison study was carried out to evaluate the production of the popular heirloom tomato, Cherokee Purple (*Solanum lycopersicum* L. 'Cherokee Purple'), under organically managed high tunnel and open field systems. Crop yield, fruit quality, microclimate and disease incidence were examined. Results of this study suggest that with proper management techniques, high tunnels can optimize yields, increase fruit quality and provide season extension opportunities.

## Top Findings

- High tunnel tomatoes were harvested 3-4 weeks earlier than field-grown tomatoes.
- The high tunnel and field systems achieved similar total yields the first season, but high tunnel yields were 33 percent greater than the open field in the second year. This suggests better year-to-year consistency with the high tunnel system.
- Fruit cracking, cat-facing, blossom-end rot and insect damage were the major categories of defects in both growing systems. Management practices (e.g., irrigation, temperature, pest management) and variety selection are key to minimizing these defects.

**COVER PHOTO:** The experimental site consisted of two high tunnels and adjacent field plots, located at the Center for Environmental Farming Systems in Goldsboro, N.C. *Photos courtesy Suzanne O'Connell*

- During a late-spring freeze, the high tunnels provided enough protection (+4 degrees) to prevent visible cold damage to the crop.
- Incidence of both tomato spotted wilt virus (TSWV) and grey leaf spot (GLS) were lower in the high tunnel compared to the open field in 2007 and 2008, respectively, suggesting high tunnels can provide protection from various diseases.

# Methods

### Experimental Design

The experiment was conducted at the Center for Environmental Farming Systems (CEFS) from 2007 to 2008 in Goldsboro, N.C. The two high tunnels used were snow-arch design (96 feet by 30 feet by 12 feet) with bows every 4 feet, an inflated double polyethylene film roof, twin-wall polycarbonate end walls and an automated '6' Z-Lock drop-down curtain system (Atlas Greenhouses Inc.; Alapaha, Ga.). Two equivalent field plots were established as controls. Each field plot was 96 feet by 30 feet, and was established 50 feet from each high tunnel with a parellel orientation. The high tunnels were oriented east-west in order to be perpendicular to the prevailing winds (cover photo). **Precaution.** The field site was managed according to USDA National Organic Program standards, but it is best to say it was in a transitional phase during the experimental time period.

The main treatment (high tunnel vs. field growing system) was replicated four times (two blocks per high tunnel and two blocks per corresponding field plot). Blocks were utilized to assess microclimate variability. Experimental units in both the high tunnel and field system consisted of six plants per row. Rows were 12 feet long with plants set at 24-inch in-row spacing. Rows were 4.6 feet apart, resulting in a planting density of approximately 4,840 plants per acre (approximately 9 square feet per plant). Unsampled guard rows were included on terminal ends of each plot. The regionally popular heirloom, indeterminate cultivar Cherokee Purple was used.

### Systems Management

Cultural management practices specific to each system were followed in an effort to optimize system production capability. Both years, planting dates in the high tunnel system were the third week of March; while planting dates in the field were approximately one month later, the third week of April (after the threat of frost had passed). Because the high tunnel system was planted earlier, fruit harvesting began three to four weeks earlier than the field system each year (see "Results"). Black polypropylene landscape fabric was used as a weed barrier in both systems during the growing season. A cover crop of winter rye and hairy vetch was planted in both systems during the autumn of 2007.

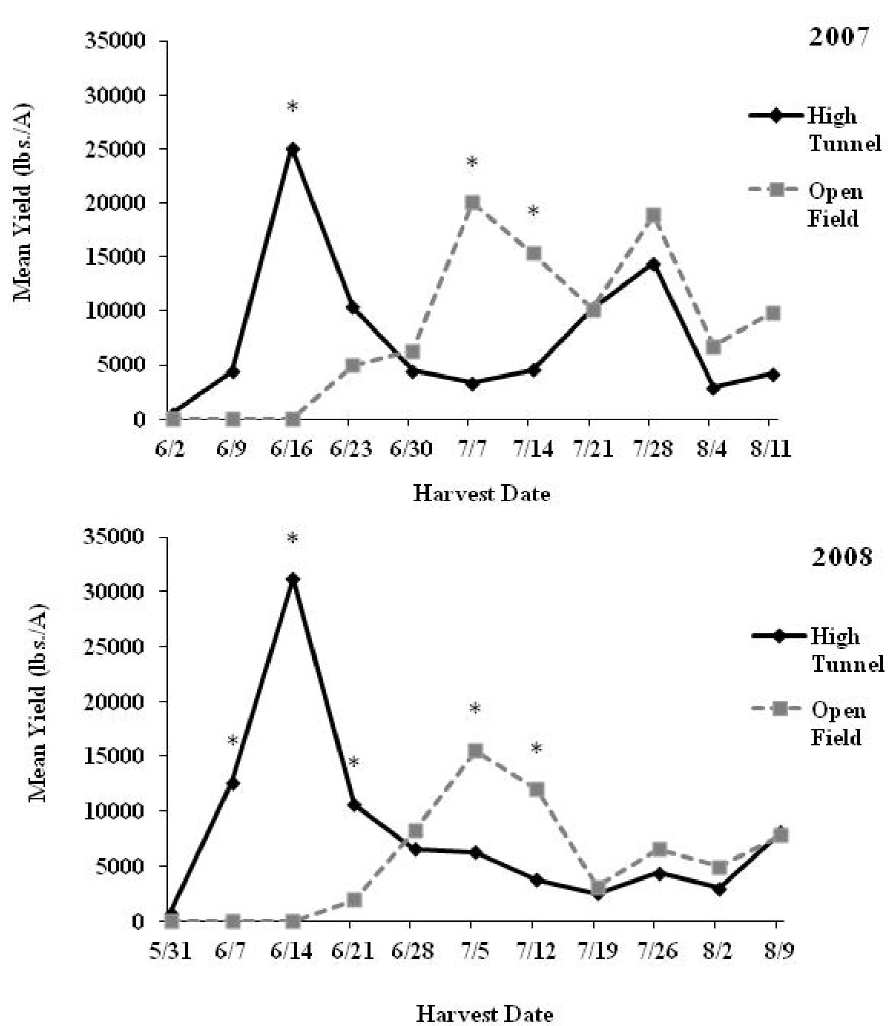


**FIGURE 1.** Average weekly harvest yield over time in the high tunnel and field system, 2007 and 2008. *Represents significant differences between the growing systems according to Tukey's mean separation test ($P \leq 0.05$) for each harvest date. Each year was analyzed separately. Adapted from O'Connell et al., 2012. HortScience 47(9):1283–1290.

**TABLE 1. COMPARISON OF MEAN TOMATO YIELD IN HIGH TUNNEL AND FIELD SYSTEMS, 2007 AND 2008[1]**

| YEAR | SYSTEM | TOTAL YIELD WEIGHT (TONS PER ACRE) | PERCENT MARKETABLE | MARKETABLE YIELD | | NON-MARKETABLE YIELD | |
|---|---|---|---|---|---|---|---|
| | | | | WEIGHT (TONS PER ACRE) | AVG. SIZE (POUNDS) | WEIGHT (TONS PER ACRE) | AVG. SIZE (POUNDS) |
| 2007[3] | High tunnel | 42.24 a[2] | 36% b | 15.18 b | 0.49 a | 27.06 a | 0.46 a |
| | Field | 46.20 a | 65% a | 29.92 a | 0.57 a | 16.28 b | 0.44 a |
| 2008 | High tunnel | 44.89 a | 69% a | 31.07 a | 0.44 a | 13.83 a | 0.44 a |
| | Field | 30.09 b | 47% b | 14.05 b | 0.37 b | 16.04 a | 0.37 a |

[1] Adapted from O'Connell et al., 2012. HortScience 47(9):1283–1290.
[2] Values followed by the same letter are not significantly different within a column according to Tukey's mean separation test (P≤0.05).
[3] Each year was analyzed separately.

Irrigation was delivered via a single drip tape (per row). Irrigation in the high tunnels and field system was administered equivalently, with one exception: The field system did not receive irrigation for 24 hours following substantial rainfall events (more than 0.5 inches per day). In 2007, plants received a total of 30 to 90 minutes of irrigation (depending on crop growth stage) daily, at 9 AM. In 2008, irrigation protocols were slightly modified to include a second watering of 30 to 90 minutes at 1 PM.

In the high tunnels, the apical meristems of the plants were pinched to encourage the development of two main leaders. A trellis system of vertical strings every 10 inches was used to support the tomato vines, which were attached with plastic plant clips. In the field system, the Florida stake-and-weave training system was used. Seven-foot-tall metal posts were pounded into the ground between every other plant. Polyethylene string was wrapped around the posts, encompassing the plants and holding them upright. Leaf pruning was done up to 1 foot above the ground. Vines were not topped.

The high tunnel's side drop-down curtain system was operated manually in 2007 and with automatic mechanized controllers in 2008. In the beginning of the growing season, sidewall curtains were lowered (i.e., opened) when ambient air temperatures inside the tunnels exceeded 65 degrees during the daytime, and were closed in the evening. As the season progressed, the sidewall curtains were kept open when both day and nighttime temperatures were consistently above 55 degrees.

Pest management decisions were based on weekly scouting. Treatment decisions were based on established integrated pest management thresholds for organic systems, when available. Insecticidal soap, predator releases (i.e., predatory wasps and aphid midges), applications of *Bacillus thurigiensis (Bt)*, and hand removal of pests were used to manage potato aphids, Lepidopteran species (i.e., tomato hornworms) and stink bugs.

During the fall of 2006 and 2007, both systems received one ton per acre of limestone. Each growing season, a combination of pre- and post-planting fertilizer was applied, which contributed a total of 100 pounds of N per acre to each system each year. Pre-plant fertilizers included organic compost (2-2-2), feathermeal (12-1-0), sulfate of potash (0-0-50) and winter cover crop residue (2008 only); post-plant inputs included the soluble "Phytamin 801" fertilizer (6-1-1).

**Sampling Protocols**

Harvests were conducted twice per week from late May to early August. Tomatoes were picked from the pink to red stages. Qualitative judgments relating to marketable and non-marketable fruit were based on observations from regional direct sales outlets for organic heirloom tomatoes. Non-marketable fruit was sorted into different categories based on types of defect. The number of individual tomatoes as well as the total weight of fruit for each category was recorded. Assessments of foliar and soil-borne diseases were conducted regularly. A variety of microclimatic measurements were recorded by automatic data loggers located within each replicated plot.

## Results

**Production**

The high tunnel harvest began approximately three weeks earlier than the field system, across both years (Fig. 1). Peak harvest occurred between the first and third weeks of June for the high tunnel system and the first two weeks of July for the field system (Fig. 1). The total fruit yield (marketable and nonmarketable) in both weight and number was similar for the high tunnel and field system across both years, but percent marketability was significantly different exhibiting a strong year-by-system interaction. As a result, each year was analyzed separately.

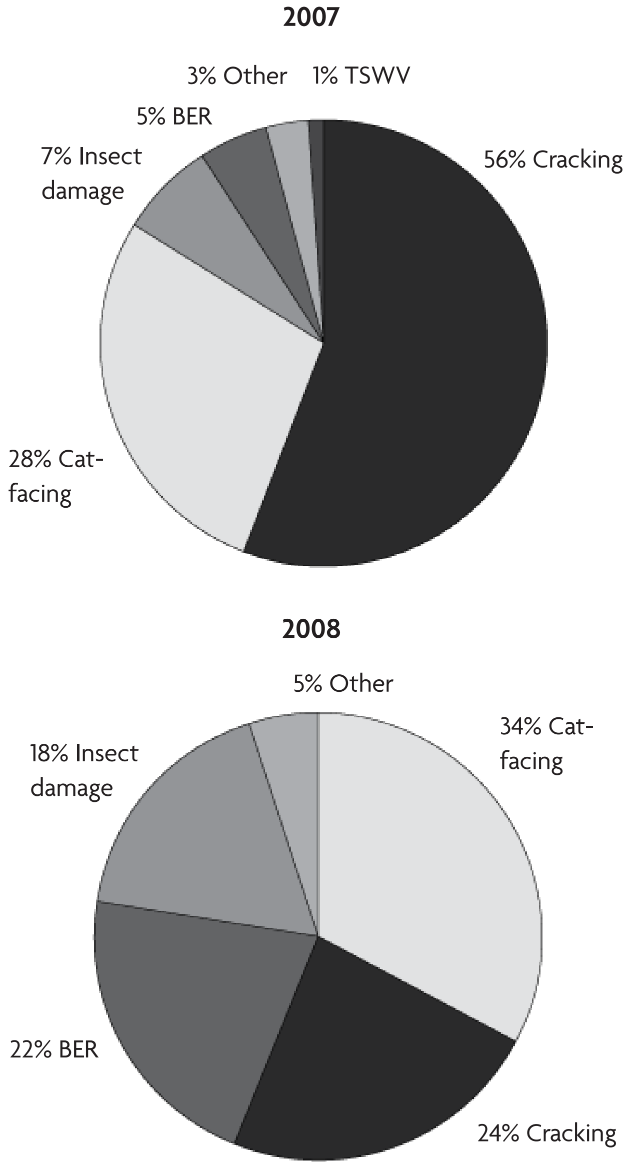


**FIGURE 2.** Breakdown of non-marketable fruit damage in the high tunnel system, 2007 and 2008. BER=blossom end rot. TSWV=tomato spotted wilt virus. Individual fruits were counted as having multiple disorders if more than one was present. Adapted from O'Connell et al., 2012. HortScience 47(9):1283–1290.

In 2007, the total fruit yield (marketable and nonmarketable) in both weight and number was similar for high tunnel and field systems, however, the marketable fruit weight was 45 percent less in the high tunnel than in the field system (Table 1). In 2008, the total fruit yield (marketable and non-marketable) in both weight and number was greater in the high tunnel than the field system (Table 1). The marketable fruit weight was 55 percent greater in the high tunnel.

In 2007, more than half of fruit damage in the high tunnel was due to cracking, cat-facing and insect damage (Fig. 2). The high tunnel system had a greater incidence of cracking and cat-facing compared to the field. Cracking, cat-facing and insect damage continued to be major impediments to fruit quality in 2008, although the incidence of cracking was reduced by about 20 percent and 10 percent in the high tunnel and field, respectively. In 2008, insect damage in the high tunnel system accounted for 18 percent of the non-marketable fruit compared to 47 percent for field system.

### Microclimate

Both growing seasons were warmer than the regional average from 2003 to 2010. The high tunnel had greater mean air temperatures and growing degree days (GDD) compared to the field from mid-March through May across both years, while differences were generally not significant from June through mid-August. The high tunnel system accumulated greater GDD than the field system over the entire season.

Each spring in either March or early April, frost threatened to damage the high tunnel crop, but did not. For example, from March 21-26, 2008, the temperature dropped to 31 degrees in the field, but to only 35 degrees in the high tunnel (Fig. 3). Although the difference between minimum daily temperatures of the high tunnel and field was only a few degrees (4 degrees), it was enough to prevent the high tunnel plants from showing any signs of external cold damage.

### Disease Incidence

In 2007, the incidence of tomato spotted wilt virus (TSWV) was particularly high throughout the region. Overall, the high tunnel exhibited less frequent TSWV compared to the field (data not shown). In 2008, TSWV incidence was very low (less than 1 percent overall incidence) across both systems. In 2008, an epidemic of gray leaf spot, caused by *Stemphylium* spp., led to rapid foliar damage and subsequent defoliation of the tomato crop in the field (Fig. 4). In mid-July, the mean percent leaf area damaged (%LAD) from gray leaf spot was 1 percent within the high tunnel and 7.5 percent in the field. Two weeks later, while the mean %LAD rose to 24 percent in the field, the mean %LAD from gray leaf spot inside the high tunnel remained at trace levels throughout the rest of the season (Fig. 4).

## Discussion and Conclusions

Data from this project suggests that in eastern North Carolina, high tunnels can advance a summer tomato crop by three to four weeks. The protection from low temperatures, earlier accumulation of GDD and greater ability to manage the high tunnel environment allows growers to supply tomatoes for early markets. Many growers report that early tomatoes can obtain premium prices as well as help with developing customer loyalty, both of which can result in greater profits.

An economic analysis was conducted using a range of mar-

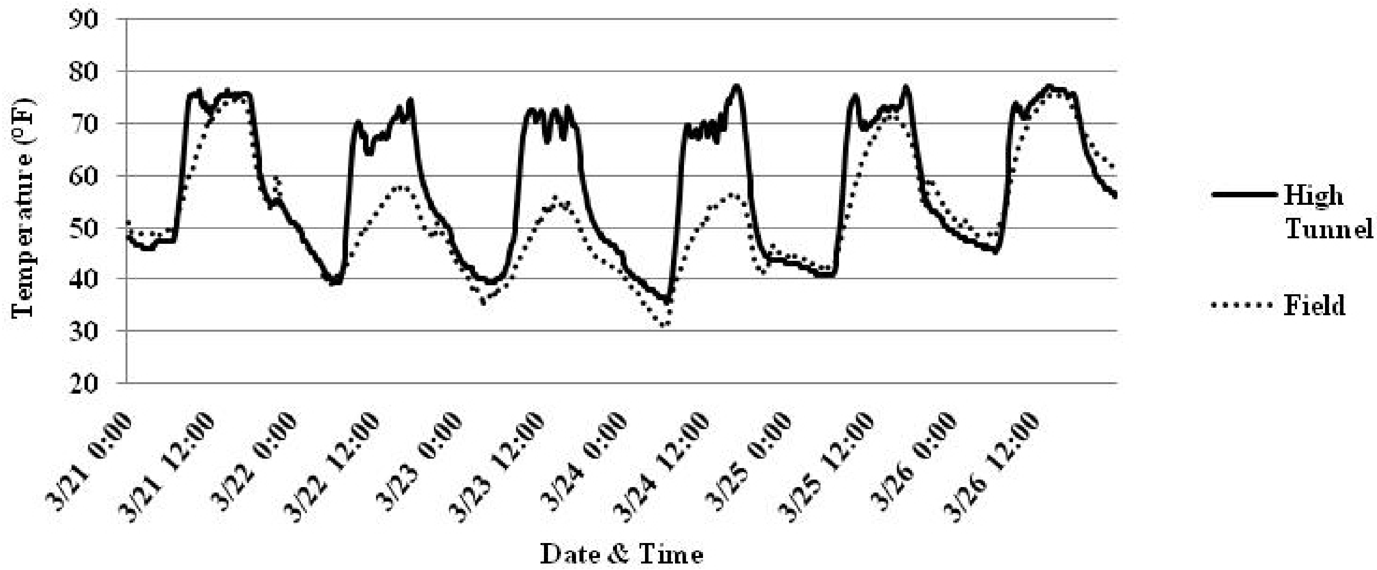


**FIGURE 3.** Mean minimum air temperatures during a cold spell for the high tunnel and field system, March 21-26, 2008. Measurements taken every 15 minutes. Adapted from O'Connell et al., 2012. HortScience 47(9):1283–1290.

ket prices, from $1.60 per pound to $3.60 per pound, and a range of marketability levels, from 35 percent to 80 percent. Both systems were profitable except at the lowest price point and the lowest percent marketability level for the 2007 high tunnel yield. At $2.60 per pound—the seasonal average sale price reported by growers for the region—and depending on percent marketability levels, the payback period for high tunnels ranged from two to five years. (For the complete economic analysis, see References.)

The high tunnel and field systems were both capable of producing approximately 89,200 pounds per acre (45 tons per acre) of organic, heirloom tomatoes, however, only the high tunnel demonstrated this level of productivity for two consecutive seasons. This suggests reduced yield variability with high tunnel systems compared to the field. Overall, the high tunnel system produced an average of 18 pounds of fruit per plant compared to 16 pounds per plant in the field system.

The ability of the high tunnels to accrue more daytime heat resulted in the accumulation of GDD at a faster rate than the field in the early growing season across both years (March to May). Growers wanting to further optimize early season production may consider tomato varieties with fewer days-to-maturity and/or more deterministic characteristics.

Although the high tunnel system gives the grower additional control over the microclimate compared to the field, it is not always possible to maintain optimum daytime or nighttime temperatures for crop growth. Increases in nighttime temperatures in the high tunnel compared to the field were modest. However, on the coldest evenings, the difference of just a few degrees appeared to provide frost protection to the high tunnel transplants when temperatures dropped below 32 degrees in the field. The inflated double polyethylene film roof likely gave greater freeze protection compared to a single polyethylene film found on some high tunnel structures. In addition, residual soil heat absorbed during the day releases from the soil during the night, increasing the air temperature (Baille et al., 2006). This absorption was maximized in our system with the addition of black polypropylene landscape fabric over the soil.

The popular Cherokee Purple tomato variety appears to

A cover crop of rye and vetch grown inside the high tunnel is terminated. *Photo courtesy Suzanne O'Connell* be very susceptible to a number of fruit defects. The percent marketability of the tomato crop fluctuated from 36-69 percent in the high tunnels and 47-65 percent in the field across the two study years. In 2007, only 36 percent of the high tunnel fruit harvest was considered marketable; in 2008, this increased to 69 percent. The difference in marketability across the years was primarily due to a decrease in fruit cracking incidence. A well-established organic farm in the same region achieved an average of 75 percent marketability with their Cherokee Purple crop in 2007 and 2008 (Rivard et al., 2010) and so we believe this would be a practical level to achieve over time.

While the Cherokee Purple variety appears to be susceptible to cracking, modifications to cultural management practices may help limit the level of damage. In 2008, slight modifications were made to our management protocols, including: more frequent yet shorter irrigation intervals, and less frequent sucker pruning in the high tunnel system during harvest period in order to provide more shade to developing fruit. One or a combination of these factors may be responsible for decreased fruit cracking during our second season. Picking fruit more frequently and/or at an earlier ripeness stage may also help decrease cracking incidence.

Cat-facing was another major factor that affected fruit quality. More frequent exposure to low temperatures during early growth may increase the incidence of cat-facing damage. Greater exposure of high tunnel plants to cold temperatures in the early spring, as opposed to the later planted field system, may have led to greater cat-facing incidence. In order to decrease cat-facing, growers may consider a delayed planting date, using supplemental heating in high tunnels during cold weather, covering plants or the tunnel structure with additional insulating fabrics, optimizing daytime heat storage, and/or using less susceptible varieties. Blossom end rot (BER) was the third most common physiological disorder which occurred across both systems. Lower BER incidence may be achievable with less susceptible varieties as well as modified cultural practices pertaining to irrigation, fertilization, pruning and training.

Overall, pest types were similar in the high tunnel and field systems with few exceptions. The high tunnel system was subject to an aphid outbreak (*Macrosiphum euphorbia*) early in the first season. Because the high tunnel was primarily a closed system in early spring, the outbreak was successfully controlled by a combination of organic pesticide applications and a series of predator releases. We found a similar composition of major pests (*Lepidoteran sp.* and *Acrosternum hilare*) in the high tunnel and field systems, which had planting dates that were offset by one month, but were physically in close proximity. Insect damage to fruit was significantly greater in the field during the 2008 compared to the 2007 season, although the reasons for this are unclear.

Due to the lack of consistent disease pressure across multiple growing seasons, we were only able to capture one year of data each for TSWV and gray leaf spot. Although it is difficult to make firm conclusions, the data indicates that high tunnels help protect organic tomato crops from TSWV and gray leaf spot incidence. Others have predicted that high tunnels help to manage leaf-infecting pathogens by reducing leaf wetness (Xiao et al., 2001). In the case of gray leaf spot, we saw evidence to support this claim.

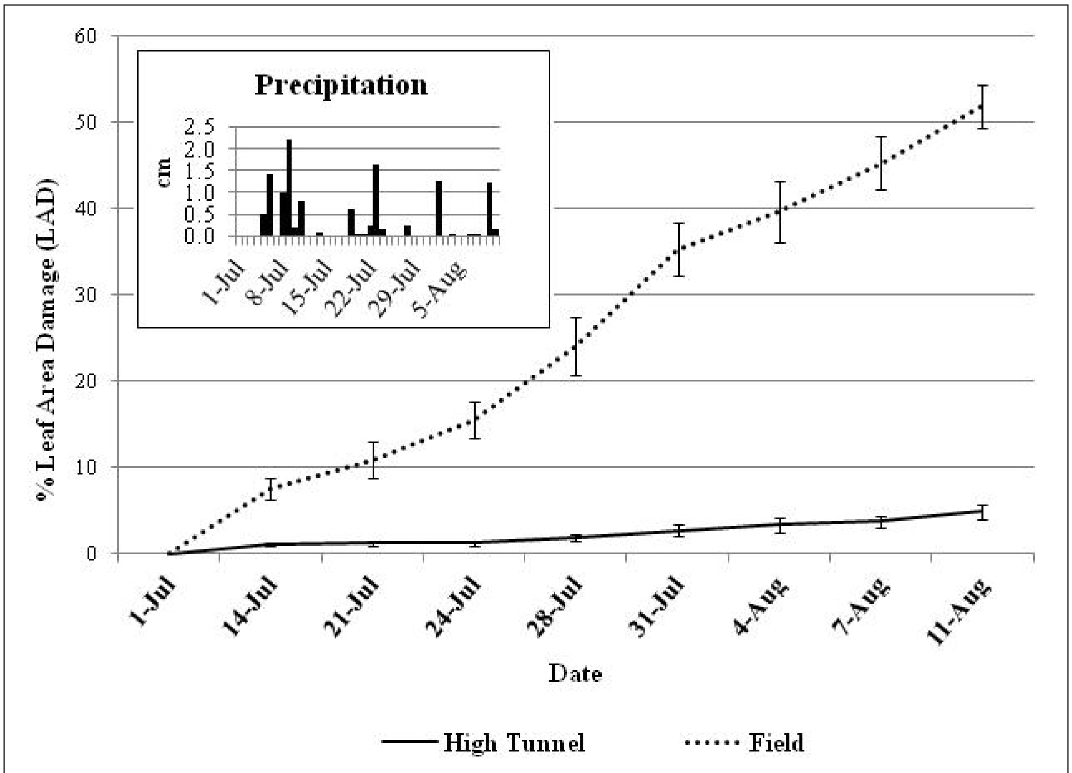


**FIGURE 4.** Percentage of leaf area damage (%LAD) caused by gray leaf spot (*Stephylium* spp.) for the high tunnel and field system, 2008. Precipitation data supplied from the North Carolina State Climate Office weather station located one mile from the project site. Adapted from O'Connell et al., 2012. HortScience 47(9):1283–1290.

Although both systems were planted with the same winter cover crop mixture between the 2007 and 2008 growing seasons, the shoot biomass in the high tunnels was 43 percent greater than the field. This action may have introduced greater variability between the growing systems in 2008. It also demonstrated that increased cover crop growth under high tunnels can be a valuable management tool for producers to consider as they can improve soil quality, contribute and recycle nutrients, and break pest and disease cycles (SAN, 2007).

Earlier harvests, cold temperature protection and more consistent yields were the main advantages of high tunnel production in this study. The ability of the high tunnel as a closed system can also encourage the adoption of environmentally friendly practices to manage pests and improve soil quality such as beneficial insect releases, solarization and extended-season cover cropping. Climate change models predict that the Southeast region will experience more extreme weather events (i.e., greater frequency and intensity of droughts and hurricanes), increased rates of summer warming, and be subject to amplified levels of pests and diseases (Karl et al., 2009). High tunnel systems should be able to mitigate some these factors and risks by providing additional protection and management opportunities for wind, rain, pests and temperature fluctuations as well as offering season extension possibilities.

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