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Production System for Horticultural Crops Grown in the Penn State High Tunnel

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SUMMARY. At the Pennsylvania State University (Penn State) High Tunnel Research and Education Facility, a system of production of high-value horticultural crops in high tunnels has been developed that uses plastic mulch and drip irrigation. The Penn State system involves small-scale, plastic-application equipment that prepares and applies plastic mulch and drip-irrigation tape to individual raised

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beds. It differs from the production system developed by researchers at the University of New Hampshire in which drip-irrigation tape is manually applied to the soil surface and then the entire soil surface in the high tunnel is covered with a black plastic sheet. An overview of the production system used in the Penn State high tunnels is presented in this report.

The High Tunnel Research and Education Facility (HTREF) was established in 1999 at Penn State as part of the Center for Plasticulture, which is a clearing house for research and educational efforts in the field of plasticulture. The HTREF consists of 28 high-tunnel research units each 17 ft (5.2 m) wide and 36 ft (11.0 m) long, three units each

17 ft wide and 96 ft (29.3 m) long, one unit 21 ft (6.4 m) wide 36 ft long, one unit 30 ft (9.1 m) wide and 36 ft long, and a support building located at the Horticulture Research Farm, Russell E. Larson Research Center, Rock Springs, Pa. Initially, the system of crop production developed by Dr. Otho Wells and colleagues from the University of New Hampshire, Durham was used at Penn State (Sciabarrasi and Wells, 1999; Wells, 2000; Wells and Loy, 1993). The New Hampshire system of crop production involved rototilling the soil, manually applying drip irrigation tape on the soil surface, and then covering the entire surface of the soil inside the high tunnel with a 6-mil-thick [0.006-inch (0.1524-mm)] sheet of black plastic and then planting the crop through the plastic 3 to 5 inches (7.6 to 12.7 cm) from the drip irrigation lines (Wells, 1996) (Fig. 1).

The Penn State high-tunnel design afforded a more convenient access inside the tunnels for performance of tillage operations and allowed the team to develop a mechanized raised-bed production system that included a small tractor-mounted plastic layer that could make raised plastic-covered beds and apply drip irrigation tape at the same time. This system of production is more closely aligned to current plasticulture field production practices discussed by Lamont, 1996 (Fig. 2). The objective of this paper is to present



Fig. 1. New Hampshire system of crop production for high tunnels in which the drip irrigation tape is placed on the soil and then the entire soil surface is covered with a solid sheet of 6-mil-thick [0.006-inch (0.1524-mm)] black plastic through which the crop is planted, in this case tomatoes.

an overview of the raised bed crop production system and equipment used at the Penn State HTREF.

Overview of the Penn State system

As discussed by Lamont et al. (2002), the Penn State high-tunnel end walls were designed with a larger, hinged section and two smaller sections on each side that swing outward, so that the two smaller sections (wings) are opened first and then the larger, hinged center portion of the end wall

is raised up and held in place by two 2×2 -inch (5.1-cm) poles to accommodate equipment for tillage and application of the plastic mulch and drip irrigation.

SOIL PREPARATION AND FERTILIZATION. In the first operation, the soil inside the tunnel is tilled using a small four-wheel-drive, 21-horsepower tractor with a three-point-hitch-mounted rototiller. Before tilling, if required, compost or other organic material can be added to the soil to maintain the organic matter content. At this time

20% to 30% of the recommended nitrogen and potassium and all the phosphorus for the crop can be broadcast and incorporated in the top 8 inches (20.4 cm) of soil.

APPLICATION OF THE PLASTIC MULCH AND DRIP IRRIGATION TAPE. Working with two commercial companies, researchers at Penn State helped develop small plastic mulch/drip irrigation tape applicators that are now commercially available (Nolt's Produce Supplies, Leola, Pa., or Reddick Fumigants, Williamston, N.C.) for use in both high tunnels and in field production (Fig. 3). These applicators are used to make a 3 to 4 inch (7.6 to 10.2 cm) high, raised plastic mulch covered bed, 18 inches (45.7 cm) wide with a drip irrigation tape [8 mil [0.008 inch (0.2032 mm) thick], 12-inch (30.5-cm) emitter spacing, 0.45 gal/min (1.7 L·min⁻¹) flow rate at 8.0 lb/inch² (55 kPa); (T-Tape, T-Systems International, San Diego, Calif. or similar drip tape products)] buried 2 to 3 inches beneath the beds either in the center or offset, depending on crop to be planted on the beds. The width of the plastic mulch is 3 ft (0.9 m) wide and varying in thickness. The beds are spaced 44 inches (1.1 m) apart (bed centers) which provides four raised beds in a 17-ft-wide tunnel. Crops can be planted in either single- or double-rows with various in-row spacings as suggested in Table 1.

Transplanting is accomplished by using a bulb setter to punch holes in the plastic mulch at the desired spacing. Researchers are working on developing a small, mechanized transplanter for use with this system. At transplanting, a starter solution made using 10N-22.7P-8.3K or 12N-20.9P-6.6K mixed to a concentration of 3 lb/100 gal of water (3.6 g·L⁻¹) is applied at the rate of 6 fl oz (177 mL) of solution per transplant. The remaining recommended nitrogen and potassium fertilizer can be applied during the cropping season via the drip irrigation system using a fertilizer injector. At Penn State, a fertilizer injector (DI-16; Dosatron International, Sun City, Fla.) is mounted on the sidewall of the high tunnel and used to inject the fertilizer (Lamont et al., 2002).

WEED CONTROL. It is important to site a high tunnel on ground where the perennial weed problems are minimal. Any perennial weeds should be removed before erection of the high



Fig. 2. Four raised beds spaced 44 inches (1.1 m) apart in a 17-ft-wide (5.2-m) high tunnel.



Fig. 3. Small plastic mulch/drip irrigation tape applicators [Nolt's Produce Supplies, Leola, Pa. (right) or Reddick Fumigants, Williamston, N.C. (left)] used to make a 3- to 4-inch (7.6- to 10.2-cm) high, raised plastic mulch covered bed 18 inches (45.7 cm) wide with a drip irrigation tape.

Table 1. Suggested spacing of horticultural crops when transplanted or seeded in high tunnels.

Crop	Within-row spacing (inches) ^z	No. of rows (12-inch spacing between double rows)
Vegetables		
Honeydew melon	24	Single (option trellis)
Cucumber	12-14	Single (option trellis)
Summer squash	36	Single
Eggplant	18-24	Double (staggered planting)
Pepper	18-24	Double (staggered planting)
Tomato (staked)	18-24	Single
Lettuce	6-12	Double
Spinach	4	Double
Swiss chard	8	Double
Kale	8	Double
Kohlrabi	6-8	Double
Onion	6-8	Double
Leek	4-6	Double
Garlic	4-6	Double/triple
Potato	6-10	Double (staggered planting)
Cabbage	12	Double (staggered planting)
Broccoli	12-16	Double (staggered planting)
Cauliflower	12-16	Double (staggered planting)
Okra	12-16	Double (staggered planting)
English pea	3	Double (option trellis)
Small fruit		
Raspberry	18	Single (bare ground, 6 ft between rows)
Blackberry	18	Single (bare ground, 6 ft between rows)
Strawberry	14	Double (8 inches between rows)
Cut flowers		
Small-size plants (12-20 inches tall)	8	Double (14 inches between rows)
Large-size plants (>20 inches tall)	12	Double (14 inches between rows)

^z1 inch = 2.54 cm, 1 ft = 0.3 m.

tunnel. The first flush of weeds that may appear once the ground has been tilled and the plastic mulch and drip irrigation tape applied are easily removed with a sharp hoe. Given the naturally dry conditions in a high tunnel, any subsequent weed growth in the row middles is minimal.

ROWCOVERS. Several spunbonded polypropylene rowcovers, including Typar T-518 (Ken-Bar, Reading, Mass.) and Agribon (Polymer Group Inc., Mooresville, N.C.), have been successfully used in the high tunnels. They have been utilized over wire hoops similar to the system described by Wells (1998). They are used to primarily provide additional daytime warming and also to provide some freeze protection to the crop on cold nights. If the temperatures are going to be very cold then a portable radiant propane heater is used to maintain adequate heat in the high tunnel, dependent on the crop being grown. Thermo-reflective screens (Polysack Plastic Industries, Nir Yitzhak, D.N. Negev, Israel) are used to trap the heat generated during the day, both in the

early spring and late fall to help extend the production season. The thermo-reflective screens are placed over supports directly above the crop in the late afternoon and removed the following



Fig. 4. Onion variety trial grown in a high tunnel using black plastic mulch with drip irrigation.

morning when temperatures in the high tunnels rise.

INSECT AND DISEASE CONTROL. A program of insect scouting and use of biological control measures has been practiced for most insect pest species. In most instances disease problems are minimal, but fungicide applications are made, if required. Good sanitation, such as keeping the grass mowed around the high-tunnels, keeping weeds removed in the tunnels, and removing plant material, is practiced in and around the high tunnel production area. In the Commonwealth of Pennsylvania the ruling on what pesticides can be used in a high tunnel is based on interpretation made by the Pennsylvania Department of Agriculture, Bureau of Plant Industry (J. Lake, personal communication). The interpretation is if the roll-up sides are closed then only materials labeled for greenhouses can be used but if the sides are opened up then materials labeled for use in field production can be used in the high tunnel. The question of what pesticides can be used in a high-tunnel needs to be addressed by the appropriate regulatory agency in each individual state. The only disease found to be a problem was powdery mildew of cucurbits (*Erysiphe cichoracearum*). If temperatures are high and moisture remains on the leaf surface then conditions are favorable for the spread of powdery mildew. The lack of rainfall on the crops grown in the high tunnels also enhances the



Fig. 5. Kathy Demchak, Small Fruit Extension Specialist, with primocane-bearing raspberries which she is evaluating in high tunnels.

conditions favorable for the development of powdery mildew. The main insect pests which have required control measures in the high tunnels are the green peach aphid (*Myzus persicae*) and greenhouse whitefly (*Trialeurodes vaporariorum*).

WATER MANAGEMENT. Water needs for a given crop are determined using a combination of pan evaporation data (an evaporation pan is located in one high tunnel), crop coefficients (Snyder et al., 1987) and direct soil measurements using tensiometers (Hartz, 1996) placed in the crop row at the 6- and 12-inch (15.2- and 30.5-cm) depths. The use of drip irrigation minimizes water usage and also keeps the crop foliage dry, helping to reduce disease and weed problems.

Crops

The following crops have been grown successfully using the Penn State plasticulture system of production.

VEGETABLES. A wide variety of vegetable crops have been grown successfully in a high tunnel. The high tunnel allows growers to produce crops over a longer period of time and in some climate even produced year-round. Many times the plastic mulch is double-cropped with the first crop being removed and the second crop being planted on the plastic. The following vegetables have been grown successfully in the high tunnels: tomato (*Lycopersicon esculentum*), eggplant

(*Solanum melongena*), pepper (*Capsicum annuum* Gros-sum group), muskmelon (*Cucumis melo*), summer squash (*Cucurbita pepo*), cucumber (*Cucumis sativus*), spinach (*Spinacia oleracea*), swiss chard (*Beta vulgaris* var. *cicla*), lettuce (*Lactuca sativa*), broccoli (*Brassica oleracea* var. *italica*), cabbage (*Brassica oleracea* var. *capitata*), cauliflower (*Brassica oleracea* var. *botrytis*), kale (*Brassica oleracea* var. *acephala*), kohlrabi (*Brassica oleracea* var. *gongyloides*), okra (*Abelmoschus esculentus*), onion (*Allium cepa*) (Fig.4), leek (*Allium ampeloprasum porrum*), garlic (*Allium sativum*), pea (*Pisum sativum*), and specialty potato (*Solanum tuberosum*) for red, white, and blue potato salad on the 4th of July. In addition, a wide variety of herbs such as dill (*Anethum graveolens*) have been grown in the high tunnel.

SMALL FRUIT. The extended production season and improved shelf-life of these products make high tunnel production a very viable option for the direct marketer. Primocane-bearing red raspberries (*Rubus idaeus*), (Fig.5) and thornless blackber-

ries (*Rubus* subgenus *Eubatus*) are produced on bare ground with drip irrigation. Strawberries (*Fragaria × ananassa*) are grown using the small raised bed with drip irrigation.

CUT FLOWERS. There are many options for cut-flowers in the high tunnels, ranging from herbaceous perennials over-wintered for spring cut-flower production to summer annuals, and natural season fall mums. This production system permits cut-flowers to be harvested earlier in the spring and later in the fall compared to cut flowers grown in the field, and provides excellent flower quality (Fig. 6).

Summary

The Penn State system of production of horticultural crops in high tunnels described above provides benefits such as, increased warming of the soil in the high tunnel in the spring, facilitates more accurate application of water and fertilizer via the drip irrigation system, and reduces the compaction of the soil, compared to flat soil covered with a plastic sheeting (Lamont, 1993). It also helps eliminate some of the rodent (field mouse) problems encountered with the New Hampshire system of drip irrigation tape under a solid plastic sheeting covering the entire inside surface of a high tunnel by eliminating that large surface area under

Fig. 6. Snapdragons (*Antirrhinum majus*) grown in a high tunnel.



which the mice can build nests. Also the large sheet of plastic covering the entire soil surface of the high tunnel tends to billow up due to air movement underneath and causes transplants to end up under the sheet of plastic. The Penn State high tunnel system of production and associated equipment continues to be evaluated on a wide array of horticultural crops.

For more information on the high tunnels and plasticulture there are two web sites of interest: the Penn State Center for Plasticulture at <<http://plasticulture.cas.psu.edu>> (Wodecki et al., 2001) and the American Society for Plasticulture at <<http://www.plasticulture.org>> (American Society for Plasticulture, 1999)

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