Literature Cited

- Albregts, E.E., G.J. Hochmuth, C.K. Chandler, J. Cornell, and J. Harrison. 1996. Potassium requirements of drip-irrigated strawberry. HortScience (In press.)
- Clark, G.A., A.G. Smajstrla, D.Z. Harman, and F.S. Zazueta. 1990. Injection of chemicals into irrigation systems: Rates, volumes and injection periods. Fla. Coop. Ext. Bul. 250.
- Cook, W.P. and D.C. Sanders. 1991. Nitrogen application frequency for drip irrigated tomatoes. HortScience 26:250–252.
- Hanlon, E.A., G. Kidder, and B.L. McNeal. 1990. Soil, container media, and water testing. Fla. Coop. Ext. Circ. 817.
- Hartz, T.K. 1994. A quick test procedure for soil nitrate-nitrogen. Commun. Soil Sci. Plant Anal. 25:511–515.
- Hartz, T.K., R.F. Smith, M. LeStrange, and K.F. Schulbach. 1993. On-farm monitoring of soil and crop nitrogen status by nitrate-selective electrode. Commun. Soil Sci. Plant Anal. 24:2607–2615.
- Hochmuth, G.J. 1994. Sufficiency ranges for nitrate-nitrogen and potassium for vegetable petiole sap quick tests. Hort Technology 4:218–222.
- Hochmuth, G.J. 1992. Fertilizer management for drip-irrigated vegetables in Florida. Hort Technology 2:27–32.
- Hochmuth, G.J. and G.C. Clark. 1991. Fertilizer application and management for micro (or drip) irrigated vegetables in Florida. Fla. Coop. Ext. Spec. Ser. SS-VEC–45.
- Hochmuth, G.J. and E.A. Hanlon. 1995. Commercial vegetable crop nutrient requirements. Fla. Coop. Ext. Circ. SP–170.
- Hochmuth, G.J., D. Maynard, C. Vavrina, and E. Hanlon. 1991. Plant tissue analysis and interpretation for vegetable crops in Florida. Univ. Fla. Coop. Ext. Spec. Ser. SS-VEC–042.
- Hochmuth, G.J., E. Hanlon, G. Kidder, S. Hensel, W. Tilton, J. Dilbeck, and D. Schrader. 1993. Fertilization demonstrations for the tri-county potato production area of northeast Florida. Proc. Fla. State Hort. Soc. 106:190–198.
- Locascio, S.J. and A.G. Smajstrla. 1989. Drip-irrigated tomato as affected by water quantity and N and K timing. Proc. Fla. State Hort. Soc. 102:307–309.
- Locascio, S.J., S.M. Olson, F.M. Rhoads, C.D. Stanley, and A.A. Csiszinsky. 1985. Water and fertilizer timing for trickle-irrigated tomatoes. Proc. Fla. State Hort. Soc. 98:237–239.
- Locascio, S.J., J.M. Myers, and J.G.A. Fiskell. 1982. Nitrogen application timing and source for drip irrigated tomatoes, p. 323–328. In: A. Scaife (ed.). Proc. 9th Intl. Plant Nutr. Colloq., Warwick Univ., England.
- Magdoff, F. 1991. Understanding the Madgoff pre-sidedressing nitrate test for corn. J. Proc. Agr. 4:297–305.
- Pier, J.W. and T.A. Doerge. 1995. Concurrent evaluation of agronomic, economic, and environmental aspects of trickle-irrigated watermelon production. J. Environ. Qual. 24:79–86.
- Reisenauer, H.M. (ed.) 1983. Soil and plant tissue testing in California. Univ. Calif. Bul. 1879.
- Smajstrla, A.G., D.S. Harrison, and G.A. Clark. 1985. Trickle irrigation scheduling I: Durations of water applications. Fla. Coop. Ext. Bul. 204.
- Thompson, T.L. and T.A. Doerge. 1995. Nitrogen and water rates for subsurface trickle-irrigated romaine lettuce. Hort Science 30:1233–1237.
- Tyler, K.B. and O.A. Lorenz. 1991. Fertilizer guide for California vegetable crops. Univ. Calif., Davis, Dept. Veg. Crops Special Publ.
- Vitosh, M.L. and G.H. Silva. 1994. A rapid petiole sap nitrate-nitrogen test for potatoes. Commun. Soil Sci. Plant Anal. 25:183190.

Rowcover and High Tunnel Growing Systems in the United States

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Summary. Rowcovers and high tunnels are two intensive production systems used by commercial growers to extend the season and to improve yields of vegetables and strawberries. There are many types of rowcovers. These materials are summarized with descriptive information, primary use, and cost. The basics of high tunnel construction are presented to facilitate setting up a high-tunnel system.

Most horticultural crops respond favorably to protection from environmental extremes, particularly in northern United States. Protective growing may include several cultural systems; however, this paper considers only two types of protective growing systems: rowcovers and high tunnels. There are many reports of the benefits of these systems nationally (Hochmuth, et al., 1993; Lamont, et al.; Matthews-Gehring 1988; Purser, 1993; Soltani, et al., 1995; Wells and Loy, 1985; Wells and Loy, 1993) and internationally (Jensen and Malter, 1994; Wittwer and Castilla, 1995). Also, there are reports of expanded uses of rowcovers and high tunnels (Hancock and Simpson, 1995; Wells, 1995; Williams, 1994). The purpose of this paper is not to reiterate the benefits, rather to provide an overview of the types and uses of rowcovers and pictorial details on the construction and layout of high tunnels.

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Fig. 1. Spunbonded rowcovers protect crops against animal damage. However, in some cases, large animals such as deer may badly damage these covers by trampling them.

Rowcovers

Rowcovers are generically made from plastic. The primary materials used for covers are clear polyethylene, spunbonded polyester, and spunbonded polypropylene. The spunbonded covers are fabric-like materials consisting of fibers arranged in a random order in contrast to a woven pattern. Except for heavy-weight freeze protection covers, light transmission through spunbonded materials is adequate for crop growth. All of these materials are relatively lightweight (0.3 to 1.75 oz/yd²) (1 oz/yd² = 34 g/m²) and are used for covering either single or multiple rows of crops. The lightest covers (0.3 oz/yd²) are used primarily for insect control, the medium weight covers (0.5 to 0.6 oz/yd²) for growth enhancement and freeze protection

Fig. 2. Wide spunbonded covers (50 ¥ 800 feet) are applied easily over sweet corn immediately after planting. The cover is secured by covering the edges with soil.

(down to about 28 °F), and the heaviest weight covers (1.0 to 1.75 oz/yd²) for freeze and winter injury protection, although there is a newer polypropylene material (1.25 oz/yd²) that is used for growth enhancement and freeze protection. Other uses include wind protection and animal deterrent (Figs. 1–4).

Rowcover terminology

Rowcover. A lightweight, flexible, and transparent material applied over either a single row or multiple rows and either supported with hoops or not supported (floating). The rowcover material may be either nonporous (polyethylene) or porous (spunbonded).

Spunbonded. Not woven. Small-diameter, continuous filaments of polyester or polypropylene are extruded (spun) in a web form onto a collection belt. The fibers then are bonded with heat and pressure into a thin sheet of flexible and porous fabric (Vaughn, 1992). Although the material appears white, reflectance is minimal and light transmission is about 80% . A UV inhibitor is incorporated into the fibers to decrease the rate of photodegradation of the covers.

Fig. 3. When sufficient slack is provided at application, sweet corn (and other crops) will easily push up the cover as the crop develops.

Floating. There is no supplementary support of the cover. It floats over the top of the crop and is pushed up as the crop grows. Floating covers may be applied at the time of seeding or transplanting; however, floating covers may be detrimental to crops such as tomato and pepper due to the friction of the cover on the growing point of the plants.

Narrow cover. Generally used to cover a single row of crops or a crop bed with three to four closely spaced rows. These covers are usually no wider than about 6 feet and may be either hoop-supported or floating.

Wide cover. Generally a lightweight cover (spunbonded or perforated polyethylene) that spans multiple rows. These covers range in width from 10 to 50 feet and in varying lengths. While they are most often used in the floating mode, supplementary, strategically placed hoops might be needed

Fig. 4. Under windy conditions, floating covers need supplemental hoops to protect crops (such as summer squash in this photo) from abrasion.

Table 1. Summary of rowcover materials for crop growth and freeze protection.^z

Cover material	Mode of support	Thickness or wt	Width × length (ft)	Primary use	Price (¢/ft ²)	Cost of cover (\$/acre) ^y
Narrow covers						
Solid polyethylene	Hoops	1.1 mil	6 × 1000	Growth	1.23	537 ^x
Slitted polyethylene	Hoops	1.1 mil	6 × 1000	Growth	1.30	566 ^x
Perforated polyethylene	Hoops	1.1 mil	6 × 1000	Growth	1.30	566 ^x
Spunbonded polyester	Floating	0.6 oz/yd ²	5.6 × 2550	Growth	2.15	872
Wide covers						
Spunbonded polyester or polypropylene	Floating	0.5–0.6 oz/yd ²	50 × 500	Growth	2.66	1085
Spunbonded polypropylene	Floating	1.25 oz/yd ²	15.5 × 300	Growth	4.20	1833
Spunbonded polypropylene	Floating	0.3 oz/yd ²	8.5 × 1640	Insect control	2.15	936
Spunbonded polypropylene	Floating	1.76 oz/yd ²	21.3 × 820	Freeze protection	3.72	1618

^zNot all rowcover materials from all companies are listed. Representative types, sizes, and costs are presented.

^yPrices will vary due to different sizes of covers and company price differentials.

^xHoops are an additional \$80/acre based on 10-year use.

^wThis is a heavy-duty material with much greater durability than lighter-weight materials, but with similar light transmission.

^vIntended for freeze protection only. Very durable material.

under windy conditions to prevent damage to crops such as tomato, pepper, and summer squash.

Hoops. Wire, preferably galvanized, is formed into an arc by inserting the ends of the wire into the soil on either side of the row. For ample rigidity, the wire size should be no smaller than no. 9. The length of the wire for each hoop is 70 to 80 inches depending on row width. The height of the

hoop at the center of the row is generally 15 to 18 inches.

Mil. One thousandth of an inch (generally applicable to plastic film).

There are many different types and sources of rowcover materials. Also there is a wide variety of widths and lengths. Accordingly, prices are quite variable. The major representative rowcover materi-

als are outlined in Table 1 with descriptive information, including the price per square foot and the approximate cost of materials per acre. Because of the large number of manufacturers and/or suppliers, commercial sources of these covers are not included. Most grower-oriented trade magazines carry ads and publish annual buyers' guides with a complete listing of rowcover suppliers.

Fig. 5. This is a high tunnel ready for growing a wide variety of crops, e.g., tomato, pepper, cucumber, summer squash, strawberry, or flowers. The dimensions of this unit are 14 feet wide, 36 feet long, and 6.5 feet high at the ridge. Construction consists of metal bows (about 1 inch in diameter) connected to metal posts, which are driven into the ground 4 feet apart. The end walls have minimal framing and can be removed easily to accommodate the free movement of power tillage equipment. Although this high tunnel is used for research, a commercial unit is very similar, as wide as 20 feet and as long as 96 feet. Tunnels are covered with 6-mil, greenhouse-grade polyethylene, which is left on year-round. While it could be removed during the winter, it is easier to leave it on, although snow removal is necessary during heavy snowfall. Taking the time to square and level the tunnel carefully during set-up will make subsequent steps much easier.

Fig. 6. The plastic covering is secured to the tunnel by sandwiching it between a hipboard (attached to the bows) and a batten board, which is nailed or screwed to the hipboard. The plastic should be pulled taut and then firmly secured with nails or screws spaced about 18 inches apart. Without a firm connection between the boards, the plastic will slip and tear during high winds. Warped boards are ineffective for maximum hold. Sheetrock screws work well. Note the cordless drill.

Fig. 7. Ventilation is accomplished by rolling up the sides of the tunnel to the batten board, or part way up as dictated by ventilation needs. The maximum opening is 3 to 3.5 feet. A convenient ventilation system consist of a metal pipe to which the edge of the plastic is taped. Duct tape works fine. To ensure that the plastic rolls up evenly from end to end, the pipe should lie exactly parallel to the tunnel when the taping is done. Attach the plastic to the pipe about every 2 feet.

Fig. 8. A sliding "T" handle serves as a means for rolling up the plastic and also as a stand to adjust the height to which the plastic is rolled. It takes 10 to 15 seconds to roll up one side. Even on a 96-ft tunnel, the "T" handle supplies sufficient leverage for easy operation. A simple alternative to a "T" handle is a hand crank. More elaborate and expensive roll-up mechanisms are commercially available.

Fig. 9. After the tunnel is covered, one line of trickle irrigation tubing is laid down for each row that is to be planted. If the crop is planted in a single row, the tubing is offset by about 6 inches; if a double row, the line is run down the center. The tubing is pulled taut and secured at each end, care being taken to prevent soil from getting into the ends of the tubes. Tying a hard knot in the distal end of the tubing is adequate for restraining water flow. Before laying the irrigation lines, the soil should be firm, moist, and fortified with nutrients based on a soil test.

Fig. 10. The final step before planting is the application of a single sheet of 6-mil black plastic mulch over the entire soil surface. The plastic warms the soil, retains soil moisture, and controls weeds. To achieve the maximum advantage of the plastic, the soil should be completely covered, right up to the baseboards. The plastic is secured with string, wire pegs, weights, or any other material to prevent the plastic from billowing up over young transplants during gusty winds. It even might be necessary to attach a string down the center of the tunnel or a couple of strings across the tunnel. Applying the plastic during the heat of the day reduces the amount of slack, as seen in this photograph. For all practical purposes, the tunnel is now ready for planting.

Fig. 11. Individual roll-up sides easily facilitate ventilation based on the crop, the stage of crop growth, wind direction, and wind speed. For example, the windward side might be rolled up part way while the leeward side might be fully open. This would accommodate temperature and humidity control without potential damage to young plants.

Fig. 12. High tunnels will withstand snow if the structures are not too wide (about 20 feet) and if there is sufficient roof pitch to allow the snow to slide off. These structures are not heated! Internal supports are good insurance against heavy snow loads. Snow should be removed from the sides of the tunnels.

Fig. 13. Although high tunnels have no permanent heating system, many growers install a portable propane heater to protect against occasional freezing temperatures.

High tunnels

High tunnels are not greenhouses (Wells and Loy, 1993), although the greenhouse principle is the basis for the function of a high tunnel. High tunnels are so designated to distinguish them from low tunnels (rowcovers over single rows), and to emphasize that their management differs from that of an automated greenhouse. High tunnels have no external connections other than water for trickle irrigation. They are stand-alone

units sited on good soil and at locations where they can be vented manually each morning and closed each evening. Overall, high tunnels are simple to construct and manage. A pictorial description of high tunnels is shown in Figs. 5–13.

Conclusion

Rowcovers and high tunnels enhance crop production primarily through temperature control, but they also reduce wind movement, may control

insects and diseases, and deter animals.

Because there are so many different rowcover materials on the market, the types of materials have been descriptively summarized. A grower will still need to discuss with suppliers the pros and cons and the cost of the various materials available.

High tunnels are increasing in popularity with growers who want earliness and improved quality and yields of a wide array of horticulture crops. High tunnels are not as mechanically sophisticated as greenhouses, but with careful management, high productivity is achievable.

Literature Cited

- Hancock, J. and D. Simpson. 1995. Methods of extending the strawberry season in Europe. *HortTechnology* 5:286–290.
- Hochmuth, G.J., S.J. Locascio, S.R. Kostewicz, and F.G. Martin. 1993. Irrigation method and rowcover use for strawberry freeze protection. *J. Amer. Soc. Hort. Sci.* 118:575–579.
- Jensen, M.H. and A.J. Malter. 1994. Protected agriculture—A global view. World Bank tech. paper no. 253. The World Bank. Washington, D.C.
- Lamont, W.J., G.A. Clark, G.J. Hochmuth, T.K. Hartz, and O.S. Wells. 1994. Using plasticulture technology for the intensive production of vegetable crops. *Proc. Amer. Soc. Hort. Sci. Seminar*, Lexington, Ky.
- Matthews-Gehringer, D. and J. Hough-Goldstein. 1988. Physical barriers and cultural practices in cabbage maggot (Diptera: Anthomyiidae) management on broccoli and Chinese cabbage. *J. Econ. Entomol.* 81:354–360.
- Purser, J. 1993. Plastic mulch and row covers to produce warm season crops in Alaska. *Proc. Natl. Agr. Plastics Congr.* 24:49–53.
- Soltani, N., J.L. Anderson, and A.R. Hamson. 1995. Growth analysis of watermelon plants grown with mulches and rowcovers. *J. Amer. Soc. Hort. Sci.* 120:1001–1009.
- Vaughn, E.A. 1992. Nonwoven fabric primer and reference sampler. INDA. Assn. Nonwoven Fabrics Ind., Carey, N.C.
- Wells, O.S. 1995. Production of high tunnel strawberries. *Proc. New England Veg. Berry Conf.*, Sturbridge, Mass. p. 83–84.
- Wells, O.S. and J.B. Loy. 1985. Intensive vegetable production with rowcovers. *HortScience* 20:822–826.
- Wells, O.S. and J.B. Loy. 1993. Rowcovers and high tunnels enhance crop production in the northeastern United States. *HortTechnology* 3:92–95.
- Wells, O.S. and J.P. Pollard. 1996. Early strawberries with high tunnels. *American Fruit Grower* 116(1):22H–22I.
- Williams, C.H. 1994. Extending the outdoor flower growing season. *Proc. New England Greenhouse Conf.*, Sturbridge, Mass. p. 75–79.
- Wittwer, S.H. and N. Castilla. 1995. Protected cultivation of horticultural crops worldwide. *HortTechnology* 5:6–23.