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Appropriate Technology Transfer for Rural Areas

# ORGANIC GREENHOUSE VEGETABLE PRODUCTION

**HORTICULTURE SYSTEMS GUIDE**

ATTRA is the national sustainable agriculture information center funded by the USDA's Rural Business -- Cooperative Service.

**Abstract:** *Organic greenhouse vegetable production is regularly practiced by certified organic farmers and market gardeners, and has potential for wider adaptation by established greenhouse operators and entry level growers as a niche market or sustainable method of production. This publication focuses on organic methods of greenhouse vegetable production, and it is supplemented with a listing of greenhouse resources.*

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## Introduction

Although several Extension bulletins are available on greenhouse vegetable production, few of these concentrate on organic production methods. This publication presents an overview of greenhouse production systems and profiles several farmers raising organic vegetables in greenhouses. It is hoped this will give new growers ideas of how to set up their systems, and provide more experienced farmers with examples of alternative methods of production.

The term greenhouse means different things to different people. A greenhouse used to be a structure formed of glass, with a heating (and usually cooling) system that was used year-round, but especially in winter. Then came houses built of thermoplastic (Plexiglas and others), followed by Quonsets covered with plastic, which may or may not be heated, have one or two layers, and be used year-round or for only a few months every year. The type of greenhouse you have will largely be determined by your crop and your capital and, to a lesser extent, by your management intensity and your market strategy.

For the purposes of this publication, a greenhouse can be any of the above. Another ATTRA publication, *Season Extension Techniques for Market Gardeners*, contains further information on protected shelter structures such as cold frames, high tunnels or "hoophouses," and low tunnels.

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**The Greenhouse Vegetable Industry**

> *Small-scale growers who plan on direct market sales may want to think twice before getting into this business in a region that is already saturated.*

The U.S. greenhouse vegetable industry is a mixture of small, family-run operations in the 2,500 to 10,000 square foot range and a small number of large, multi-acre facilities 10 acres or more in size. The larger greenhouses often use waste heat from a power plant or other source of cogeneration (1).

Current U.S. production estimates are somewhere around 800 acres (2). In comparison, Mexico has about 450 acres, Canada has about 1,600 acres, and Holland has over 11,000 acres (3, 4). In the latter part of the 1990s, Canadian greenhouse vegetable production grew at a rate of 20% a year. How has Canada been able to generate this huge growth? "Significant new greenhouse vegetable production technology that was transferred to commercial producers has been primarily responsible for dramatic yield increases over the last 7–8 years, estimated at 100–120% for tomatoes and 70–80% for cucumbers" (3). Canada is strongly supporting its greenhouse growers, both with research and with investment dollars. Their research facilities at Harrow are recognized as topnotch the world over. Although most Canadian greenhouse vegetables are not produced organically, there has been an emphasis of late to use IPM strategies, rather than pesticides, to accommodate the growing market of consumers who want pesticide-free produce. Most of the organic produce imported into the U.S. is now coming from Mexico.

Tomatoes are the leading greenhouse vegetable crop, followed by European cucumbers, lettuce, peppers, and culinary herbs such as basil, sage, and rosemary. See the ATTRA publications on these specific vegetables for more information. In addition, growers aiming at niche markets raise specialty crops, greens, and Oriental vegetables.

The leading states in greenhouse vegetable production are California, Florida, Colorado, Arizona, Ohio, Texas, and Pennsylvania—all with over one million square feet of production each (2). This is where the centers of production exist, both as a source of competition as well as a source of technical assistance. Small-scale growers who plan on direct market sales may want to think twice before getting into this business in a region that is already saturated.

**How Can Small Producers Compete?**

With so much competition from Canada, Mexico, and overseas, how can small farmers realize a profit raising greenhouse vegetables? One issue of increasing importance to consumers is vegetables grown with minimum pesticides. The public has also become educated on the values of locally grown produce: it's fresher, it tastes better, and it may even be less expensive, since there are fewer shipping costs involved. Also, money paid to a local farmer is re-invested in the local community and helps to keep that economy strong.

Year-round production is key to maintaining the greenhouse's profitability. However, this does not necessarily mean that growers should be producing the same crop year-round. (Winter tomatoes bring more money than do summer ones.) Another option would be to raise a crop other than vegetables, like bedding plants for early spring sales or poinsettias for Christmas. The grower may decide that the most cost-efficient way to use his or her greenhouse during the summer is to shut it up to solarize the soil and "cook" insects (and their eggs) that are present.

Small growers must find niche markets. It is pointless to try to compete with mass merchandisers like Wal-Mart, because the small grower will always lose. What are some niche markets for organic greenhouse vegetable producers? Some of the general niches have already been mentioned: consumers are looking for organic, locally grown, early-season produce. Whatever the niche market, it is important for growers to realize that the nature of niche markets is for them to disappear after a while. Oversupply or lowered demand will create lower prices. The market will change to favor one product and disfavor another. This may happen when mass merchandisers enter the market, when the popular press promotes a particular vegetable, or when new medical evidence points to increased or decreased health benefits from certain vegetables.

A good example of changes in a niche market is the salad greens industry. Fifteen years ago, leaf lettuce was almost impossible to find. When leaf lettuces were introduced to the general public, few people accepted them. When chefs in finer restaurants began using them, more affluent people began asking for them in markets. The undersupply led to extremely high prices; as much as $16 per pound was not uncommon. More and more small growers began producing salad greens, but it wasn't until large growers entered the market that the price per pound went down significantly (to $6–10 a pound). Many growers can still get $4–6 a pound for greens, but as more large growers enter the market, this price will continue to drop. Long before the market has bottomed out is when small growers need to diversify and find ways to add value to their crops, like offering pre-cut, washed and ready-to-eat mixed lettuces.

Labor and energy are usually the two greatest greenhouse expenses. If small growers can find a way to decrease costs of either or both of these, their chances of making a profit are strengthened. How can they do this? Cheap sources of energy are key. Sunlight, decomposing compost, and animal heat are three ways to decrease energy costs.

### Solar Greenhouses

Greenhouses can be designed to take advantage of solar radiation and cut fuel expenses. Solar greenhouses are popular with small-scale growers. These are super-insulated greenhouses designed to collect and retain solar energy. The technology associated with solar greenhouses is rather detailed. In addition, the literature on solar greenhouses is quite large. To help growers identify some of the best resources on this topic, ATTRA compiled the *Solar Greenhouses* Resource List.

One recent publication that features organic vegetable production in a solar greenhouse is Anna Edey's book *Solviva: How to Grow $500,000 on One Acre and Peace on Earth*. Solviva is Edey's award-winning solar-powered and animal-heated greenhouse on Martha's Vineyard. The book discusses greenhouse design, function, construction, and management. Ms. Edey includes numerous energy-efficient designs like water walls and growtubes. She also tells how much everything costs, which is invaluable for market gardeners. *Solviva* is available for $38 from:

> GFM Books
> PO Box 3747
> Lawrence, KS 66046
> 800-307-8949

### Composting Greenhouses

Heating greenhouses with waste heat generated by compost is a second option that takes advantage of local resources and integrates different farm activities. In a composting greenhouse, heat and carbon dioxide are generated from manure-based compost contained in a special chamber attached to one side of the greenhouse.

Compost-heated greenhouses gained a lot of attention from work undertaken at The New Alchemy Institute at Falmouth, Massachusetts. The New Alchemy Institute was one of the premier appropriate technology centers that operated in the 1970s and 80s. The Institute published widely on ecology, wind energy, solar energy, bioshelters, solar greenhouses, integrated pest management in greenhouses, organic farming, and sustainable agriculture.

Though the technology to implement compost-heated greenhouses exists, they are seldom done on a commercial scale. ATTRA can provide more information on this topic on request.

**Related publications from ATTRA include:**

- Hydroponic Vegetable Production
- Aquaponics: The Integration of Hydroponics with Aquaculture
- Solar Greenhouses Resource List
- Organic Potting Mixes
- Disease Suppressive Potting Mixes
- Sources of Organic Fertilizers and Amendments
- Season Extension Techniques for Market Gardeners
- Integrated Pest Management for Greenhouse Crops
- Greenhouse IPM: Sustainable Aphid Control
- Greenhouse IPM: Sustainable Thrips Control
- Greenhouse IPM: Sustainable Whitefly Control
- Compost Teas for Plant Disease Control
- Use of Baking Soda as a Fungicide
- Organic Greenhouse Tomato Production
- Organic Greenhouse Pepper Production
- Organic Greenhouse Cucumber Production
- Organic Greenhouse Lettuce Production
- Organic Greenhouse Herb Production
- Organic Plug and Transplant Production

<u>Animal-Heated Greenhouses</u>

Small animals like chickens and rabbits produce heat and carbon dioxide in addition to products like eggs and meat. A few growers have taken advantage of this fact and integrate animals with greenhouses as a source of heat. However, it can be a challenge to keep livestock in a greenhouse—the higher temperature and humidity of a greenhouse are generally not healthy for animals.

Anna Edey, mentioned above, uses an "earth-lung" to filter out the toxic ammonia gas from the rabbit and chicken manure she uses in her Solviva greenhouse. In addition, she keeps her chickens in a poultry room attached to the greenhouse where temperatures do not fluctuate from about 70°F.

In 1996, there was a SARE-funded project headed by Rick Meisterheim in Michigan titled "Permaculture Greenhouse System." He raised chickens in the greenhouse and found that they raised the overall temperatures inside the greenhouse by an average of 8°F. This proved to be very helpful in raising vegetable transplants. Rick was able to set out seedlings much earlier than other years, thus increasing the length of time his CSA generated income (5).

Again, bio-heated greenhouses hold interest among small-scale growers who are focused on bio-integrated systems as a form of energy efficiency and biomass utilization. Of the three greenhouse-heating methods summarized here, solar greenhouses have the least risk and hold the most promise for commercial-scale ventures. Nevertheless, for those individuals seeking information on bio-heated greenhouses, ATTRA can supply more information on request.

**Organic Greenhouse Production**

As defined by the USDA in 1980 (6), organic farming is a system that excludes the use of synthetic fertilizers, pesticides, and growth regulators. Organic farmers rely heavily on crop rotations, crop residues, animal manures, legumes, green manures, organic wastes, and mineral-bearing rocks to feed the soil and supply plant nutrients. Insects, weeds, and other pests are managed by mechanical cultivation, and cultural, biological and biorational controls.

*No single fertilizer will provide all of the essential elements required, but a combination of organic products can be devised.*

Organic certification emerged as a marketing tool during the 1970s and 80s to ensure foods produced organically met specified standards of production. The Organic Foods Production Act, a section of the 1990 Farm Bill, enabled the USDA to develop a national program of universal standards, certification accreditation, and food labeling. Early in 1998, the USDA released a draft of the new standards for public comment. Public opposition to these proposed standards was vocal, sending a message to the USDA that more work was necessary. A new draft of organic standards may be released in 2000. In the meantime, organic certification will continue to occur at the state level for most of the country. For more information on these organizations, ask for ATTRA's *Organic Certifiers* resource list and *Organic Certification* publication.

Growers may choose organic methods for a variety of reasons. One of the attractions of growing organic produce is that it sometimes brings a 10–30% premium in the marketplace. As organically grown produce becomes more commonplace, however, premiums may be the exception rather than the rule, and motivation beyond market premiums should be considered. These may include the possibility of reduced input costs, improved farm safety, reduced environmental impact, and a better functioning agroecosystem.

Greenhouse technology and horticultural practices differ little between conventional and organic greenhouse production. The main variations are concerned with pest control and fertility. The ATTRA publication *Integrated Pest Management for Greenhouse Crops* examines the first issue; the second issue is addressed in the following sections.

Fertility

Although the process is more complicated, it is possible to obtain adequate nutrients from organic sources, but it takes more careful and creative management. No single fertilizer will provide all of the essential elements required, but a combination of organic products can be devised.

Organic fertilizers have not been well researched in greenhouse vegetable production. However, a 1999 study performed at the University of Kentucky analyzed several products for the levels of nutrients they supplied. The researchers were attempting to prove that organic fertilizers could supply nutrients at the same level as synthetic fertilizers. Products derived from algae (Algamin, a liquid, and Maxicrop, a powder), bat guano, and fish waste (GreenAll Fish Emulsion, a liquid, and Mermaid's Fish Powder) demonstrated nutrient levels comparable to conventional, synthetic fertilizers used for greenhouse plant production (7). The report concluded that these organic fertilizers could not be used as a concentrate for injector systems, but they would be suitable in a capillary mat subirrigation system. For information on how to obtain these products, see the **Resources** section.

In 1993, Premier Peat Moss in Canada conducted research on organic wastes from the

| Fertilizer | N-P-K | Shoot wt. (grams) |
|---|---|---|
| Crab-shell meal | 8.2-1.5-0.5 | 18.8 |
| Blood meal | 12.5-1.1-1.0 | 18.5 |
| Dried whey sludge | 5.3-2.5-0.9 | 18.3 |
| Feather meal | 13.6-0.3-0.2 | 17.3 |
| Fish meal | 10.1-4.5-0.5 | 17.1 |
| Meat meal | 7.7-3.1-0.7 | 16.3 |
| Cottonseed meal | 6.5-1.1-1.6 | 16.2 |
| Fish-scale meal | 10.0-3.7-0.1 | 15.8 |
| Distiller's dried grains | 4.3-0.9-1.1 | 14.5 |
| Soybean meal | 7.5-0.7-2.4 | 14.4 |
| Wheat bran | 2.9-1.4-1.3 | 13.5 |
| Alfalfa meal | 2.5-0.3-1.9 | 10.8 |
| Canola meal | 6.0-1.1-1.3 | 10.8 |
| None (control) | 0-0-0 | 10.3 |

agri-food industry and their ability to fertilize greenhouse tomato transplants (8). The researchers found that meal from blood, feathers, meat, crab shells, fish, cottonseed and whey by-products increased shoot weight by 57–83% over non-fertilized plants. The results of their study are shown on page 5.

Liquid fertilizer applied through irrigation lines—a technique known as fertigation—is a common practice in greenhouse production. Nitrogen and phosphorus are the two primary nutrients injected through fertigation systems. Fertigation can provide supplemental doses of these nutrients, especially at critical periods during the growing season such as fruit filling. However, fertigation is not a substitute for a complete soil-based fertility program.

The injection of organic fertilizers into low-volume irrigation systems like drip emitter and micro-sprinkler is non-conventional, because the standard method relies on commercial synthetic fertilizers that are highly soluble in water. The major concern with organics is clogging of emitters and pores with particulate matter and algae.

In the early 1990s, researchers in California concluded that fertigation with certain organic fertilizers *is* feasible (9). Spray-dried fish and

**Organic Strategies for Nutrient Deficiencies***

| *Element* | *Deficiency Symptoms* | *Remedy* |
|---|---|---|
| Nitrogen (N) | Old leaves turn pale green then yellow with reddish veins and midribs. Stunted growth. | Dried blood, fish meal, or guano extracted in water. Add greater amounts in your next compost batch. |
| Phosphorus (P) | Stunted growth, dull green leaves with purple tints. Old leaves scorch at the edges and wither early. Early, premature bolting. | Add reactive rock phosphate or extract of guano in solution. Add greater amounts of guano, bone meal, or fish meal to the next compost batch. |
| Potassium (K) | Small, dark, bluish-green, glossy leaves, curving slightly backwards. Old leaves with yellow patches, scorched edges cured upwards. Small root system. | Add more kelp extract to the nutrient solution. Add greater amounts of ashes to the next compost batch. |
| Calcium (Ca) | Young leaves cupped backwards, with white spots around the edges. These later turn brown. Forward rolling of the leaf margin. | Add lime in solution. Add greater proportions of bone meal, gypsum, or dolomite to the next compost batch. |
| *Element* | *Deficiency Symptoms* | *Remedy* |
| Magnesium (Mg) | Leaves become bronzed, and later, yellow patches appear between the leaf veins. | Dolomite or serpentine in solution. Add greater amounts of dolomite and animal manures to the next compost batch. |
| Sulfur (S) | Purpling of old leaves, which then shrivel. Young leaves small and yellow between the veins. | Sulfur in solution. Greater proportions of gypsum and poultry manure required in the next compost batch. |
| Manganese (Mn) | Veins stand out clearly with yellow in between. As the plant ages, small dead spots and papery areas appear. Slow root growth. | Add extra kelp extract. |
| Boron (B) | Split or thin misshapen roots. Roots with torn patchy surface and dull skin. | Add extra kelp extract. |
| Iron (Fe) | Very pale leaves, especially the youngest early in the season. Veins stay dark. | Add more kelp extract or place some rusty nails in the bottom of the nutrient tank. |

**Reprinted with permission from: Morgan, Lynette. 1997. Organic fertilizers for hydroponics. The Growing Edge. November-December. p. 32-35, 37-39.*

poultry protein fertilizers were injected through various drip, drip-tape, and micro-sprinkler irrigation systems, with even distribution and minimal clogging. The protein products are easy to use because they are finely ground and sold dry. The N-P-K analysis for both fish and poultry protein is 14-0.5-0.7. At the time of the study, the material cost $1.60/lb., or $12/lb. of nitrogen. In comparison, sodium nitrate costs about $2/lb. of nitrogen. For product information on spray-dried protein fertilizers, see the **Resources** section.

Neptune's Harvest®, with fish, seaweed, and fish-seaweed blends, is a product line that is popular with organic growers using drip systems. (For more information on Neptune's Harvest, see the **Resources** section.) David Hertzell, an organic greenhouse tomato grower in Kansas, applies Neptune's Harvest through his drip-tape system at 32-oz./400 gallons water every ten days. He and other growers prefer the blended mix to straight seaweed, because they feel the nutrient ratios of trace elements are not as balanced in seaweed alone. David also uses rock phosphate at 10 lbs/85′ row, as well as blood meal, bone meal, and alfalfa meal. He uses alfalfa mulch, a heavy application of leaf-mold compost, and cover crops. He also solarizes his soil every five years.

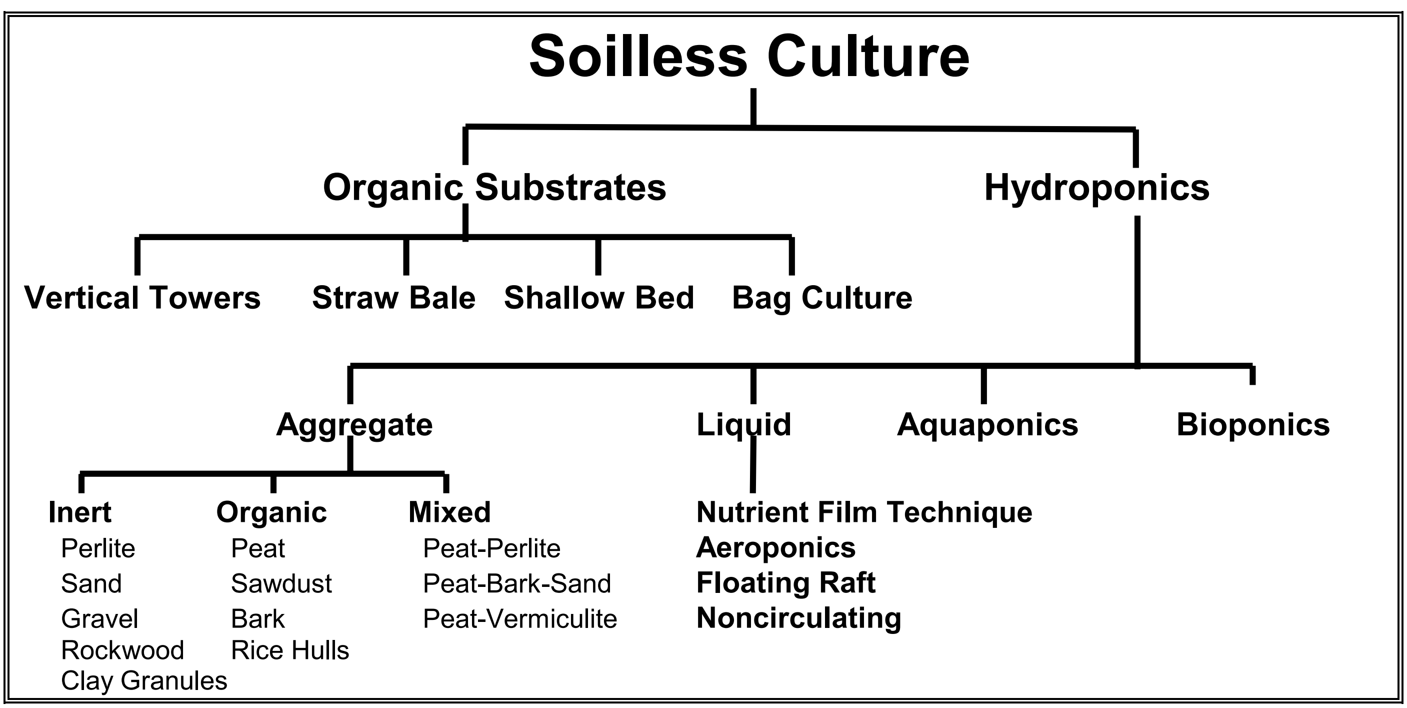
In an excellent article on organic fertilizers for hydroponic systems, Dr. Lynette Morgan suggests remedies for nutrient deficiencies. The table on page 6 is excerpted from her article (10).

James Baker raises organic cucumbers, tomatoes, chives, and squash in Israel. He applies 20–25 cubic meters (706 to 882 cubic feet) of compost per quarter acre in the first year of production, then 10 to 15 cubic meters (353 to 530 cubic feet) on following crops. In addition, he uses feather meal for nitrogen, basalt rock for iron and trace elements, and applies bat guano through his irrigation system. Says Baker, "I'd prefer to use poultry manure, but that's not strictly organic because the chickens are fed antibiotics and hormones, and aren't fed organic grain" (11).

**Soil vs. Soilless Culture**

Greenhouse production is based on either soil or soilless culture. In soil culture, vegetables are produced in the native soil or in a loamy soil brought inside the greenhouse. Soilless culture, the production of plants in a soilless medium, can be done via hydroponics or with an organic (or artificial) substrate.

The two broad categories of soilless culture are illustrated in the diagram below, with examples of media used in each.



In 1974, 70 percent of U.S. production was based on soil culture and 30 percent on soilless culture. By 1988, a significant shift to soilless systems had occurred, with soil systems making up only 40 percent of the acreage (12). The majority of large producers in Canada raise tomatoes, cucumbers, and peppers in rockwool, and lettuce is usually raised with a nutrient film technique (NFT) system (3). Bag culture is often practiced in the U.S., however. The chief reasons soilless culture became so popular are: a) the elimination of fumigation and steam treatments for soil-borne diseases; b) ease of installation; c) technical assistance available for soilless systems; and d) fertility control through commercial soluble fertilizers.

Five greenhouse production methods suitable for organic production are covered in the following material: soil culture, bag culture, vertical towers, straw bale culture and shallow bed culture. Although an overview of hydroponics is discussed in this publication, see ATTRA's *Hydroponic Vegetable Production* for more in-depth information.

**Soil Culture**

In soil culture, also known as ground culture, vegetables are raised on level ground as well as in mounded beds. Soil culture is more popular with organic growers than hydroponic methods. One of the reasons organic growers prefer soil culture to hydroponics is that soil-building practices are an already familiar concept based on decades of research and experience.

Production techniques used in ground culture are similar to intensive market gardening methods used in the field. Rear-tine tillers or mechanical spaders are used in soil preparation, and specialized wheel hoes and hand tools are used for cultivation and weed control. Organic fertilizers and soil amendments are extensively used to feed the soil.

In Quebec, organic farmers raising greenhouse tomatoes by the ground culture method use two rows per bed raised about one foot high. Compost is applied at a rate of 1.2 to 2.4 cubic yards per 1000 sq. feet. The first year it is applied 5–6 times per growing season at 5–6 week intervals. In years two through four the compost is applied at a lower rate. Following compost application, the beds are covered with straw mulch. Soil organic matter in these greenhouses ranges from 10–12% up to 25–30%.

In contrast, the Luebkes, one of the best known organic farming families in Austria, fertilize greenhouse tomatoes at a rate of 8 tons/acre/year (13). However, they use Controlled Microbial Compost™—a high quality, microbially inoculated compost prepared under aerobic (oxygen-present) conditions. In addition to compost, green manures are an integral part of the Luebke soil management program. After the green manure is mowed but prior to plowdown, the green residue is sprayed with a microbial inoculant to speed decomposition and enhance humus formation. Soils treated in this manner have tested at 15% organic matter. More information on CMC compost is available from ATTRA on request.

ATTRA publications that explain sustainable fertility management in more detail include *Sustainable Soil Management*, *Non-Conventional Soil Amendments* and *Farm-Scale Composting Resource List*.

*Cover Cropping in Ground Culture Systems*

Cover crops fit nicely into ground culture systems that include a crop-free rest period (in summer, for example). Short-term cover crops include legumes, buckwheat, annual ryegrass, oats, rapeseed, and oilseed radish. Often, the choice of cover crop will depend on the vegetable rotation and the intended purpose. Cover crops can replenish and help build organic matter in soils, increase microbial activity, add nitrogen, and help prevent or suppress diseases and nematodes, especially when brassica and oilseed radish cover crops are used.

Marty Legant, who raises 2 acres of organic winter tomatoes by the ground culture method in Parowan, Utah, has an 8-week period in which cover crops occupy his greenhouse. He's raised buckwheat and oats in the past, and has plans to try hairy vetch. At plowdown, he inoculates the green manure with vitamin B-12, sugar, and a catalyst to help speed decomposition and enhance humus formation.

Anna Edey, whose primary commercial crop is salad greens, recommends the following (14).

> For average soil, add, per square yard: 4 gallons of compost, 4 cubic feet of peat moss, 1-2 pounds of soft rock phosphate, 1-2 pounds of greensand, and lime if needed. Spread it out evenly and blend thoroughly by rototilling twice, rake it smooth and level, and then water well enough to soak through to the full depth.
>
> The next day sow buckwheat seed, spaced ¼ to ½ inch apart, cover lightly and water it well. Let the buckwheat grow for about two to three weeks, to about 10-12 inches high, then turn it under and sow another round of buckwheat. Repeat these buckwheat cycles until the growing beds in the greenhouse are ready to be filled.
>
> In order to maintain highest soil fertility, the soil needs to be enriched with compost and minerals four to five times per year. I recommend that every area of the greenhouse…receive a buckwheat treatment once a year.

An alternative to growing cover crops inside the greenhouse is incorporation of freshly chopped cover crops or pasture-grown forages transported from a nearby field. These are called green-leaf manures.

### *Weed Control in Ground Culture Systems*

Strategies for non-herbicidal weed control inside the greenhouse include a combination of hand hoeing, mechanical cultivation, steam pasteurization, soil solarization, mulching (fabric, plastic, or organic mulches), and poultry grazing.

Poultry grazing is a unique method of "biological" weed control that may be an option for some greenhouse growers. This system is used by Lynn Shanks, a vegetable grower near Bixby, Oklahoma (15). Mr. Shanks raises greenhouse tomatoes and early-season cantaloupes by the ground culture method. To manage weeds, he houses jungle fowl from India in the greenhouse to "graze" on weeds. The jungle fowl are also deft at picking insects off the vegetable plants without damaging any fruits. (Jungle fowl should not be confused with the domesticated chicken, which is notorious for pecking at tomatoes in the garden). The impressive aspect of this system is that weeding requires no labor, mulching, or cultivation on the part of Shanks' family.

### *Soil Disinfection in Ground Culture Systems*

A major concern in ground culture systems is soil sterilization or pasteurization for control of soil-borne pathogens. Methods of disinfection—including solarization, steam, electrical heat, and biological control—are covered in the ATTRA publication titled *Integrated Pest Management for Greenhouse Crops.*

### *Resources on Ground Culture Systems*

*The New Organic Grower*, a 340-page book by Eliot Coleman, is one of the best resources on intensive market gardening. Many of the techniques he describes—especially fertility, weed control, and soil blocking—are readily adaptable to greenhouse ground culture. Coleman has also written two books dealing with year-round production of food. The first is *Four-Season Harvest*, which focuses on using cold frames and high tunnels. The second is *The Winter Harvest Manual: Farming the Back Side of the Calendar*. This small book concentrates on commercial winter production of fresh vegetables in cold climates without supplementary heat. See the **Resources** section for more information.

**Soilless Culture**

Soilless culture methods usually have higher yields than ground culture systems. Another advantage of a soilless system is easier control of disease problems. In the soilless techniques described below, the media can be disposed of after one crop has been grown, or it can be pasteurized relatively easily.

Bag Culture

*Bag culture has become the preferred method of greenhouse vegetable production in many parts of the U.S. because it is easy to establish and manage successfully.*

In bag culture, plants are grown in a soilless medium contained in lay-flat or upright polyethylene bags (2–5 gallons in size) and fed with liquid fertilizers through drip irrigation lines. Media can be peat/vermiculite, sawdust, rockwool, rice hulls, pine bark, peanut hulls, or mixes of any of those. Bag culture is adaptable to both aggregate hydroponics fed with liquid fertilizers as well as standard soilless culture, in which the bulk of fertility is supplied via compost-based potting mixes.

Upright bags should be purchased at greenhouse supply houses, since household garbage bags are usually not strong enough. Upright bags usually contain one plant per bag. Lay-flat bags are closed and are made of 4-mil, UV-protected polyethylene. Lay-flat bags often have two or three plants per bag. Bags are most often placed in double rows in the greenhouse.

Bag culture is well suited to the production of upright and vining crops like tomatoes, cucumbers, and peppers. Bag culture has become the preferred method of greenhouse vegetable production in many parts of the U.S. because it is easy to establish and manage successfully. One problem with bag culture is the potential for excess fertilizer solution to leach out of the drainage holes in the bags and into the greenhouse soil.

Adapting bag culture to standard soilless production in a certified organic greenhouse operation requires specially formulated organic potting mixes. An organic potting mix should not include any synthetic fertilizers or wetting agents. Growers can purchase certified organic potting mixes from a commercial supplier, or mix their own. Organic bag cultured vegetables may include a combination of incorporated, topdressed, liquid-fed, and foliar-fed fertilization systems. See ATTRA's *Organic Potting Mixes* publication for a summary of media and fertilizers that can be used in organic production systems; this publication includes recipes for organic potting mixes collected from the alternative agriculture literature and interviews with organic farmers.

Adapting bag culture to soluble hydroponics or bioponics requires special hydroponic formulas and ingredients. These are covered in ATTRA's *Hydroponic Vegetable Production* publication.

Vertical Towers

A form of bag culture is the vertical tower. Long bags full of media are hung from support wires or beams, and plants are placed in slits or holes made on the sides of the bag. The appeal of this system is the very efficient use of greenhouse space; since the plants are using vertical space, very little floor space is needed.

The most popular vertical tower is a patented system called Verti-Gro. Verti-Gro uses square, styrofoam pots, which are stacked 8–10 pots high and can be re-used for 5–10 years. Tim Carpenter, who owns the company, recommends using perlite and coir (coconut fiber) for media. Fertilizer is supplied by a drip irrigation system, in which solution flows from the topmost to the bottom box and into a gravel support base, where it can be captured and re-used. Crops that have been grown with this system include lettuces, strawberries, herbs, tomatoes, greens, spinach, nasturtium, and cut flowers. For more information on this system, contact:

Verti-Gro, Inc.
720 Griffin Rd.
Lady Lake, FL 32159
800-955-6757
352-750-4202
http://vertigro.com

Straw Bale Culture

Straw bale culture was an important method of greenhouse cucumber production in Europe and Canada prior to the development of rockwool and NFT hydroponics. Bale culture can be especially useful as a method to avoid soils contaminated with diseases or in greenhouses with concrete or gravel floors. Based on limited experience in Canada in adapting straw bale culture to organics, this method appears to have merit where one of the aforementioned conditions exists.

*In considering straw bale culture, the cost of the bales and topcapping compared with costs of a comparable production system such as bag culture, will need to be weighed.*

In bale culture, the greenhouse floor can be concrete or lined with plastic or fabric mulch, and bales are laid out in rows. Bales are pre-wetted with manure tea, which initiates decomposition and causes the bales to heat up. On the average, about 7 gallons of water are required for a normal 50 lb. bale. When the temperature of the bales cools down to below 110° F, they are capped with six inches of a compost-based potting mix to accommodate the root balls of the transplants. Normally, planting would take place on about the eleventh day.

Fertilizers topdressed to the bales include dry bone meal, sul-po-mag, and an organic nitrogen source. Manure tea, seaweed, and fish-seaweed blends are used as liquid fertilizers. As the bales continue to ferment and decompose, heat and carbon dioxide are generated and these byproducts promote plant growth by warming the roots and enriching the greenhouse atmosphere.

In considering straw bale culture, the cost of the bales and topcapping compared with costs of a comparable production system such as bag culture, will need to be weighed. Also, in organic culture, a major factor would be the availability of certified organic straw. Herbicide residues in straw can cause serious injury to greenhouse crops.

Canadian studies conducted in the 1960s and 1970s showed that:

- Spring-grown cucumbers grown on straw bales yielded an average of 21% more fruit than soil-grown plants, although fall-sown plants did not have a yield increase.
- Wheat straw bales provided the best results, followed by clover straw. Timothy/alfalfa hay bales gave poor results.
- Using half a bale per plant caused no significant loss in yield.
- Using a plastic sheet under the bales caused a 9% reduction in yield
- There is little or no difference in yield between bales placed on the soil surface and those buried or half-buried in a trench.
- Growing in straw bales was economically feasible for spring-sown plants (16).

Missouri farmer Eric Hemple raises organic arugula, squash, green beans, onions, eggplant, tomatoes, and cucumbers using the straw bale method. A neighbor provides organic straw bales at a price of $3 each. Hemple places the bales between two sheets of corrugated tin braced with stakes to create a more uniform growing surface. He uses a sterile potting mix as his capping medium and bone meal, blood meal, fish emulsion, and rock phosphate as his fertilizers. Hemple uses a drip irrigation system and warns that careful attention to watering is essential, as are proper nutrient levels. He sells all his products at retail and estimates that he is receiving a gross return of 50 cents per square foot of bale space per week (17).

Shallow Bed Culture

Shallow bed culture, also known as thin layer culture, is the production of sprouts or herbaceous herbs and vegetables in a thin layer—1 to 3 inches in depth—of potting mix or compost laid on top of plastic mulch or woven weed barrier. Herbaceous crops adapted to shallow bed culture include specialty lettuces, greens, cresses, and selected culinary herbs.

At least one commercial sprout grower in California uses this method in the production of organic wheat grass, sunflower, and buckwheat sprouts. Root-zone heating tubes are laid underneath the plastic to provide bottom heat. In turn, they rest on top of polystyrene panels laid directly over the greenhouse soil. Gas-fired water heaters are used to heat the water, but such a system could easily be retrofitted to solar collectors located outside the greenhouse. Narrow boards are laid out every three feet to walk up and down between the beds to seed, water, and harvest.

Jay Fulbright, a commercial lettuce and specialty greens grower in Arkansas, has three growing systems. In the first, he amends his soil with compost and pelletized chicken litter and plants directly into the ground. In the second system, he uses tables made of 2x8 lumber and places 3½" of compost onto 2x4 welded wire mesh, covered with perforated plastic to allow for drainage. All the greens are hand-harvested using this system. The third method involves placing 4" of compost and chicken litter directly onto polypropylene sheets laid on the ground. Jay devised the third method in order to cut down on labor; he hopes to be able to use a salad harvester. He is now harvesting an average of 300 pounds of lettuce per week, which he sells to restaurants and specialty groceries.

Education Concerns for Hunger Organization (ECHO), a nonprofit organization that works in agriculture development, is promoting the shallow bed method as a technique for rooftop gardening in urban settings. The beds they describe are deeper—3 to 6 inches in depth—and are more typical of standard trough culture using a soilless mix. They've achieved good success raising a variety of vegetable crops using locally available materials such as leaf mold and compost.

ECHO has published several reports on shallow bed culture and low-tech hydroponics. For more information, see their web site at http://www.echonet.org/azillus/azch17ov.htm or contact them at:

Educational Concerns for Hunger Organization (ECHO)
17391 Durrance Rd.
North Ft. Myers, FL 33917
941-543-3246
http://www.echonet.org

**Hydroponics**

In hydroponics, plants are grown in a soilless medium and fed with fertilizer nutrients dissolved in solution. There are two broad categories of hydroponics: liquid hydroponics and aggregate hydroponics.

Liquid systems feature the nutrient film technique (NFT), aeroponics, floating raft, and noncirculating water culture. Aggregate systems include inert, organic, and mixed media contained in bag, trough, trench, and bench setups.

Liquid systems like NFT are often managed as closed, or recirculating systems. Aggregate systems are commonly managed as open, or flood and drain fertigation systems.

There are three basic approaches to organic hydroponic vegetable production: a) soluble organics, also known as hydro-organics, b) integration of hydroponics with aquaculture, also known as aquaponics, and c) bioponics.

Hydro-organics is based on hydroponic solutions derived from organic fertilizers like fish meal, spray-dried blood, and guano. Aquaponics is based on recirculating aquaculture in which irrigation effluent from fish tanks is used to fertigate sand or gravel cultured hydroponic vegetables. For more information, see the ATTRA publication *Aquaponics*. Bioponics, or "living hydroponics," is based on inoculating the hydroponic medium with microorganisms. See ATTRA's *Hydroponic Vegetable Production* for more information on bioponics.

*The greenhouse vegetable business is competitive.*

The key difference between organic and chemical hydroponics is the source of fertility and presence of microorganisms. Microbes are essential to organic systems because they help regulate pH and availability of nutrients. In addition, bioponic researchers claim that enzymes produced by the microbes interact with plant roots and stimulate biochemical processes in the plants which enhance the flavor of bioponic produce. For more information on hydroponics, see ATTRA's publication *Hydroponic Vegetable Production.*

**Variety Selection**

Variety or cultivar selection plays an important role in greenhouse vegetable production. Cultivars often originate in greenhouse breeding programs where selection is based on disease resistance and ability to perform under greenhouse climatic conditions. Greenhouse seed vendors and the Cooperative Extension Service can recommend appropriate cultivars. Seed suppliers are listed in the **Resources** section below. See the ATTRA series of publications on specific greenhouse crops for other recommendations.

**Economics of Greenhouse Vegetable Production**

Greenhouses are expensive to build and operate. A commercial greenhouse (30′ x 100′) with complete heating, cooling, and ventilation systems will cost between $10,000 to $30,000 to erect and equip.

Low cost greenhouses—like hoop houses and attached solar greenhouses—can be constructed for as little as $500 to $1,500. Hoop houses are similar to plastic Quonset greenhouses but are not equipped to heat or cool, and are used primarily for season extension. Solar greenhouses work fine for small-scale production—especially for the production of transplants and cool-season lettuces—but may not provide adequate space or climate control for commercial tomato, cucumber, or pepper production.

Otto Wells, a professor at the University of New Hampshire, found that growing tomatoes in an unheated 14x96-foot hoop house in New Hampshire could be profitable, if he realized a yield of 2000 pounds and sold the tomatoes for $1.60/lb. Using these estimates, the grower would earn a net return of 71 cents per pound (18).

The greenhouse vegetable business is competitive. Wholesale markets for off-season produce often become saturated and cause produce prices to drop. Competition stems from an established domestic industry as well as Dutch imports. In addition, field-grown Mexican produce frequently sells at half the price of greenhouse produce. Local and specialty markets provide alternative outlets, but the volume of produce that can be moved is much less than what can be shipped to distant markets.

Greenhouse vegetable yields determine potential gross sales. Typical yields of greenhouse tomatoes are 20 to 30 lbs. per vine, or 2–3 lbs. per square foot. Greenhouse cucumbers yield around 2 dozen fruits per vine. Greenhouse peppers yield 2½ -3 lbs./sq. ft. A study conducted in Missouri in the winter of 1995–96 showed that supplemental lighting of tomatoes increased total yields from 12,444 kg to 18,840 kg. Because the lighted tomatoes were larger, they brought a better price and resulted in additional revenues of $25,000 (19).

Prior to sinking lots of money into a greenhouse venture, growers should examine produce prices in their region and estimate their cost of production. Historically, the breakeven price for most greenhouse tomatoes has been around

75 cents per pound, with selling prices ranging from 90 cents to $1.60 per pound. The break-even price for cucumbers is similar—around 75 cents per pound (18-21).

*Eliot Coleman and his wife Barbara Damrosch raise organic produce in their greenhouses in Maine. They charge $6.25/lb for salad mix, $3.00/lb. for bulk spinach, $1.25-$2.00 for carrots, and $3.00/lb for baby turnips. They dropped scallions because they couldn't make money from them (22).*

Estimates of net income from conventional greenhouse tomatoes range from $3,100 to $18,500 per greenhouse unit (21, 23). These estimates are for good yields and favorable market conditions. Low yields, or a dip in the market, can lead to negative returns to the grower.

The following estimates from 1994 are associated with a double polyethylene greenhouse: the greenhouse itself would cost about $6–$7 per square foot; hydroponic equipment would be an additional $1.50–$2.00 per square foot; land cost, site preparation, foundations, concrete floors, and utilities would be an extra $3.50–$4.00 per square foot (24).

As a suggestion, growers should gather all the economic data they can about the greenhouse vegetable business before building a greenhouse. Also, take a look at other greenhouse business enterprises and determine if vegetables are really the best deal. As an example, greenhouse vegetable growers in some parts of the country have begun to diversify into bedding plants because that market is more lucrative.

**Developments in the Greenhouse Industry in the Last Decade**

One exciting development is the introduction of bumblebees for greenhouse tomato pollination. Pollinating by hand is expensive (in terms of labor), tedious, and time-consuming. Several companies are now raising bumblebees to be used for indoor pollination. Although the hives are expensive, they pay for themselves many times over.

There have also been many new biorational pesticides in the last five years. Some of these biorational pesticides (also known as least-toxic, environmentally friendly, or biopesticides) include *Bt*, *Beauveria bassiana*, and Cinnamite™, which was just released in 1999 for control of several greenhouse pests.

Use of biological control agents has also increased in the last decade. Much more is known about how to use these insects to their fullest advantage and about how to apply insecticides while preserving predators. For more information on these, see the ATTRA publication *Integrated Pest Management for Greenhouse Crops.*

Additionally, new cultivars bred exclusively for greenhouse growing are now available to small growers. Seed vendors like DeRuiter's are constantly testing new cultivars for greenhouse production. Although seed for greenhouse crops is still more expensive than for field crops, it has become more affordable. Growers themselves have been testing cultivars for suitability in greenhouse work, especially in the area of heirloom vegetables.

Another change that is occurring is in the field of greenhouse coverings. Modern greenhouse plastics are resistant to breakdown from ultraviolet light and are rated to last several years. This reduces annual expenses for materials, labor to reglaze, and fees for landfill disposal. Structured sheets are the deluxe alternative to Quonset-style plastic houses. They are more expensive to purchase and install, but they provide optimum environmental controls and have a very long life. Research into the chemistry associated with greenhouse glazing is aimed at energy savings, pest control, and enhancement of plant growth.

**Summary**

Organic greenhouse vegetable production has potential as a niche market for out-of-season produce and as a sustainable method of production. Soil-based systems are readily adaptable to certified organic production, but special care must be taken for soil-borne disease control. Soilless systems can also be adapted to organic culture, and systems like bag culture are easy to get into. Little research is available for specific organic production systems, potting mixes, and fertilizer regimens, however, and growers must use best available knowledge and improvise.

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**Greenhouse Vegetable Seed Sources:**

Crop King
5050 Greenwich Rd.
Seville, OH 44273
800-321-5656
http://www.cropking.com/
*Sell treated seed only.*

De Ruiter Seeds, Inc.
3001 Bethel Rd., Suite 118
Columbus, OH 43220
614-459-1498
http://www.deruiterusa.com/
*Can special-order untreated seed.*

Hydro-Gardens, Inc.
P.O. Box 25845
Colorado Springs, CO 80936
888-693-0578
http://www.hydro-gardens.com/
*Sell untreated and treated seed.*

Petoseed Co., Inc.
1905 Lirio Ave.
Saticoy, CA 93004
805-647-7386
*Sell untreated and treated seed.*

Stokes Seeds, Inc.
P.O. Box 548
Buffalo, NY 14240
800-396-9238
http://www.vaxxine.com/seeds/seedpage.htm
*Sell some untreated seed.*

**Suppliers of Organic Fertilizers:**

(For a complete listing of suppliers of organic fertilizers, see ATTRA's publication *Sources for Organic Fertilizers & Amendments*.)

Algamin
Peaceful Valley Farm Supply
PO Box 2209
Grass Valley, CA 95945
888-784-1722

GreenAll Fish Emulsion
Peaceful Valley Farm Supply (see address above)

Neptune's Harvest
Neptune's Harvest Fertilizer
88 Commercial Street
Gloucester, MA 01930
800-259-4769

Maxicrop
Maxicrop International, Inc.
[Contact: Per Ohrstrom]
PO Box 964
Arlington Heights, IL 60006
800-535-7964

Mermaid's Fish Powder
Peaceful Valley Farm Supply (see address above)

Spray-dried protein fertilizers
California Spray Dry Co.
P.O. Box 5035
Stockton, CA 95205
209-948-0209

**Resources:**

Books:

Coleman, Eliot. 1992. Four Season Harvest. Chelsea Green, Post Mills, VT. 212 p.
*Inspired by Scott and Helen Nearing's garden in the late '60's and based on the author's success with harvesting fresh vegetables year-round in New England, this book contains details on design, construction, and management of the outdoor garden, cold frames, tunnels,*

*and root cellars. It includes growing tips for 50 vegetable crops, a planting schedule for extended harvests for all locations in the US, and sources of tools and supplies. Available for 19.95 from:*

Chelsea Green Publishing
P.O. Box 513
Lebanon, NH 03766
800-639-4099

Coleman, Eliot. 1995. The New Organic Grower: A Master's Manual of Tools and Techniques for the Home and Market Gardener, 2nd Ed. Chelsea Green, White River Junction, VT. 340 p.

*Written primarily for the market gardener with 1 to 5 acres, the book is based on over 25 years of study and personal experience. It covers everything from land selection to marketing, including soil fertility management, field layout and spacing, rotations, direct seeding, transplanting, cultivation, season extension, and integration of livestock into the vegetable system. Extensive chapter notes and annotated bibliography. Available for $24.95 from Chelsea Green (see address above).*

Coleman, Eliot and Barbara Damrosch. 1998. The Winter Harvest Manual. Four Season Farm, Harborside, ME. 56 p.

*Emphasis is on commercial production of greenhouse vegetables. Available for $15 from:*

Four Season Farm
RR Box 14
Harborside, ME 04642

Grotzke, Heinz. 1990. Biodynamic Greenhouse Management. Biodynamic Farming and Gardening Association, Kimberton, PA. 112 p.

*One of the few publications specific to organic greenhousing. Grotzke has chapters on soils, fertilization, and biodynamic preparations, but they are short on technique and mostly contain insights on the biodynamic view of greenhousing. He states that soilless culture systems lack essential microorganism activity and therefore only soil-based potting mixes or ground culture systems can produce biodynamic quality produce. Available for $12 from:*

Fertile Ground Books
PO Box 2008
Davis, CA 95617
800-540-0170
http://www.agaccess.com/

Twenty-one separate fact sheets comprise the 137-page *Greenhouse Vegetable Guide*, which treats topics ranging from locating and constructing the greenhouse to insects and diseases attacking greenhouse vegetables. Included is an 18-page fact sheet on production economics, marketing, and financing of greenhouse vegetables. It is available for $10.00; make checks payable to TAEX. Contact:

Greenhouse Publications
Room 225 HFSB
Texas A&M University
College Station, TX 77843-2134

Hydro-Gardens, Inc. in Colorado Springs, Colorado, carries a large selection of publications on greenhouse vegetable production. See their web site for a complete listing. Contact:

Hydro-Gardens, Inc.
P.O. Box 25845
Colorado Springs, CO 80936
888-693-0578
http://www.hydro-gardens.com/

<u>Selected Publications available from Hydro-Gardens, Inc.</u>

Florida Greenhouse Vegetable Production Handbook. $19.95

Greenhouse Tomatoes, Lettuce & Cucumbers, by S.H. Wittwer and S. Honma. $17.95

Nutritional Diseases in Glasshouse Tomatoes, Cucumbers, and Lettuce, by Roorda van Eysinga and K.W. Smilde. $53

Vertical Plant Production Manual. $35

Greenhouse Tomato Instructional & Plant Culture Manual. $10

Growing Greenhouse Tomatoes in Soil and in Soilless Media. Available only on the Internet.

Soilless Culture of Commercial Greenhouse Tomatoes. $3

Greenhouse Cucumber Instructional and Plant Culture Manual. $10

Growing Greenhouse Cucumbers in Soil and in Soilless Media. Available only on the Internet.

Cucumber Diseases, by W.R. Jarvis and V.W. Nuttall. $5

The Cultivation of European Cucumbers in Greenhouses. By Nunhems Seed Company, Holland. $5

Greenhouse Pepper Pamphlet. $2

Periodicals:

*The Growing Edge* is a bi-monthly magazine that focuses on hydroponics and high-tech gardening from an ecological angle. The emphasis is on greenhouses, hydroponics, artificial lighting, drip irrigation, and other protected culture methods. Special issues have featured articles on bioponics and organic soilless culture. Back issues are available. Contact:

The Growing Edge
New Moon Publishing
341 SW 2nd Street
Corvallis, OR 97333
800-888-6785
http://www.growingedge.com/
*$26.95/year*

**Trade Publications:**

*The trade journals listed below regularly review greenhouse developments and products. The buyer's guide issues are a comprehensive source of supplies.*

Greenhouse Grower
Meister Publishing Company
37733 Euclid Ave.
Willoughby, OH 44094
440-942-2000
440-942-0662 Fax
http://www.greenhousegrower.com
*$29/year for 12 issues; Buyer's Guide issue every summer*

GMPro (Greenhouse Management & Production)
Branch-Smith Publishing
PO Box 1868
Fort Worth, TX 76101
800-434-6776
817-882-4120
817-882-4121 Fax
http://www.greenbeam.com
*12 issues/year; free to qualified greenhouse growers; $96/year for non-growers*

Greenhouse Product News
Scranton Gillette Communications, Inc.
380 E. Northwest Hwy.
Des Plaines, IL 60016-2282
847-298-6622
847-390-0408 Fax
http://www.greenhouseproductnews.com
*$30/year for 12 issues*

GrowerTalks
Ball Publishing Co.
P.O. Box 9
335 N. River Street
Batavia, IL 60510-0009
630-208-9080
630-208-9350 Fax
http://www.growertalks.com
*$25/year for 14 issues*

American Vegetable Grower
Meister Publishing Co.
37733 Euclid Avenue
Willoughby, OH 44094
440-942-2000
440-942-0662 Fax
http://www.greenhousegrower.com
*$15.95/yr, 12 issues. Buyer's Guide published in July issue.*

**Web Sites:**

http://www.ces.ncsu/edu/depts/hort/hil/hil-32-a.html
Greenhouse Vegetable List of References

http://www.cahe.nmsu.edu/pubs/_circulars/circ556.html
Greenhouse Vegetable Production
New Mexico State University

*An excellent overview of greenhouse vegetable production. The circular includes information on Site Selection, Greenhouse Design, Greenhouse Coverings, Environment, Soil Culture, Hydroponic Culture, Carbon Dioxide, IPM, and Disease. The circular is specific to tomato, cucumber, and lettuce production.*

http://aggie-horticulture.tamu.edu/greenhouse/ghhdbk/handbook.html
http://aggie-horticulture.tamu.edu/greenhouse/guides/green/green.html
Texas Greenhouse Management Handbook
Texas A&M University, Aggie Horticulture

*Comprehensive information on Greenhouse Structures, Greenhouse Heating Requirements, Growing Media, Growing Media & pH, Fertilizing Greenhouse Crops, Calculating Parts Per Million, Diagnosing Nutritional Deficiencies, Irrigating Greenhouse Crops, Monitoring the Quality of Irrigation Water, Treating Irrigation Water, Managing Soluble Salts, Air, Water and Media...Putting Them All Together, and Additional References for Greenhouse Management.*

http://ext.msstate.edu/pubs/pub1957.htm
Starting A Greenhouse Business
Mississippi State University, Cooperative Extension Service

*This information sheet provides an overview of factors to be considered by the greenhouse business. The cost estimates used are intended for informational purposes only, since costs vary depending on the supplier and crop mix selected.*

http://www.greenhouse-bbs.com
Greenhouse Industry Trade Show On-Line

*Online resource to greenhouse growers, suppliers, buyers, and researchers.*

http://www.ext.vt.edu/departments/commhort/commhort-30.html
Update on Production Costs/Expected Returns Budget for Greenhouse
Virginia Cooperative Extension

http://www.cals.cornell.edu/dept/flori/tcwres1.html
Controlled Environment Agriculture Information Resources 1996
Cornell University College of Agriculture and Life Sciences

*An online resource listing of publications (books & journals) on the following topics: Conferences, Trade Journals, Newsletters, Industry Organizations, Greenhouse Suppliers, Diagnostic Services, Business Planning & Operation, Cropping Systems, Greenhouse Management, Photosynthesis Management, Greenhouse Crop Production, General Crop Production, Post Harvest Horticulture, and Interiorscaping.*

The electronic version of **Organic Greenhouse Vegetable Production** is located at:
http://www.attra.org/attra-pub/ghveg.html

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