Greenhouse Vegetable Production

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Introduction

Greenhouse vegetable production is a highly intensive enterprise requiring substantial labor and capital inputs. Because of this, potential growers should carefully consider all of the factors necessary for a successful enterprise.

Greenhouse vegetable production is in many ways a 24-hour-a-day commitment. Greenhouse maintenance, crop production and handling emergencies require constant vigilance. Every 4,000 square feet of greenhouse space requires an estimated 25 to 30 hours of crop care and upkeep.

Greenhouse structures require constant maintenance and repair. Many of the selected greenhouse covers must be replaced on a regular basis. Heating, cooling and watering systems must be maintained and routinely serviced. In addition, contingency plans and backup systems must be in place in case any of these major systems should break down. Even a one-day loss of cooling, heating or water during a critical period can result in complete crop failure.

Along with the essential skills, capital and labor to build, maintain and grow a crop, producers must develop markets willing to pay the relatively high prices necessary to make the enterprise economically viable. Greenhouse-grown vegetables cannot compete with comparable field-grown crops based on price; therefore, greenhouse-grown vegetables often are marketed to buyers based on superior quality and off-season availability.

Finally, the personality and skills of the person or people involved in the enterprise should be considered. As mentioned earlier, this can be a 24-hour-a-day commitment. If you don't have the personality to commit and to be available day or night as needed, then this is not for you. In addition, a successful greenhouse vegetable production operation requires mechanical aptitude, crop production skills and business acumen.

Although greenhouse production is an intensive undertaking, it can be very satisfying and rewarding. One advantage of greenhouse vegetable production is the relatively small amount of area required compared with field-grown produce. In addition, the return on investment can be good if the requisite markets can be found.

Site Selection

Several factors should be considered in selecting a suitable site. Whenever practical, the site should be level or nearly so. Sloped sites are not completely out of the question, but they do raise construction costs considerably because the site must be leveled or terraced to accommodate the new structure.

Zoning regulations must be checked to determine if a greenhouse is allowed at the chosen location. In this regard, care concerning waste disposal (irrigation water runoff, etc.) should be considered.

The site should be near a power source and have a ready supply of usable water. Typically, water from a well is better than surface water because there is less likelihood of disease and algae contamination. Water is critically important in greenhouse production, especially if one of the various hydroponic systems, as outlined here, is used. The water used in the fertilizer solutions must be tested before beginning the crop cycle. Water in Georgia can range from acid to alkaline depending on the source. In addition, the water may contain significant levels of dissolved minerals, particularly calcium and magnesium. City water systems may be troublesome for growers, especially if the water has been chlorinated. Chlorine can cause problems for plants, particularly lettuce.

Availability of labor is very important. Although much of the work in crop production is repetitive and tedious, one should not expect suitable labor performance at minimum wage levels. Labor that is conscientious and skilled, or at least trainable, is less expensive and more reliable in the long run.

Access to good roads and proximity to expected markets should also be considered. Modern refrigeration and transportation reduces the need to locate the facility near markets, but shipping costs are reduced when the facility is nearer the expected markets.

Figure 1. Greenhouse design can vary from stand-alone to gutter connected.

Greenhouse Types, Designs and Construction

Greenhouses can range from simple homemade designs to sophisticated prefabricated structures. Materials used to construct a greenhouse frame can be wood, PVC, aluminum or steel; coverings can be glass or various rigid or flexible plastic materials.

Several factors should be considered when choosing a particular greenhouse design, not the least of which are local building codes. Make sure all building codes are met and necessary permits secured before construction begins. Structural load from environmental forces as well as for trellises should be considered in the design. Sufficient heating and cooling capacity must be incorporated into the design to meet the crop's needs for the given geographic location. Because of the specialized nature of a greenhouse structure, obtaining a proven design before construction begins is advisable. In addition, an experienced designer and builder may be in order. Figure 1 shows several different styles of greenhouses.

Several covers can be used with a greenhouse. The most widely used covering materials are ultraviolet (UV) light resistant polyethylene plastics. These covers are often installed two layers thick with an inflated air space between. This increases the cover's insulating capabilities while reducing the chances of a catastrophic loss because of wind-induced flexing. These materials are specially manufactured for the greenhouse industry. Common polyethylene plastic is not the same, because it has not been manufactured to withstand UV radiation. Common polyethylene will not last a year; UV resistant polyethylene plastic is designed to last one to four years, depending on the grade. Many of these coverings have additives to reduce condensation in the house as well as to trap more infrared (heat) radiation.

Rigid plastic materials such as polycarbonate have advantages and disadvantages. The initial cost is higher than polyethylene but generally less than glass. Light transmittance is greater than polyethylene but, again, less than glass. Impact resistance is the best of any material available. Rigid plastic materials are available in different grades with guarantees ranging from five to 20 years. They are also available in single- (corrugated) or double-layer construction.

Glass is an excellent choice for high light transmission and longevity. Glass can last 25 years or more. Glass does have some disadvantages, such as high initial cost and low impact resistance.

Production Methods

Several different methods can be used to produce vegetables in a greenhouse. These include planting directly in the soil within the greenhouse, using containers with soilless mixes, nutrient film technique (NFT), rockwool production and production in perlite. The last three techniques are called hydroponic production because all of the nutrients required by the plant are supplied in the irrigation water.

Soil System

Planting directly into the soil requires the least amount of initial labor. The big disadvantage is possible disease, insect and weed problems that can be present in the soil. This problem can increase over time with successive cropping, particularly if the same crop is grown repeatedly. Fumigating the soil may minimize these problems. Care must be exercised when using a chemical fumigant in an enclosed structure; removing the greenhouse cover before fumigation may be advised.

Soil solarization, in which the greenhouse structure itself acts as the solarizing unit, may control some problems with the soil system. This works best if the soil is turned and moistened during the hot summer months. The house is then closed for at least two weeks to reduce the number of soilborne pathogens.

Soil fertility should be determined and managed with soil testing. As with any field soil, the soil pH should be adjusted to 6.0 to 6.5. Soluble salts buildup can be particularly severe with the soil system. To minimize this problem, the house can be uncovered when not

in production to allow rainfall to leach the soil. In addition, use fertilizers that do not contribute excess soluble salts. This would include calcium nitrate, potassium nitrate, triple superphosphate, diammonium phosphate, potassium sulfate and sulphate of potash-magnesia.

Plants should be mulched to control weeds, retain soil moisture and prevent soil compaction. Plants can be set in plastic mulch, or organic mulches can be used.

Container System

Planting in a typical soilless potting media can also be successful. Many different manufactured media are available, most of which are peat based and include various blends of peat with perlite, vermiculite, sand or ground pine bark. In addition, these media may have fertilizer and/or wetting agents added. Usually the amount of fertilizer incorporated in these media is not sufficient to carry the crop to completion. The disadvantage of these media is that they can harbor various pathogens. Although these media are generally pathogen free when sold, the high organic matter present is an ideal substrate to support the growth of microorganisms that may be introduced to the greenhouse over time. In addition, using large quantities of this material can be costly.

Fertilizer sources can be either soluble or slow-release formulations. Follow a fertility program similar to one used for greenhouse ornamental production.

Hydroponic Systems

The various methods of hydroponic production have become the de facto standard for producing greenhouse vegetables. These methods are very clean, with no organic material present. In addition, they give the grower complete control over the crops' nutritional needs. This allows the grower to maximize growth and fruit production. The disadvantage of this method is that it requires calculating and measuring exact amounts of fertilizers. This usually means handling several different fertilizer compounds. Mistakes in calculations or quantities used are more likely to show up as deficiencies or toxicities in the crop than in other methods employed. See Table 1 and the section on preparing fertilizers for a complete discussion of this topic.

Figure 2. In perlite bag culture, plants grow in polyethylene bags filled with perlite. Note the fertigation emitter at each plant.

Plants can be grown in various media in these systems; all are essentially nutrient free. In one system called the nutrient film technique (NFT), plants are placed in a polyethylene tube that has slits cut in the plastic for the roots to be inserted. Nutrient solution is pumped through this tube, bathing the roots. The solution recirculates, and nutrients are added as depletion occurs. Other systems use rockwool as the supporting medium. More recently, polyethylene bags of perlite have been used as the supporting medium (Figure 2).

Regardless of the production system, most will require some type of automation to supply water. This is particularly important in any of the hydroponic systems.

Crop Selection

Several vegetables have been successfully produced in a greenhouse, including cucumbers, peppers, lettuce, herbs and, by far the most important, tomatoes. Each has different requirements for production.

Cucumbers

Cucumber varieties grown in greenhouses are known as European types. These special cucumbers are parthenocarpic; that is, they produce fruit without the need for pollinization. In fact, care should be taken to avoid pollinization by non-parthenocarpic cucumbers because this will result in bitter, misshapen fruit.

Cucumbers are a warm season crop; therefore, greenhouse temperatures should not be allowed to drop below 65°F. Seed germination can occur with media temperatures above 60°F, but optimal germination occurs at 85° to 95°F.

Typically, cucumbers will be germinated in flats of rockwool or foam blocks, usually with a single seed per well to ensure plants can be transplanted with minimal root damage. Plants should be transplanted to final spacing in the greenhouse when they are large enough to handle without damage. They will usually be ready for transplanting in two to three weeks under optimal conditions.

Cucumbers are vining crops, so they are grown with a trellis system. As the plant is trained, all fruit below 24 to 30 inches are removed to maximize foliar growth. Above this height, fruit are allowed to set. Several different trellis systems have been developed to produce greenhouse cucumbers. These systems, using

either one or two wires strung approximately 8 feet above the crop, are referred to as single and V-cordon systems. Both single and double rows of plants can be used with the single cordon system. In either case, the plants are trained up a string to the suspended wire where the plant is draped over the wire. At this time, the plant may be pinched and two laterals allowed to grow down to the ground, or the primary stem may be allowed to continue growing to the ground. In either case, all other laterals are removed as they appear and at least one fruit is allowed to develop at each node. In the V-cordon system, two wires are suspended so that the plants can be alternately strung to one wire or the other. This results in a V-shaped system of plants growing to the respective wires. In all other ways they are treated the same as the single wire system in terms of pruning laterals and draping over the wire.

In addition, the in-row spacing will differ between the two systems. In the single cordon system, plants are spaced 12 to 18 inches apart. If a single wire with a double row is used, the plants are spaced 18 to 24 inches apart with 2 feet between the double rows. With the V-cordon system, the plants are spaced 12 inches apart with plants alternatively strung to one wire or the other.

Between-row spacing for the double-row single-wire system is 5 to 6 feet; for the single-row single-wire system, 4 to 5 feet. With the V-cordon system, between-row spacing is 5 feet.

Fruit matures continuously as the plants grow. Flower opening to harvestable fruit will take between 10 and 14 days. Therefore, harvesting is a continual process usually done three times a week. Harvested fruit must be protected from desiccation and bruising because the skin is rather tender and prone to water loss. Greenhouse cucumbers are individually shrink-wrapped to restrict desiccation and extend shelf life. This is a labor-intensive process.

Peppers

Peppers require a long growing period to reach transplant size. This may be from 30 to 85 days depending on the time of year and greenhouse conditions. Because of this, a fertility program should begin shortly after the plants have emerged and continue throughout the production cycle.

Optimal temperature for pepper seed germination is between 80° and 85°F. After germination, the greenhouse temperature should be lowered to about 75°F. A relative humidity of 75 percent is ideal for pepper growth. Higher humidity will encourage disease development.

After transplanting, greenhouse temperatures should be maintained above 60°F and below 100°F, with ideal growth between 70° and 85°F. Plants should be pruned to the two strongest stems, and these should be supported by tying to a wire suspended 8 feet above the plants. All lateral stems are removed for the first five to seven nodes above the ground. Above this, plants are allowed to branch from the two main stems. One to two fruit will set per node. Plants are often vibrated or trellis wires tapped to ensure proper pollination and fruit set.

Leafy Vegetables

The most important leafy vegetable grown under greenhouse conditions is lettuce. Many different types and varieties of lettuce can be grown under greenhouse conditions, including specialty types. Generally, the looseleaf, butterhead and romaine or cos types are grown in greenhouses rather than the crisp head types. Many varieties specifically developed for greenhouse production are available. A crop of lettuce can be produced from seed in about 35 to 45 days. Greenhouse lettuce is harvested earlier and thus is smaller than those grown in the field. Seed are germinated at 75°F and should emerge in two to three days. When seedlings are large enough to handle, they are transplanted to their final spacing based on the production system and lettuce type grown. In float systems, they may be moved twice after seeding to an initial spacing of 16 square inches per plant after 10 to 11 days and to 41 square inches per plant 21 days after seeding.

Tomatoes

Tomatoes selected for greenhouse production are indeterminate types. Indeterminate tomatoes continue to grow and set fruit throughout their life cycle. Varieties selected for greenhouse production fall into two broad categories: large beefsteak or slicing types and cluster or hand types. The larger types are harvested singly. The cluster or hand types are harvested in clusters of four to seven fruit and are sold with the cluster stem still attached.

Tomatoes can be seeded into various soilless mixes as well as into rockwool or foam cubes. The seed should be kept at 75° to 80°F during germination. Seedlings emerge in seven to 10 days. Plants for transplanting should be available in about three to four weeks after seeding. Make sure the medium the plants will be grown in is thoroughly moistened with water or dilute nutrient solution. If bags of perlite are used for production, they should be moistened as described above, and the irrigation emitters should be placed in each bag before slits are cut to allow excess solution to drain away. In general, for perlite bag culture or rockwool culture, plants are set 18 to 24 inches apart in the row with a between-row spacing of 4 to 5 feet. Plant spacing for tomatoes in the soil system should have a between-row spacing of 3 feet and an in-row spacing of 16 to 18 inches. Plant spacing

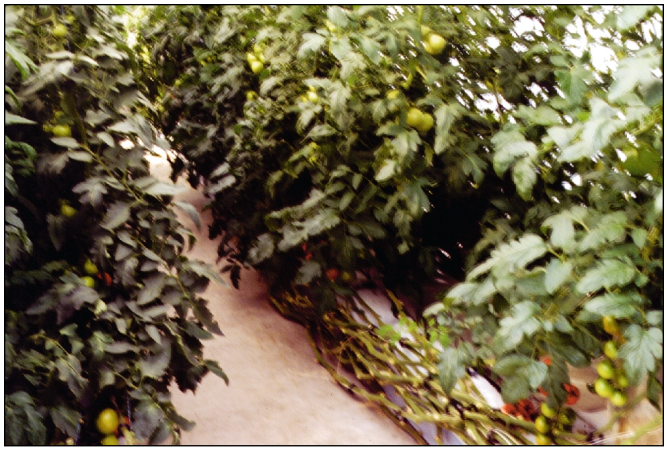

Figure 3. Indeterminate tomatoes are trained up a string supported by an overhead wire. After the plants have reached the wire, some of the string must be unwound each week and the plants lowered and leaned. This results in plants 30 feet or longer.

can vary widely depending on individual preferences and needs. Indeterminate tomato varieties are trained to a single stem and supported by twine. Spacing will vary based on the system used.

Tomatoes are usually transplanted to their final spacing in the greenhouse in September for winter and spring production. High temperatures can be a problem at this time of year. The grower should try to keep temperatures at 80° to 85°F as much as possible. Using fans, cool pads and shading the house are all methods that can help reduce the temperature. The best yields for tomatoes occur with day temperatures of 80° to 85°F and night temperatures of 62° to 72°F. Temperatures higher or lower than this range can result in fruit quality problems. High temperatures can result in flower abortion.

The indeterminate tomato varieties grown in greenhouse culture must be trellised and pruned on a regular basis. Over the 10 months the plants are in production, they will grow as long as 30 feet. Clearly, the greenhouse will not be able to accommodate the plants vertically. Therefore, the plants are trellised up a string to a cable suspended about 8 feet above, at which time the plants are lowered and leaned. Sufficient string is used with each plant so that the string can be unwound and extended as the plants are lowered and leaned (Figure 3). As the plants continue to grow, they are periodically lowered from the overhead cable and leaned. At the same time, more string is unwound to accommodate the growing plant.

The plants must be pruned and the fruit thinned throughout the crop cycle. As the plants grow up the string, lateral branches are removed from leaf axials while the main stem is allowed to continue to grow. Fruit must be thinned as they form in the flower clusters. The variety will determine how many fruit should be left at each flower cluster. Hand or cluster tomatoes can support more fruit in a cluster than larger types, which may only support three to five fruit per cluster.

The flowers must be vibrated or shaken in order to ensure pollination. This can be done with an electric tomato pollinator, an old electric toothbrush, a modified door bell motor or a small lawn blower. The flowers must be vibrated or shaken each day that flowers are produced. The best time to do this necessary operation is between 10 a.m. and 3 p.m. During overcast or rainy days, pollen will not be dry enough to adequately pollinate the crop; therefore, plants must be shaken during sunny, dry days.

Bumblebees are also available to handle pollination. These small hives can be purchased commercially and placed in the greenhouse. These hives will last from eight to 12 weeks. Bumblebees tend to be more efficient at pollinating flowers, but less aggressive, than honeybees.

Fertilization

The solution pH is critically important when growing plants hydroponically. The nutrient solution has no buffering capacity like that in solid media. This means that pH can readily change during the production cycle and must be monitored and adjusted to 5.5 to 6.5.

Most hydroponic production systems require the use of two stock solutions (Figure 4). This is done to avoid precipitates that can occur if all the nutrients are mixed in a concentrated form in a single stock tank. Mixing calcium nitrate with phosphorus materials can result in insoluble calcium phosphate. In addition, calcium sulfate can precipitate when calcium nitrate is mixed with magnesium sulfate. To avoid these problems, one stock solution is prepared with calcium nitrate and iron chelate. The remaining materials are mixed in a second stock solution.

Nutrient requirements are listed in parts per million (ppm) as shown in Table 1 for various stages of green-

house tomato growth. Any combination of chemicals that meets these requirements is acceptable, including prepackaged materials. Growers may find that purchasing stock chemicals rather than prepackaged materials is cheaper. Once they feel comfortable mixing these materials, they will have the added benefit of allowing more fine tuning of plant nutrient needs. Table 2 is an example of the type and amount of material required to meet the needs of a tomato crop throughout a crop cycle. This information is given as an example only. Any combination of fertilizers that meet the needs outlined in Table 1 will work.

Figure 4. Dual tanks and injectors ensure that chemicals will stay concentrated in the solution.

Insect and Disease Control

Modern greenhouse design has tried to minimize or eliminate insect and disease problems so that plants can be grown pesticide free under many conditions. Some of the innovations have included using ultra-fine screening over all openings to prevent insects, including thrips, from entering the house (Figure 5). Building a vestibule at all entrances is also helpful in preventing insects from entering the greenhouse (Figure 6).

Preventing insects from entering the house is the best way of controlling insect problems. Plants should, however, be inspected daily for insect infestations. If pesticides are to be used, care must be exercised in selecting materials. Products that are registered for field use may not be registered for greenhouse use. In addition, caution should be exercised when applying pesticides because certain materials, such as emulsifiable concentrates, can cause plant damage under greenhouse conditions.

Moving fan jets to ground level and automating the watering and fertilizing process have eliminated free water on plant surfaces, which reduces disease incidence. The use of disease resistant varieties when available have also helped reduce disease problems. As mentioned above, care should be exercised when selecting products for disease control in greenhouses. For more information on insect and disease control under greenhouse conditions, contact your local county Extension office.

Harvesting and Handling

Harvesting of tomato, pepper and cucumber will be a continual process throughout the growing cycle. All of the lettuce, on the other hand, will be ready at the same time after seeding. Tomatoes and peppers are harvested with stems attached and are packed that way to avoid bruising and damage. Care should be taken so that tomatoes are not stored or transported with other vegetables such as peppers, lettuce or cucumbers. Tomatoes produce ethylene during the ripening process that can damage other vegetables.

Harvest should occur during the cooler part of the day, and the vegetables should be protected from heat. Harvested material should be precooled as soon as possible if this is part of the postharvest procedure. Table 4 shows the best precool method and storage conditions for optimal storage life.

The USDA has grade standards for greenhouse-grown tomatoes, cucumbers and lettuce as well as grade standards for sweet peppers. These standards are available from the USDA at:

Agricultural Marketing Service
USDA, Room 2056 South Blvd.
Washington, D.C. 20250

This information is also available on the Internet at www.ams.usda.gov/standards.

Figure 5. Fine mesh screening over openings prevents insect entry.

Figure 6. Vestibules at all entries help prevent insect entry.

Table 1. Final nutrient solution concentration at various stages for tomato, cucumber and leafy vegetables (ppm)

	N	P	K	Ca	Mg	S	Fe	B	Cu	Mn	Zn	Mo
Tomatoes*												
Transplant to first cluster	65	50	120	80	40	56	2.8	0.7	0.2	0.8	0.2	0.05
First cluster to second cluster	75	50	120	92	40	56	2.8	0.7	0.2	0.8	0.2	0.05
Second cluster to third cluster	95	50	150	104	40	56	2.8	0.7	0.2	0.8	0.2	0.05
Third cluster to fifth cluster	114	50	150	127	48	66	2.8	0.7	0.2	0.8	0.2	0.05
Fifth cluster to termination	148	50	208	127	48	66	2.8	0.7	0.2	0.8	0.2	0.05
Peppers†												
Seedling to termination	225	40	350	175	40	56	2.8	0.7	0.2	0.8	0.2	0.05
Cucumbers†												
Seedling to first fruit	133	62	150	130	50	70	2.5	0.44	0.05	0.62	0.09	0.03
First fruit to termination	240	62	150	260	50	70	2.5	0.44	0.05	0.62	0.09	0.03
Leafy Vegetables†												
Seedling to termination	200	62	150	210	50	70	2.5	0.44	0.05	0.62	0.09	0.03

* Hochmuth, G. (ed.) 1991. *Florida Greenhouse Vegetable Production Handbook Vol. 3.* Florida Cooperative Extension Service Publication SP-48.
† Fertility levels are based on Canadian recommendations. Lower levels of fertilizer may be required, particularly during early stages of production.

Table 2. Example of fertilizers and amounts to meet tomato production needs as outlined in Table 1

	Amount required in 100 L of final solution				
Fertilizer	**Transplant to first cluster**	**First cluster to second cluster**	**Second cluster to third cluster**	**Third cluster to fifth cluster**	**Fifth cluster to termination**
Phosphoric acid (54% P_2O_5)	9.3 L	9.3 L	9.3 L	9.3 L	9.3 L
Potassium chloride	16.7 g	16.2 g	20.1 g	19.1 g	26.8 g
Magnesium sulfate	40 g	40 g	40 g	48 g	48 g
Potassium nitrate	45.6 g	52.6 g	67.4 g	80.7 g	106.8 g
Calcium nitrate	38.1 g	43.8 g	49.5 g	60.5 g	60.5 g
Micronutrient stock (see Table 3)	1 L	1 L	1 L	1 L	1 L

Table 3. Micronutrient stock solution

Fertilizer	Grams per 100 liters
Manganese sulfate (25% Mn)	32
Solubor (20% B)	35
Copper sulfate (25% Cu)	8
Zinc sulfate (23% Zn)	8.7
Iron chelates (10% Fe)	280
Sodium molybdate (39% Mo)	1.3

Adapted from Hochmuth, G. (ed.) 1991. *Florida Greenhouse Vegetable Production Handbook Vol. 3.* Florida Cooperative Extension Service Publication SP-48.

Table 4. Optimal storage conditions for greenhouse-grown vegetables

Vegetable	Precooling method*	Temperature (°F)	Relative humidity	Storage life (days)
Cucumber	FA	50-55	95%	10-14
Pepper	FA	45-55	90-95%	14-21
Lettuce	VA, HY, PI	33	95-100%	14-21
Tomato	ROOM, FA	50-55	90-95%	7-21

* FA – forced air, HY – hydrocooling, VA – vacuum cooling, PI – package ice, ROOM – room temperature
Adapted from Hochmuth, G. (ed.) 1991. *Florida Greenhouse Vegetable Production Handbook Vol. 3.* Florida Cooperative Extension Service Publication SP-48.

Table 5. Conversion Table

1 pound = 454 grams
2.2 pounds = 1 kilogram
1 gram = 1,000 milligrams
1 gallon = 3.78 liters
1 liter = 1,000 milliliters
1 milligram per liter = 1 part per million
1 pound = 16 ounces (mass)
1 gallon water = 8.3 pounds
1 quart = 0.95 liters
1 gallon = 128 ounces (volume)
1 gallon = 3,780 milliliters

For Additional Information

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