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Greenhouse Crops and Cropping Systems for Commercial Aquaponics

Jeremy M. Pickens[1], Jason Danaher[2], and Daniel Wells[1]

The aquaponics industry is in its infancy and faces many challenges, ranging from balancing nutrients in the system to food safety. Fortunately, a foundation for successful plant production in controlled environments is used by the greenhouse vegetable industry. This factsheet is a general overview of crops and growing systems used in the commercial greenhouse vegetable industry that have the potential to be adapted to aquaponic production systems.

Growing hydroponic vegetables in greenhouses allows producers to control the growing environment for extended or year-round production. Other benefits of greenhouses are biosecurity, insect exclusion, and protection from weather. Because hydroponic greenhouse vegetable production and aquaponic vegetable production are essentially the same, it is also practical for commercial aquaponic crops to be grown in greenhouses.

Greenhouses and aquaculture systems require a substantial capital investment and often higher operational budgets per unit area than conventional agricultural enterprises. Greenhouse crops must be profitable to cover the costs associated with growing indoors in intensive systems. Fortunately, valuable information from the greenhouse industry can be obtained on what growing systems are most practical and successful. Greenhouse produced crops can be divided into two primary categories: leafy vegetables and fruiting vine crops.

[1] Auburn University
[2] Pentair Aquatic Eco-Systems, Inc.

Leafy green crop production

Leaf crops are popular in aquaponic systems because they are relatively easy to grow and have short production cycles, allowing for quicker cost recovery and return on investment. Most leafy greens grown in greenhouses can be finished from transplant in 30 to 40 days. Of the leafy greens grown, lettuce is by far the most common, with romaine, loose leaf, and butter head cultivars dominating production. Other common vegetables in this category are spinach, Swiss chard, kale, and pak choi. Herbaceous herbs such as basil, cilantro, parsley, and mint are also popular. Most leafy crops are sold by the head or by clippings (as in the case of herbs) and can be sold monthly because of their quick production time. Bulky, slower-growing crops such as iceberg lettuce, romaine hearts, and cabbage are typically avoided because they are not worth the space and time they require.

A variety of hydroponic plant production systems can be integrated into a closed, recirculating aquaponic system to produce leafy greens, but the two systems most often used are the nutrient film technique (NFT) and deep water culture (DWC). Most growers use DWC systems, also known as raft systems. Transplants are planted in holes cut into the foam rafts. The rafts float on top of a nutrient solution into which the roots grow (Fig. 1). Most aquaponics raft systems are modeled after the University of the Virgin Islands System (UVI System). This system has been extensively validated through both research and commercial trials. For a complete description of the UVI system see SRAC Publication No. 454, *Recirculating Aquaculture Tank Production Systems: Aquaponics – Integrating Fish and Plant Production.* Raft systems have traditionally used 4 foot × 8 foot (1.2

Figure. 1. This lettuce is growing on rafts floating on a nutrient solution into which the roots grow.

× 2.4 m) polystyrene sheets with thicknesses of 0.75 to 1.5 inch (1.9 to 3.8 cm). Growers may decide to cut the board into sections for easier handling and to prevent rafts from cracking when being moved. Water depth in raft systems can range from 6 to 12 inches (15 to 30 cm). Tank walls can be made from treated lumber or concrete blocks and then a plastic liner is laid down within the walls to retain the nutrient solution.

Holes of a specific diameter are cut into the sheet to support inert media such as rockwool, foam cubes, or net pots. It is advisable to create a template from a sheet of ¼-inch (6-mm) plywood that has the specific hole spacing and pattern desired. This template can then be placed over individual polystyrene boards to expedite the production process.

Nutrient Film Technique (NFT) systems use a series of plastic channels through which a thin film of nutrient solution is constantly recirculated. The plastic channels usually measure 4 inches wide (10 cm) and 6 to 12 feet long (1.8 to 3.6 m; Fig. 2). Transplants are placed in holes cut in the tops of the channels. Roots grow into the channel where they are fed by the nutrient solution. NFT systems are almost always recirculating and any water not absorbed by the plants is returned to the fish production. Water is delivered to each channel through drip irrigation, where each channel receives water through a ¼-inch drip tube regulated by a pressure-compensating emitter (Fig. 3).

Deep Water Culture (DWC), or raft systems, are by far the most common method of producing leafy greens in aquaponics, while hydroponic growers tend to use NFT. Raft systems are considerably less expensive. For a standard 30 foot × 96 foot (9 m × 29 m) greenhouse, a raft system can cost \$4,000 to \$5,000 compared to an NFT system that may cost up to \$10,000. The channels for an NFT system can last considerably longer than the foam rafts and are easier to clean. Raft systems, however, reduce the risk of crop loss during power outage because contact between the nutrient solution and plant roots does not depend on recirculating pumps, as in NFT systems. In addition, raft systems rarely have issues with acute solids accumulation when there is adequate mechanical filtration before water reaches

Figure 2. Nutrient Film Technique (NFT) systems are a series of plastic channels through which a thin film of nutrient solution is constantly recirculated.

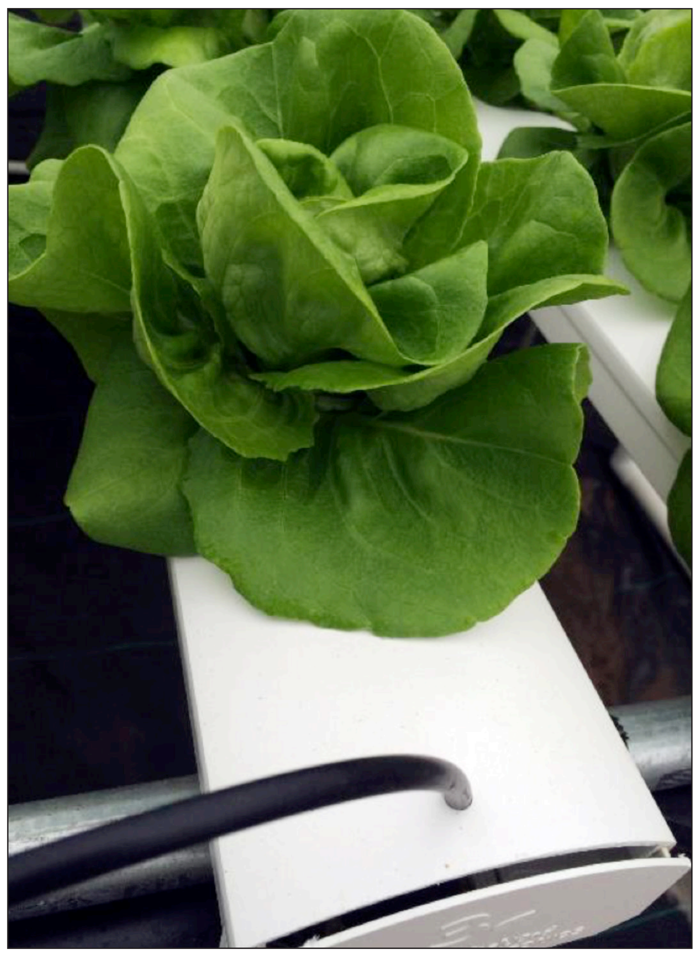

Figure 3. Water is delivered to each NFT channel by drip irrigation. Each channel receives water through a drip tube that is regulated by a pressure-compensating emitter.

the plant growing area. Because the water delivery system involves micro orifices, NFT systems for aquaponics are prone to clogging and require more efficient filtration than DWC systems.

With both systems the cropping culture details will be almost identical. Two- to 3-week-old seedlings are commonly used as transplants. The transplants will have been grown in either a foam media cube or a net pot filled with soilless substrate (Fig. 4). Most commercial growers currently use foam media. Transplants are placed directly into the DWC or NFT system. DWC systems offer more flexibility in plant spacing and can use 4-, 6-, or 8-inch (10-, 15-, or 20-cm) centers. A 4 foot × 8 foot (1.2 m × 2.4 m) raft could have 48 to 88 plant sites depending on the desired final market size. Most NFT channels have holes cut on 7- to 8-inch (18- to 20-cm) centers, although custom channels are available. The higher the plant density, the smaller the plants and greater the input costs (labor, seeds, and media) per unit. A common plant density using 8-inch centers would be 2.25 plants per square foot (24.2 plants/m^2).

Figure 4. Two- to 3-week-old seedlings are commonly used as transplants. The transplants are grown in either a foam media cube or a net pot filled with soilless substrate.

Plants are often planted on a staggered schedule for weekly harvest. A standard 30 foot × 96 foot (9 m × 29 m) greenhouse can hold 600 to 1,100 plants per week, depending on growing conditions, plant health, and greenhouse space utilization. Harvest size will depend on the end use of the product. Some chefs or consumers prefer specific size plants for direct consumption or processing. In general, it is common to harvest bib lettuce and loose-leaf lettuce when plants reach 5.5 ounces (156 g) per unit 4 to 5 weeks after transplanting. The product will often have some root mass included in the weight.

Lettuce should be handled carefully at harvest. Because it is consumed raw, proper food safety procedures should be followed to ensure quality is maintained. Plants usually are packaged in boxes (multiple plants) or plastic clam shells (individual plants). Leaving roots attached to the plant can increase the shelf life of the product several weeks when stored at near freezing temperatures and high humidity.

Vine crop production

Vine crops are fruiting crops that can be trained vertically in the greenhouse on a trellis system. Popular vine crops for greenhouse production include tomato, pepper, cucumber, eggplant, and some small melon crops. In the southeastern United States, tomatoes are the most popular greenhouse vine crop because of their marketability. High plant densities are achieved by training these plants vertically on cable trellis systems.

There is limited research on growing vine crops in aquaponic systems. Some growers have successfully used raft systems, but little validated data is available. In the commercial greenhouse industry, vine crops can be grown using Rockwool slabs, large NFT channels, or soilless culture. In the Southeast, most greenhouse growers use soilless culture.

Soilless culture involves growing plants in a highly porous media containing no mineral soil. The most common media components are pine bark or perlite. The media is contained in plastic nursery pots or plastic bags. Some growers are using the Dutch bucket system, as it allows for the collection of liquid leached from the pots. Soilless systems use drip irrigation; each plant has its own pressure-compensated emitter(s) to deliver the nutrient solution. An irrigation controller allows for frequent irrigation throughout the day, sometimes as often as 20 times per day. Each irrigation is short, lasting 2 to 3 minutes or enough time for the container to leach 20 percent of what is applied. For biosecurity reasons, most commercial growers in the Southeast do not recycle the solution leached from the containers. Soilless culture integrated with aquaponics is probably best suited for decoupled systems in which the nutrient solution is not returned to the fish system. Research has shown integrating soilless vine crop production with aquaponics is possible, but more research is needed.

In any growing system, vine crops are trellised to allow them to be trained vertically, increasing plant density. Plants are trained on strings suspended from a wire cable trellis. Trellis systems often have two cables per plant row. Cables are positioned 7 to 8 feet (2.1 to 2.4 m) above the row and are spaced 24 to 30 inches (61 to 76 cm) apart. Between-row spacing will vary from 5 to 6 feet (1.5 to 1.8 m), depend-

Figure 5. Trellis systems are often constructed with two cables per plant row. Cables are positioned above the rows and are spaced 24 to 30 inches (61 to 76 cm) apart. Between-row spacing will vary depending on the crop.

ing on the crop. A 30-foot-wide (9-m-wide) greenhouse can accommodate five double rows of trellised vine crops (Fig. 5).

Unless the greenhouse is specifically designed for the trellis, the greenhouse end wall should not be used to support the trellis cables. The weight of the crop has been known to severely damage greenhouse walls. Trellises can be supported with steel pipes or large pieces of lumber (Fig. 6). Trellis cables are typically positioned at the same height as the greenhouse gutters or eaves, which in some commercial greenhouses can be as high as 20 feet (6 m). In these high ceiling greenhouses, movable scaffolding is required to train and harvest crops. Small growers in the Southeast often have a trellis height of 7 to 8 feet (2.4 m). A trellis system can be constructed for less than $2,000 for a standard 30 foot × 96 foot (9 m × 29 m) greenhouse.

Figure 6. Unless the greenhouse is specifically designed for the trellis, do not use the greenhouse end wall to support the trellis cables. The weight of the crop has been known to severely damage greenhouse walls. Trellises can be supported with steel pipes or large pieces of lumber.

Greenhouse tomatoes

In the southern states, greenhouse tomatoes are often grown in the off-season so growers can take advantage of the lack of high-quality, locally grown tomatoes on the market. While tomatoes can be grown year-round in a greenhouse, most growers market tomatoes from late fall to late spring. This is largely to avoid competing with the considerably less-expensive field tomatoes available during warmer months. While the harvest period for tomato production is only half of the year, the greenhouse will be committed to production almost the entire year. It takes at least 2 months from transplant for the plants to produce harvestable fruit. Transplants are planted in early August, with the first harvest occurring in late October to early November. The crop may last until June before it becomes to too hot in the greenhouse.

A two-crop (fall and spring) production schedule can produce similar yields to one long crop system spanning from August to June. The two-crop system involves transplanting in late summer, with the first crop terminated in December. In January, a second crop is planted and harvest will begin in mid-March. The two-crop system is most efficient where it is difficult to carry mature plants through the cold winter months. In late winter, plants are typically less vigorous, resulting in lower yields and increased disease pressure. Day length is shorter and overcast skies are frequent during January and February, which further reduces yield in late winter. The two-crop system may also reduce costs by reducing the amount of heat needed to produce the crop, although some sales may be lost when production is interrupted.

Most greenhouse vegetable growers plant indeterminate tomato varieties that are selectively bred for the greenhouse environment. Indeterminate tomatoes continue to grow and fruit indefinitely until the plant succumbs to disease. While there is a demand for heirloom varieties, these varieties were not selectively bred and likely will not tolerate low light levels (typical during off-season production) or common tomato diseases. Also, heirloom varieties often have considerably lower yields than greenhouse varieties. Yields for greenhouse tomato varieties average 20 to 25 pounds (9 to 11 kg) per plant, but higher yields are possible. Greenhouse tomatoes are usually planted in double rows with 14 to 16 inches (36 to 41 cm) between plants and 4 to 5 feet (1.2 to 1.5 m) between rows. It is not recommended to have less than 4 square feet (0.37 m^2) per plant.

Greenhouse tomatoes are trained to a central vine by removing all lateral growth (suckers; Fig. 7) at least once weekly throughout the life of the crop. Plants are grown vertically on strings suspended from a cable trellis. The string

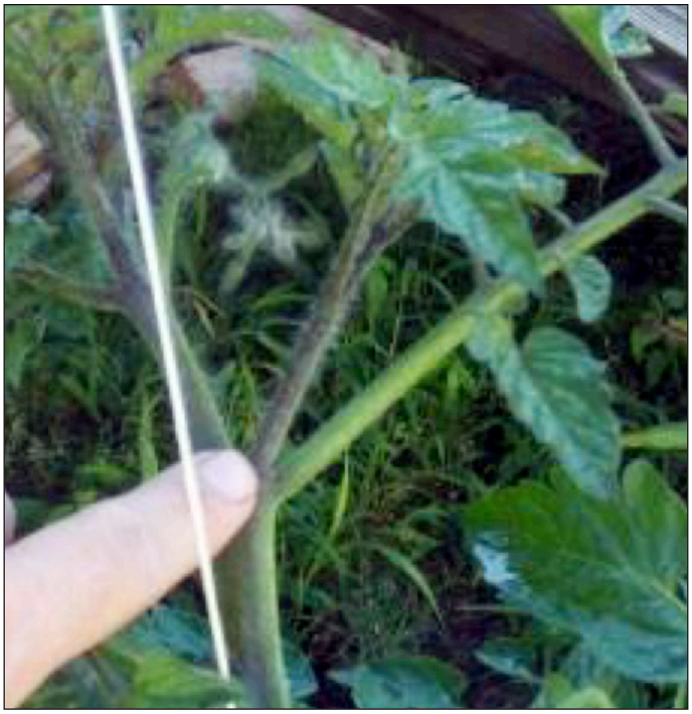

Figure 7. Greenhouse tomatoes are trained to a central vine by removing all lateral growth (suckers) at least once weekly throughout the life of the crop.

Figure 8. Tomato plants are grown vertically on strings suspended from a cable trellis. The string is wrapped around a spool that attaches to the trellis. Once the tomato reaches the cable some of the string is released from the spool. This lowers the plant and the spool is then slid down the cable trellis.

is wrapped around a spool that attaches to the trellis. Once the tomato reaches the cable, some of the string is released from the spool. This lowers the plant and the spool is then slid down the cable trellis (Fig. 8). This technique is called "leaning." Plants can eventually reach lengths of more than 15 feet (4.6 m), but only about 6 to 8 feet (1.8 to 2.4 m) are vertical at any given time; most of the plant runs horizontally above the ground.

Greenhouse tomatoes require mechanical pollination (vibrating devices or leaf blowers) or the use of bumble bees. Boxes of bumble bees can be purchased and placed in the greenhouse. Bumble bees are shipped overnight and must be replaced about every 2 months.

Tomatoes have the strictest temperature requirements of all greenhouse crops. Daytime temperatures should be maintained between 70 and 82 °F (21 and 28 °C), while night temperatures should range from 62 to 64 °F (16.6 to 17.8 °C). Higher than optimal temperatures can result in poor pollination, physiological fruit disorders, and poor fruit quality. Lower than optimal temperatures can cause flower abortion and nutrient deficiencies, resulting in reduced yields.

Greenhouse cucumbers

High-quality cucumbers are becoming a popular greenhouse crop. They are seedless, thin-skinned, and allow for value-added packaging. Seedless cucumbers do not require pollination because they are parthenocarpic, meaning that fruit will form without the fertilization of the ovule.

Because of their thin skin, seedless cucumbers are subject to moisture loss and decreased crispness. To prevent moisture loss, seedless cucumbers are often wrapped or covered with plastic film. The European types are 8 to 12 inches long (20 to 30 cm) and individually wrapped. The Beit Alpha types are marketed as mini cucumbers and are usually 4 to 6 inches long

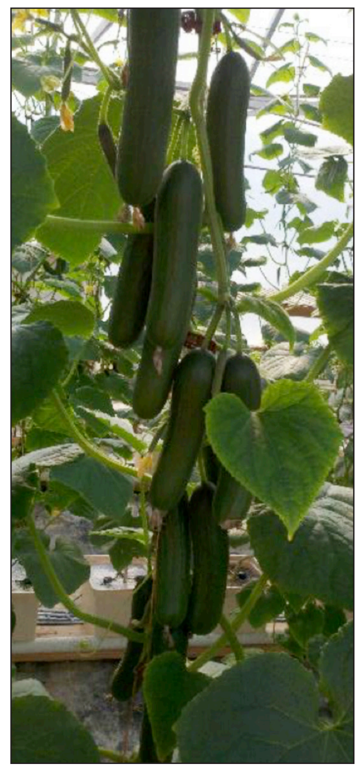

Figure 9. To prevent moisture loss, seedless cucumbers are often wrapped or covered with plastic film. The European types are individually wrapped after harvest. The Beit Alpha types (above) are marketed as mini cucumbers.

(10 to 15 cm; Fig. 9). Mini cucumbers are harvested at 3 to 4 ounces (85 to 113 g). Beit Alpha cucumbers are often sold in small trays wrapped with plastic. These trays may contain four to five fruits.

Cucumbers grow at such a fast rate that it is too labor intensive to lean the vines like tomatoes. European cucumbers can be trained using either the vertical cordon or V-cordon system. The primary difference between them is that the vertical cordon system uses a single row, while the V-cordon system uses two rows. The V-cordon system uses two trellis cables spaced 2.5 to 3 feet (76 to 91 cm) apart and suspended over plant rows. Plants are alternately trellised to each cable, forming a "V" pattern. The vertical cordon system involves a single row onto which plants are trellised. In both training systems plants are trained to a central vine by removing any secondary growth (lateral branching).

For either the vertical cordon or V-cordon training system, when the plants reach the cable they can be further trained by using either a draping method or the renewal umbrella method. With the draping method, plants are grown over the trellis cable and allowed to grow down until they reach the greenhouse floor. When the plant reaches the floor some growers may choose to terminate the crop or grow the crop back up the original string that forms a sort of circle with the vine. The draping method is popular with the fast growing Beit Alpha varieties.

With European cucumbers, the renewal umbrella system is popular. Two lateral shoots are allowed to grow down on each side of the primary vine. These hanging vines are pruned to a single leader, with the exception of one lateral branch near the trellis cable. These two lateral branches will become the new hanging vines. When fruit are harvested from the 5th to 6th node, the hanging vine is pruned back to the lateral branch remaining near the cable. This branch will then become the new hanging vine. This process is repeated until crop termination. Beit Alpha cucumbers may be trained differently.

One cucumber crop can be grown using the umbrella system for most of the year, but yields may be greater if three crops per year are planted, each averaging about 110 days per cycle. With both seedless cucumber types, care must be taken to thin fruit early in plant development by not allowing fruit to develop below 2 to 2.5 feet (61 to 76 cm). Too great of a fruit load can cause fruit abortion or distorted fruit.

Yields will vary greatly depending on temperature and plant density. High light levels will support plant densities of 3.3 square feet per plant, with yields as high as 20 pounds (9 kg) per plant under optimum growing conditions. Cucumber yield is highly influenced by light and temperature. Cucumbers can withstand summer temperatures of up to 100 °F (38 °C) and can survive low temperatures if protected from frost. The optimum temperature range is 65 to 90 °F (18 to 32 °C), with higher yields at the warmer end of that range.

Other considerations when choosing a crop

Cost

Labor is the greatest variable cost associated with vegetable production. Regardless of the crop, a good rule of thumb for labor demands associated with greenhouse vegetables is 20 to 25 labor hours for a 30 foot × 96 foot (9 m × 29 m) greenhouse. This labor includes sowing seeds, planting, harvesting, and other activities related to production. It does not include time associated with marketing and delivering the product.

Cash flow is also an important consideration. Leaf crops have a shorter turnover than fruiting crops. It may take 2 months after transplant to harvest the first tomato, but a head of butter head lettuce can be ready for market in 30 days.

Growers must also consider return on investment. The growing systems described cost $2,000 to $10,000.

Marketability

Before considering growing a crop as a commercial enterprise you must decide whether the crop is marketable. Marketability can be influenced by several factors, including demographics. Will people pay a premium price for the product in the targeted area? Is the population in the target market area(s) large enough to handle the output of your facility? It is very difficult to market high-end vegetable products in rural areas. The quantity of the product available and receivable also plays a role in the marketing of a product. Large greenhouse vegetable producers can market to large grocery stores and wholesale distributers. Delivering small quantities to markets far from the farm may not pay for the delivery costs.

If you aspire to sell large quantities to bulk markets, take time to investigate whether they will buy aquaponicly grown produce. Most bulk or wholesale markets such as grocery stores or vegetable brokers are requiring Good Agriculture Practices (GAP) certification and limited liability insurance. GAP certification, new food safety legislation, and insurance availability may limit your ability to sell aquaponic produce to some markets.

Profitability

Because of the expense of aquaponic systems, they must be operated almost year-round at maximum densities to cover the depreciation on the facilities and equipment. A good approach to take when deciding what to grow is the real estate approach. Consider that every square foot of an aquaponic system and greenhouse is going to cost you money. You need to have a crop that will pay the rent. There are only a few vegetable crops that are grown in greenhouses commercially, but there are many other specialty crops that have potential in local niche markets (squash blossoms, edible flowers, baby vegetables, etc.). Commercial growers in any field of agriculture should consider opportunity costs before beginning an enterprise. Opportunity costs are those associated with a choice when a different choice would allow for greater gain. An example of opportunity cost would be if an aquaponic grower chose to grow a low-value crop like corn when a greater return could be achieved with tomatoes or lettuce.

Mixing crops

Mixing crops in a greenhouse can cause problems associated with temperature requirements, pest management, and product quantity. For example, growing both tomatoes and lettuce in the same greenhouse would be difficult because tomatoes require warmer temperatures than lettuce during the winter months. If half of a greenhouse is planted in lettuce and the other half in tomatoes, the entire house must be kept at the optimum night time temperature for the tomatoes. That means far less energy efficiency. If too many different crops are grown in the same greenhouse, the quantity of each may be too small for each crop to support your market. Some crops are also just pest magnets and may not be worth the trouble. For example, strawberries have the potential to be a highly marketable greenhouse crop in the Southeast, but they often have insect and disease problems when grown indoors.

Summary

For the aquaponic grower, the crop(s) and plant system(s) to use should be determined by your goals. A hobbyist's goal might be having fun or overcoming the challenge of growing in an integrated system. However, the commercial grower should be focused on return on investment. Fish systems, plant systems, and facilities for each are expensive. Before making any investment, study growing methods and available markets closely. Remember that the hardest part of specialty crop farming is selling the product, so first, understand your potential markets, then work from there.

Suggested readings

Hochmuth, R.C. 2015. Greenhouse Cucumber Production—Florida Greenhouse Vegetable Production Handbook, Vol 3. University of Florida, Institute of Food and Agriculture Sciences.

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USDA United States Department of Agriculture National Institute of Food and Agriculture

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