Greenhouse Plant Production

Traits of the ***floriculture*** industry, such as consumer demand, marketing channels, crops grown and methods of culture are changing. The seemingly insatiable desire for new varieties, an emerging mass market for floriculture products, new technology and world competition are but a few of the driving forces behind this change.

The floriculture industry is built primarily around bedding plant and flowering plant production, but foliage plant production is also a part of the mix. The widespread use of annuals and herbaceous perennials in municipal and commercial landscape settings is creating new markets. Interior plantscape firms are also doing well in larger cities, where developers desire to use foliage plants for improvement of indoor air quality and creation of pleasant environments in which to work, dine and shop.

Greenhouse Structures

The production of most floriculture crops differs greatly from other horticultural production. Floriculture crops require a greenhouse to maintain precise growing conditions. Greenhouse structures give the grower control of environmental factors within the structure. Temperature, water, humidity, and light to some extent, can all be regulated by growers.

Types of Greenhouses

The efficiency, productivity and cost of a greenhouse structure are greatly influenced by its design and by the type of materials used for construction. Since there are many designs to select from, it is important to become familiar with the advantages and disadvantages of each (Figure 12-3).

Detached (freestanding) greenhouses stand independently of one another. The most common type of detached greenhouse for commercial production is the Quonset (arched bay). These houses are constructed from arched rafters and usually have solid end walls for additional support. Quonset greenhouses are suitable for the production of most crops, but the growing area is somewhat restricted near the side walls. This reduces efficiency as well as productivity. Freestanding greenhouses offer the advantages of low overall initial investment and flexibility of operation. However, they are generally more expensive to construct and are more expensive to heat and cool than larger houses on a square foot basis.

Figure 12-3. Examples of a freestanding gabled greenhouse and gutter connected curved arch (quonset) greenhouses.

Ridge and furrow (gutter connected) greenhouses are connected at the eave by a common gutter. Generally, lack of an internal wall below the gutter allows for increased efficiency. Ridge and furrow greenhouses may be gabled or curved arch. Gabled houses are usually suitable for heavy coverings, such as glass, while curved arch houses are covered with lighter materials (polyethylene or polycarbonates). Several connected ridge and furrow greenhouses are often referred to as a range. On an area basis, greenhouse ranges require a lower initial cost than do smaller standalone houses. Greenhouse ranges are also easier to heat and cool than smaller houses because they have proportionally less wall space exposed to the outside environment.

Greenhouse Framework

Aluminum, steel and wood are among the most popular materials for greenhouse frame construction. Of these three, aluminum frames are the longest lasting. Aluminum is corrosion resistant, lightweight, and can be prefabricated into various shapes and thicknesses to form structural components. These components can be permanently glazed (covered with translucent material) and have low maintenance requirements. Aluminum frames have a high initial cost and require the services of experienced personnel during construction.

Galvanized steel frames offer high strength and a long life at less expense than aluminum frames, although maintenance costs of steel frames may be higher. The high strength of steel makes it possible to use smaller structural elements, minimizing shading caused by the frame.

Wood frames have a low initial cost, but high maintenance costs. Wood is less commonly used because it deteriorates quickly in the moist environment of a greenhouse; it is also flammable. If wood is used, it should be pressure treated with preservatives to resist decay. Water-based preservatives such as chromated copper arsenate (CCA) or ammonium copper arsenate (ACA) are the best preservatives to use in greenhouses. Creosote and pentachlorophenol (PCP) give off fumes toxic to plants and should not be used. Painting wooden frames white will also improve lighting conditions within the greenhouse.

Service Buildings

While crop production occurs in the greenhouse, many other tasks are performed in a service building called a ***headhouse***. A headhouse (Figure 12-4) is usually attached to the greenhouse and serves as a storage area for growing media, containers, labels, and other such materials. Potting and packaging of plants usually takes place in the headhouse.

Greenhouses should also include an ***airlock entrance*** design. This entrance porch or vestibule has two airtight doors that reduce the amount of air infiltration and heat loss when the exterior door is opened. It prevents direct ingress of wind, insects, soil, and spores into the greenhouse. Such an entrance has the additional advantage of making doors easier to open and close when the fans are running. The double entrance also prevents short circuit air flow patterns (interruption of horizontal movement through the greenhouse) when ventilation fans are in operation.

Figure 12-4. A headhouse service and storage building connected to a greenhouse range.

Comparison of Glazing Materials

Glazing Material	***Advantages***	***Disadvantages***	***Light Transmission***	***Lifespan (years)***
Polyethylene (poly) film	► Inexpensive ► Easy to install	► Not very durable ► Humidity levels can become quite high	85% – 90% (one layer) 70% – 75% (two layers)	1 – 3 yrs
Fiberglass	► Fairly inexpensive ► Lightweight ► Extremely durable ► Fairly high light transmittance	► Degrades in UV light ► Light transmission diminishes with time	85% - 90%	5 - 10 years
Polycarbonate structured sheets	► Good light transmission ► Good insulation ► Resists hail damage ► Easy to work with ► Fire resistant	► Expensive	80 – 90%	10 yrs
Acrylic structured sheets	► Good insulation ► High light transmission	► Less flexible than polycarbonates ► Expensive ► Prone to hail damage	86% - 91%	10 – 20 yrs
Glass	► High light transmission ► Glass overlap allows air exchange	► Breakable ► Initially expensive ► Heavy ► Very poor insulation properties	Up to 92%	25 + yrs

Source: Adapted from Greenhouse Production by Ronald J. Biondo

Figure 12-5. Comparison of the advantages and disadvantages of commonly used greenhouse glazing (covering) materials.

Glazing Materials

The covering of a greenhouse is often referred to as ***glazing***. Glazing materials must transmit the maximum amount of sunlight to the crop while also holding heat gain or loss to a minimum. There are several considerations in choosing a glazing material. ***Durability*** or the life of the material before it needs to be replaced is an important factor. ***Light transmission*** is another. Certainly, the ***cost*** of material needs to be evaluated. Metals are good conductors of heat and the heat loss or gain through an aluminum or steel frame can be significant. Therefore, a fourth consideration is that of ***heat loss***, which affects heating bills (Figure 12-5).

Glass has a high initial cost, a lifetime of 25 years or longer, low maintenance requirements, and transmits light very well. However, it requires skilled labor for construction and is subject to breakage. Glass is heavy and requires the use of strong framing with large structural elements that can block light. Overall, glass has poor insulation properties. As a result, synthetic sheets and films have replaced glass as the glazing material used in most greenhouses.

Polycarbonate structured sheets are the most widely used structured sheet glazing. They are commonly manufactured with a "twin wall" held together by ribs. The resulting appearance is hollow tubes, side by side, running the length of the sheet (Figure 12-6). The tubing effect provides insulation and cuts heating costs. Polycarbonates have a good light transmission rating, typically achieving 80% to 90%. They resist hail damage, are easy to work with and flexible, and are also fire resistant. Polycarbonate sheets are treated with ultraviolet (UV) light inhibitors and are typically guaranteed for 10 years against yellowing and loss of light transmission. A drawback is that polycarbonate sheets are expensive.

Acrylic structured sheets are manufactured with twin walls in the same fashion as polycarbonate sheets and provide good insulation. The high light transmission, 86% to 91% of the photosynthetic range, is second only to glass. Acrylics last at least 10 years. The material will not yellow over time, will keep its rigidity and strength and will not become brittle. Acrylics cost a bit more than polycarbonates; they are also less flexible than polycarbonates, and are more prone to hail damage.

Fiberglass reinforced plastic (FRP) sheets are not as widely used since the introduction of polycarbonates and acrylics. Fiberglass sheets are less expensive than glass but more expensive than polyethylene. They are lightweight, extremely durable, do not require the extensive structural components of a glass house, and have a fairly high light transmittance. Unfortunately, fiberglass degrades when exposed to ultraviolet light, which causes the fibers to swell, resulting in a significant decrease in light transmission. The life span of fiberglass can be as short as five years under certain conditions.

Polyethylene film is the most widely used glazing material (Figure 12-7). This material is low in cost, light weight, available in easy-to-apply wide sections, and has a high light transmittance. Unfortunately, it also has a very short life. Regular grades have a lifetime of only nine months in Florida. Ultraviolet stabilized grades, which last from eighteen months to four years, still require more frequent replacement than most other glazing materials. Common grades of polyethylene are transparent to infrared radiation. Newer grades block harmful UV rays that can damage plastic, plus delay the exit of infrared radiation, thereby maintaining a warmer environment and saving energy. Some poly films contain additives that help reduce condensation from dripping.

The use of double layers of polyethylene film can add insulating value to the glazing system with only a small reduction in light transmittance. ***Double poly construction*** utilizes a small fan to inflate the area between the two layers. This dead air space greatly improves the insulating properties of the greenhouse. When compared to a single layer of polyethylene film, the double poly system reduces heat loss or gain by 35% to 40% with only a 10% reduction in light transmission.

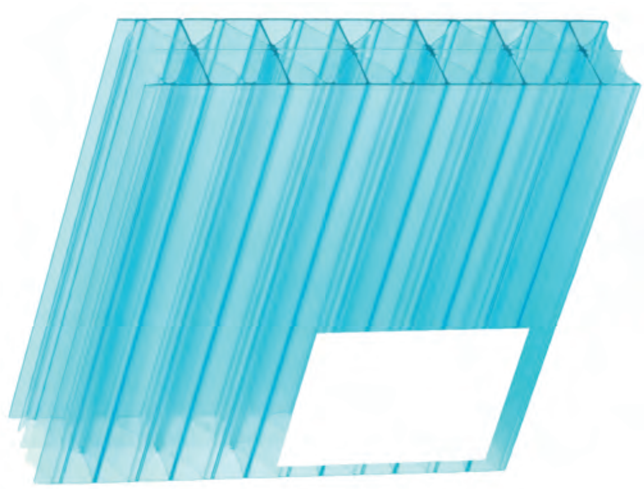

Figure 12-6. Example of polycarbonate twin wall characteristics.

Figure 12-7. Polyethylene film covering greenhouse.

Benches and Walkways

Benches are made from materials that can withstand the wet conditions in a greenhouse. Since they must be strong enough to carry a lot of weight, they are usually constructed from heavy gauge expanded galvanized steel, aluminum and plastic. An alternative material for benches is rot-resistant wood, such as redwood or cedar. Regardless of the material, benches must allow water to drain from containers and for proper air circulation. Benches used for ebb-and-flow culture (subirrigation) are watertight to accommodate periodic flooding with dilute fertilizer solutions.

The recommended width of benches is three feet when working from one side and six feet when working from both sides. Benches should be 32 to 36 inches high for convenience of working. A three to four foot wide aisle should be provided along the length of smaller greenhouses to permit transport of plants and materials. In larger greenhouse ranges, an eight-foot center drive should be provided for larger transport equipment. Since the goal is to use as much space as possible for the growth of crops, side aisles should be kept narrow, often a minimum of 18 inches wide.

Movable bench systems (Figure 12-8) can increase production space up to about 90% of the floor space. Rolling benches rest on pipes. This allows each bench to be rolled from side to side. With this system, adequate space needs to be kept for only one aisle, which can be shifted to any position. One person can easily roll a large bench to create the aisle space.

Some greenhouse ranges grow potted plants directly on the floor. In this case, the floor must be paved for sanitation and weed control. A disadvantage of growing on the greenhouse floor occurs with crops that require extensive hand labor operations. Working at ground level is fatiguing and takes its toll on labor efficiency.

Concrete walkways between rows in the greenhouse and between buildings facilitate moving materials and can improve sanitation. Walkways control the movement of traffic into and around the production area and can minimize tracking contaminated soil or plant material into the greenhouse.

photo by delta t solutions, www.deltatsolutions.com

Figure 12-8. Galvinized metal, movable greenhouse bench system with underbench heating arranged longitudinally.

Greenhouse Heating

Forced air heating systems are most commonly used in new greenhouses. They are relatively inexpensive and have low maintenance requirements. Heated air is supplied by unit heaters or furnaces. Unit space heaters, either floor mounted or supported on overhead framework, are normally fueled with either natural or LP (bottled) gas or fuel oil; fans are used for heat distribution. This system requires a relatively moderate capital investment, is simple to install and provides for easy expansion of facilities. If unit air heaters are used, they should be spaced and directed to blanket the entire area with heated air.

Gas burns efficiently, but all forms must be vented to avoid toxic fumes. Gas or oil fired units produce carbon dioxide gas, which is necessary for improved plant growth. However, other gases, harmful to humans (carbon monoxide) and many plants (ethylene, sulfur dioxide and unburned hydrocarbons), are also byproducts of combustion. These can cause serious problems if the exhaust gases from unit heaters are not properly vented to the outside and if adequate intake air is not available for combustion.

Traditional ***hot water/steam heating systems*** with boilers are not widely used in Florida, but there is a variation of these systems used to provide bottom heat that has proven to be very effective and efficient. In these systems, water is heated in a modified hot water heater and pumped through an extensive tubing system mounted to the bench. Heat is radiated from the tubes and absorbed by pots on the bench. The medium in the pots is maintained at a constant temperature; this allows air temperatures to be held at a much lower point than with traditional systems. The overall effect is improved plant growth and reduced energy costs.

Solar heating is often pondered as a partial or total alternative to fossil fuel heating systems. A greenhouse itself is a solar collector. Some of its collected heat is stored in the soil, plants, greenhouse frame, walks, and so on. The remaining heat can be excessive for plant growth and is therefore vented to the outside. This excess vented heat must be directed to storage for subsequent use during a period of heating. Heat derived in this manner could provide up to half of the total heat requirements for greenhouses in the southern United States. Factors that could make the use of solar heating in greenhouses a more imminent possibility include the increasing efficiency of collectors and/or an inexpensive, high capacity heat storage medium, continued escalation of fuel prices, and concerns about sustainability.

Heat Distribution

Uniform heat distribution, air movement and ventilation in greenhouses is most frequently accomplished with ***polyethylene convection tubes*** (poly tubes) or fanjet systems commonly installed in conjunction with unit heaters (Figure 12-9). Poly tubes are generally attached near the heater and are inflated when the blower fan is turned on. The heat is forced through the tube and distributed into the house from holes perforated in the poly tube. These systems may also be used in combination with ventilation and circulation equipment.

photo by springtime greenhouses

Figure 12-9. Gas-fired unit heaters with a fan jet and poly tube distribution system.

Heating System Maintenance

An important step in the proper maintenance of a greenhouse heating system is to establish an orderly plan for inspection of the system's components. These components include the heaters and all other elements of the structure that affect the efficient operation of the heating system. Each heating system component should be inspected annually before the heating season. Only people thoroughly familiar with greenhouse heating systems and their application to specific plant growth requirements should be allowed to design and supervise the installation and maintenance of the heating system.

Cooling Systems

Greenhouses operating under summer conditions require cooling systems for optimum plant growth and worker efficiency. Temperatures can easily exceed 100^{0}F in Florida greenhouses during the summer if they are not equipped with cooling systems. Such high temperatures reduce crop quality as well as worker safety and productivity.

Natural ventilation can reduce the inside temperature to close to that of the outside air. This air exchange is accomplished using ridge and side vents and is satisfactory for many operations (Figure 12-10). Cooler outside air enters through side vents and is distributed throughout the structure. As the air warms, it rises and exits through the ridge vent. A total vent area equivalent to 15% to 30% of the floor area is recommended for effective cooling.

photo by gale albritton

Figure 12-10. Cooling of a sawtooth style greenhouse range using natural ventilation.

Forced convection using fans can lower air temperatures 5^0 to 10^{0}F below those found in greenhouses cooled by natural convection only. The opening through which the air enters the greenhouse must be relatively large and extend across the entire wall on which it is located, or uneven airflow patterns and temperature distributions will result.

Evaporative cooling is the most common method for reducing the temperature inside a greenhouse. The basis of any evaporative cooling system is the evaporation of water into an airstream. As water evaporates, energy is lost from the air, causing its temperature to drop.

The most commonly used method of evaporative cooling is the fan and pad system (Figure 12-11). Fan and pad systems consist of exhaust fans at one end of the greenhouse and a pump circulating water through and over a porous pad installed at the opposite end of the greenhouse. Water drawn through the pads cools the air and increases humidity. The air will be at its lowest temperature immediately after passing through the pads. As the air moves across the house to the fans, the air picks up heat from solar radiation, plants, and soil, and the temperature of the air gradually increases so that the exhausted air will likely be 7^0 to 8^{0}F higher than the entering air.

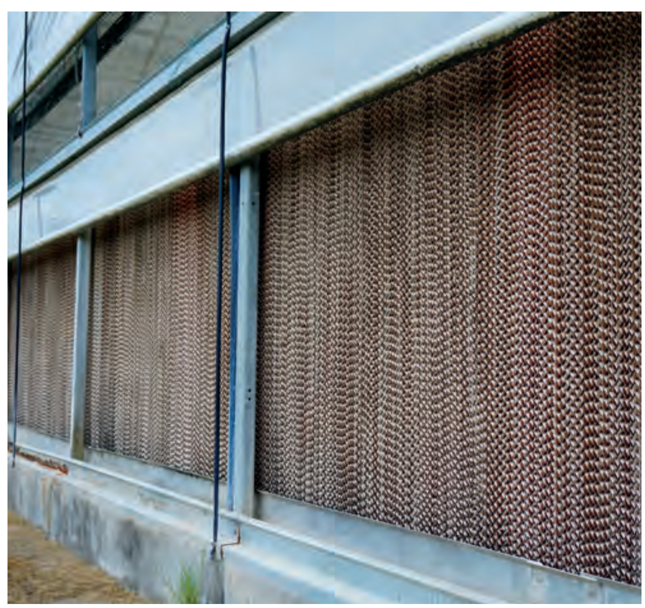

Figure 12-11. Evaporative fan and pad cooling system.

Evaporative cooling pads do have problems. They lose efficiency due to clogging from impurities in the water, algae growth and decay over time, thus decreasing the ability to function as designed. If a pad area is totally or partially clogged, very little, if any, air will pass through that portion of the pad. If the pad has holes, the air will move directly through them. This means less contact between air and water, and much less cooling. When a pad has decayed, the only alternative is to install a new one.

High pressure mist or fog cooling is another method of greenhouse cooling. Water is sprayed into the air above the plants at a high pressure, causing a fine mist or fog to fill the structure; as the droplets evaporate and fall, they cool the air. The cooling achieved from high pressure fog or mist is comparable to that obtained from a fan and pad system, but some problems have been experienced with clogging nozzles. Mist or fog systems are more expensive than fan and pad systems, but they can provide more uniform temperature distributions and evenly high humidity levels than fan and pad systems.

Cooling System Maintenance

The efficiency of greenhouse evaporative cooling systems can be greatly reduced by compacted cooling pads, improper operation of fans, greenhouse doors remaining open and insufficient water supply to cooling pads. The air temperature inside the greenhouse increases whenever the efficiency of evaporative cooling is reduced. It is very important to keep the building as tight as possible so the entering air will be forced through the pads. Make sure that all doors and other openings are kept closed except when in use and that any gaps in greenhouse coverings are sealed. If not, air will be pulled through these openings rather than through the cooling pad and reduce system efficiency.

Temperature and Light

Shading is used to control light and lower interior temperatures. ***Liquid shading*** provides a coating that blocks the sun's rays. The main problems with liquid shading compounds are that once applied, shading density is not easily changed, and the material must often be

Figure 12-12. Motorized energy curtains used for shading during the day and heat retention at night.

removed in the fall. A liquid shading compound must be designed to diffuse light rays and reflect heat. It must also be formulated in a way it will not have harmful effects on the glazing material. Factors to consider when choosing a liquid shading compound include ease of application and removal, effects on the crop, and cost of the material.

Fabric shadecloth materials can be used to screen out varying amounts of unwanted radiation in a greenhouse. Most shadecloth is black because that color naturally resists the sun's harmful UV radiation. However, black shadecloth absorbs heat and can transfer and hold some of this heat. As a result, the shadecloth should be mounted on the exterior side of the glazing for the greatest reduction in heat load. Shadecloth is available in other colors, such as white, and is also aluminized to reflect heat. These materials are usually more costly than black shadecloth. Most shadecloth fabric has a life expectancy of approximately 10 years.

Interior energy curtains (Figure 12-12 on the previous page) are automated systems utilizing fabrics that insulate the greenhouse at night and shade crops during the day. They lower energy losses by adding two or more stagnant air layers between the interior of the greenhouse and the glazing. They also reduce cold air infiltration and radiant heat loss. Computerized environmental management systems open and close the curtains based on preset light levels or temperatures. The shade produced by curtains results in temperatures up to 10^0F cooler than in full sun. The curtains have an opposite effect when closed at night by containing heat energy within the greenhouse. The energy savings in terms of fuel costs range between 25% and 35%. The greatest disadvantages of curtains have been poor mechanical reliability, incomplete sealing after closure, and possible damage to curtains and plants from condensation.

Climate Controllers

There are several types of thermostats and environmental controllers that regulate temperature. Regardless of how sophisticated this equipment is, there are some very basic factors that must be considered if the system is to operate properly.

Temperature sensors should be placed at plant level in the greenhouse. Sensing devices hung at eye level are easy to read, but do not provide the necessary input for optimum environmental control. Since environmental conditions can vary significantly within a small distance, it is also important to have an appropriate number of sensors throughout the production area.

Poor temperature readings will similarly result if ***thermostats*** are mounted in the direct rays of sunlight. Consequently, a north facing position or placement in a protected location is desired. ***Aspirated thermostats*** use small fans to draw air through protective modules that shield temperature and humidity sensors from direct sunlight exposure. The aspirated unit provides an actual ambient temperature reading, rather than radiant temperature.

photo by wadsworth control systems

Figure 12-13. A computerized environmental monitor and control system with an aspirated thermostat integrates the control of greenhouse cooling, heating, hortizontal air flow fans, shutters, and pad pump in single or multiple zones.

Computer monitoring and control systems (Figure 12-13) can be used to provide constant regulation and close control of the greenhouse environment. These systems are expensive, but they are accurate and offer the greatest range of use. All pieces of automated equipment can be controlled together in a synchronized fashion. This precise control results in lower energy costs and greater productivity of plant materials.

Production Considerations

The design of growing areas is strongly influenced by factors such as irrigation and drainage, materials handling, cultural and maintenance requirements of the plants, size of the containers, and costs involved. Layout of the site must be efficient if the nursery is to be productive as well as competitive.

The most desirable location for greenhouse placement is influenced by land characteristics (elevation, topography, and drainage). Climatic factors such as temperature and wind influence crop planning and production schedules. To enhance crop performance, greenhouses are generally oriented north-south for maximum light interception inside the greenhouse and minimum shading effects of structural components within the roof.

In addition, accessibility to needed commercial services should be considered along with the availability of shipping facilities and proximity to main roads. The supply of utilities (electricity, water and fuel) must be considered, and communications between buildings or growing areas must be planned to achieve optimal business operations.

Planning and Crop Selection

Planning a schedule of operations from plant selection to harvest is essential to business success. The process begins with a strategic plan that identifies market potential and client needs (Figure 12-14).

Nursery and greenhouse managers should consider growing plants for which there is an expanding market, that are well suited to the

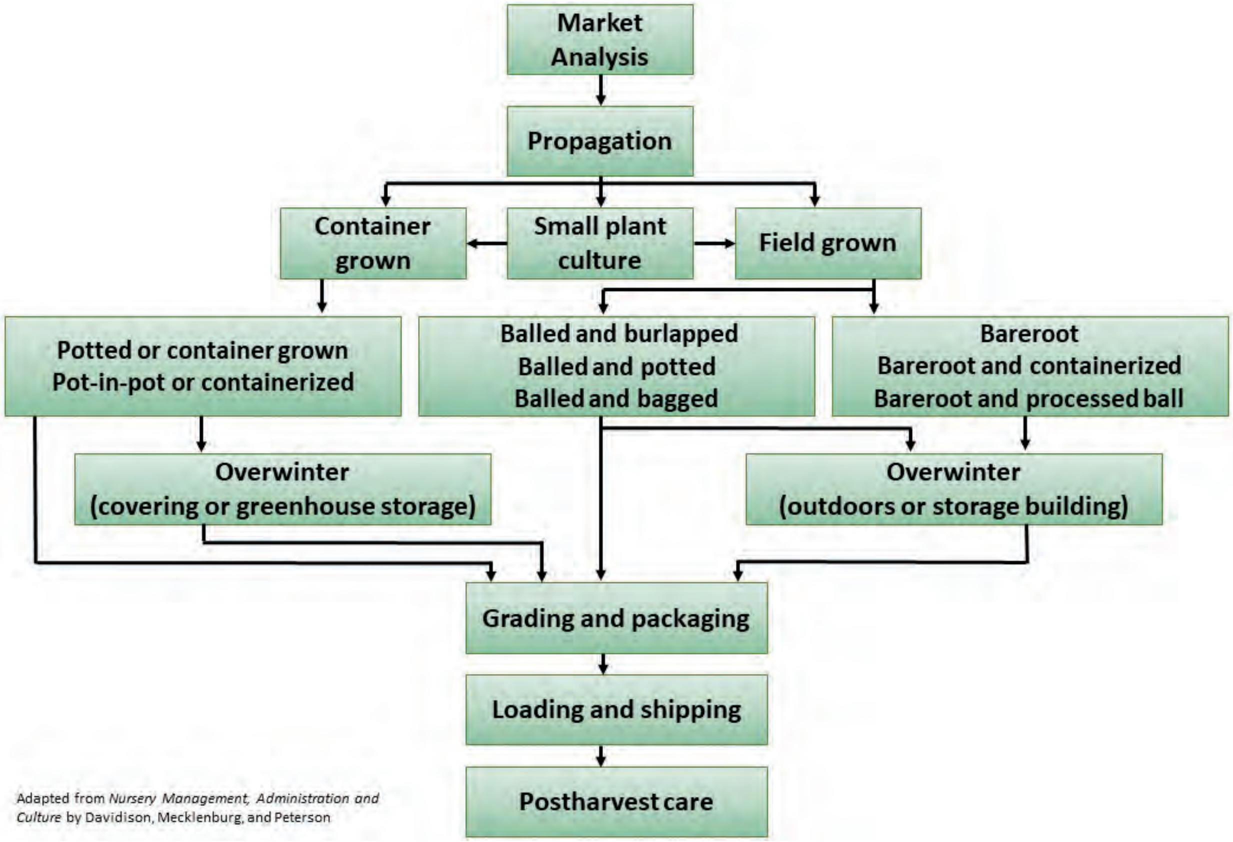

Figure 12-14. Diagram of nursery production processes for container and field grown culture.

Except for production of greenhouse specialty crops (Figure 12-21), microirrigation has been labor and cost prohibitive for production in smaller (1-gallon or less) containers because of the higher cost of installation and maintenance when compared to overhead irrigation. Consequently, it has been mainly used in the nursery to produce larger plants (5-gallon or greater). A well-designed and managed microirrigation system can have an efficiency of 90% to 95%, meaning that less than 10% of applied water is wasted.

Water may also be applied to greenhouse crops using ***subirrigation*** or capillary mats on specialized benches. However, in areas where soluble salts are a problem, mats do not provide for leaching, thereby increasing the risk of salt injury.

photo by gale allbritton

Figure 12-21. Drip irrigation system in greenhouse foliage crops.

Irrigation Frequency and Amount

Frequency of irrigation is largely determined by existing environmental conditions. During active growing periods, growers must irrigate container plants at least once a day and often two to three times. This frequency of irrigation means that growers must consider the physical characteristics of growing media (for example, water holding capacity and drainage) very carefully, particularly where soluble salts are a problem. Often, nutritional problems, such as magnesium and micronutrient deficiencies, arise as the result of excess leaching. In these cases, special attention must be given to media amendments and nutritional regimes to provide for optimum plant growth.

The amount of irrigation water to apply in container production is perhaps more important than how and when to irrigate. A general rule of thumb is to apply 10% to 15% more water than the container will hold. This facilitates leaching at each irrigation interval and reduces the potential for accumulation of soluble salts. Of course, the rate of irrigation must be low enough to allow the water to percolate through the growing media as opposed to overflowing the top of the container, a particular caution if hand watering. This is especially important when using soluble fertilizers in irrigation water to liquid feed plants.

Water Quality

Water quality can have a huge impact on plant growth, especially in soilless plant production systems where intensive management of water and nutrients is required. Irrigation water quality impacts nutrient levels and availability as well as other chemical characteristics of the soilless media substrate. Poor quality water applied with overhead irrigation can damage foliage, change media pH, or result in unsightly foliar residues or stains. Use of poor quality water in irrigation systems can clog mist nozzles and microirrigation emitters. Irrigation,

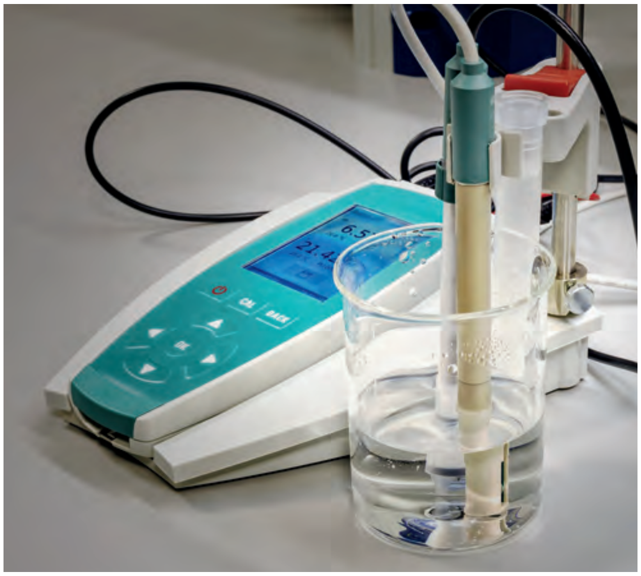

Figure 12-22. Water quality testing equipment.

Water Quality Standards for the Production of Greenhouse and Nursery Crops

Quality	Electrical conductivity EC X 10^{-3} (millimhos)	Total soluble salts (ppm)	Sodium content (% Salts as Na)	SAR	pH
Excellent	0.25	175	20	3	6.5
Good	0.25 - 0.75	175 - 525	20 - 40	3 - 5	6.5 - 6.8
Permissible	0.75 - 2.0	525 - 1400	40 - 60	5 - 10	6.8 - 7.0
Doubtful	2.0 - 3.0	1400 - 2100	60 - 80	10 - 15	7.0 - 8.0
Unsuitable	>3.0	>2100	>80	>15	>8.0

Source: Information obtained from Greenhouse Management Handbook by Texas A&M AgriLife Extension Service

Figure 12-23. Guidelines for interpretation of irrigation water quality in greenhouse and nursery crop production.

fertilization, pesticide efficacy, and efficiency of production are more easily managed when using good quality water. Therefore, water testing before and during production cycles is recommended (Figure 12-22).

A standard test that measures the majority of critical water quality factors is acceptable for most plants, including bedding plants, potted flowering crops, trees and shrubs. Water testing should be regularly repeated since the quality of water from the same source will vary over time. For example, drought can reduce the volume of stored water, which may result in an increased concentration of minerals.

Factors that influence water quality are electrical conductivity, alkalinity, calcium and magnesium, sodium, chloride and pH. Substances present in irrigation water can also impact irrigation equipment by causing corrosion of parts or clogging of emitters.

Remember, a water quality test can help identify and diagnose problems. Understanding how the information conveyed in a water quality report affects plant production decisions is a first step in the proper management of irrigation practices and in making any required maintenance adjustments. The table in Figure 12-23 presents guidelines on the interpretation of selected irrigation water quality standards. The *Plant, Soil and Water Relationships* chapter provides more detailed information about the chemical properties of container media as influenced by water and fertilizer.

Water Treatment

Although cultural management techniques may be used to deal with some water quality problems, certain situations require more drastic action. Growers in coastal regions, on islands, or in areas where saltwater intrusion has occurred may use water treated through a process known as ***reverse osmosis*** (RO) to remove potentially harmful salts (Figure 12-24). RO water is cheaper than distilled or deionized water and the overall quality is the same.

Unfortunately, the use of RO water does not solve all the problems associated with soluble salts. In fact, it can create some very unique situations that are, in many respects, more difficult to correct. For example, growers generally take for granted the micronutrients present in irrigation water. When certain

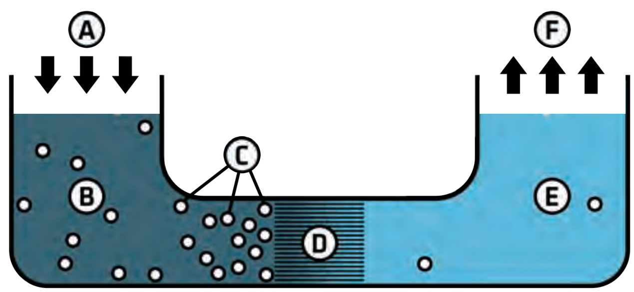

photo by colby fisher, wikimedia

Figure 12-24. Reverse osmosis (RO) is a water purification technology that uses a semipermeable membrane to remove ions, molecules and larger particles from drinking water. Water desalination is accomplished using reverse osmosis. The system applies pressure (A) to saltwater (B). Salts (C) cannot pass through the semipermeable membrane (D) and are filtered out of the solution. This results in potable water (E) that is moved into the distribution system (F).

Liquid Feeding

Liquid fertilization (***fertigation***) programs are not the most efficient delivery system, especially when overhead irrigation is used. The soluble nature of liquid fertilizer results in leaching or runoff of a great deal of the nutrients before uptake by the roots. To compensate, growers often increase either the rate or frequency of application, resulting in waste and the potential for ground or surface water contamination. Consequently, many nurseries using overhead irrigation have abandoned this form of nutrient delivery in favor of controlled-release fertilizers. Injection of liquid fertilizer through microirrigation systems may be more cost effective, and the problems inherent in overhead delivery may be minimized.

Greenhouse plants are often provided with ***constant liquid feeding*** using fertilizer injectors (or proportioners) in combination with microirrigation systems (Figure 12-29). These devices mix precise volumes of concentrated fertilizer solution and water together, which is then applied to plants in exact proportions during irrigation. With fertilizer injectors, growers can easily modify rates and provide exact levels of nutrients. This is especially important with soilless media that have a low cation exchange capacity. Constant liquid feed (CLF) programs also reduce labor, because plants are fertilized when they are watered. Additionally, all plants of a particular crop receive the same levels of nutrients, aiding in the production of a uniform crop.

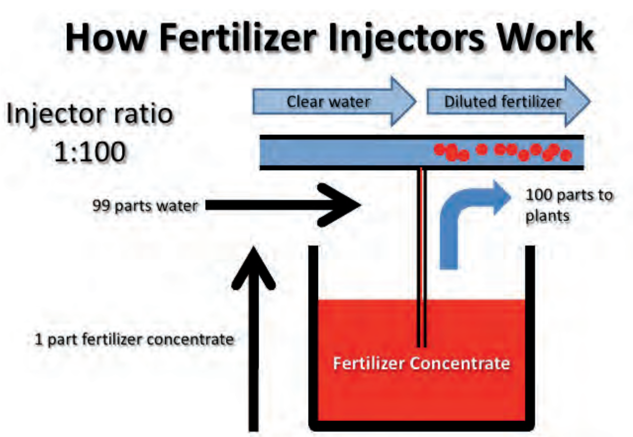

photo by colorado state university extension

Figure 12-29. Injectors take small amounts of concentrated chemicals from a stock tank and introduce it to a water line for delivery. One part of stock solution is mixed with "x" parts of water, where "x" is determined by the injector ratio.

The most important factor in this fertilization program is to apply enough water at each irrigation to leach pots thoroughly. This prevents the accumulation of soluble salts from previous irrigations. Growers using fertigation methods are also required to install a ***backflow preventer*** in the water lines through which fertilizers or pesticides are injected. Backflow preventers stop back siphonage of contaminated water into the clean water system in the event that negative pressure (suction) develops.

Foliar Feeding

Foliar feeding can supplement soil and liquid fertilization, especially where certain nutrients are deficient and need to be incorporated into the plant quickly when pH is negatively impacting nutrient solubility. This is because the nutrient is in a water solution and the moisture is absorbed straight into the leaf. Feeding through the leaves works more quickly than adding fertilizer to soil where it must be taken up through the root system. However, foliar feeding is not a substitute for root feeding. Research does suggest that foliar feeding programs enhance resistance to pest and disease attack, perhaps because minor nutrient deficiencies can be quickly corrected using this technique.

Application Rates

Slow-release fertilizer rates for potting media incorporation are calculated based on soil volume and are measured in ounces per cubic foot (oz/ft^3) or pounds per cubic yard (lbs/yd^3). Nutrients in solution for liquid feeding are measured in ***parts per million*** or ***ppm***. Growers can refer to tables in reference books or to injector system instructions to determine the amount of fertilizer needed to reach a desired ppm. If no chart is available, a correct calculation of the amount of chemicals injected per gallon of water can be determined using the formula found in Figure 12-30.

Calculating ppm

Formula
desired concentration in ppm ÷ % of element in fertilizer × 75

Figure 12-30. Formula for calculating liquid fertilizer rates in ppm.

Monitoring Nutrients

A large percentage of nutritional problems can be identified with pH and soluble salt (EC) measurements. Some of the most common causes and symptoms result when these measurements fall outside the desired range.

Remember, nutrient availability is largely determined by the pH of a growing medium. While some nutrients (such as iron) have been found to be more soluble at low pH values, many other essential elements are rendered insoluble at a pH below 4.5.

Adequate fertility is important to maintain optimum plant growth. However, fertilizers are forms of salts and therefore contribute to the total soluble salt content of the growing medium. If fertility levels are too high, injury from soluble salts may occur. Thus, the application rate of nutrients must be based on the quality of irrigation water as well as the fertilizer's ***salt index*** (Figure 12-31). The lower the index value, the smaller the contribution a fertilizer makes to the level of soluble salts.

When media tests indicate soluble salts in the media are too low, either the frequency of fertilizer application and/or the concentration of fertilizer can be increased. When soluble salt readings are too high, salts can be leached from the media by applying clear water to saturate the media, then reapplying clear water to flush salts from the media.

If pH and EC are both in the good range and yet the plants still look poor, a deficiency or toxicity of a single nutrient may be the issue. Consequently, a media sample (and sometimes a foliar tissue sample) will need to be sent to a media testing laboratory to determine the specific nutrient that is creating a problem.

Nursery and greenhouse managers should establish a working relationship with a reliable

Practice Calculating Parts Per Million

Step 1:

A rule of thumb in calculating ppm is that one ounce (oz.) of anything in 100 gallons of water equals 75 ppm; therefore, 75 is considered a conversion constant.

To calculate the ppm contained in one ounce of fertilizer, first solve for B

A x 75 = B

A = the % active ingredient (AI) in the fertilizer
B = ppm contained in one ounce of fertilizer in 100 gallons of water

Example: The fertilizer used to supply nitrogen is calcium nitrate with an analysis of 15-0-0. Calcium nitrate contains 15% N; therefore, 0.15 x 75 = 11.25. This means if one ounce of calcium nitrate is dissolved in 100 gallons of water, the solution will contain approximately 11.25 ppm N.

Step 2:

To calculate the number of ounces of material required to make up a desired ppm concentration, solve for C:

C = desired ppm concentration / B

B = ppm contained in one ounce of the material in 100 gallons of water (from above)
C = ounces of fertilizer to add to 100 gallons of water to achieve the desired concentration

Example: To make a 250 ppm solution of calcium nitrate, first multiply the active ingredient percentage (AI) x 75 (.15 x 75 = 11.25). Next, divide the desired concentration by 11.25 (250 / 11.25 = 22). Therefore, to make a 250 ppm solution of calcium nitrate, add 22 ounces to 100 gallons of water.

If the injector system delivers 1:100 (one gallon of concentrate mixed with 99 gallons of water for a total of 100 gallons), 22 ounces of fertilizer is needed for each gallon of concentrate. If the tank holds 5 gallons of concentrate, then 110 ounces (22 x 5 = 110 oz) of fertilizer are needed to deliver 250 ppm.

independent soil testing laboratory that can perform an array of tests to document a variety of soil characteristics. It is the responsibility of the grower to understand the information these tests can and cannot provide and to be specific about the data required to make good growing decisions.

Chemical Growth Regulation

Naturally occurring or synthetic chemicals, known as plant growth regulators (PGRs), regulate all growth and development of plants. PGRs may promote, inhibit, or modify plant growth and development.

Natural chemicals produced by plants to regulate growth are called ***hormones***. The five different hormones produced in plants are auxins, gibberellins, cytokinins, ethylene, and abscisic acid (Figure 12-32). Each hormone promotes several different plant responses, and each is effective at very low concentrations. The different categories of plant hormones trigger varied plant responses. Each interacts with other hormones in complex ways to produce plant responses.

Chemical compounds that regulate growth, but are not produced by plants, are called ***synthetic growth regulators***. A number of synthetic compounds are utilized in the nursery and greenhouse industry. With the use of growth regulators, the final plant height can be made shorter than the natural height, terminal buds can be pinched (destroyed), cold requirements can be chemically substituted, and rooting can be promoted. Some synthetic growth regulators are more effective than others on specific crops.

Synthetic auxins are used in the horticulture industry to promote rooting of cuttings and are called ***rooting hormones***. Cuttings are treated with these synthetic growth regulators to increase the number of cuttings that form roots, to speed rooting, to increase the number and quality of roots, and to increase the uniformity of roots.

Relative Salt Index for Several Fertilizers

Fertilizer	***Supplied Element***	***Salt index***
Potassium chloride	K	116
Ammonium nitrate	N	105
Sodium nitrate	N	100
Urea	N	75
Potassium nitrate	N and K	74
Ammonium sulfate	N and S	69
Calcium nitrate	N and Ca	53
Magnesium sulfate	Mg and S	44
Diammonium phosphate	P	34
Concentrated superphosphate	P	10
Gypsum	Ca and S	5

Adapted from the Greenhouse Management Handbook by Texas A&M AgriLife Extension Service

Figure 12-31. Salt content of common fertilizer components.

Growth retardants are another synthetic growth regulator widely used in the greenhouse industry. These chemicals inhibit the action of gibberellins on stem elongation. As a result, plants are more compact, more attractive, often greener, and easier to transport. Although growth is slowed, flowers tend not to be affected.

The concentration of a growth regulator varies according to the crop, its stage of growth, and the weather conditions. However, the use of PGRs is an inexpensive alternative to manual pinching, disbudding and other production tasks; they also improve crop quality.

As with any chemical, certain precautions need to be followed when working with growth regulators. It is important to read the label and follow all safety precautions when mixing and during application. Be aware that the right growth regulator has to be applied to the proper plant at the proper time and rate in order to achieve desired results.

The Effects of Plant Hormones on Growth and Development

Physiological Activity	*Auxin*	*Gibberellin*	*Cytokinin*	*Ethylene*	*Abscisic Acid*
Seed germination			Promotes		Inhibits
Growth of seedling into mature plant	Cell elongation	Cell elongation and division	Cell division & differentiation		
Apical dominance	Inhibits lateral bud development		Promotes lateral bud development		
Flower initiation			Stimulates flowering in some plants		
Flower development and ripening	Development	Development		Promotes ripening	
Leaf abscission	Inhibits		Inhibits	Promotes	
Winter dormancy		Breaks dormancy			Produces dormancy
Seed dormancy		Breaks dormancy			Promotes dormancy

Source: Greenhouse Production by Ronald J. Biondo

Figure 12-32. Comparison of plant growth regulator effects on growth and development.

Maintenance Considerations

A well-maintained nursery or greenhouse operation requires attention to the details of irrigation, fertilization, staking and pruning, monitoring and responding to pest problems, and scheduling many other routine activities to guard against varying problems that may occur. Cleanliness is advised for sanitation and prevention, but it is also good business management. It is much easier to sell plants to potential buyers if the nursery is clean, orderly, and well kept. Visitors and employees usually equate a clean, neat nursery with efficiency and good management.

Pruning Nursery Plants

There are several objectives to consider when pruning container grown nursery stock. The first is to get as large a plant as possible, as quickly as possible, while at the same time obtaining a healthy plant with a form or shape that will be marketable. Usually, this means a plant that is dense, compact, symmetrical, healthy, and vigorous, and that can be sold at a profit. Another important objective of pruning is to produce a plant that transplants successfully. Consequently, a good balance between root and shoot growth in container culture is vital to the successful establishment of a plant when it is installed in the landscape.

Growers should use a combination of pruning methods to produce compact growth in the natural shape of the plant. This includes ***heading back*** terminal buds to increase the density of thin plants along with ***thinning out*** branches to reduce density and produce a plant that is taller and wider. Thinning may be used to increase the size of flowers and fruit by reducing the number of flowering branches after buds have developed. This increases the amount of water and nutrients available for flower buds left on the plant. Heading back plants before flower buds are set increases the number of branches and flowers, but will usually reduce flower and fruit size.

The number of times pruning will be required from first potting until plants are sold will vary depending on natural growth habit of the plant species, fertilization level, time in

Sustainable Production

Much of the effort expended on moving towards sustainability is about energy. This is a key consideration in both how energy is generated and how it is used, especially in greenhouse and equipment use. Consequently, the horticulture industry has a natural role in this movement.

Sustainable horticulture practices also aim to reduce levels of synthetic (or petroleum based) fertilizers and pesticides, use integrated pest management systems to deal with insects, diseases and weeds, and focus on building the soil to promote plant health.

Water is another sustainable issue. Federal regulations and regional irrigation restrictions have caused growers to become more aware of water, fertilizer and pesticide use, and to manage them more judiciously. New technologies and best management practices have emerged to help reduce water use and runoff, contributing to more efficient and environmentally friendly operations.

Another emphasis on sustainable nursery and greenhouse production is eliminating runoff, regardless if the fertilizer source is synthetic or organic. Leachate or runoff containing nutrients, especially nitrogen (N) and phosphorus (P), as well as pesticide residues from plant nurseries, are considered a non-point source of pollution. Excess N and P inputs can lead to ***eutrophication*** of natural waterbodies, which results in accelerated plant and animal productivity, and contributes to an eventual decline in these ecological systems.

By using water and nutrients efficiently and by controlling their movement both onsite and offsite, nurseries can become sustainable operations and be a part of the larger movement that stresses greater efficiency of resource use balanced with environmental stewardship. It seems that sustainability as a concept may be vague, but the specific strategies are becoming clearer. As more nurseries experiment and test these alternative technologies, there will be more successes to serve as examples.

Sustainable Strategy Alternatives

While some sustainable technologies require nurseries to make major changes in their production practices, many are already being used by growers. Some of these include:

- use of better soil media components;
- use of compost as a soil conditioner, fertilizer or a natural pesticide for the soil;
- use of mycorrhiza to help plant roots do a better job of absorbing water and nutrients;
- reduction of nitrogen use to avoid runoff;
- application of organic forms of fertilizer to help recycle animal and plant byproducts;
- incorporation of biological pest control into management systems;
- use of mechanical weed control measures; and
- use of biodegradable containers.

Best Management Practices (BMPs)

In order to be a good steward of the environment, the development of best management practices (BMPs) for container plant producers continues as a cooperative effort between the Florida Nursery, Growers & Landscape Association (FNGLA), the Florida Department of Agriculture and Consumer Services' Office of Agricultural Water Policy (OAWP), and the University of Florida's Institute of Food and Agricultural Sciences (UF/IFAS). The *Water Quality/Quantity: Best Management Practices for Florida Nurseries* guide (Figure 12-46) outlines important environmental considerations for container nurseries. The intent of the guide is to help growers implement sound management practices that promote sustainable production.

As provided for by statutory rule, BMPs for container nursery crops provide a waiver of state-imposed liability for cleaning up contaminated surface water or groundwater provided the owner or nursery operator has (1) filed a notice of intent with the Florida Department of Agriculture and Consumer Services (FDACS), (2) implemented and carried out the appropriate BMPs, and (3) maintained the necessary records of using BMPs.

The waiver is provided on the premise that a nursery operator is using the best production practices. Therefore, water leaving the nursery property is presumed to meet state water quality standards and will not impair the natural waters of the state. Additional benefits of using BMPs include:

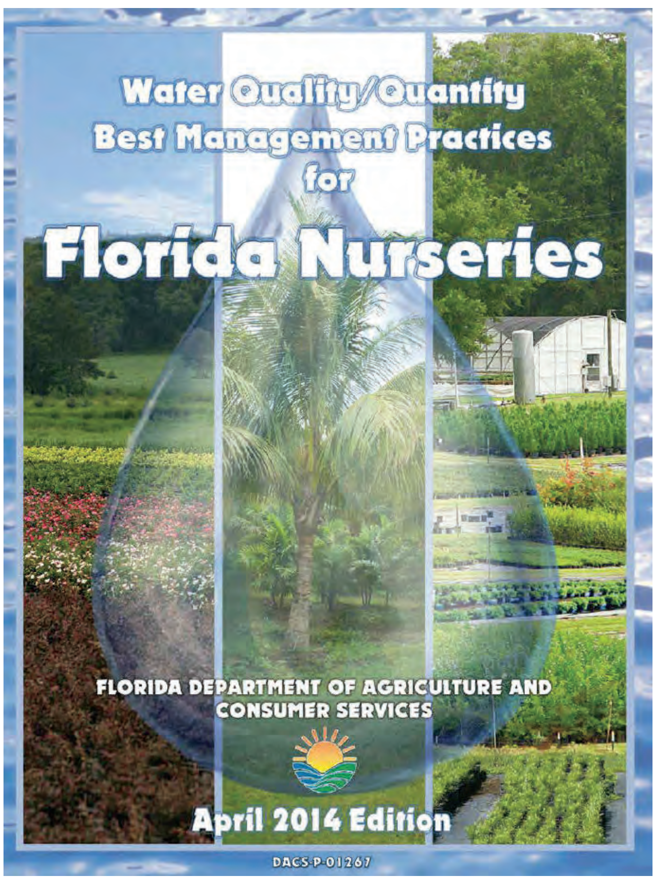

Figure 12-46. Best management practices guide for Florida nurseries to meet state water quality standards.

- protection from duplicate regulations at the local level;
- eligibility for USDA Natural Resources Conservation Service and possibly other cost share funds for retrofitting or implementing water conserving irrigation systems;
- improved production efficiency and possibly reduced production costs; and
- a demonstration that the industry can exercise its ability to determine the “best” cultural practices and voluntarily use these practices rather than be confronted with mandatory regulations.

Summary

In 2020, Florida ranked second in the nation in the production of greenhouse and nursery products. Increasing environmental concerns and legislation in many states and in other countries require the industry to take a more comprehensive, sustainable approach to production techniques.

Sustainable practices can increase plant marketability and reduce environmental impact. Evaluating and optimizing nursery and greenhouse production practices can help profitability by reducing costs for inputs such as water, fertilizer, and pesticides. In addition to being good stewards of soil and water, further benefit from the application of best management practices can avoid conflicts with regulators and neighboring communities.

It cannot be emphasized enough that business management and plant culture are equally important for success. As the horticulture production industry continues to thrive and grow, sustainable management will require long term solutions to problems of energy, pest management, trained labor, water quality, production practices and plant nutrition for a diverse range of crops and complex agricultural and environmental issues.