

# Greenhouse Management

A Guide to Operations and Technology



Ted Goldammer

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## **A Guide to Operations and Technology**

**By Ted Goldammer**

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### **Feedback/Acknowledgement**

In preparing such a book we anticipate there will be errors, and we encourage the reader to send us comments. From simple typographical errors, to missing topics, errors in data or interpretation, and even suggestions for new approaches to explaining greenhouse management, all suggestions are encouraged. We are planning to follow up eventually with a second edition and any comments or ideas for improvement are most welcome. Please send your ideas to: [apexbookpub@gmail.com](mailto:apexbookpub@gmail.com). In closing, we acknowledge the work of the many researchers in the international horticulture community that we have drawn upon in formulating this book, and also appreciate the feedback from greenhouse managers who helped shape the book.

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# Introduction

*Greenhouse Management: A Guide to Greenhouse Technology and Operations* provides detailed, step-by-step instructions, in layman's terms for ALL aspect's commercial greenhouse plant production. The text is a complete reference on greenhouse technologies and operations, and the science of growing crops. *Greenhouse Management* systematically starts the reader off by providing an in-depth discussion of greenhouse structures and design, glazing, heating and cooling, environmental control systems, lighting, carbon dioxide enrichment, growing media, irrigation and fertigation, plant nutrition, seed and plant propagation, and pest management. Finally, a series of appendices provide numerous data relevant to greenhouse management and operations. The information in this easy-to-use guide is distilled from a variety of sources, including scientific literature, extension publications, trade publications, and grower experience and has the added value of numerous citations to more in-depth discussion on many topics. The book is thoughtfully organized presenting a seamless flow of topics within chapters making it easy to find specific information that interests the reader. No one concerned with greenhouse management can afford to be without this book.



and cool the greenhouse because the exposed wall surface area is reduced. It is cheaper, and thus more feasible, to automate the single consolidated space inside a gutter-connected greenhouse than the multiple equivalent spaces in several freestanding greenhouses. Management is more efficient when personnel are all in one room with the supervisor, as opposed to being scattered about in multiple locations without supervision. Movement of materials and product into and out of the greenhouse requires less labor in a single large space than in numerous small spaces. Another advantage of a gutter-connected house is the ease of installing a retractable energy and shade curtains. While retractable screens can be added to a freestanding greenhouse, they are very costly and difficult to install and maintain. A gutter-connected greenhouse by design allows for relatively easy expansion of the greenhouse when additions are planned.

Some of the disadvantages are the difficulty in zone heating for different crops and applying fumigant type insecticides as well as to prevent the spread of insects and diseases unless internal walls are erected. Another drawback is that the gutters collect snow in the gutters, making removal very difficult. To prevent this, additional heat lines must be located under the gutters to melt the snow. These same gutters produce shadows that reduce the light intensity and often delay the maturity of a crop. In gutter-connected greenhouses large area can create stagnant air pockets, especially when horizontal air flow (HAF) fans aren't used.

### Light Distribution Patterns

Gutters or curtains placed in a north-to-south orientation will cast a shadow that is constantly changing while the sun moves east to west throughout the day. In contrast, gutters or curtains placed in an east-to-west orientation cast a relatively fixed shadow as the sun moves through the sky. Fixed shadows create a poorer light distribution pattern that results in poorer uniformity for flowering and for water usage. As a result, plants growing within the shadow pattern may flower a few days to a week slower than other plants in the same greenhouse. Also, uniform watering can be challenging, since the shaded plants will dry out more slowly than the neighboring plants receiving more light. Thus, a north-to-south orientation of gutters and curtains is preferable in most production situations.

### Sawtooth Greenhouses

Sawtooth greenhouses are constructed with one roof slope having a vertical side, all above the gutter (See Figure 1.7). Depending on manufacturer, the roof can be either arched or straight. The vertical side of the roof permits a great amount of natural ventilation as the vent opening

is at the peak of the house, allowing the warmer air to rise and escape. The elevated portion of the sawtooth opening is directed leeward to the prevailing winds to aid in ventilation. Open sidewalls facilitate this energy-efficient cooling strategy. Louvers or roll-up curtains at the top of each vertical wall can be closed when the house needs to be heated. Sawtooth greenhouses are often naturally ventilated. The sawtooth greenhouse is constructed of trusses welded or bolted together and affixed to gutter posts. Purlins or girts are placed perpendicular to the trusses along the slope. Roof glazing for the straight sawtooth design is polycarbonate, while the arch design facilitates the use of polycarbonate or double poly.



Figure 1.7 Sawtooth greenhouse

### Venlo Greenhouses

The Netherlands developed a ridge-and-furrow structure called the *Venlo greenhouse* (See Figure 1.8). The galvanized steel superstructure supports a gable glass roof. The Venlo was designed to use single panes of glass from the peak to the gutter rather than lapped glass and uses no purlins or girts in the roof structure, thereby maximizing energy efficiency and light transmission into the structure. With the roof glazed exclusively in glass, the Venlo offers maximum light to the greenhouse crop—especially important in low-light northern regions and on crops that require maximum light. However, the need for an internal shade system does exist, as heat buildup will occur because of prolonged intense sunlight. The typical Venlo utilizes natural ventilation, as the panel vents on each roof slope provide adequate air movement when paired with-side and/or gable vents. The roof vents are separately operated. The roof vents are controlled thermostatically or by computer. They cut energy costs by using natural ventilation to cool the greenhouse. The structure is rust free, requires no maintenance, and lasts for years. The polycarbonate sides and end-walls provide thermal insulation and regulate the temperature inside the greenhouse. In the Netherlands, Venlo type greenhouses are typically used to produce

# 2

## Greenhouse Glazing

The greenhouse glazing or glazing as it is referred to in the industry, represents the greatest decision in selecting the design for the greenhouse. The selection of a glazing is crucial for attainment of an optimal controlled environment, particularly relating to the solar radiation intensity and the type (diffuse/direct and partial or full spectrum of the sun) of solar energy that reaches the plants inside the greenhouse. Diffused light is better than direct light. Various glazing materials have radically different response to environmental conditions such as solar irradiance, wind, snow, and hail; and are by composition and manufacturing parameters quite different in physical properties. Key characteristics that should be considered in selecting glazing is the cost, its durability (how long it lasts), its weight and ease of repair or replacement, how much light is transmitted through the material, transparent versus translucent, and how much energy moves through the material. Greenhouse glazing can be divided into three groups; plastic films, rigid plastics, and glass. The plastics can be further subdivided into generic materials such as polyvinyl chlorides, polyethylenes, polypropylenes, fiberglass, polycarbonates, acrylics, and polyesters, to name a few.

### 2.1 Types of Greenhouse Glazing

The National Greenhouse Manufacturers Association (NGMA) lists three categories of materials for glazing commercial greenhouses. Type I glazing materials are thin plastic films, which include polyethylene, ethylene vinyl acetate (EVA), polyvinyl chloride (PVC), polyvinyl fluoride (PVF), and polyester films. Type II glazing materials are ridged plastic panels, which include fiberglass-reinforced plastic (FRP), acrylic, polycarbonate, polypropylene, PVC, and PETG (glycol-modified polyethylene terephthalate). Type III glazing materials are glass (e.g., annealed, tempered, and laminated). A description of some of the more common types of glazing materials follows.

#### Plastic Films

Flexible plastic films, including polyethylene, ethylene tetrafluoroethylene (Tefzel), polyvinyl chloride (PVC), and polyester, have been used for greenhouse coverings. Plastic film is currently the leading greenhouse covering for two reasons. First, film plastic greenhouses with permanent metal frames cost less than glass greenhouses. Even greater savings can be realized when film plastic is applied to less permanent frames, such as the cheaper Quonset greenhouses. Second, film plastic greenhouses are popular because the cost of heating them is approximately 40 percent lower compared to single-layer glass or fiberglass reinforced plastic (FRP) greenhouses. Along with the advantages of film plastic are some disadvantages. These covering materials are short-lived compared to glass and rigid plastic panels. Ultraviolet (UV) light from the sun causes the plastic to darken, thereby lowering light transmission, and to become brittle, which subjects it to breakage in the wind.

#### Polyethylene Film

Polyethylene, sometimes also known as polythene or poly, has always been and still is the principal choice of film plastic for greenhouses in most of the world (See Figure 2.1). The major advantage of polyethylene film plastics is cost, which are considerably less expensive to purchase and install than glass. Plastic glazing generally provides more diffuse light than glass. Diffuse light can potentially reach deeper into the plant canopy than direct light, since diffuse light is scattered more uniformly throughout the greenhouse. Polyethylene film is very light in weight. Thus, the film does not require a structural support system. The poly covering simply needs to be stretched to all four edges of the greenhouse structure and securely attached. Poly films are fastened to the greenhouse at the edges by special poly locking extrusions. The ease of replacement of poly glazing is an important factor in reducing the manpower

content plays a huge role in the efficiency of the biomass system. As the water content rises, the burning efficiency diminishes. Biomass boiler manufacturers report that most complaints around poor boiler performance are a result of poor-quality fuel.

## Comparing the Cost of Heating Fuels

When choosing heating fuels, you may want to compare the cost of different heating fuels or energy sources. Because heating fuels are measured and sold in different units, such as gallons of oil and propane, cubic feet or therms of natural gas, or kilowatt-hours (kWh) of electricity, comparing the price of fuels in dissimilar units is not meaningful. A more useful comparison is the price or cost of fuels based on the heat content of the fuels, such as dollars per million Btu of heat content. The Btu is the American standard measure of energy content of a fuel and can be used to compare fuel costs. Table 4.2 shows the energy content of several common fuels.

**Table 4.2 Average Heating Value of Various Fuels**

Fuel Type	Heat Equivalent
Natural Gas	100,000 Btu/therm
Propane	92,500/gal
Kerosene (No. 1 fuel oil)	135,000 Btu/gal
Fuel Oil No. 2	138,500 Btu/gal
Fuel Oil No. 6	153,000 Btu/gal
Wood Chips – 45%	7,600,000 Btu/ton
Wood Pellets	16,000,000 Btu/ton

The efficiency of heating equipment depends to some extent on the type of fuel used. Natural gas and propane boilers are typically more efficient than other types of heaters. The efficiency of the heater also has an impact on the final cost per usable unit of energy. Manufacturers are required to report the efficiency of their equipment using standard testing procedures. This information allows the grower to determine how much of the energy going into the heating equipment comes out as productive heat. Oil heaters tend to be less efficient but the cost per unit of input energy may be less than for propane or natural gas, offsetting the difference in efficiency. Electric heat is efficient and sometimes appropriate on a small scale, but the cost per unit of energy is typically much higher than other energy sources. Larger heating systems can often use more than one type of fuel and can switch between fuels depending on which has the lowest current cost. In some

cases, it may be worthwhile to retrofit existing equipment for dual fuel use to improve efficiency and reduce costs. The formula for this calculation is:

$$$/\text{Btu} = [(\text{fuel price per unit} \times 1,000,000 \text{ Btu}) \div \text{Btu per unit of fuel}] \div \text{system efficiency}$$

For example, calculate the heat value content (\$/Btu) for propane with an average price per gallon of \$1.19/gallon assuming the propane heating system has an 85 percent efficiency.

$$$/\text{Btu} = [(1.19 \times 1,000,000) \div 92,500] \div 0.85$$

$$$/\text{Btu} = \$15.13 \text{ per million Btu}$$

However, there are other factors and issues related to the selection of a heating fuel or system:

- Costs of heating system installation, operation, and maintenance
- Availability of fuels, especially during the heating season
- Environmental issues associated with the production, transport, and consumption of fuels

## 4.9 Renewable Energy for Greenhouses

Given the upward trend in both price and worldwide demand for a finite supply of fossil fuel, coupled with concerns about global climate change, many greenhouse farmers are switching to renewable energy. Renewable energy is a term for any nontraditional energy form, source, or technology differing from the current popular forms, sources, or technologies. Use of renewable energies instead of fossil fuels has many environmental, social and economic benefits and results in mitigation of the greenhouse effect. Greenhouses require heat and power to produce various crops. The quantities of electricity and heat needed depend on the local climate, the greenhouse construction and the cultivated crop. In general, it can be said that the most of energy used is consumed for their heating. Among renewable energy sources solar energy, biomass energy, geothermal energy, and wind energy have been used for covering the heating needs of the greenhouses. Depending of the specific area, the local availability of the above-mentioned renewable energy sources is an important factor for their use in greenhouses. However, greenhouses apart from heating require electricity for lighting, cooling and operation of various electric devices (e.g., motors, valves, pumps, fans, etc.).

### Solar Energy for Greenhouses

Greenhouses were used as solar collectors long before scientists began the search for efficient methods of



a system that uses wireless sensors with built-in radio transmitters to communicate with the base unit. Some monitoring systems can accommodate a combination of hardwired and wireless sensors.

## Types of Greenhouse Sensors

Sensors include those that are commonly used for weather stations as well as sensors to monitor the water status of the soil or substrate, and sensors that can be used to monitor humidity, carbon dioxide, and solar radiation levels.

### Temperature Sensors

The single largest advantage of using greenhouses to grow crops is the ability to provide desirable temperatures for plant growth and development. Measuring and controlling air temperature is common in many production systems because it has the largest effect on plant temperature. Additionally, substrate temperature is important for propagators of cuttings and seeds because there are specific substrate temperature requirements for seed germination and callus and root development. Finally, by measuring plant temperature, you can determine whether plants are warmer or cooler than the air temperature.

#### Air Temperature

Temperature thermostats/sensors are typically housed in aspirated boxes that are suspended close to the crop they are monitoring (See Figure 6.1). Direct sunlight striking a thermostat/temperature sensor will result in elevated temperature measurements. The aspirated unit uses a fan to draw the air through, providing an actual ambient temperature reading, rather than radiant temperature. With the use of an aspirated unit, the temperature range may be only 2 or 3 degrees plus or minus the desired setting compared to a non-aspirated unit with a range of 4 or 5 degrees. Closer control of the greenhouse air temperature gives better control and timing of the crop being grown. Since temperature gradients exist in greenhouses with even the best of heating and cooling systems, placement of the thermostat/sensor is very important. For accurate measurement of air temperature, a thermostat/temperature sensor should be placed just above or at the height of the crop being grown. If the thermostat/temperature sensors were placed several feet above the plants, an inaccurate reading of the air temperature for that greenhouse crop would result. Typically, thermostats/temperature sensors are placed in the middle of the structure for small greenhouses. In large greenhouses and ridge-and-furrow greenhouses, the growing area is divided into small zones. The thermostats or temperature sensors are placed in the middle of each zone that has its own heating and cooling equipment control. This so-called

*zoned heating* results in accurate temperature control for large growing areas. It also allows for various temperature regimes within a large greenhouse. Zoned heating and cooling make it possible to grow multiple crops with differing temperature requirements all in the same range.



Figure 6.1 Aspirated temperature/humidity sensor

#### Substrate Temperature

Root zone temperature is also an important factor in managing plant health. Thermocouples (i.e., sensors) are typically used connected to data loggers or data loggers with internal sensors. Thermocouples consist of two wires of different metals twisted and brazed or held together. Additionally, some of these units will calculate and report the minimum, maximum, day and night temperatures, as well as the day/night differential (DIF). Hand-held infrared (IR) thermometers can also be used to determine instantaneous or real-time root zone temperature.

#### Plant Temperature

Besides the temperature of the greenhouse air, the temperature of the crop or the plant is also very important. Plant temperature controls the rate of plant development. For instance, the temperature of plant tissue affects the rate of leaf unfolding, flower bud development and stem elongation. The temperature of the plant is measured with an IR (infrared) camera. The thermal radiation (IR radiation) emitted by the plant stands for a certain temperature of the plant. The plant temperature depends on the greenhouse temperature in combination with the incoming and outgoing radiation. During the day, the plant temperature is often higher than the room temperature, while at night the plant temperature is often lower due to outgoing radiation. Especially when the sky is clear, the difference between the greenhouse temperature and plant temperature can be considerable. By providing more insight into the plant or crop temperature, it is easier to anticipate the situation. For example, by closing

# 8

## Carbon Dioxide in Greenhouses

The growth and health of plants is the result of the photosynthesis process in which the energy of the sun is used by the plant in combination with carbon dioxide ( $\text{CO}_2$ ) and water to synthesize organic matter, while giving off oxygen. Consequently, carbon dioxide is one of the three major components responsible for plant growth. Carbon dioxide is present at a concentration of approximately 340 ppm in the atmosphere. However, this is an average and the actual concentration in a given location can vary. Climatic changes can cause a 4 to 8 percent variation in carbon dioxide concentration daily or seasonally due to increases or decreases in solar radiation, temperature, humidity, and the passage of storm fronts. In a greenhouse filled with plants, carbon dioxide concentration will closely follow ambient outside concentrations during the day as long as ventilation is provided. Carbon dioxide concentrations rise during the dark period because plants are not using carbon dioxide for photosynthesis and respiration by plants. During light periods in which ventilation is not required, carbon dioxide levels may fall below ambient level, especially in tightly sealed greenhouses. During the winter, carbon dioxide levels can easily drop below 340 ppm to 150 to 200 ppm during the sunlight hours, which has a significant negative effect on the crop. Ventilation during the day can raise the carbon dioxide levels closer to ambient but never back to ambient levels of 340 ppm. An extremely low carbon dioxide level of around 100 ppm will completely prohibit carbon dioxide uptake and growth. Depletion only occurs at daytime, caused by photosynthesis ( $\text{CO}_2$  uptake which requires light). Supplementation of carbon dioxide is seen as the only method to overcome this deficiency and increasing the level above 340 ppm is beneficial for most crops. Increased carbon dioxide levels will shorten the growing period (5 to 10%), improve crop quality and yield, as well as, increase leaf size and leaf thickness.

### 8.1 Carbon Dioxide Supplementation in Greenhouses

In general, carbon dioxide supplementation is the process of adding more carbon dioxide in the greenhouse, which increases photosynthesis in a plant. Carbon dioxide supplementation is also called *carbon dioxide enrichment* or *carbon dioxide fertilization*. Although benefits of high carbon dioxide concentration have long been recognized, advances in new technologies and automation in the greenhouse industry has dramatically increased the need for supplemental carbon dioxide. With the development of improved lighting systems, environmental controls and balanced nutrients, the amount of carbon dioxide is the only limiting factor for maximum growth of plants. Without additional input of pure carbon dioxide, the carbon dioxide content of the atmosphere in the greenhouse can be reduced to less than 50 percent in some cases of its normal content in air. This shortage of carbon dioxide reduces the efficiency of photosynthesis and can have several negative effects on the health and development of greenhouse crops. In addition, over the past 10 years, we have also seen greenhouse growers seal up their greenhouses in an effort to control their heating bills during the winter. An apparent result of tightly sealing the greenhouse is a reduction of carbon dioxide levels within the greenhouse below ambient levels found outdoors. Thus, keeping the other growing conditions ideal, supplemental carbon dioxide can provide improved plant growth. However, carbon dioxide supplementation does not always translate into increased profits in the greenhouse due to other limiting factors such as adequate levels of nutrients, temperature, water, and light. The grower must understand that if there is one limiting factor for production then increasing one factor alone will not always increase overall production. Only if the grower is supplying all the other factors and the only limiting factor



breeding ground for powdery mildew or mold, which gone unnoticed can spread throughout, rotting the fruit and destroying produce. Conversely, when humidity levels are too low, plants transpire at a rate much quicker than that of nutrient uptake. The nutrients or minerals do not transpire through the plant, only the water does. So, this leaves behind a concentrated level of nutrients in the plant that will cause a nutrient burn. Whether the humidity is too high or too low, plant growth and development is affected if humidity is not properly controlled.

## 10.2 Vapor Pressure Deficit

Vapor pressure deficit (VPD) offers a more accurate characteristic for describing water saturation of the air than relative humidity because VPD is not temperature dependent. Vapor pressure can be thought of as the concentration, or level of saturation of water existing as a gas, in the air. As warm air can hold more water vapor than cool air, so the vapor pressure of water in warm air can reach higher values than in cool air. There is a natural movement from areas of high concentration of water vapor to areas of low concentration of water vapor. Just as heat naturally flows from warm areas to cool areas, so does water vapor move from areas of high vapor pressure, or high concentration, to areas of low vapor pressure, or low

concentration. This is true for any given air temperature. Vapor pressure deficit is used to describe the difference in water vapor concentration between two areas. The size of the difference also indicates the natural *draw* or force driving the water vapor to move from the area of high concentration to low concentration. The rate of transpiration, or water vapor loss from a leaf into the air around the leaf, can be thought of, and managed using the concept of VPD. Plants maintained under low VPD (high humidity) have lower transpiration rates while plants under high VPD (low humidity) can experience higher transpiration rates and greater water stress. Vapor pressure deficit units are most often expressed in standard pressure units such as millibars (mb) or kilopascals (kPa) (1 millibar = 0.1 kilopascals, 10 mbar = 1 kPa). Vapor pressure deficit is sometimes expressed in mass deficit concentration units such as grams of water per cubic meter of dry air ( $\text{g}/\text{m}^3$ ). The units of measurement can vary from sensor to sensor, or between the various systems used to control VPD.

### Vapor Pressure Deficit and Plant Transpiration

A key point when considering the concept of VPD as it applies to controlling plant transpiration is the vapor pressure of water vapor is always higher inside the leaf than



**Figure 10.1**

Vapor-pressure deficit can tell a grower a lot more about the greenhouse environment than relative humidity can. Knowing VPD levels can help growers make adjustments that will lead to healthier plants.

steam and thereby cut down the length of time required to pasteurize the soil as well as more effective in controlling soil-borne diseases, insects, nematodes, and weeds. The substrate should not be dry. Dry substrate acts very much as an insulator, resisting the conduction of heat and causing the substrate to warm up slowly. The addition of water speeds up the rate of pasteurization, but there is an optimum level of water beyond which further additions again slow down the speed of pasteurization. As a general rule, soil moisture is best at near field capacity. Because it takes about 5 times as many Btu's to heat 1 pound of water as compared to 1 pound of soil, very wet soil should be avoided.

## Ammonium Toxicity

High levels of ammonium can be released by soils or substrates high in organic matter after pasteurization. When the soil is heated to 180 degrees F (83°C), most of the bacteria that convert organic matter to nitrate are killed. However, the bacteria that convert organic matter to ammonia are hardier and often survive. Therefore, several weeks after steaming it is not unusual that high ammonia nitrogen is found in the soil. Often levels are high enough to burn roots. Ammonium toxicity can be avoided by not over pasteurization and by delaying the use of the media until 2 weeks of more after pasteurization.

## Steam Application

Soil steam sterilization is a farming technique that sterilizes soil with steam in greenhouses. Pests of plants such as weeds, bacteria, fungi, and viruses are killed through induced hot steam. The length of time and temperature for killing the pests may vary according to pest and type of soil.

### Surface Steaming

The easiest system to set up but the least effective is to lay perforated pipe on top of the soil bed. A porous canvas hose is often used because it is easier to handle than pipe and works as well. Place a tarp or other covering over the treated area. If you choose to use steam heat, the tarp must be able to withstand the temperature of the steam. Using continuous sheets is best for disease and nematode control because the entire area is disinfested. Seal the edges of the tarp to prevent loss of heat. This is usually done by covering the edge with soil or by other means such as *snakes* used by commercial structural fumigators. *Snakes* are tubes about 20 feet (6 m) long filled with water or sand. They are placed on the covering edges and provide weight to hold it in tight contact with the ground surface. Heavy link chain also works well. Steam injected on the top of the

soil only penetrates to about 8 to 10 inches (20.3 to 25.4 cm) deep which may not be adequate for some greenhouse crops. For efficient soil steaming, the soil should have a good tilth and be neither too wet nor too dry.

### Buried Pipe Steaming

A better system uses perforated poly pipe buried 12 inches (30.5 cm) or deeper under the top of the bed. This allows the bed to be rototilled or cultivated without disturbing the pipe. The bed or bench is covered with a canvas cover to retain the steam. Steam injected in the pipe rises toward the surface and gives uniform control throughout the bed.

### Chamber (Vault) Steaming

Chamber steaming is commonly used by propagators and some potted plant growers. Metal containers, flats, wooden boxes, and clay pots are filled with the growing medium. They are placed in a closed space or vault. Steam is introduced until the proper temperature is reached. After steaming is completed, the containers are removed and allowed to cool before planting.

### Mobile Steam Application

A new approach to soil pasteurization is the use of mobile low-pressure steam units for disinfecting ground soil in the greenhouse (See Figure 12.1). Typically, temperatures in these units do not exceed 195 degrees F (90°C). The labor cost is almost negligible since the steaming unit is pulled by a tractor and only needs to be turned at the end of each bed row.



Figure 12.1 Mobile steam applicator



hr, 0.5 L/min) and a mature crop with an upper limit of 31.7 gph (2 L/min). Flow rates beyond this range are often associated either with oxygenation or nutritional problems: too rapid and the water becomes too deep and oxygenation of the roots are inadequate; too slow and the result is lack of nutrients, especially for plants with roots downstream. The delivery of nutrient solution may be continuous in a 24-hour cycle, or intermittent (alternating watering and dry periods to improve oxygenation of the root system). Another possibility—a compromise between these two approaches—is the continuous recirculation of the nutrient solution during daylight hours (dawn to dusk) and the automated switching off at night.

### **Floating Raft System**

Floating raft system consists of horizontal, rectangular-shaped tanks 6 to 12 inches (15 to 30 cm) in depth holding a large volume of nutrient solution (See Figures 14.3 and 14.4). Plants are grown on floating polystyrene sheets on a nutrient solution where the plants are placed in the holes. The plant roots are partially or totally submerged in several inches of nutrient solution. Raft systems have traditionally use 4 × 8 feet (1.2 × 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. 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 0.25-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. Crops that prefer wet rooting conditions grow better than those that prefer dry conditions. Several leafy salad crops such as lettuce (e.g., romaine, Boston, Bibb, and leafy lettuces), mustard greens, mizuna, mint, chives, and kale generally grow well in these systems.

### **Nutrient Solution**

The nutrient solution from the beds is recirculated through a nutrient tank of 1,000 to 1,250 U.S. gallons (4,000 to 5,000 L). There the solution is aerated by an air pump, chilled with a refrigeration unit, and then pumped back to the far ends of each bed. The solution in the beds is static, with a circulation of 0.5 to 0.8 gallons per minute (gpm) (2 to 3 L/min). During the growing season, the oxygen concentration in the nutrient solution should range between 5 and 6 milligrams per liter (mg/L). It is standard practice when growing lettuce in a raft culture system to use a water chiller in the nutrient tank to



**Figure 14.3**

The floating raft system is suited for growing small, lightweight crops such as lettuce, spinach, endives, or herbs such as basil, parsley, and cilantro.

too large to fit through an equivalent 200 mesh (0.074 mm) filter. The device does not remove organic material. Water entering the separator rotates around it, developing centrifugal forces that cause the heavier particles to move to the outer edge of the separator, which then settle out of water into a collection chamber at the bottom. Water flows out of the separator and goes through regular filtration. For proper operation, a sand separator must be sized to match the flow rate, using information provided by the manufacturer on the relationship between flow rate and

pressure drop. A properly selected separator will have a pressure drop of 5 to 11 pounds per square inch (psi) when operating. If the flow rate is too small for a given sand separator, it will not be effective in removing sand; a flow rate that is too large will cause excessive pressure losses. No maintenance is required, however periodic opening of the purge valve is necessary to flush out accumulated solids. A centrifugal sand separator is normally installed on the discharge side of the pump, upstream of any filtration unit.

**Table 16.5 Comparison of Filter Types**

Filter Type	Principles of Operation	Target Contaminants, Advantages, and Limitations
Sand separator (hydrocyclone)	Used centrifugal forces to separate sand and other solid material out of water.	No moving parts. Rapid removal of large amounts of soil, sand and large particles as a pre-filtration step. Prevents clogging of pipes, sprinklers etc. Some versions used to take out coagulated/flocculated fine organic materials. Will not remove particles smaller than fine sand.
Rotating drum filter	Water is passed through a rotating screen which separates debris from water; screen continually sprayed to clean.	Large amounts of organic and inorganic debris
Media filter	Selective removal of chemicals based on the filter media. Cleaned by backwashing. Used to filter both physical and biological material.	Three-dimensional filtering. Larger capacity than screen filter. Greensand: removal of iron and manganese. Activated carbon: removal of organic compounds such as pesticides and plant growth regulators (PGRs). Not well suited to low flow systems (<25 to 50 gpm). Most applications require multiple media tanks.
Screen filter	Used when primary plugging hazard is physical (suspended solids).	Relatively inexpensive. Well suited to systems using ground water. Less expensive designs require manual cleaning.
Disc filter	Several stacked, flat, grooved discs. Water forced under pressure around the discs and through the grooves to remove the filtered material. Cleaned by backwashing. Used to filter both physical and biological material.	Batteries of parallel filters will accommodate high flow systems. High pressure needed during automated backflushing. Booster pump may be required. Not suited to applications where sand is significant plugging hazard.
Fiber media filter	Gravity-fed water passes through a fabric which is indexed forward as the fabric clogs and water level backs up. Pore size varies depending on fabric type and depth.	Various pore sizes available for the cloth from 10 to 200 microns.
Cartridge filters	Cartridge filtration uses a physical process—straining water through porous media. It can exclude particles 0.2 micrometers (µm) or smaller. Removal of specific material depend on the cartridge material.	Cartridge filters are an effective and inexpensive way to treat irrigation water. Cartridge filters are easy to operate and maintain, making them suitable for small systems with low-turbidity influent. Cartridge filtration systems require water with low turbidity. Polypropylene cartridges become fouled relatively quickly and must be replaced with new units. Although these filter systems are operationally simple, they are not automated and can require relatively large operating budgets.
Reverse osmosis	High pressure is used to force the source water through a filter retaining the contaminants on one side of the filter in a concentrated brine and pure water on the other side.	Very clean water is produced. Removes low molecular weight compounds. Removes salts, sugars, metals, pesticides, and nutrients as well as pathogens. Requires pre-treatment to improve efficiency. A large amount of concentrated <i>brine</i> to be managed. High capital cost required. When used for recycling over a prolonged time, can cause some nutrient deficiencies

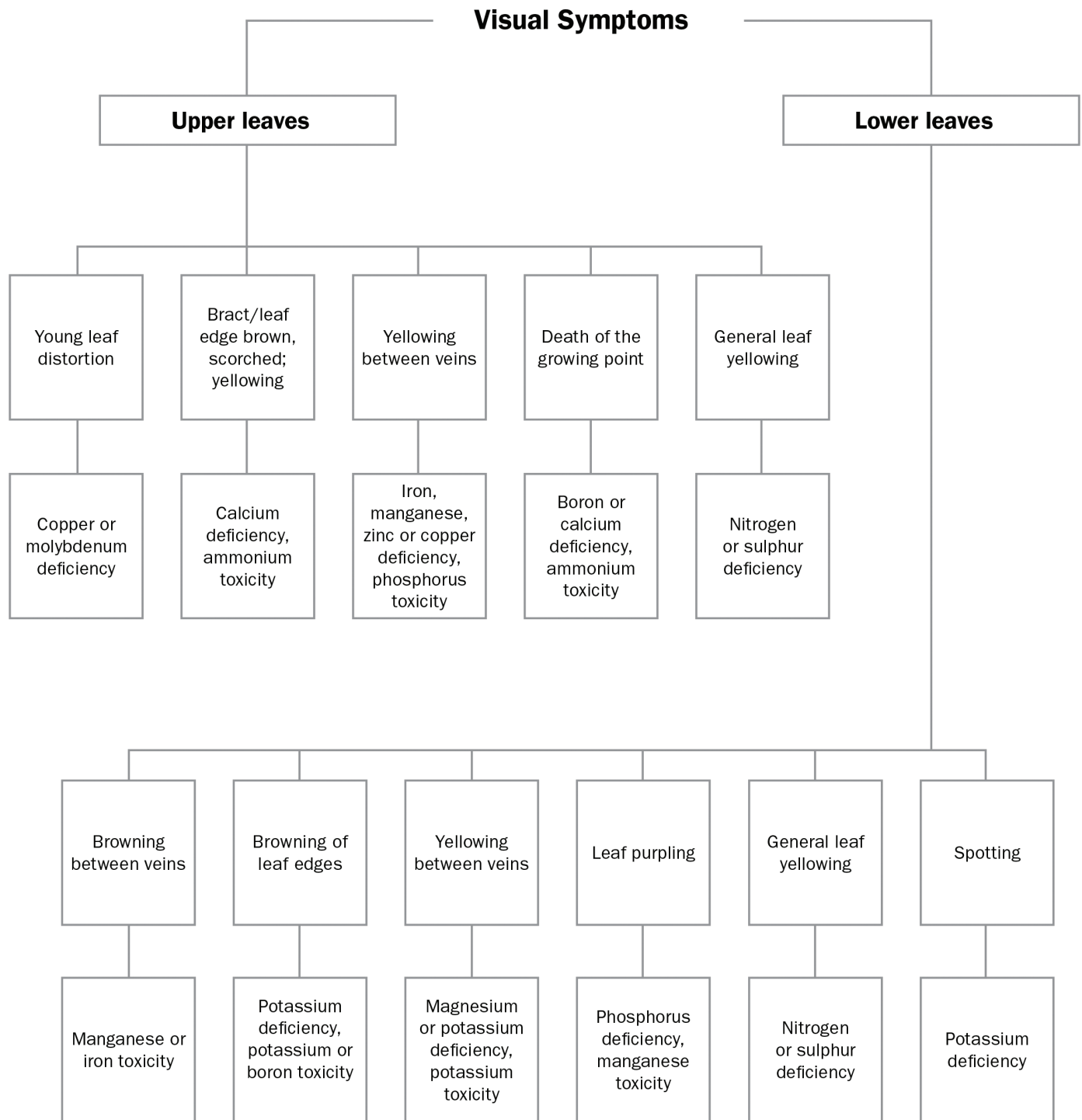


Figure 18.2 Key to determining nutrient disorders in greenhouse crops

## Media Testing

Growing media analysis at periodic intervals during the production cycle is one of the best ways to track the fertility status of a crop. Samples are taken and sent to a commercial or university lab for analysis of the media nutrient content. Some growers object to media testing

because of the cost and time required to collect samples. However, this must be compared with potential crop loss. Usually a compromise can be found between the cost of processing many samples and gaining the information needed to track a crop's fertility status. The results of the growing media test show only the nutrient content of the media at the time the sample was taken. The test does not



variations in water pressure. Simple in design, the water enters one side of the unit, forcing up a piston. This action draws in the stock solution from a stock tank under the unit and into the chamber of water. The force of the water then pushes the piston back down, expelling the mixture of water and fertilizer out the other side always in proportion to water flow. In most cases, the limiting factor with these injectors is the minimum and maximum water flow rates permissible. Precise control over the amount of injected chemicals, smaller stock tanks, and broader injector ratios has made positive displacement injectors an industry standard in greenhouse operations.

### **Dosatron Injectors**

Dosatron injectors operate without electricity, using water pressure as the power source (See Figure 20.4). They are installed directly in the water supply line. Water drives the injector, which takes up the required amount of concentrate directly from a stock tank containing concentrate solution. The amount of concentrate is directly proportional to the volume of water entering the injector, irrespective of variations in water flow or pressure, which may occur in the main irrigation line. Dosatron injectors can be installed in a variety of system configurations in addition to being installed directly in the irrigation line. Special configurations allow bypassing with clear water, injecting multiple solutions (series), and increasing water flow (parallel). Standard Dosatron units allow for injection of most acids (depending on the concentration of the acid and water temperatures).



Figure 20.4 Dosatron injector

### **DosMatic Injectors**

DosMatic® injectors, acquired by Hydro Systems, operate without electricity and use water pressure as the power source. They are installed directly in the water supply line. Water drives the injector, which takes up the required amount of concentrate directly from a stock tank containing concentrate solution. Inside the injector, the concentrate is mixed with the water, and the water pressure forces the solution downstream. The amount of concentrate is directly proportional to the volume of water entering the injector despite variations in water flow or pressure, which may occur in the main waterline. The injector ratio can be adjusted while in use. A wide range of combinations of water flow and injector ratios can be accommodated, e.g., low flow and low injection, low flow and high injection, to high flow and low injection, and high flow and high injection. Standard DosMatic units allow for injection of most acids and disinfectants.

### **Anderson Ratio:Feeder Injectors**

Anderson Ratio:Feeder injectors feature positive displacement and volume proportioning by either a flow metered electric pump or water pressure, depending on the model (See Figure 20.5). All units have adjustable feed ratios and can be adjusted while the injector is in use. A mixing tank is often plumbed in-line between the point of concentrate injection and delivery to the crop. Models in this line of injectors can have from one to many separate injection heads to allow for injection of multiple stock solutions. All models can handle a wide range of chemicals, including acids. Models are also available for small or large application and for stationary or portable installation. Many of the models require electricity, but you can use a rechargeable battery pack or solar cell.

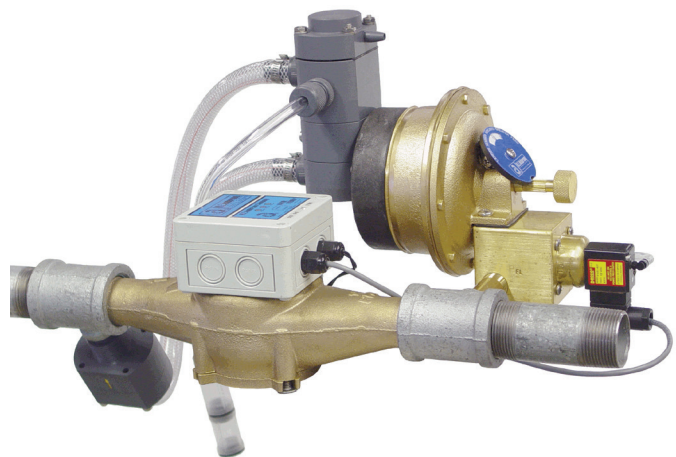


Figure 20.5 Anderson Ratio:Feeder injector

# 22

## Plant Propagation from Seed

A number of plants, particularly vegetables, annuals, and herbs, can be grown from seed in greenhouses. There are several advantages to propagating plants from seed. The process of growing more plants from seed is known as sexual propagation. Seeds have three main parts. The outer seed coat protects the seed, while the cotyledons or seed leaves provide a food source during germination. The seed is made up of three main parts: the outer seed coat, which protects the seed; a food reserve (e.g., the endosperm); and the embryo, which is the young plant itself. In plants that are self-pollinated, every seed produced will carry the same genetic makeup as the original parent plant, barring mutations. In cross-pollinated plants that have two parents, the seed will contain a mixture of genes from the egg parent plant that bore it and the pollen parent plant that was the source of pollen for fertilizing the egg. This continual reshuffling of the genetic *deck of cards* provides for many different gene combinations, thus helping to ensure the survival of a species in a changing environment. For propagation to succeed, it is important to start with high-quality, viable seeds. Mature seeds will germinate when exposed to favorable conditions.

### 22.1 Seed Quality

Because nearly all bedding plants are produced from seed, the use of high-quality seed is extremely important. The grower who tries to save on production costs by purchasing cheap, low quality seed may end up losing everything. Low quality seed often germinates poorly and slowly and produces weak seedlings. The result is a delayed, smaller-than-planned crop of low quality.

#### Good Germination Percentages

Good quality seed has a high germination percentage (well over 90%). This germination percentage should be printed on the seed packet. Only seed that is packaged for the

current production year should be purchased. Seed carried over from the previous year may have reduced germination percentages and lower vigor if the seed was not properly stored. High quality seed germinates rapidly and shows subsequent vigorous seedling growth.

#### Graded, Primed, and Pelleted Seed

Producing plug-grown bedding plants has resulted in a demand for high-quality seeds with high germination rates that germinate uniformly. The combination of mechanical seeders and market demand has placed pressure on seed companies to consider seed quality as part of the overall effort to breed new cultivars. Several seed treatments are used in an effort to improve seedling stands in plug flats. There are three types of seed: (1) graded seed, which is sorted by physical characteristics; (2) primed seed, which is partially germinated; and (3) pelleted seed, which is coated.

##### Graded Seed

These are cleaned seeds that have been physically separated by size, shape, weight, or density. Grading seed for size uniformity improves seeder performance while also producing more consistent rates of emergence. Typically, individual seed with poor germination and survival may be smaller than normal, have a different shape, or weigh less than normal. Mechanical techniques have been developed to remove unusual seeds from a lot of seed.

##### Primed Seed

Seed priming is done to increase the speed, uniformity, and overall percentage of seed germination. Seed priming involves soaking the seed prior to planting. Soaking starts the germination process, but the seed is planted before germination is completed. Seeds that have been primed may be then dried down and stored for a period, or they may be planted soon after priming. Extreme care must be taken to ensure that seeds are not *over-primed*, or progress



**Figure 24.2**

Greenhouse with sticky cards to monitor insect activity and sticky tape strung horizontally for mass trapping.

above the top foliage. One way to easily position sticky cards is to attach each card vertically to a bamboo stake with a clothespin. As the crop grows, cards can be moved up. Alternatively, cards can be hung from above using wire or string with a binder clip tied to the end at bench level, and the height of the trap can be adjusted by tying a loop in the string or bending the wire. This method is recommended because it has the advantage of maximizing the number of insects caught while they are traveling on prevailing air currents. It is important to record the types and numbers of pests caught on the trap and to graph the results over time. When pest populations start to increase, greenhouse growers can take immediate corrective action. Growers should also look at pest population graphs after pesticide or biological control agent applications to see if the treatment was successful. This will be apparent by a large decrease in pest populations soon after treatment. If no such decrease in population occurs, it may be time to try a different pesticide or biological control agent.

### Sticky Tape

Mass trapping products such as sticky tapes are also available for management of thrips, whiteflies, leafminers and fungus gnats (See Figure 24.2). While sticky cards are primarily used just to alert you to insect infestations, mass trapping tools are used to reduce and manage insect infestations. Mass trapping relies on using enough surface area of the attractive sticky tapes to capture and reduce pest numbers. Sticky tape can be difficult to apply, as the rolls can be heavy and awkward. If the tape is not applied correctly it will lead to twisting and drooping, reducing the surface area. Tape is usually used only as a post application, therefore limiting its effectiveness within the crop itself.

The post row application can be very effective in stopping the migration of pests from one house to another.

### Potato Disks

Potato disks are used to monitor for fungus gnat larvae. Cut a fresh potato into disks 1 inch (2.5 cm.) in diameter and 0.25 to 0.5 inches (0.6 to 1.2 cm) in thickness; then press the disks into the growing medium in tagged or flagged pots. For plug trays, potatoes may be cut into small *French fry* shapes or wedges and inserted into the growing medium. In general, use 5 to 10 potato wedges per 1,000 square feet of greenhouse production area. After 2 days, inspect the undersides of the potato disks and/or wedges for the presence of fungus gnat larvae, which have distinct black head capsules. Record the number of larvae located on each potato disk or wedge, and those present on the surface of the growing medium.

### Indicator Plants

Indicator plants attract pests and possibly natural enemies. Many pests show a distinct preference for certain plants over other plants. Indicator plants can be more accurate than sticky cards, because they give evidence of non-flying as well as flying stages of pests. It is known that some plants are more attractive to pests than others. They can be used as indicator or sentinel plants to detect pests or diseases early. Growers can use them to scout for pests quickly without having to check the whole crop. If the pest is found on an indicator plant, a grower will need to inspect nearby susceptible crop plants to determine if a management action is needed. Some common examples of indicator plants are beans for detection of two-spotted spider mites; flowering chrysanthemums for western flower thrips; marigolds for thrips; sweet peppers

ingredients. Polyoxin D is reportedly very effective in controlling black root but not as effective as thiophanate-methyl. *Thielaviopsis* should really be controlled through use of pathogen-free plugs or cuttings and maintaining the potting medium pH below 5.5. Growing plants under stressful conditions can make this disease worse. Appendix G, *Fungicides and Bactericides Labeled for Greenhouse Use*, lists fungicides and bactericides, labeled for control of plant diseases in greenhouses.

## Botrytis Blight

Botrytis blight caused by *Botrytis cinerea* is one of the most common fungal disease of greenhouse crops. The disease is often referred to as gray-mold because it produces a crop of gray fuzzy-appearing spores on the surface of infected tissues. Plants may be attacked at any stage, but new tender growth, freshly injured tissues, and dead tissues are most susceptible. *Botrytis* readily attacks healthy or senescing, soft, nutrient-rich flower or bract tissues of most flowers including cyclamen, geranium, rose, and poinsettia. *Botrytis cinerea* occurs wherever there is high humidity and soft plant material. This disease is often a problem in overwintering polyhouses where stagnant moist air and day/night temperature fluctuations result in condensation on the plant. The disease is primarily a problem in container stock. However, dense seedling beds may also be affected.

### Disease Cycle

The grey mold fungus is ubiquitous in the greenhouse. Microscopic spores can routinely be detected from plant material and air currents. Spores may germinate on plant surfaces in the presence of high relative humidity or standing water on plant surfaces and can be produced within a wide range of temperatures in the greenhouse. The fungus can penetrate the plant directly or enter through natural plant openings and wounds that may be created by taking cuttings or stripping leaves from a plant. Spores can be dispersed readily by splashing water or air currents. The fungus can survive long-term as hard resting bodies called sclerotia. These structures can form in or on diseased tissues and persist in the greenhouse year-round. *Botrytis* infections usually occur during cool, wet or humid weather conditions, which favor infection and sporulation. Free moisture containing dissolved nutrients in combination with air temperature determine the severity of the initial infection and subsequent lesion development. Optimal conditions for *Botrytis* growth are temperatures between 72 to 77 degrees F (22 to 25°C) and relative humidity (RH) at or above 85 percent, or when microscopic free moisture forms on plant tissue because of cooler plant tissue temperature compared with the surrounding

air temperature. The fungus can also be a post-harvest problem, becoming established at temperatures of 32 to 50 degrees F (0 to 10°C).

### Symptoms

The most obvious initial symptom of grey mold is the rapid development of a gray fuzzy growth on flowers and other infected plant parts (See Figure 26.2). The grayish growth is actually large quantities of spores produced by the fungus. Sepals and petals are often the first portions of the flower to show symptoms. Although *Botrytis* attacks plants and flowers at any stage, new tender growth and aging or dead tissues are preferred. Flowers petals provide an excellent food source for the production of spores. Petals of badly infected flowers stick together and become matted. During production, blossom and bud blight often precede and lead to infections on leaves and stems. These less obvious symptoms show as tan colored spots on leaves or cankers on stems that can eventually cause entire branches of plants to wilt, while the rest of the plant appears healthy.



Figure 26.2 Botrytis blight on New Guinea impatiens

### Cultural Management Strategies

Once *Botrytis* develops, it cannot be effectively controlled with fungicides alone. The key to suppressing *Botrytis* is to keep the plant canopy dry especially from dusk until dawn. Using drip irrigation or watering plants at the base instead of sprinkling or watering overhead will help to prevent *Botrytis* and many other leaf spot diseases.



## Nozzle Nomenclature

There are many types of nozzles available, with each providing different flow rates, spray angles, droplet sizes and patterns. Some of these spray tip characteristics are indicated with a four- or five-digit number designation on the tip. Remember, when replacing tips, be sure to purchase the same tip number, thereby ensuring your sprayer remains properly calibrated. For example, the TeeJet 11004 nozzle has a 110-degree spray angle and applies 0.4 gallons per minute (gpm) at the rated pressure of 40 pounds per square inch (psi) (See Figure 28.1). Each type of spray tip is rated under different operating conditions. For example, TeeJet® standard flat spray tips are rated in gallons per minute whereas the TX ConeJet® hollow cone tips, which have much lower capacity, are rated in gallons per hour. Most manufacturers code nozzles, and with access to the manufacturer's guide you can determine the type of nozzle, spray angle, composition, and gallon per minute output at recommended psi. Some manufacturers identify nozzles with a four- or five-digit number designation. The first numbers are the spray angle followed by the discharge rate at a rated pressure.

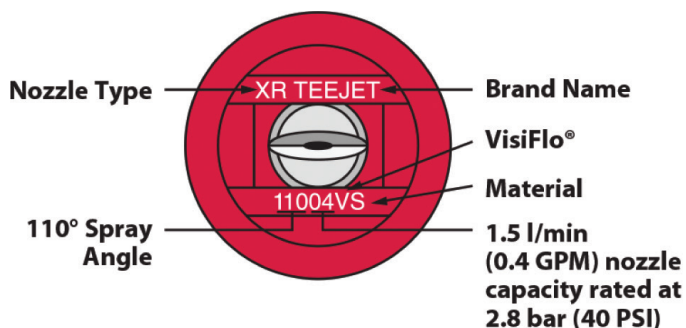


Figure 28.1 Nozzle nomenclature

## Nozzle Types

Nozzles can be categorized as follows: (1) hydraulic nozzles, (2) air-shear nozzles, and (3) rotary atomizers (controlled droplet applicators). Hydraulic nozzles create droplets by the expenditure of hydraulic pressure; air-shear nozzles require the moving air to create a venturi effect, which pulls the liquid into the air stream and forms droplets; and rotary atomizers use centrifugal force generated by a rotating cage or disc to create droplets.

### Hydraulic Nozzles

Hydraulic nozzles operate on the principle of driving a liquid under pressure through an orifice considerably smaller than the diameter of the feed line. The change from large to small diameter results in a large increase in the liquid's velocity, which in turn causes the stream of

liquid exiting the nozzle to become unstable and to break up into small drops. Hydraulic nozzles consist of a body, cap, filter, and tip. There are many types of hydraulic nozzles available for spraying pesticides. Major nozzle manufacturers market several ranges, each available with an extensive set of different flow rates, distribution patterns and spray angles so that users can select the correct nozzle for a specific application. On all hydraulic nozzles, the pressure of liquid at the orifice will influence the flow rate, spray angle, and the droplet size. Hydraulic spray nozzles fall into three basic categories: (1) cone, (2) flat-fan, and (3) air induction.

**Cone Nozzles.** Cone nozzles are used primarily when plant foliage penetration is essential for effective insect or disease control and when drift is not a major concern. At pressures of 40 to 80 psi, these nozzles produce small droplets that readily penetrate plant canopies and cover the underside of the leaves more effectively than any other nozzle type. However, because of the small droplets produced and high operating pressures, these nozzles produce patterns which are very susceptible to drift and generally not recommended for broadcasting herbicides. The two common styles of cone nozzles available are the full-cone and hollow-cone (See Figure 28.2).

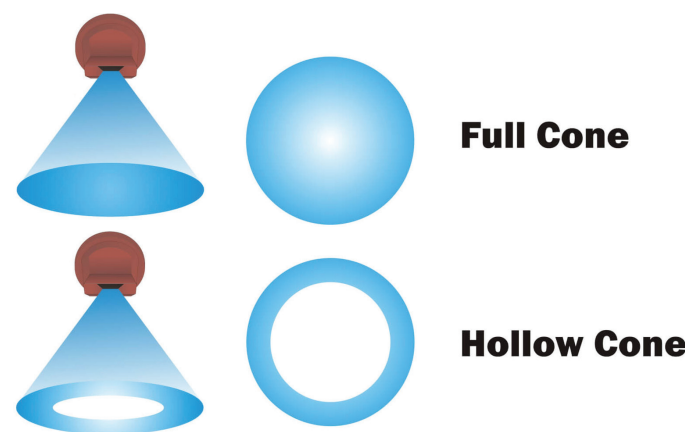


Figure 28.2 Cone nozzles

**Flat-Fan Nozzles.** Flat-fan nozzles are widely used for broadcast spraying of herbicides and some insecticides (See Figure 28.3). They produce a tapered-edge, flat-fan spray pattern. Less material is applied along the edges of the spray pattern, so the patterns of adjoining nozzles must be overlapped to give uniform coverage over the length of the boom. Normal operating pressure is variable depending on the nozzle used. Lower pressures produce larger droplets, which reduces drift potential, while higher pressures produce small drops for maximum plant coverage, but small drops are more susceptible to drift. Flat-fan nozzles are available in several spray discharge angles. These nozzles