Unit IV: Plant Growth

Lesson 1: Environmental Effects

This unit discusses five aspects of plant growth. Lesson 1 examines the environmental effects of light, temperature, indoor gases, and air quality on plants grown in a greenhouse. Also discussed are plant processes that were detailed in Unit III, Lesson 2. The remaining lessons describe the effect of growing media, irrigation, nutrients, and fertilizer on plant growth.

Light in the Greenhouse

To successfully grow plants in a greenhouse, sufficient light must be available for photosynthesis to occur. Typically, indoor plants require a high concentration of light, but this depends on the species. Greenhouse crops get their source of light either directly from the sun (solar heating) or artificially through high-intensity-discharge (HID) lamps. The advantage of lamps is that they provide light during winter and on cloudy days, and they extend the length of "daylight" for the plants. HID lamps in particular are the most efficient type of supplemental lighting in greenhouses because 27% of the electrical energy is converted to light. These lamps are available in various power ratings. If correctly spaced in the greenhouse, they provide 600-1,000 foot-candles of light (explained below) for a reasonable price.

Light is broadly characterized by its intensity, duration, and quality, as explained below.

Light Intensity

Light intensity refers to brightness and quantity; it is measured in foot-candles (f.c.). One foot-candle equals the amount of light that hits a surface 1 foot away from a standard wax candle. At noon on a clear sunny day, the f.c. value is 10,000. Plants vary in how much light intensity they need, as summarized in Table 4.1. Tropical foliage plants, impatiens, African violets, and ferns favor low f.c. levels, whereas lilies, roses, geraniums thrive at high f.c. levels.

Table 4.1 - Light Intensity Requirements of Plants as Measured in Foot-Candles

Plants' Required Light Intensity	**Foot-Candles**
Low	500-1,2500
Medium	1,250-2,500
High	More than 2,500

Time of day, location of the window, and season of the year determine the level of light intensity in a greenhouse. The sun's intensity is greatest at noon. By about 10 a.m. and again at 4 p.m., the longest shadows are cast, so light is less intense. Plants near a southern window receive prolonged exposure to light. A northern exposure offers less light. Because the sun is closer to the Earth during the summer, the light is more intense. During the winter, less direct light is available.

A sufficient amount of light intensity enhances photosynthesis and promotes growth. A healthy plant has thick stems, increased height, a developed leaf area, plentiful roots and flowers, large flowers, rich pigment, and short internodes. (Internodes are parts of the stem or other plant parts that are located between two nodes.) But any extremes in light intensity affect whether plants can thrive in the greenhouse.

If the light intensity is too low, photosynthesis diminishes. This stunts the plant's growth and creates long internodes that weaken the stems. Flowering is delayed or may stop completely. There is less pigment and leaf area. If light shines on just one side of the plant, the plant bends toward the source of light (phototropism). Its stems also curve to the light, but the roots turn away.

If light intensity is more than 2,500 f.c., it exceeds the plant's photosynthetic requirements. This accelerates respiration within the cells. As a result, the available food supply (glucose) is substantially depleted. Consequently, the plant's growth is stunted. Typical adverse effects are reduced pigment, small leaves and flowers, and scorched or dried leaves and flowers. In addition, the flowers become yellow and bleached.

Light Duration

The amount of light received throughout the day - the photoperiod - affects the plant's growth rate. As stated in the previous unit, plant growth results from photosynthesis; photosynthesis occurs only in the presence of light. Light duration and light intensity are interrelated. The quantity of available light varies with the greenhouse's latitude and the season of the year. As indicated above, during the summer, light is more intense. The days are long and the nights are short. The photoperiod for summertime plants is long. The reverse is true for plants cultivated during winter: the days are short and nights are long.

The greenhouse owner can increase light duration by using artificial lights and decrease the amount of light by placing dark cloths over the growing structure or above the crop

Plants react to the length and timing of light and darkness (photoperiodic responses) during their major developmental stages: flower bud initiation, bulb and tuber formation, bract coloration, and plantlet formation. Flowering plants are categorized into four types based on their photoperiodic responses: short day (long night), long day (short night), intermediate day, and day neutral. These responses measure the duration of *darkness* rather than the amount of light the plant receives.

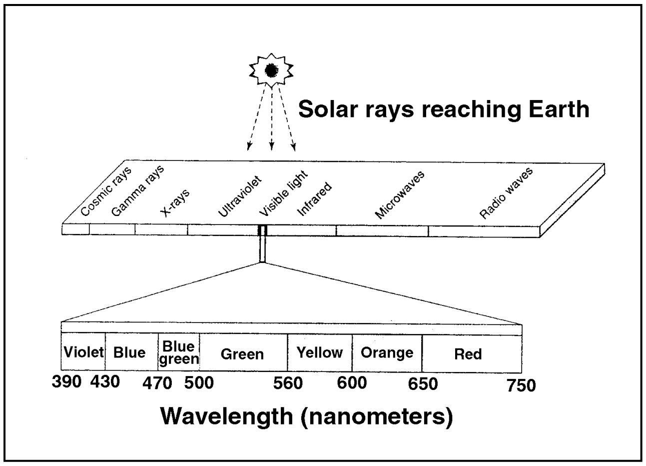
Each type of plant has a certain "critical period" during which it must receive a specific amount of darkness. During this time, plants are also exposed to brief interruptions of light. The most effective time for this "pulse" of light to occur is midway through the period of darkness. Each species has a specific time when this pulse of light is advantageous to its growth cycle.

Under continuous light, short-day (long-night), plants (e.g., poinsettias) do not bloom. A very precise, limited amount of light is required. Long-day (short-night) plants (e.g., asters) typically flower in the summer. Dahlias, another example, produce the desired flowers, not tubers, when nights are short. Intermediate-day plants, such as certain grasses, do not bloom if the days are either too short or too long. A final category, day-neutral plants, responds only to the developmental needs of the plant, not to the photoperiod. Corn, cucumbers, and tomatoes belong in this group.

Light Quality

Quality of light refers to the spectrum of color - wavelength - as measured in nanometers (nm). Figure 4.1 shows the wavelength of light with respective nanometer values and the corresponding rays for each band of color. The sequence of the colors is determined by the wavelength of light. Wavelengths longer than red are called "infrared"; wavelengths shorter than violet are "ultraviolet."

Figure 4.1 - Radiant Light Spectrum



Ultraviolet (UV) light has a very short wavelength and is invisible. UV light is very damaging; excessive levels stifle photosynthesis and injure parts of the plant. Plants grown in high altitudes receive too much UV radiation; as a result, their growth is stunted. Installing appropriate coverings that screen out damaging rays compensates for excessive UV light.

White (visible) light is actually a combination of all the colors in the spectrum. Photosynthesis uses only selected wavelengths.

If plants are grown only under blue light, photosynthetic activity is extremely high. The plants are shorter, darker, and have hardened tissues. Blue light stimulates stem length and strength, increased branching, and color in the leaves and flowers.

The wavelength of green light provides very low photosynthetic activity. This is because chlorophyll - a green pigment essential to photosynthesis - *absorbs* all visible wavelengths except green. Green is *reflected* and thus is easily detected.

Red light provides very high photosynthetic activity. Plants grow readily, stems elongate, and seeds germinate rapidly. In addition, red light is the most effective wavelength for interrupting the critical period in long-day plants.

Far-red light (higher nanometer value than red light) promotes flowering in short-day plants and inhibits flowering of long-day plants. Infrared light is invisible. Its heat causes overheating within plant cells; consequently, the stomata close and photosynthesis ceases.

Temperature

Each plant's ability to grow depends on specific temperature levels. If the temperature is below the minimum level, growth slows, flowering is delayed, and the color of leaves and flowers intensifies. If the temperature is above the maximum level, general growth is inhibited and causes premature smaller flowers, smaller leaves, reduced stem diameters, and diminished coloring. The optimum temperature is the level at which growth is the greatest. Temperature also influences the developmental processes described below.

Seed germination is greatly affected by temperature. Typically, the optimum air temperature is 60-70^{o}F (15-21^{o}C). Heating the bottom of the benches that support the plants increases the rate of germination. Each crop varies in its heat requirements for germination. The greenhouse owner can maximize the operation by identifying the correct temperature for each crop.

Temperature is an important factor in photosynthesis. The minimum temperature varies among plant species. The maximum temperature is usually 95^{o}F (35^{o}C). The growth rate increases as the temperature rises until 95^{o}F is reached. When the temperature exceeds 95^{o}F, the growth rate drops quickly and then stops completely because enzymes are deactivated. (Enzymes are large, complex proteins that activate chemical reactions within cells.) The optimum temperature in most plants is 50-75^{o}F (10-24^{o}C).

Other plant processes respond to temperature. Respiration increases with the rise of temperature. This depletes the food supply needed to fuel cellular metabolism. At extremely low temperatures (32-34^{o}F) (0-1^{o}C), the respiration rate slows enough to keep plants, cut flowers, fruits, and vegetables fresh for extended periods. This gives the greenhouse owner more time to display crops in retail operations.

The rate of transpiration increases as the temperature of the leaf rises. The leaves are sensitive to warm or cold air currents and drafts, cold air radiating from the greenhouse's sides on cold nights, and condensation (moisture on leaves that is colder than the air).

Gaseous Elements

Several gases found inside the greenhouse affect plant growth. *Oxygen* is essential for plant respiration. Adequate amounts occur naturally. *Carbon dioxide* is a key ingredient in photosynthesis. CO_2 promotes plant growth and flowering. Through plant respiration and the decay of organic matter, sufficient amounts of CO_2 occur naturally in the greenhouse. However, if the fans are turned off, hindering air circulation, the amount of CO_2 is limited. The greenhouse owner can adjust inadequate levels of CO_2 by installing a CO_2 generator. (Refer to Unit II, Lesson 2.)

Water vapor (humidity) is also important to the greenhouse's internal climate. The optimum relative humidity (RH) in most greenhouses is 45-85%. High RH (over 85%) promotes fungal diseases; low RH can increase transpiration and stunt plant growth. Low RH produces shorter plants, fewer new shoots, less leaf growth, smaller flowers, and stiff upright stems. The greenhouse owner can increase the relative humidity by installing a humidifier and placing trays of water under the benches.

The greenhouse may contain detrimental air pollutants that impair plant growth and crop yield and also harm personnel. Some of these harmful gases are listed in Table 4.2.

Table 4.2 - Greenhouse Air Pollutants

Air Pollutants
Ammonia
Asbestos
Chlorine
Ethylene
Fluoride
Mercury
Natural gas
Nitrogen dioxide
Peroxyacetyl nitrate
Pesticides
Sulfur dioxide
Wood preservatives

Soil with organic matter that is pasteurinzed through steam releases ammonia, which is detrimental to plants. Asbestos particles suspended in the air damage the lungs. Any ceiling tiles or building materials containing asbestos should be replaced. If released from an aerosol can, chlorine and fluorine destroy ozones. (Ozone is a form of oxygen found above the Earth's surface that filters out harmful ultraviolet rays.)

Ethylene is a toxic gas found most often in greenhouses. It is produced when exhaust gases from unit heaters accumulate but cannot escape. Greenhouses heated with natural gas also produce pollution. Both of these pollutants can be eliminated with an ample exchange of outside air into the greenhouse. Mercury is found in various control devices in the greenhouse, e.g., high-intensity-discharge lamps. If such a device breaks and the mercury spreads over the floor, contamination may occur.

Nitrogen dioxide from outside automobile exhaust fumes can adversely affect greenhouse-grown plants if there is improper ventilation. Pesticides intended to rid plants of diseases may be toxic if excessive and concentrated amounts are applied. Wood preservatives containing creosote and pentachlorophenol are also toxic to plants.

Summary

Light, temperature, gaseous elements, and air quality are environmental factors that influence plant growth within the greenhouse. Identifying plants' unique environmental requirements and devising specific approaches to meet them help ensure healthier and more profitable crops for the greenhouse owner.

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Unit IV: Plant Growth

Lesson 2: Growing Media and Containers

Growing media - the materials in which plants are cultivated - are fundamental to successful crop production. Plants depend upon soil-based media or specialized mixtures ("soilless" media) for development. This lesson focuses on the importance of growing media and highlights the qualities of soilless mixes. Information about types and materials of growing containers is also presented.

Importance of Growing Media

As the material in which plants grow, the growing medium provides essential nutrients to the roots by absorbing minerals and water. Its key functions are to secure the roots so the plant is upright and to facilitate the exchange of oxygen and CO_2, required for plant growth. In order to promote growth, the medium should hold enough water at the roots (water-holding capacity) and be able to drain properly.

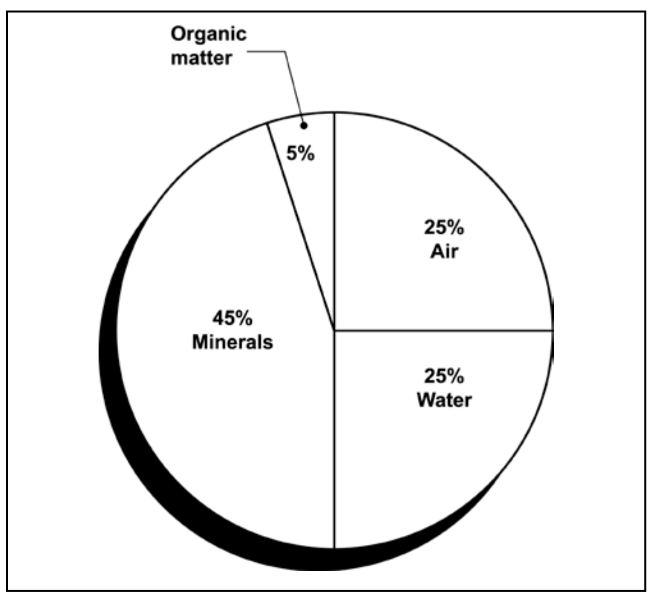
Loose, well-aerated medium results when there is enough air space at the roots. This is known as "porosity": tiny openings (pore spaces) between solid particles. The total amount of pore space determines how well the growing medium can retain air and water. Levels of available oxygen are a function of porosity: inadequate pore space means that a shortage of oxygen develops when too much water is supplied. The size and distribution of individual pores determine the rate of gas exchange and drainage. This influences the effectiveness of the growing medium. The ideal medium has a mixture of large and small pore spaces.

The growing medium's temperature impacts the activity of microorganisms (e.g., soil bacteria, fungi, insects) and the absorption rate of water and fertilizer. When the temperature ranges from above 32^{o}F (0^{o}C) to slightly over 110^{o}F (44^{o}C), the greatest amount of activity occurs. At that point, microorganisms convert organic nitrogen fertilizers in the soil to forms that can be readily absorbed. (See Lesson 5 in this unit.)

Desirable features in the growing medium are that it be loose and well aerated, have a suitable pH level and cation exchange capacity, and drain well. (These chemical characteristics are discussed in further detail below.) The medium should be able to hold enough water for plant growth and be free of unwanted seeds, weeds, insects, and pathogens.

Physical characteristics of the growing medium are composition, texture, and structure. The *composition* of an ideal soil-based growing medium is 45% minerals, 5% organic matter, 25% water, and 25% air (pore spaces), as seen in Figure 4.2. Actual field soil can be amended so that it achieves this composition. (Refer to the section on pasteurization.)

Figure 4.2 - Composition of Soil-Based Growing Medium

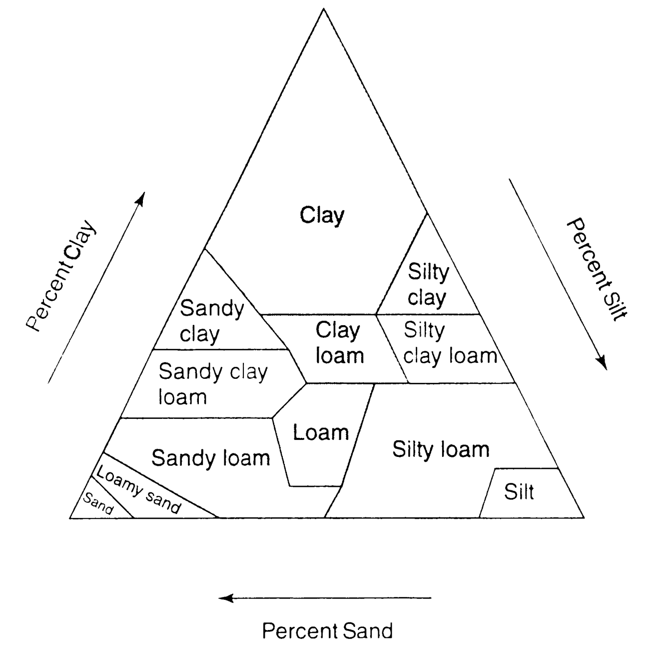


The mineral components of naturally occurring soil are sand, silt, and clay. Sand is the largest particle. Silt particles, formed by water breaking down minerals, are smaller than sand. Clay, the smallest particle, fills the gaps between the other particles. Organic matter is made up of decayed plant and animal residue. The air portion of soil is made up of oxygen, carbon, and hydrogen.

Soil *texture* refers to the size, distribution, and proportion of sand, silt, and clay particles. Water retention and air porosity are related to the soil's texture. Soil containing mostly sand (large particles) is composed of large pores. Soil with a majority of small, finely textured particles (clay) has small pores that resist the flow of water and therefore increase the soil's water-holding capacity.

If the soil contains equal amounts of all three particles, it is a "loam." However, pure loam is not found in the field. Usually, one of the mineral particles predominates. Soils are therefore identified according to the proportion of mineral content: "sandy clay," "silty clay loam," etc. The classification of various soil types is depicted in a triangle, as shown in Figure 4.3. The combination of particles determines whether the soil texture is fine, medium, or coarse.

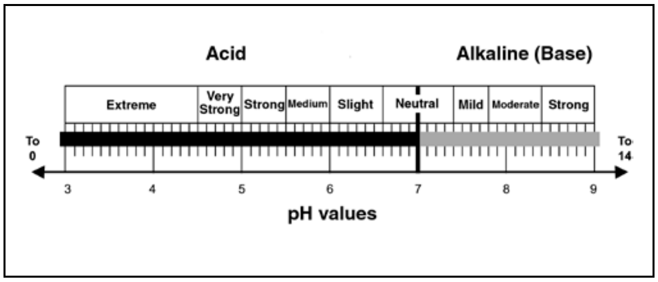
Figure 4.3 - Soil Texture Triangle



Soil structure refers to how the three types of particles are combined and arranged. This factor affects water-holding capacity, porosity, soil's ability to transmit water into the plant (permeability), and the rate of water absorption into the roots (infiltration). An aggregate of sand particles promotes drainage. However, soil with too much sand does not hold moisture. A combination of mostly clay particles retains water and keeps the soil moist. But too much clay hardens the soil surface, preventing needed drainage. Rearranging the soil's structure alters its texture. The amount of these three particles can be changed until the desired result is achieved. Adding organic matter, for example, improves soil structure because it increases pore space.

Two important chemical characteristics of the growing medium are pH and cation exchange capacity (CEC). A soil's *pH* measures the level of alkalinity or acidity and ranges from 0 to 14. A value of 7 is neutral; above 7 is alkaline (base); below 7 is acidic. See Figure 4.4

Figure 4.4 - pH Scale



The pH is the concentration of the hydrogen ion: an electron with an electrical charge. It determines whether the soil can receive nutrients. The pH for most soils ranges from 4.0 to 8.5. Most greenhouse crops need a pH level ranging from 5.5 to 6.5. The pH of the greenhouse's growing medium ranges in levels of acidity and alkalinity. Different plants thrive in various levels of acidity. For example, the color of a hydrangea differs with the type of soil: it is pink in acidic soil and blue in alkaline soil.

In soil with a high pH (alkaline), many nutrients separate from their solution, depriving the plant of sustenance. Nutrients in acidic soil may become overly concentrated and harmful to the plant. The growing medium's pH level must suit the needs of each plant.

Cation exchange capacity (CEC) measures the soil's ability to hold nutrients; it gauges soil fertility. Fertile soil attracts and retains essential nutrients, promoting plant growth. A cation is a positively charged ion in a solution. The soil's clay, silt, and organic particles have negative charges that attract and hold cations. A clay particle in soil has a large surface area, making the cation's absorption more efficient. The amount of exchangeable cations is expressed in milliequivalents (meq) per 100 grams (g) of soil at pH 7 (neutral). For greenhouse media, the best CEC level is 6-15 meq/100 g.

Pasteurizing Field Soil

For greenhouse plants, using just field soil is inefficient and ineffective. The texture of outdoor, naturally occurring soil tends to be dense and bulky; therefore, it drains poorly and does not aerate properly. The nutrients in field soil vary in quantity and quality, making precise duplication difficult. The soil may also contain weeds, insects, excessive amounts of pesticides, or diseases that can harm the growing plant. Another drawback is that hauling soil from the field into the greenhouse is heavy work and can be quite expensive.

However, field soil can be used to cultivate greenhouse plants if it is amended to create the desired characteristics. This change is accomplished through pasteurization, a process whereby only harmful organisms are killed. The goal is to kill as many weed seeds as possible and to destroy all pathogenic bacteria and fungi. During pasteurization, organisms that are beneficial to plant growth are not eliminated.

The three methods of pasteurization are steam, chemical, and electrical. *Steam* pasteurization applies heat to the soil. The soil must be thoroughly mixed after steaming. (Fertilizers cannot be pasteurized; they should be added after steaming.) Air is introduced into the steam and administered at 140^{o}F (60^{o}C) for 30 minutes. It is important to regulate the temperature. Excessively high temperatures kill the beneficial organisms that destroy the disease-causing organisms and would increase the level of toxic substances in the soil. Steam pasteurization allows planting to resume as soon as the soil cools. Another advantage is that this method increases drainage and aerates the soil because the heat causes the small soil particles to stick together. It is also an inexpensive process.

Chemical pasteurization, less effective than steam, produces highly toxic fumes. In some cases, all workers and plants must clear the area for 24 hours to several weeks. The gases used during this process are effective only if the soil is the correct temperature, which depends on the chemical used. Some of the chemicals used include chloropicrin (tear gas), which attacks weed seeds, fungi, and nematodes (tiny round worms that attack plant roots); and basamid (DMTT). The soil should be 60^{o}F (15.5^{o}C) or warmer, preferably 70^{o}F (21^{o}C). All crops must be removed from the greenhouse.

After application, the soil needs 10-21 days' exposure to fresh air before it can be used for planting. Individuals applying chloropicrin should wear airtight masks to avoid inhalation. Vapam, applied between 50^{o}F (10^{o}C) and 90^{o}F (21^{o}C), also kills weeds, fungi, and nematodes and requires removing all plants from the greenhouse. In order for vapam to spread evenly throughout the soil, it must be watered thoroughly. The treated soil needs 2-3 weeks of fresh air before planting can resume.

It is important to note that chemical pasteurization has the potential to endanger the environment. Greenhouse owners should stay up-to-date on acceptable usage of chemical fumigants.

Electrical pasteurization, typically not used in commercial greenhouses, handles only small amounts of soil. It is neither an efficient nor a cost-effective process.

Disinfecting tools, used pots and flats, plant supports, and benches can prevent contamination inside the greenhouse. Steaming clay and wooden containers rids these items of pathogens. Plastic pots, however, should be fumigated with appropriate chemicals. The shoes of anyone entering the greenhouse can spread pathogenic soil, thereby endangering the growing plants. Standing on the benches must be forbidden. Another useful policy is placing a fiber mat inside a shallow tray filled with a disinfectant solution and requiring people to wipe off their shoes on the mat.

Advantages of Soilless Growing Medium

As the name indicates, soilless growing medium contains no naturally occurring field soil. It is preferred for use in greenhouse operations for several reasons. It is lightweight, making shipping inexpensive. Its capacity for drainage and porosity prevents roots from rotting. Because its composition is consistent, reproducing uniform amounts of high-quality mixtures is easy and efficient. Soilless medium is also free of unwanted seeds, weeds, insects, and pathogens. The greenhouse owner can buy ready-to-use bags of soilless medium or custom mix the medium as needed for individual plants. As a nonreactive (inert) medium, it contains very low amounts of nutrients. Soilless growing medium does not require pasteurization because during manufacturing, the elements are processed at very high temperatures.

Ingredients in Soilless Mixes and Soil Amendments

Soilless mixes are composed of organic elements and mineral soil amendments. Organic materials provide beneficial ingredients to the media. Rich in nutrients, they improve the soil's physical structure. In addition, organic matter increases the medium's water-holding capacity, aeration, drainage, and cation exchange.

Organic soilless mixes are composed of peat, wood residues, and coir. *Peat* is made from peat moss, sphagnum moss, humus, decomposed plants, and decayed animal residue. Fibrous peat moss can hold 15-20 times its weight in water. This water-holding capacity is further enhanced by adding perlite and vermiculite (discussed below) as well as other materials. Peat moss also is valuable because it has ample quantities of pore space that hold air and water essential for plant growth. By total volume, the porosity of peat moss is 85-98%. (For greenhouse-grown plants, the desired total pore space by volume is not less than 50%.)

Sphagnum moss peat is fairly acidic, but adding finely crushed limestone adjusts the pH level. Another component is humus, which is decomposed organic matter. Rich in nutrients, as humus decays it releases nitrogen, sulfur, phosphorous, and carbon dioxide into the soil. As CO_2 is released, it combines with water and creates weak acids in the soil that break down other minerals. (The nutrients found in minerals are detailed in Lesson 4 of this unit.)

Additional ingredients of soilless media may include decomposed plants (e.g., rotted leaves) and decayed animal matter (e.g., manure), but if contaminated or overly concentrated, these additions to the medium would require pasteurization to be usable.

Wood residues are by-products of the lumber industry and are valuable amendments of soilless media. Although wood loses nitrogen through decomposition, supplementary applications of nitrogen make wood residues a productive addition to the growing medium. Leaf mold from maple, sycamore, and oak improves drainage, aeration, and water-holding properties of the medium. Composted sawdust also may be added but caution is required. If it is obtained directly from the sawmill, high levels of nitrogen must be supplied; these levels must be stabilized before incorporating the sawdust into the medium. Another issue is that the medium's pH may change. Finally, cedar and walnut trees produce toxins in the sawdust. Bark from hardwoods (e.g., oak and maple) and softwoods (e.g., pine trees) contribute nutrients to the medium. However, just as with sawdust, care is advised. Certain trees (e.g., walnut and cherry) contain toxins that inhibit growth.

Coir is the fibrous outer layer of the coconut husk, a by-product of the coconut industry. Thanks to its excellent air porosity and water retention, coir helps the growing medium absorb moisture easily and drain quickly.

<u>Mineral (inorganic) materials</u> offer several advantages to the growing medium. They improve the physical structure of soil-based media and increase aeration and drainage. Four types of inorganic materials are usually found in soilless mixes. *Sand* is finely ground stone; the type used with growing media comes from mountain rocks. Thanks to its large particle size, sand provides good porosity and aeration by admitting large quantities of air into the growing medium. It promotes drainage but cannot hold sufficient quantities of water for the emerging plant. Its weight can support the growing plant.

Perlite (volcanic rock) expands and becomes porous when heated to approximately 1,800^{o}F (982^{o}C). It has a neutral pH, holds three to four times its weight in water, and improves drainage and aeration. Although it is low in nutrients, perlite is ideal as a seed-germinating medium for rooting cuttings

Vermiculite (mica compound) when heated to about 1,400^{o}F (760^{o}C) develops a layered structure that helps retain water and fertilizer. When moist, vermiculite does not expand, thereby reducing its water-holding capacity. It absorbs fertilizer and contains sources of magnesium and potassium that the plants can access through their roots. Horticultural vermiculite comes in a range of sizes suitable for various plants. However, in its raw form, vermiculite can contain hazardous dust that is harmful to greenhouse personnel.

Calcined clay, heated to 1,300^{o}F (704^{o}C), forms heavy, porous particles made up of many smaller water-holding pores. The clay's high cation exchange capacity indicates that nutrients are retained in the medium. This specialized clay also adds volume to the medium and improves the soil structure.

<u>Other materials</u> may be used in soilless media. *Polystyrene foam* (a by-product of Styrofoam in beads or flakes) is light and improves aeration. It does not absorb water and has a low pH. Its CEC

is low. *Rock wool* is formed when a mixture of basalt, coke, and limestone is melted at 2,700-2,900°F (1,482-1,600°C). Its water-holding capacity is great: it holds 3-4% solid matter and 96-97% pore space. When saturated, it drains 15-17%, which promotes root growth. But rock wool deteriorates very slowly and is not biodegradable. As a result, the question of responsible disposal arises. Environmental agencies of several countries forbid dumping rock wool in landfills. Whether its use in the United States will persist is currently not known; the greenhouse owner should stay apprised of any regulatory changes.

Selecting Growing Containers

When selecting growing containers, the greenhouse owner considers how the plant grows: its height, width, shape, and requirements for root space. Another factor is the intended market. Retail operations generally use larger pots than wholesale businesses.

Basic Types of Containers

Various types of containers are available for specific purposes. (The next section describes the composition and differentiating features of the materials used for plant containers.) Rooting containers are usually made from peat, an organic material. *Peat pots* are filled with growing media.

Peat pellets are self-contained growing units that expand when watered. Seeds and cuttings are pressed directly into the pellet; no additional growing medium is required. When the plant develops, the pellet is transplanted into the soil. *Peat strip*s are containers made up of 6-12 square peat pots that are joined together, forming an individual unit. Plants are grown in each pot. Figure 4.5 illustrates three types of rooting containers made from peat. Rooting containers also can be made from plastic flats, metal flats, plastic foam cubes, or rock wool fibers.

Figure 4.5 - Peat Containers

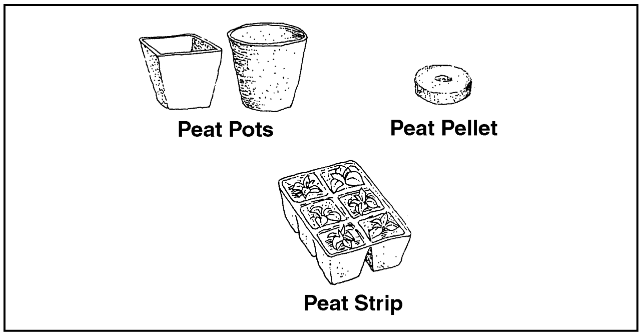
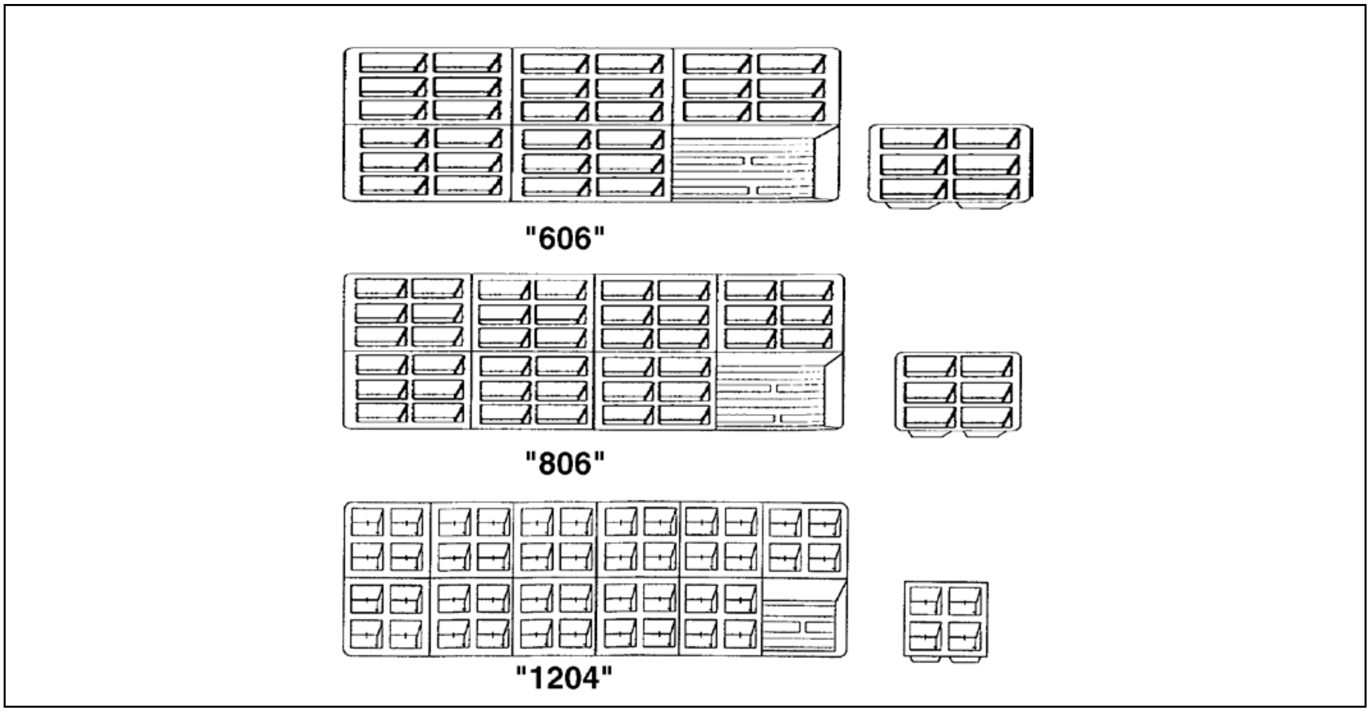


Figure 4.6 - Identifying Cell Packs

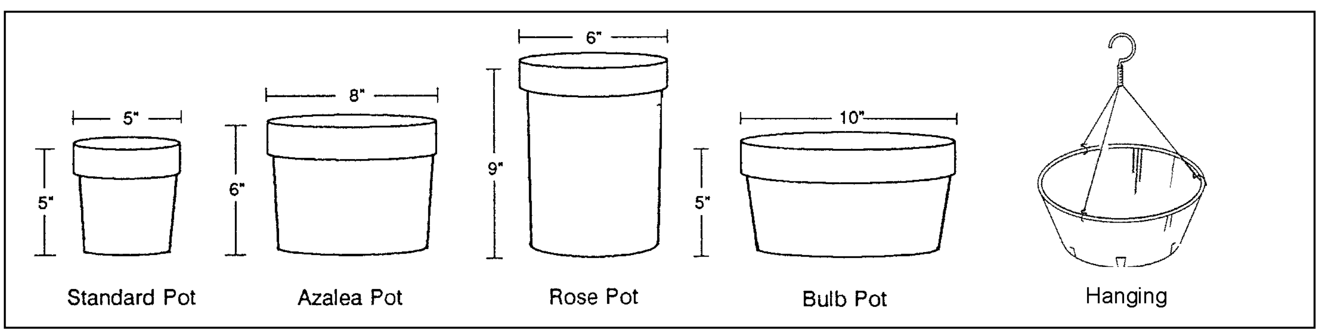


<u>Bedding plant containers</u>, made of plastic, produce essential crops for the retail greenhouse owner. *Multicell packs*, typically containing 36, 48, or 72 cells per flat, are usually used to produce spring flowering annuals. See Figure 4.6 as shown above.

Plant packs usually contain one to six cells per unit and six to eight units per flat. Most bedding and garden vegetable plants are grown in these containers. *Individual pots*, usually made of plastic, come in assorted sizes; 2-4 inches is the most common. These pots are used to produce larger bedding plants.

<u>Foliage and flowering plant containers</u> range from 2 to 12 inches or larger. The width and depth of *standard pots* are equal. This type of pot is best for plants that are not top heavy. The height of an *azalea pot* is 3/4 of its width, making it ideal for shorter plants with spreading foliage. Its wide base provides stability for top-heavy plants. The height of a *rose pot* is 1 1/2 times its width. It is ideal for plants with large, deep root systems. In a *bulb pan*, the width is twice the depth and is best for shallow-rooted plants. *Hanging baskets* are suitable for many types of plants, especially those whose foliage drapes over the container, such as English ivy. Figure 4.7 illustrates these pots.

Figure 4.7 - Container Shapes



Common Materials for Growing Containers

<u>Plastic</u> is the most common material used for plant containers. Round plastic pots, grouped together, effectively circulate air. Square containers maximize space efficiently; the greenhouse owner can group them close together on benches. However, less air circulates among square pots, which can lead to diseased leaves.

Plastic containers offer several advantages. They are lightweight, making lifting and shipping easy, and inexpensive. New plastic pots are sterile and can be used immediately; used containers must be sterilized with liquid chemicals. Plants grown in plastic containers are less likely to have fertilizer residue or algae buildup and require less watering. Finally, these containers come in a wide selection of sizes, shapes, and colors.

But there are some disadvantages to using plastic. The first problem is that they are not porous, which means that the material does not “breathe.” As a result, the root system has less aeration and the growing medium can become waterlogged. Another drawback is that plastic containers can crack and become brittle with age. Also, using plastic pots presents an environmental concern of how to dispose of them in a responsible manner.

For centuries, <u>clay</u> has been used as a plant container. It is porous; aeration and gas exchange between the plant and the environment optimize growth. Clay pots drain very well, which prevents the growing medium from becoming waterlogged. They are also sturdy, less likely to tip, durable, and can be steam sterilized and reused. The disadvantages are that plants dry out faster and require watering more frequently. Fertilizer residue and algae accumulate in clay pots. In addition, they are heavy to lift and ship, and they break easily. Clay pots also tend to be relatively more expensive than plastic or peat pots.

Peat pots are made from peat moss that is pressed into sheets and formed into shapes. Seedling roots grown in peat pots penetrate directly through the container into the soil. The entire peat container can be transplanted into the soil, thereby reducing stress and lessening damage to the roots. Unfortunately, peat pots do not last very long and they can dry out quickly and become difficult to rewet.

Summary

Having high-quality growing media is essential to successful crop development. Soilless mixes are preferred, but field soil may be used if it is pasteurized to achieve desirable characteristics. Water-holding capacity, aeration, and drainage are key factors that determine whether plants thrive. A medium's pH and cation exchange capacity are additional considerations. Organic matter, minerals, and other materials contribute amendments that offer unique assets. Various types of plant containers in different materials accommodate specific needs for greenhouse-grown plants.

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Unit IV: Plant Growth

Lesson 3: Irrigation

Plants cannot survive without water. Of all the cultural practices that the greenhouse owner performs, irrigation contributes most directly to the growth and healthy development of plants. Lesson 3 addresses general factors affecting irrigation in the greenhouse, explains how often to water crops, provides guidelines for watering plants correctly, and describes several irrigation methods.

Irrigating Greenhouse Crops

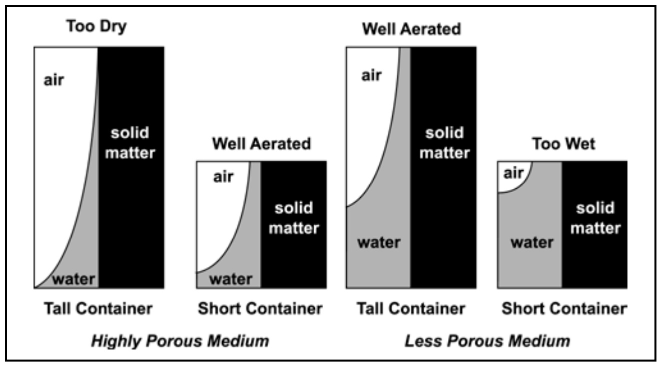
Proper irrigation practices and quality water are critical to crop success.

Water's major role in plant growth is to dissolve and translocate nutrients throughout the plant, as detailed in Plant Processes (Unit III, Lesson 2). Plant cells help support the structure of the plant when they are filled with water.

The *growing medium* (see Unit IV, Lesson 2) can create moisture stress in plants under certain circumstances. If the medium's capacity for absorption, retention, and drainage is inadequate, the plant suffers. As the medium's pores (capillaries) absorb and attempt to retain water, the force of gravity tries to drain water from the container. This conflicting interaction is resolved by the porosity and depth of the medium. A growing medium with large particles is porous; this facilitates drainage after irrigation. The depth of the medium relates to the height of the planting container. Water in tall containers is easily pulled through the medium; drainage is complete. In shorter containers, the medium's capillaries resist the force of gravity; therefore, water is retained in the container.

Figure 4.8 demonstrates how the relationship between the medium's porosity and depth influences absorption, retention, and drainage.

Figure 4.8 - Interaction Between Growing Medium's Porosity and Depth



Air temperature is another factor in moisture stress. During the hottest part of the day, air in the greenhouse may reach 120°F (49°C) or higher. At this point, the rate of transpiration accelerates and the relative humidity decreases substantially, depleting water from plant cells. Excessive air movement also increases transpiration because it prevents water vapor from accumulating on the leaves. Monitoring and regulating air temperature control the effects of transpiration in greenhouse-grown plants.

Basic concerns about irrigation include providing uniform watering, minimizing the amount of water/fertilizer runoff, minimizing the amount of water on foliage, and considering the integration of a fertilizer injection system directly into the irrigation system.

Water contains chemicals that can harm plants. For example, fluorine is often added to public water systems to prevent tooth decay. The amount added is 1 part per million (ppm). Yet, fluoride (the compound made from fluorine) in a concentration of just 5 parts per *billion* reduces leaf size by 25-35%. A concentration of 0.25 ppm fluoride causes necrosis in leaf tips. Softened water contains high levels of sodium that destroy soil structure, causing poor drainage. An accumulation of only 1 ppm sodium in some plants (e.g., carnations) causes the petals to stick together so they cannot open up properly.

Frequency of Crop Irrigation

Determining how often to irrigate greenhouse-grown crops depends on various factors: water-holding capacity of the growing medium, container type, internal environment of the greenhouse (humidity, temperature, and light), season of the year, and the plant itself (species, size, and stage of growth). The soil depth of the plant's roots is also a consideration.

A critical factor is knowing when to irrigate plants. The greenhouse owner can visually discern when the plant starts to wilt, dries up, or fades. If the weight of the container is unusually light, it indicates that the plant needs water. Placing a dry stick in the medium for a period of time and periodically removing it also reveal when to water the plant. If the stick stays dry, water the plant. If the growing medium clings to the stick, do not water.

Knowing the amount and frequency of irrigation for greenhouse crops prevents two detrimental consequences: underwatering and overwatering. *Underwatering* creates moisture stress if the plant is deprived of water. Then the cells shrink and the plant wilts. At this point, the stomata (pores in the leaf surface) close up to prevent any further loss of moisture. But they also restrict carbon dioxide from entering into the leaf, hindering photosynthesis and stunting plant growth. When roots have no access to water and dissolved minerals, they cannot transmit needed moisture to the leaves, stem, and emerging flower. The plant then develops shorter internodes, smaller leaves, and harder and tougher plant tissue.

Overwatering is also harmful, especially for seedlings. If overly saturated, the root system is unable to exchange gases; consequently, the amount of available oxygen is severely limited. As a result, the root tissue is damaged and the risk of disease increases significantly. Plants wilt and develop spindly, leggy stems; overall growth slows.

Basic Guidelines for Irrigation

Successful irrigation results from adhering to a few fundamental guidelines. Use the appropriate growing medium for each crop to ensure adequate absorption, water retention, and drainage. Because plants differ in how much water they require, the greenhouse owner should regulate the amount and frequency of irrigation accordingly.

Watering plants thoroughly leaches (flushes) soluble salts and excess nutrients that can harm the root system if they accumulate in the growing medium.

The proper method for watering is to irrigate the entire area around the roots, ensuring that the root system never dries out completely. Control the flow of water to prevent water from spilling over the top of the container. Irrigate plants until water drains from the bottom of the pot. The best time to irrigate is early in the day to replenish the water that evaporated from leaves and flowers. To prevent disease, do not directly moisten the foliage and flowers because this induces decay. Also, prevent pathogenic contamination by keeping the end of hoses off of the floor.

Delivering Water to Plants

As mentioned briefly in Unit II, Lesson 2, the two basic irrigation systems are manual and automated. This lesson expands upon various irrigation techniques and explains how the equipment is used in each method.

The manual method uses handheld hoses and wands. This method is widely used in small greenhouse operations. However, it is labor intensive, costly, and difficult to water plants uniformly.

There are three basic automatic systems: overhead, surface, and subsurface. *Overhead delivery systems* use sprinklers to spray water over bedding plants and expose the foliage directly to water. This method is still used in some established greenhouses. However, the sprinklers have several disadvantages. If the irrigation system contains nutrients, the sprinklers deposit salt residues on the leaves. When overhead systems irrigate plants, the water might gather in puddles and oversaturate the growing medium. In addition, evaporation results from using overhead sprinkler systems. There is an increased risk of disease when the foliage is wet.

A better option is the *boom irrigation system* that waters bedding plants, potted plants, and seedlings. A water wand hangs above plants and travels across the greenhouse, spraying water onto plants. Spray stake/nozzle systems are mounted near plants and spray plants from above and from the sides. This custom-built system accommodates the greenhouse's specific dimensions, uses space efficiently, and delivers fertilizer during irrigation ("fertigation"). Compared to manual irrigation techniques (e.g., hoses), boom systems save 40% in water.

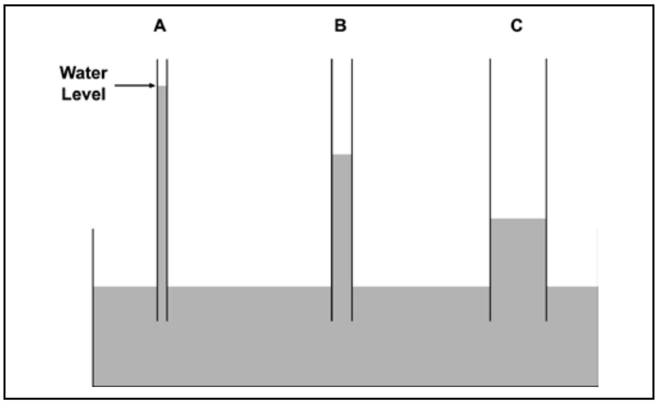
Surface delivery systems, used to irrigate cut flowers and row crops, apply water to the entire soil surface under the foliage. A uniform, optimal amount of water is applied to the base of the plant. As a result, the leaves do not get wet, reducing the rate of evaporation from the foliage and soil. The growing medium does not become waterlogged and nutrients do not leach into the soil. Drip emitters have small tubes with weights attached that are placed in individual pots. They slowly dispense drops of water directly to the medium. Drip irrigation also prevents exposing roots to pathogens that are spread by moving water. The drip irrigation system uses less water, making it an economical option, and this system has been shown to increase yields. Soaker hoses, oozing water from tiny holes, are put at the bottom of the plant. Closely planted flowerbeds are effectively irrigated with bubblers, which are similar to drip emitters but deliver a higher rate of water.

In *subsurface (subirrigation) delivery systems,* water is applied directly to the growing medium without wetting the foliage. Water is applied under the pots. The two basic methods are the capillary mat system and ebb and flood system. In the **capillary mat system**, plant containers are placed on top of a soaked, synthetic mat that rests on a level bench in the greenhouse. The bench is protected with a sheet of plastic. Dripping water runs off the bench and thereby prevents soluble salts from accumulating on the mat. The best pots to use are plastic; clay loses moisture through the sidewalls.

First, a drip tube uniformly waters the mat. The greenhouse owner places the plants on the mat and waters them from above using a hose. This creates a column of water that extends from the growing medium to the mat. Through capillary action, water is drawn upward from the saturated mat through the drainage hole into the growing medium of each plant.

The size of the medium's pore spaces affects how high the water rises. In finely textured soil with tiny capillaries, water rises to the highest level. Capillary action occurs because the water rises to a given height in "tubes" (capillaries), which have very narrow diameters. The pore spaces in the growing medium function as capillary tubes and carry the water from the mat to the roots. Figure 4.9 illustrates how pore size affects capillary action. Water rises to the highest level in the smallest capillary tube (A) and to the lowest level in the largest capillary tube (C).

Figure 4.9 - Capillary Action of Water in Growing Medium



However, capillary action also affects the quality of the growing medium. Through water evaporation, soluble salts are lifted from the bottom of the pot and deposited in undesired concentrations on top of the growing medium. To get rid of these harmful chemicals, the greenhouse owner should periodically water the plants from above. This leaches the excess salts from the top of the container and balances their distribution throughout the medium.

In the **ebb and flood system**, flats of plants rest on specially constructed, raised, waterproof benches. Each bench must be absolutely level and have a trench for the nutrient solution and several pipes to carry a certain number of gallons of water per minute. The amount of water depends on the size of the greenhouse operation. The irrigation solution (water and nutrients) is pumped from a central storage tank into the bench and spreads quickly and evenly over the growing medium. It remains on the bench for a few minutes and then drains back into the storage tank for recycling. The advantages of the ebb and flood system are that it never wets the foliage, which promotes disease, and that it can be applied any time day or night. A computer can regulate the entire operation. Ebb and flood is a completely closed recirculating system that does not contaminate the groundwater. The Environmental Protection Agency (EPA) requires the prevention of groundwater contamination from runoff due to irrigation. The ebb and flood system uses concrete floors so this mandate can be satisfied

Summary

The key to developing a healthy crop is having a well-run irrigation system that meets the specific needs of each plant. Knowing how and when to water, avoiding moisture stress and overwatering, and determining the best irrigation method help the greenhouse owner maximize yield and profit.

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Unit IV - Plant Growth

Lesson 4 - Nutrients

Without nutrients, plants would not grow. This lesson identifies the impact of macro- and micronutrients, oxygen, hydrogen, and carbon and addresses the consequences if a deficiency occurs. Factors that affect availability of nutrients into the plant are also outlined.

There is a distinction between “plant nutrition” and “plant fertilization.” Plant nutrition indicates specific chemical elements that are available (absorbed) in the plant. Plant fertilization is a procedure of adding more nutrients to supplement the growing medium.

Effect of Nutrients on Plant Growth

All plant growth and development depend upon proper nutrition. Each type of plant needs adequate levels of minerals to grow at optimum rate. Insufficient and excessive amounts of nutrients adversely affect plant growth. Greenhouse plants need more nutrients than other agricultural crops. They also require applications of fertilizers as nutritional supplements to promote plant growth. (Fertilizers are discussed in the next lesson.)

Essential Nutrients for Plant Growth

The minerals that soil needs are divided into two groups: macronutrients (major nutrients) and micronutrient (minor, or trace elements). These minerals are actually forms of soluble salt. Table 4.3 lists these nutrients.

Table 4.3 - Essential Soil Macronutrients and Micronutrients

Macronutrients	**Micronutrients**
Primary	Iron (Fe)
Nitrogen (N)	Manganese (Mn)
Phosphorous (P)	Boron (B))
Potassium (K)	Copper (Cu)
Secondary	Zinc (Zn)
Sulfur (S)	Molybdenum (Mo
Calcium (Ca)	Chlorine (Cl)
Magnesium (Mg)	Nickel (Ni)
	Sodium (Na)

A <u>primary macronutrient</u>, *nitrogen*, which is found in chlorophyll and enzymes, is essential to growth. It helps the plant resist disease and sustain environmental extremes, such as drought and freezing. Nitrogen is recycled within the plant. Plants absorb nitrogen as nitrate ions - its inorganic form. By becoming part of the plant’s

Unit IV: Plant Growth

Lesson 5: Fertilizer

Fertilizer nurtures healthy plant growth. Because each plant requires different macro- and micronutrients, the amount and formulation of fertilizer vary accordingly. This lesson highlights features of a fertilizer management plan, identifies sources and forms of fertilizer, details aspects of a fertilizer analysis, and describes techniques for applying fertilizer.

Fertilizer Management Plan

The purpose of a fertilizer management plan is to prevent and correct nutritional deficiencies. A well-managed program makes plants more resistant to disease and improves their appearance. It also ensures efficient, maximum growth, which increases the greenhouse operation's profits. To ensure abundant, healthy crops, this program should quantify the amount and frequency of fertilizer given and match specific types of fertilizer to the unique nutritional needs of each plant. Fertilizer requirements vary per species and development at key stages: seedling/cutting, vegetative (foliage growth), and flowering.

Fertilizer Sources

Plant fertilizer is derived from organic and inorganic sources. <u>Organic</u> fertilizer, from once-living matter, is made from natural components (e.g., animal manure, decayed plants, and decomposed microorganisms) and processed elements (e.g., bone meal, fish emulsion, and sewage sludge). When these materials decay, only small amounts of nutrients are released into the medium. The precise amount is unknown, making uniform application difficult. To make certain that the soil receives enough nutrients, large quantities are required. For example, to equal the fertility provided from 100 pounds of inorganic fertilizer, 1 ton of cow manure must be added. This is costly, necessitates ample storage facilities, and requires personnel capable of managing this large quantity. Also, as organic residues break down, the rate of decomposition is extremely slow and variable. A gradual, irregular breakdown of organic sources does not foster healthy development. Plants require a steady supply of nourishment.

<u>Inorganic</u> fertilizer comes from synthesized mineral salts. Its concentration is greater than that of organic fertilizer. Therefore, overfertilization must be avoided to prevent injuring the roots and burning leaf tissue. Inorganic fertilizer releases nutrients rapidly and is readily available to the plant. It disseminates evenly throughout the growing medium

Available Forms of Fertilizer

Fertilizer is available in several forms. <u>Slow-release</u> formulations offer significant advantages. Because greenhouse-grown crops are frequently watered, nutrients are leached from the growing medium. But thanks to industrial processes that coat particles of slow-release fertilizers, the rate of releasing nutrients into the medium is prolonged. Plants thus receive a steady food supply. In addition, this form of fertilizer is less likely to burn the plant. A commonly used slow-release fertilizer is Osmocote, in which fertilizer particles are covered with a plastic coating. The thickness of this coating depends upon the fertilizer analysis (discussed below). The plant's roots gradually absorb a small amount of the Osmocote fertilizer solution.

<u>Granular</u> forms can be mixed into or applied on top of the growing medium; some are dissolved in water before application. They are available as

stakes or tablets and placed directly into the medium.

Liquid or dry forms of fertilizer can be injected into the irrigation system (fertigation); the amount used is measured in parts per million (ppm).

Fertilizer Analysis

The proportion of nutrients in the fertilizer formulation (called fertilizer analysis) is the percent by weight of each element, as analyzed by chemical laboratories. This helps the greenhouse owner select the appropriate fertilizer formulation for specific plants. The quantity of fertilizer used is based on this chemical analysis. A "complete" fertilizer contains three macronutrients: nitrogen (N), phosphorous (P), and potassium (K). The fertilizer label lists the percent of each of these elements in the following sequence: N-P-K. For example, a bag of fertilizer labeled 20-17-16 denotes 20% nitrogen, 17% P_2O_5, and 16% K_2O_5. Other nutrients may be included.

Calculating the Amount of Fertilizer

In their original formulations, dry and liquid fertilizers are concentrated and must be mixed with water at a specified ratio. It is important to check the dilution ratio of each fertilizer and then calculate the amount needed for the mixture. The fertigation equipment has to be calibrated so it delivers the proper dilution ratio.

Concentration rates are calibrated in parts per million, as calculated by the following formula:

$$\frac{\text{desired ppm}}{\text{percent of active ingredient X 75}} = \frac{\text{\# oz}}{\text{100 gallons water}}$$

- Multiply the percent of active ingredient in the fertilizer by 75 (a constant).

- Divide this number by the ppm needed. This number represents the number of ounces of fertilizer per 100 gallons of water necessary to produce the proper concentration.

To mix smaller amounts of fertilizer, use a proportion. First determine the correct number of ounces per 100 gallons, as indicated above. Then use the following formula:

$$\frac{\text{\# oz}}{\text{100 gallons of water}} = \frac{\textbf{?}}{\text{calibration ratio}}$$

- To find the unknown number of ounces (**?**), divide by the total calibration ratio. For example if the calibration ratio is 1:13, the denominator is 14.

- Cross-multiply to solve for **?** (the unknown number of ounces). The result represents the number of ounces of fertilizer to add to 1 gallon of water in order to create a solution with the correct ppm.

Applying Fertilizer

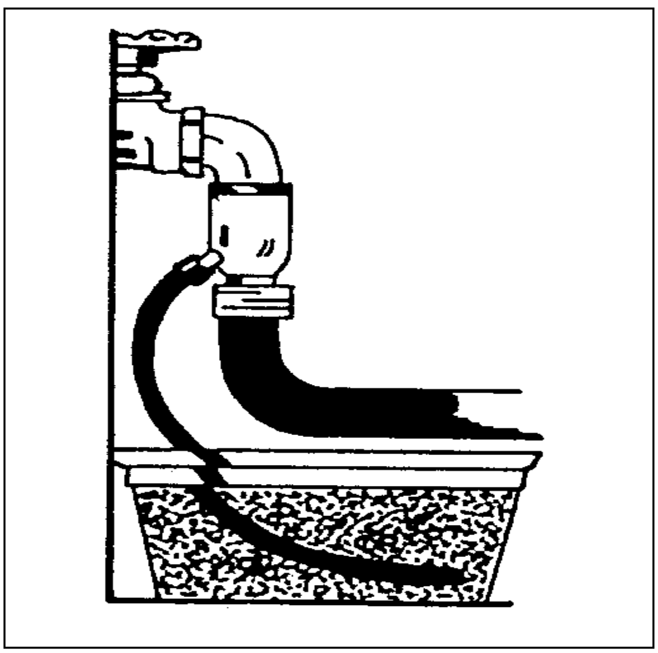
When applying fertilizer, it is essential to follow directions for a given formulation carefully, especially concerning the amount and frequency of fertilization. Insufficient fertilizer applied infrequently creates nutritional deficiencies. Excessive fertilizer applied too often is detrimental to the plant. As a general rule, the growing medium must be moist before applying fertilizer. If fertilizer is applied to a dry medium, it injures the roots.

When dry granular or liquid fertilizers are dissolved in water and applied to plants, the nutrients rapidly leach from the growing medium and are immediately absorbed by the plant's roots. Because they act so quickly, these formulations may require reapplications. But caution is required; the greenhouse owner must not apply too much of these fertilizers.

Applying low concentrations of fertilizer with each watering is a common technique. When watering, provide a balanced fertilizer to meet the needs of each plant. If the irrigation promotes sufficient drainage, no fertilizer salts will accumulate, which could harm the growing medium. A constant feed system that supplies nutrients at every watering or every other watering is generally the best irrigation method.

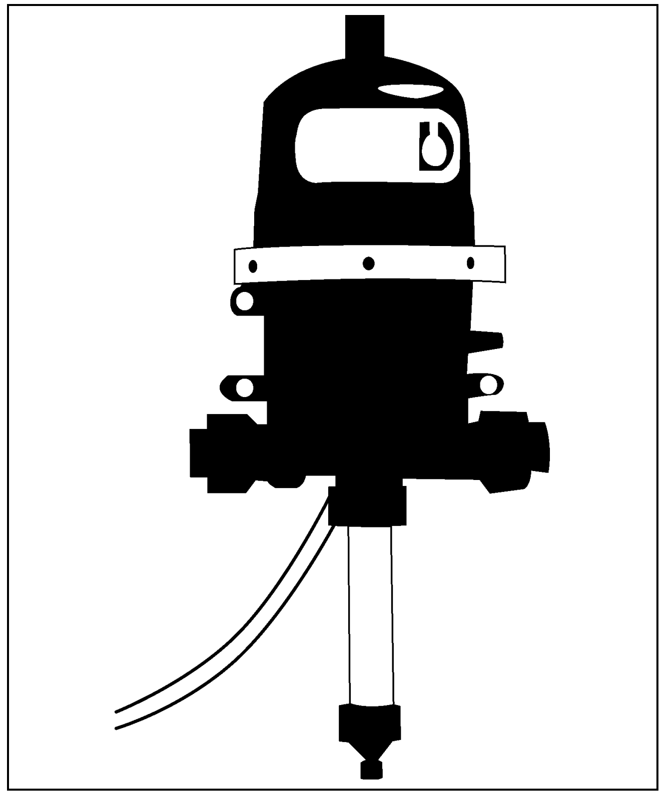
Another method of applying fertilizer is to use a hose-siphoning device. A siphon is positioned between the water outlet and hose. A narrow tube extending from the siphon is placed in the fertilizer solution. Through the force of suction, fertilizer is drawn from the solution into the tube and the stream of water. See Figure 4.12. This method is easy and inexpensive. The calibration ratio usually ranges from 1:12 to 1:16.

Figure 4.12 - Hose-Siphoning Device Used to Apply Fertilizer



Another type of device is the dosmatic injector, as illustrated in Figure 4.13.

Figure 4.13 - Dosmatic Injector



Summary

Maintaining an effective fertilizer management plan helps the greenhouse owner cultivate healthy, productive crops. Different formulations are available to accommodate nutritional needs of each plant. Calculating the correct ratio of concentrated fertilizer to water is critical. When applying fertilizer it is important to follow directions on the label. Over- or underfertilization harms the plant. Several methods for applying fertilizer are available.

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