FRIDAY MORNING SESSION

December 9, 1972

The Friday morning technical session, which was preceded by the business meeting, convened at 10:00 a.m. in the Terrace Room of the Hartford Hilton Hotel. Mr. Lawrence Carville presided.

LARRY CARVILLE: The systems of watering in plant propagation is something with which we are all concerned. We know that there is a requirement for water in a medium without roots, but we also realize that water in moderation is a requirement of success in propagation. To apply water there is the outmoded system of the hand-held sprinkling hose, the bell jar, or modifications of these. We also have the more sophisticated electronic leaf and other types of electronic controls to keep the cuttings in a high humidity situation for plant propagation. We must be cognizant of the needs of the plant for water. What is the relationship between the medium, the plant, and the quality of water which we should be applying?

To begin this morning's session, we are going to have what would constitute a classroom lecture on soils, plants and water by Dr. Bob Langhans of Cornell University.

SOILS, PLANTS AND WATER[1]

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There are many differences to consider as one makes the transition from field to container growing. The soil is shallower, there is less volume, the soil is amended and watering and fertilization are drastically changed. You should have a basic understanding of the relationship of soil moisture and aeration. We will not give you any formula for a soil mix nor any water scheme or schedule. Unfortunately, each situation, each plant, each grower is a different problem and they can be solved usually in different ways. This is a management decision and it is up to the manager. We hope to give you the information for making the proper management decisions.

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[1] The slides shown in this presentation were prepared by A. Spomer and V. Langhans and the information in the paper is from a series of articles on the subject by A. Spomer and R. Langhans published in the **Florists' Review**, Vol. 149, No. 3850: 63-64, 120; No. 3851:24-25, 61-64; No. 3853:32-33, 78-81; No. 3854: 36-37.

THE NATURE OF PLANT WATER

Water is the most important nutrient needed by plants for growth and activity. Plants consist almost entirely of water From 80 to 95% of the weight of actively growing plant tissue and of most herbaceous tissue (soft tissue such as leaves and flowers) is water. If a large tin can is weighed, filled with water and reweighed, it is found to contain about 90% water (by weight). Therefore, plants are literally living, growing containers of water. Water is more than just an inert filler in plants; it probably influences every plant activity. Plants not only contain a lot of water; they also often use hundreds of times this amount during growth. An herbaceous plant weighing 200 grams (one gram is 1/28 ounce) probably contains about 180 grams of water(90%) and may have absorbed over 100 times 180 or 18,000 grams during its growth, the actual amount depends on plant and environment. Plants and life in general cannot exist without water!

Plant water content averages about 90%; however, the actual range of water contents in different plant tissues can vary from less than 5% to more than 98%. Most plant water occurs in cells; water is found also in the cell walls and open spaces between cells. Living plant cells usually contain 95 to 98% water. The living part (protoplasm) usually consists of about 95% water, and the vacuole, a sap-filled cavity in the protoplasm, consists of about 98% water. Cell walls apparently have a relatively low water content, usually less than 40%. Water in the open spaces between cells (intercellular spaces) occurs as a vapor filling the spaces and may also occur as a thin film wetting cell surfaces. Intercellular water is normally a very small part of the total weight (about 0.002%). The actual amount of cell, cell wall and intercellular water depends on the plant species, tissue, growth stage and environmental conditions. Herbaceous tissues generally contain more water than woody tissues (90 vs 40 to 80%), younger, actively growing tissues, such as root and stem tips, usually contain more than older, nongrowing tissue (90 vs 70 to 85%), and vegetative tissues usually contain more than seed (80 to 95 vs 5%).

If all of the solid material in a plant could somehow be made invisible so that only the plant water were visible, it would be seen that the plant's form would not be visibly changed and that water actually forms a continuous phase throughout the plant. This continuous water phase is probably the most important aspect of plant water distribution. The behavior of water in plants is primarily due to this continuous water phase, which makes the plant little more than a water pipeline from the soil to the atmosphere. Water has very strong cohesive properties (molecules stick together strongly) The strong cohesive properties of water in this pipeline means that if water is pulled into the leaves, this pull is transmitted rapidly through the plant to the roots, in other words, water behaves almost like a chain or rope extending through the plant, and a pull or tension on one end is transmitted through the water phase to the other end. Water in one part of the soil-plant-atmosphere system therefore can rapidly influence water in the other parts; the water status of the roots can influence the water status of the shoot and vice versa.

Movement of Plant Water. The path of water through plants begins where it is absorbed from the soil and ends where it is evaporated into the atmosphere or incorporated into plant tissue. Water is absorbed from the soil through plant roots.

The root hair zone, just behind the root tip, seems to be the area most permeable to water; older root tissues often become water impermeable Water moves radially across the outside part of the root (epidermis and cortex) through cells, cell walls and intercellular spaces until it reaches the inside part of the root (endodermis and stele). Water movement across the endodermis apparently occurs only through cells and not through cell walls or intercellular spaces. The permeability of cells to water depends on cell physiological activity. The physiological activity of the root can therefore directly influence the rate of water absorption. Soil and plant nutrient, soil aeration, soil temperature, soil salinity, soil pH and soil pathogens all influence water absorption by affecting root physiological activity. Once water penetrates the inner part of roots and enters the translocation system (vascular system), it is easily and often rapidly translocated throughout the plant. Most of the water absorbed by plants is translocated to the leaves, where it evaporates or diffuses out of the leaf cells into intercellular spaces, through these spaces to tiny holes in the leaf surface (stomates) and out of the leaf into the atmosphere. Leaf surfaces are coated with a waxy, water-impermeably layer (cuticle); so water is lost from the plant almost entirely through the stomates. This evaporation of water from plants is called transpiration. Stomates on most plants open in the light and close in the dark or when the plant loses turgidity (wilts). The large, permeable surface of the leaf is very efficient for photosynthesis but is very inefficient in relation to water because it permits easy and rapid loss of water.

Since water exists in a continuous phase throughout the plant, a pull or tension exerted on water in one part of the plant is rapidly transmitted through the continuous water phase to other parts, resulting in a tendency for water to move into the part where the pull or tension is exerted. A general term describing the pull or tension which causes water to move is water suction (also called water potential, water tension, diffusion pressure deficit, etc.). The term **water potential**, which is analogous to water suction, has recently been adapted by researchers because it is a more precise term describing the status of plant water and will therefore eventually replace the older water suction terminology. In general, water moves from lower to higher suction (in the direction of the greater pull) Water suction in plants is primarily caused by the attraction of water to plant solids and solutes. When water is lost from the leaves by transpiration, the water suction in the leaves increases. Water suction in plant tissue also increases as cells accumulate salts and other soluble materials. When the suction in the leaves and other tissues increases, water begins to move into these tissues from tissues, such as the stem and root, which have a lower water suction. This water movement in response to suction differences is called passive water movement. Active water movement, which involves some sort of physiological pumping mechanism, has also apparently been observed in some plants but is apparently of minor importance in most plants.

Water movement in plants is controlled by soil, plant and atmospheric factors. Water loss depends on the tendency and ability of water to move from the plant to the atmosphere; this tendency is influenced by atmospheric water suction (relative humidity), plant water suction and plant stomates and cuticle. When the atmosphere is dry (low relative humidity = high water suction) and the plant's stomates are open, plant water loss will be high. Air movement also affects water loss. Water absorption depends on the tendency and ability of water to move from the soil to the plant; this is influenced by soil moisture availability, root permeability and plant suction. In general, water at the root surface will be absorbed when it is at a lower soil water suction than plant water suction.

Function of Water in Plants. Because plants consist almost entirely of water, every plant activity is probably influenced by water. Water has several direct functions in plants. Water functions as a hydraulic agent which maintains cells in a fully expanded condition (turgid) necessary for growth in size and for support. During growth, water enters cells, exerting pressure which stretches the walls, causing the cells to grow larger like expanding ballons. Water also functions as a solvent and transport agent in which all material, including nutrients, gases and plant products, move into and throughout the plant. Water is the main constituent of the cell protoplasm where it not only functions as a filler or dispersant but also as an important structural component. All life activities take place in this protoplasmic water solution. Proteins and enzymes are molecules in the protoplasm that regulate and direct life processes. Their functioning depends on the molecular structure. Water is normally bound to these molecules as part of their molecular structure. When water is withdrawn, their structure and function apparently change. Water also functions as a biochemical reagent in many physiological reactions. The most significant example is as one of the raw materials utilized by plants in the production of food (photosynthesis).

In addition to these direct functions of water in plants, water indirectly influences growth by helping to regulate plant temperature and conditioning the plant's environment (ie, soil physical, chemical and biological character).

Plant Water Deficiency. Plant water deficiency occurs whenever plants require or lose more water than they absorb over a period of time; this is often called plant water stress. Both water content and suction change during a plant water deficiency, and the size of their change depends primarily on the severity and duration of the deficiency. Water content changes are usually relatively small (5 to 15 percent), and water suction changes are often very large.

In general, during a period of plant water deficiency (water stress), plant growth processes are reduced directly or indirectly by a lack of water. A plant water deficiency affects growth in several ways; the overall effect depends on the severity and duration of the deficiency and on the plant species, part, growth stage and preconditioning. The initial effect of a water deficiency is a decreased water content or loss of turgidity and an increased water suction. This causes a reduction or stoppage or even reversal of expansion growth, loss of tissue support or wilting, closure of stomates which stops or slows carbon dioxide-oxygen exchange indirectly influencing photosynthesis and an increase, a decrease or no change in water movement, depending on the availability of soil water and on closure of the stomates. Most metabolic processes such as photosynthesis, respiration, protein synthesis and others are influenced directly or indirectly by decreased plant water content or increased plant water suction. Under prolonged or severe conditions of water stress, cells and tissue may be permanently injured or changed in other ways. Most plants adapt to repeated or prolonged water deficiency and become more able to survive subsequent periods of water stress. In some plants these changes may actually enhance product quality; water stress may result in higher sugar or other specific substance content, less succulent tissues, etc. Water stress also apparently sometimes hastens flower initiation, breaking of dormancy, flower development and onset of dormancy; delays flower initiation, flower development and breaking of dormancy; increases fruit size; decreases fruit size; changes plant morphology, and has many other effects, depending on the plant species and on conditions preceding, during and following the period of water stress. In all cases of water deficiency, however, overall plant growth is usually reduced.

THE NATURE OF SOIL MOISTURE

The soil is a kind of reservoir that stores water and other nutrients for plant use. Water is stored in this reservoir in three different forms; it is stored as solid, liquid and gaseous water. The solid form, called bound or hygroscopic water, is a thin water layer held so strongly to soil particles that it behaves like ice. The gas form is the humidity in the soil air. The liquid form, called soil moisture, wets particle surfaces and fills soil pores.

Soil moisture contains a small amount of dissolved minerals, gases and organic matter and is therefore also called the soil solution. The amount of dissolved material in the soil solution varies with soil physical, chemical and biological conditions and also with the addition of fertilizer and organic matter but is normally relatively small.

The amounts of solid, gaseous and liquid water in the soil depend on soil type and conditions. The solid and gas forms of soil water normally consititute much less than 1% of the total soil mass and are therefore not important sources of water for plants. Liquid water, however, often constitutes more than 30% of the total soil mass and is therefore the most important source of water for plant use. Liquid water is also the form that has the strongest influence on the soil physical, chemical and biological character.

Soil Moisture Retention. Water is held in the soil reservoir because it can stick to soil particles and to itself. The soil solution wets or adheres to soil particle surfaces and is also trapped or held in soil pores by a combination of adhesion to soil particles and cohesion to other water molecules. These cohesive and adhesive forces result in surface tension that forms a tightly stretched skin of water across pore openings. This surface tension skin tends either to hold water in or out of the pores. This combination of adhesion and cohesion of soil moisture, commonly called capillary activity, can also pull water into pores. Most water is held in soils by capillary activity.

The strength of soil water retention can vary tremendously between soils or within a given soil as conditions change. A measure of the strength of soil water retention is called soil water suction. The greater the soil water suction, the stronger that water is held in soils and the harder it is for plants to absorb it.

Suction. Soil suction is therefore a measure of the ease of water absorption by plants, called soil moisture availability.

Soil water suction actually is the combined result of different factors. Matric suction, the attraction of water to soil particles, and osmotic suction, the effects of solutes, are usually the most important suction components in relation to plants. Matric suction normally controls the physical status of soil water (movement, retention and content) and is therefore probably the most commonly measured component (measured with tensionmeters). Osmotic suction occasionally becomes dominant as demonstrated by the wilting of plants immediately following excessive soluble fertilizer applications or under high salt conditions. When this happens plants cannot absorb water from the soil and water may even be drawn out of the plant back into the soil (high salts may also have a toxic effect on plant growth not related to the osmotic effect).

Various terms commonly used to describe soil moisture retention are listed in part A of the Glossary. Since container soils are shallow, the term moisture equivalent usually has no practical application for these soils (explained in section on soil moisture distribution). Water retained in soils between zero suction (wet) and wilting coefficient (dry) can be absorbed by plants and is therefore available soil moisture.

Soil Moisture Content. Soil moisture content is the amount of water held in the soil reservoir. Water is held primarily in the soil pores; so the total amount and size distribution of soil pores, which are determined by soil texture and structure, affect the amount of water retained. Soils with smaller pores usually contain more water following irrigation and drainage than soils with larger pores. Finer-textured, less-compacted soils usually have greater surface area, greater total porosity and small pores and therefore greater water content than coarser-textured, more-compacted soils. Porosity is also usually greater in soils of one particle (clay or silt or sand) than in a well-graded soil (mixture of clay and silt and sand).

Soil texture and structure are not the only factors controlling soil water content. Matric suction is the primary factor influencing the water content within a particular soil. Two identical soils having different matric suction levels will contain different amounts of water. The relationship between matric suction and soil water content is called the soil moisture characteristic. As soil water content decreases, matric suction increases; as the soil dries, water becomes more strongly held. Each soil has its own specific moisture characteristic; this is probably the most important soil physical character a horticulturist can know.

Various terms commonly used to describe soil moisture content are listed in part B of the Glossary. All of these terms can be correctly used to describe container soil conditions except field capacity. Shallow field or container soils normally never reach field capacity during drainage (see section on soil moisture distribution). The soil water content between field capacity or container capacity and permanent wilting percentage can be absorbed by plants and is therefore available soil moisture.

Soil Moisture Movement. Only part of the water applied during irrigation stays in any single part of the soil; the rest moves or drains downward (called saturated or gravitational water movement). The gravitational force on water, its weight, pulls it downward, mostly through the larger soil pores. The rate of gravitational water movement depends on the size and total amount of soil pores; drainage is more rapid and complete in coarser-textured and less-compacted soils (ie, sand). Movement of the liquid water retained in the soil reservoir is called unsaturated or capillary water movement. Capillary suction forces can pull water in any direction through adhered water films and water-filled pores, always from areas of lower to areas of higher suction. The size of the water film, the amount of water-filled pores, the water path length (all depend on texture, structure and suction) and the suction gradient (part A Glossary) all influence the rate of capillary water movement. Capillary water movement is generally greater in wetter, finer-textured, more-compacted soils. Water movement through the soil as vapor is insignificant in relation to plant water use.

The initial distribution of water throughout the soil reservoir is by gravitational water movement during irrigation. Secondary or horizonontal distribution of water throughout the soil occurs by capillary water movement; this is how water absorbed by plants moves to the roots.

Soil aeration, which also influences poor water absorption, depends on the completeness of drainage; a well-drained soil will have better aeration than a poorly drained soil. In all of these ways, soil moisture movement influences soil moisture availability.

Soil Moisture Distribution. Water is not always distributed uniformly throughout a soil following irrigation. When a deep (field) soil is irrigated, it usually does not drain to a relatively uniform water content throughout most of its wetted depth (field capacity). Shallow container soils also drain to a certain water content following each irrigation, called container or depth capacity; however, in shallow containers the water content is different at different soil levels. When drainage from a shallow soil cease, the bottom of the soil is saturated (at zero suction) and the matric suction increases with height above the bottom (ie, at 10-cm height, matric suction equals approximately 15 cm water, etc.). In other words, immediately following drainage, the top of a shallow container soil is usually drier than the bottom. The actual distribution of water depends on the soil depth and the soil moisture characteristic.

Following irrigation, a coarser soil (sand) will probably be much drier at the top of a container than a finer soil (silt) and the coarser soil may not provide a good water supply for shallow-rooted plants whereas a finer soil probably will. A fine soil, however, might contain too much water, resulting in poor aeration; this, of course, depends on the soil moisture characteristic and soil depth.

THE NATURE OF SOIL AERATION

Soil aeration is the exchange of oxygen and carbon dioxide between the soil and aboveground atmospheres. These gases move in the soil primarily through the soil atmosphere; the soil atmosphere is the part of the soil volume not filled by solid or liquid phases. The solid phase (soil particles) does not completely fill the soil volume; openings left between particles are called soil pores. The liquid phase (soil moisture) adheres to particle surfaces and is held in the pores; the pores may be partly or completely filled with water. Aeration occurs primarily through nonwater-filled or open soil pores (the soil atmosphere or gas phase).

A microscopic view of the soil would show a network of interconnecting, irregular tubes or tunnels formed by soil pores honeycombing the soil structure. Oxygen and carbon dioxide move into, throughout and out of the soil through this pore network. Adequate aeration requires sufficient open or unblocked tunnels in the network to permit free gas exchange between the soil and aboveground atmospheres and free gas movement throughout the soil. Aeration tunnels can be blocked by soil particles or water. Most soils consist of a mixture of different-size particles; the proportions of the different sizes (percent of sand, silt, clay) determine soil texture. A packed, unstructured, single-particle-size soil contains about 27 percent (by volume) pore space. A packed, graded (mixture of sand, silt, clay) usually contains less pore space; this is the reason several particle sizes are mixed and packed to prepare strong, stable earth fill roadbeds and dams. This pore space reduction in a well-graded soil can be considerably modified by soil structure (grouping of individual particles into single, large particles or structural units). A compacted, well-graded, unstructured soil tends to have a large proportion of blocked or dead-end aeration tunnels. As soil water increases, open pore space decreases; smallest pores tend to fill first followed by increasingly larger pores until all are filled (saturated soil). Soil water, texture and structure interact to determine the rate of soil aeration. In general, aeration is greatest in uncompacted, well-structured, coarse-textured and low water content soils.

Soil temperature, soil biological activity, irrigation and aboveground atmospheric pressure changes also influence soil aeration. Temperature affects oxygen and carbon dioxide movement and biological activity. As soil temperature increases, gas exchange and biological activity increase. The rate of biological activity determines oxygen utilization and carbon dioxide production rates. In general, the higher the rate of biological activity, the higher the rate of oxygen utilization and carbon dioxide concentrations. Soil oxygen and carbon dioxide concentrations can each vary about 0 to 21% (the total of the two is always 21%) depending on aeration and biological activity. When a container soil (pot, planter, bench, etc.) is irrigated by flooding the surface, much of the existing soil atmosphere is purged or pushed from the soil by the water and replaced by aboveground atmosphere gases as the soil drains and dries. In some cases, a significant amount of aeration occurs by gases carried into and out of the soil, gases dissolved in irrigation water. Aboveground pressure changes — for example, those caused by turbulent air movement across the soil surface (wind pulses) tends to pump gas in and out of the soil. The relative importance of soil temperature, biological activity, irrigation and pressure changes to soil aeration varies from soil to soil and depends on plant and soil properties.

Soil Aeration and Plant Growth. Soil aeration affects plant growth dirctly by affecting root growth and physiological activity. Roots help support the shoot and attach the plant to its soil nutrient reservoir. Roots absorb all mineral nutrients and water used by the plant; root growth gives the plant a continuously expanding access to the soil nutrient reservoir, and root physiological activity determines mineral and water absorption rates. Roots act as storage organs and synthesizers of specific substances essential for normal plant growth; these root functions also are controlled by root growth and physiological activity. Roots are an extremely important part of the plant, and any factor affecting root growth and physiological activity ultimately affects the growth of the whole plant.

Normal root growth and physiological activity require a supply of oxygen and removal of carbon dioxide. All root functions require an energy source; this energy is provided by respiration (physiological conversion of plant foodstuffs). Oxygen combines with the food, resulting in the production of available energy, waste by-products (carbon dioxide and water) and other products. An oxygen deficiency retards respiration and root physiological activity. A high carbon dioxide concentration also retards respiration and may have a toxic effect on the roots. Some plants are capable of transporting sufficient oxygen for root respiration through the plant structure (leaves, stems, roots) from the aboveground atmospher however, in most cases soil aeration is the process responsible for oxygen supply and carbon dioxide removal from plant roots.

Two facets of soil aeration important to plant growth are: (1) The oxygen supply rate and (2) carbon dioxide concentration. Poor aeration can be defined as the limiting of root physiological activity or root damage due to deficient oxygen or excessive carbon dioxide. The limits of oxygen and carbon dioxide defining poor aeration in any specific situation depend on plant, soil and environmental factors. The severity of poor aeration damage to plant growth depends on the degree, duration and frequency of poor aeration and on plant species, growth stage, prehistory and aboveground environment. The damage is usually severest when poor aeration occurs during the early stages of plant (fruit, flower and leaf) development and when it is frequent or prolonged. Poor aeration symptoms include: (1) Shoot yellowing (chlorosis) caused by deficient mineral nutrient absorption or plant growth substance production; (2) wilting caused by deficient water absorption (espicially noticeable on sunny days following cloudy periods); (3) wilting during drought caused by shallow or reduced root growth; (4) abnormal, twisted shoot growth (epinasty), stunted shoot growth, and eventual tissue browning and death caused by a lack of water and mineral nutrient absorption; (5) abnormal root anatomy and morphology (abnormal multiple branching, growing up out of the soil, etc.), and (6) dead or injured roots. The overall result of poor soil aeration is reduced plant and crop growth.

Aeration may also influence plant growth indirectly by affecting the soil chemical character and by providing an environment favorable for undesirable soil microorganism (including pathogens) development.

SUMMARY AND CONCLUSIONS

Soil aeration is the exchange of gases, primarily oxygen and carbon dioxide, between soil and aboveground atmospheres. Soil aeration occurs through the network of interconnected open pores honeycombing the soil bulk. Soil texture, structure, moisture, temperature, biological activity and aboveground atmospheric pressure changes all affect the efficiency of the aeration network. The best aeration usually occurs in uncompacted, well-structured, low water content, coarse-textured soils.

Soil aeration affects plant growth directly by affecting root growth and physiological activity and indirectly by affecting soil chemical and biological character. Both the oxygen-carbon dioxide exchange rate and carbon dioxide concentration are important in relation to plant growth. Plant requirements for aeration vary with plant, soil and aboveground conditions. Symptoms of poor aeration depend on the plant and the severity of the poor aeration; in all cases, the overall effect is reduced plant growth and crop production.

It would be impossible to develop a cookbook prescribing cultural recommendations for optimum aeration in every specific situation. Not enough is known about plant aeration requirements, and it would be impossible to completely characterize all the plant environment factors which influence aeration. It is doubtful that an aeration meter will ever be developed to measure soil aeration in the same way a tensionmeter is used to measure soil moisture status. Adequate soil aeration in most agricultural situations is guaranteed through management practices developed primarily from practical experience. Because growing plants require both adequate soil aeration and moisture, certain soil conditions for crop production are sought, conditions which tend to maximize both soil moisture supply and soil aeration through soil modification (tillage and mixture) and moisture control (irrigation and drainage). The best approach to soil aeration management is to start with a good soil. Soil structure, texture and drainage should be developed or modified so the soil contains sufficient open pores after irrigation to ensure adequate soil aeration; for containers (pot, planter and bench) this usually means a coarse-textured or structured soil with free bottom drainage (container soils are normally much wetter than field soils following drainage. Irrigation frequently can then be adjusted to provide maximum water supply, without causing significant periods of poor aeration.

GLOSSARY A

Soil Moisture Retention Terms

Suction — the pressure (force per unit area) required to remove water from the soil (expressed in energy, work or pressure units). Atmospheric pressure is set equal to zero suction as a reference point. (Soil moisture tension, soil moisture stress and water potential are analogous terms often used.)

Centimeter water (or centimeter mercury) — a unit of pressure or suction equal to the pressure exerted at the bottom of a layer of water (or mercury) one centimeter deep (1 cm water equals the weight of 1 gm/cm^2 and 1 cm mercury equals the weight of 13.6 gm/cm^2).

Atmosphere — another unit of pressure or suction equal to about 14.7 pounds per square inch. One atmosphere equals about 1,033 cm water or about 76 cm mercury.

Bar — another unit of pressure of suction equal to about one atmosphere (actually about 0.985 atmosphere).

Water table a soil condition where the suction equals zero (the soil is usually saturated).

Moisture equivalent — a soil condition where the matric suction equals approximately 1/2 atmosphere or 500 centimeters water suction (laboratory approximation of field capacity).

Wilting coefficient — a soil condition where the metric suction equals approximately 31 atmospheres (31,000 centimeters of water suction) (laboratory approximation of the permanent wilting point).

Suction gradient — a soil condition where one part of the soil has a lower suction than another part (water flows along a suction gradient from lower to higher suctions).

GLOSSARY B
Soil Moisture Content Terms

Water content — the amount of water in a soil (usually a percentage based on soil dry weight, soil wet weight or soil volume).

Saturation — a soil condition where the pores are filled with water (the suction usually equals zero).

Percent pore saturation — the percentage of the soil pore volume which is water-filled.

Field capacity — the water content of a deep (field) soil after 48 hours' drainage without any other loss of water (a characteristic of each soil).

Container capacity — the water content of a container soil following complete draining without any other water loss (an analogue of field capacity except it is a characteristic of both the soil and the container).

Permanent wilting percentage — the soil water content at which a plant can absorb sufficient water to keep from wilting even in a water-saturated atmosphere.

Water-depth ratio — the volume of water contained per volume of soil.

LARRY CARVILLE: That was an excellent presentation of some basic information about soil, water and aeration of the growing medium. This talk outlines many things which we should be thinking about in our own growing operations. Since all of the papers this morning deal with water, I am going to ask that you hold all questions until the end of the morning session since some of the speakers may cover questions which you would direct to Dr. Langhans.

Our next speaker is from Greenleaf Nursery in Oklahoma, where we will be visiting in two years; he is Dave Morrison and is going to tell us about their operation with overhead watering of containers.