Soil Moisture and Aeration

The Nature of Plant Water

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INTRODUCTION *Why is water important to plants?*

Water is the most important nutrient required by plants for their growth and activity. Plants consist almost entirely of water. Eighty to ninety-five percent 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 ninety percent 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. A herbaceous plant weighing 200 grams (one gram is $\frac{1}{28}$ 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, can not exist without water!

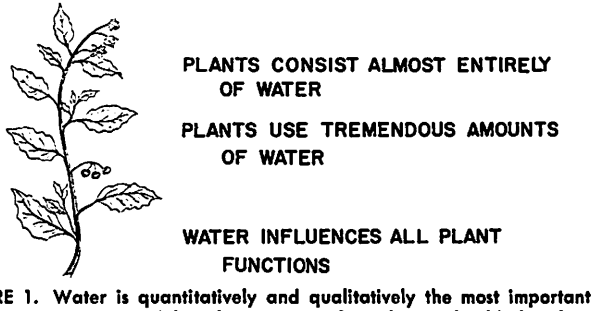

FIGURE 1. Water is quantitatively and qualitatively the most important nutrient required by plants. Every floriculturist should therefore know how water can affect plant growth.

Since water is quantitatively and qualitatively the most important nutrient required by plants, every floriculturist should know the nature and function of plant water and how it affects growth. This article, the second in a series on soil moisture and aeration (see NYSFG Bulletin 254), briefly considers the nature of plant water in relation to growth.

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THE DISTRIBUTION OF WATER IN PLANTS *Where is water in plants?*

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 also found in the cell walls and open spaces between cells (Figure 2). Living plant cells usually contain 95-98% 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 (*inter-cellular spaces*) occurs as a vapor filling the spaces and may also occur as a thin film wetting cell surfaces. Inter-cellular water is normally a very small part of the total weight (about 2/1000%). The actual amount of cell, cell wall, and inter-cellular water depends on the plant species, tissue, growth stage, and environmental conditions. Herbaceous tissues generally contain more water than woody tissues (90% vs. 40-80%); younger, actively growing tissues such as root and stem tips usually contain more than older, non-growing tissue (90% vs. 70-85%); and vegetative tissues usually contain more than seeds (80-95% vs. 5%).

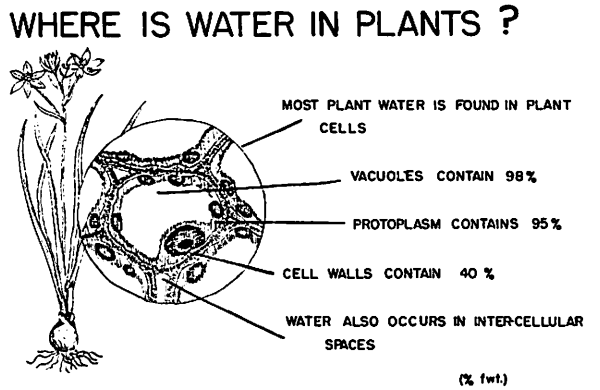

FIGURE 2. Plants consist almost entirely of water. Most plant water is found in the cells and the rest is found in the cell walls and inter-cellular spaces.

If all of the solid material in a plant could somehow be made invisible so that only the plant water could be seen, 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 (Figure 3). This continuous water phase throughout the plant 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

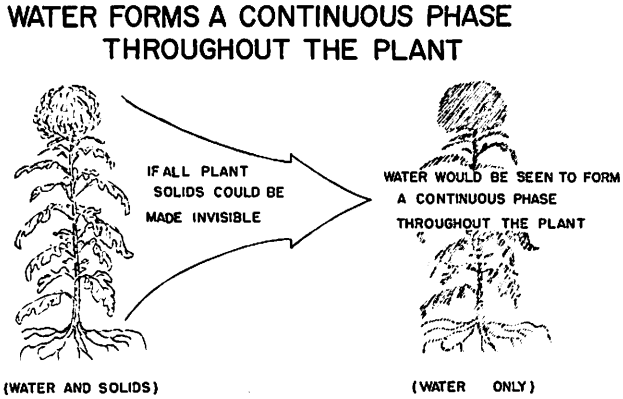

FIGURE 3. The most important aspect of plant water distribution is that it forms a continuous phase throughout the plant.

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.

In summary, water occurs in plant cells, cell walls, and inter-cellular spaces forming a continuous liquid phase throughout the plant. All plant parts are closely interrelated in terms of water relations.

THE MOVEMENT OF PLANT WATER *How does water move through plants?*

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 (Figure 4). Water is absorbed from the soil *through* plant roots.

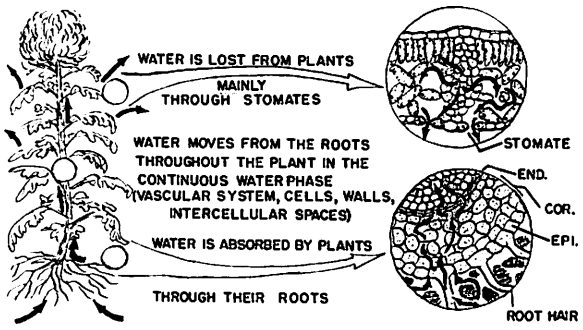

FIGURE 4. Water is absorbed through the plant's roots, translocated through the plant in the continuous water phase, and lost to the atmosphere through stomates in the leaves.

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 inter-cellular 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

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depends on cell physiological activity. The physiological activity of the root can therefore directly influence the rate of water absorption. Soil and plant nutrition, 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 inter-cellular 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 impermeable 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 the tendency for water to move into the part where the "pull" or "tension" is exerted. A general term describing this "pull" or "tension" which causes water to move is *water suction* (also called *water potential, water tension, diffusion pressure deficit,* etc.). *The movement of water through plants is actually in response to differences in the* energy status (capacity or ability to do work) *of water in different plant parts. The term* water potential, *which is analgous 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; however, the older terminology will be used in this series of articles because it is more familiar to horticulturists.* 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 humidiy = 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. These factors will be discussed in more detail in later articles in this series.

WHY DOES WATER MOVE THROUGH PLANTS ?

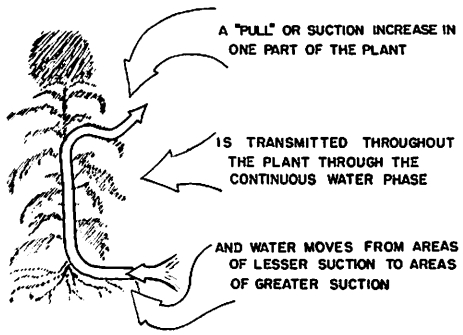

FIGURE 5. Water moves throughout the plant in response to suction differences in different plant parts.

In summary, water moves into the plant through the roots, throughout the plant in the continuous water phase, and out of the plant through the leaves. Water movement is caused by suction differences throughout the plant.

THE FUNCTION OF WATER IN PLANTS *What does water do in plants?*

Since 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 balloons. 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 their 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 psysiological reactions. The most significant example is as one of the

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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).

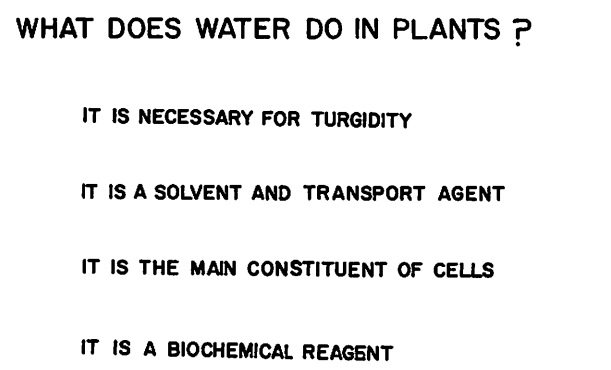

FIGURE 6. Water probably influences every plant activity.

In summary, water's main functions in plants are as a hydraulic agent, a solvent and transport agent, a protoplasmic constituent, a bio-chemical reagent, a heat regulator, and an environmental conditioner. All life depends on water!

PLANT WATER DEFICIENCY *How does a lack of water affect plants?*

Plant water deficiency occurs whenever plans 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 (5-15%) and water suction changes are often very large.

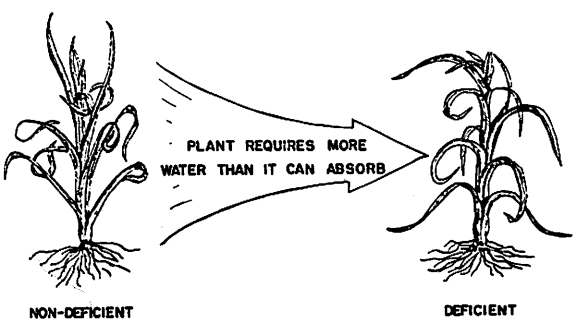

FIGURE 7. Whenever a plant uses and loses more water than it absorbs, a plant water deficit occurs.

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 pre-conditioning. 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, onset of dormancy, delays flower initiation, flower development, 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.

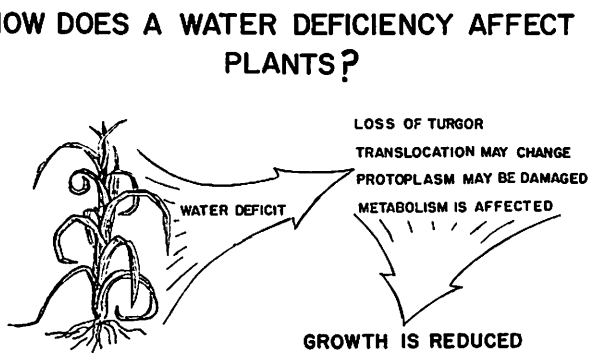

FIGURE 8. The overall influence of a plant water stress is reduced growth.

In summary, a plant water deficiency occurs whenever a plant requires more water than it absorbs. A water deficiency reduces plant growth (size).

SUMMARY AND CONCLUSIONS

Plants consist almost entirely of water and all plant activities are influenced by plant water. Water is the most important plant nutrient and a lack of it will reduce plant growth. In some instances, this may be desirable but decreased growth of most horticultural products usually means decreased product quality. In addition, water is a "vanishing" natural resource and is quickly becoming less available for horticultural use. It is therefore important that horticulturists understand how water can influence crop growth and how they can efficiently manage water

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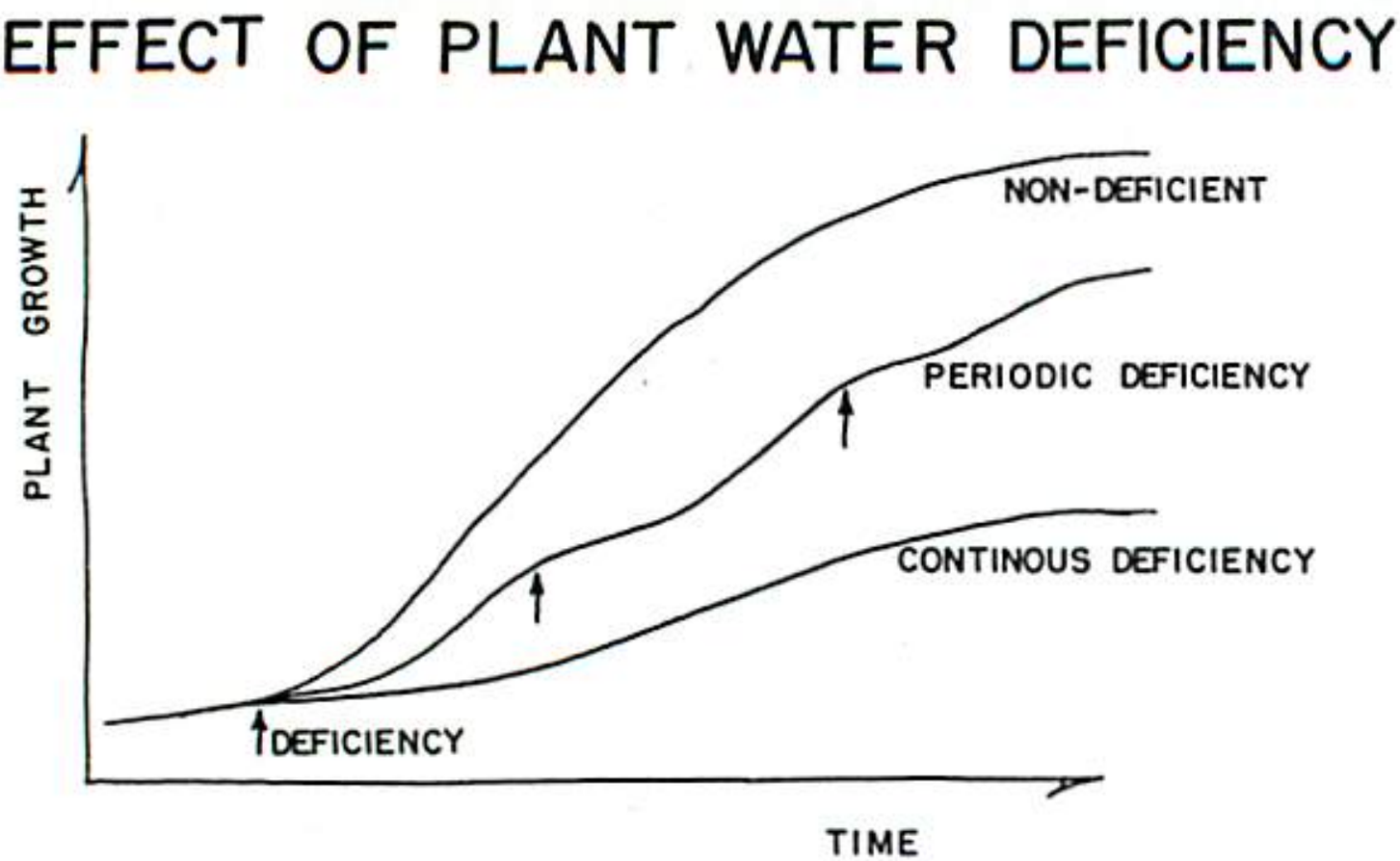

FIGURE 9. Diagram showing probable growth response of plants to water deficiency.

supply. It would be impossible to publish specific irrigation recommendations for each specific greenhouse situation, however, with an understanding of the basic principles involved, it is possible for each particular grower to acquire the knowledge necessary to develop his own irrigation program. It is hoped that this series of articles will help provide such an understanding of soil-plant-water relations.