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The Effects of Edaphic Parameters on the Application of an Electronic Moisture Controlling Device

John Michael Ruter

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Hendrik van de Werken, Major Professor

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THE EFFECTS OF EDAPHIC PARAMETERS ON THE APPLICATION OF AN ELECTRONIC MOISTURE CONTROLLING DEVICE

A Thesis
Presented for the
Master of Science
Degree
The University of Tennessee, Knoxville

John Michael Ruter
August 1986

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ABSTRACT

A main concern for producers of container grown plants is optimal water relations. Most problems occur because of poor physical properties of the media, container design, and poor irrigation practices.

The purposes of this study were (1) to determine the effects of container design on physical parameters of container media of differing bulk density and (2) to determine the effects of various edaphic parameters on the functioning of a new moisture controlling device (MCD), designed to optimize plant-media water relations.

Four container designs and four media were tested to determine the following factors: total porosity, water-holding capacity, air space, and bulk density. As bulk density increased for the four media, total porosity decreased. An experimental prototype container with a fabric bottom, placed on a column of sand, resulted in removal of the perched water table, therefore increasing air space in a given medium.

A newly developed moisture controlling device (MCD) was tested under laboratory and greenhouse conditions. The MCD was influenced by different media, soluble salt levels, and different moisture levels. The MCD responded well over the range of moisture found in container media and should prove to be useful under conditions where other devices fail. Water utilization of container grown *Coleus* was monitored using the MCD and it was found that media was the dominant factor in the time to wilting of these plants under greenhouse conditions. Milliampere readings on the MCD were highly correlated with percent water holding capacity remaining in a container, though influenced by soluble salt level and media.

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CHAPTER I

INTRODUCTION

Development of science and technology applicable to automation of container culture of ornamental plants is still in a beginning stage. New developments in this area should be geared towards increased automation and more precise quality control. Some aspects of conventional container culture such as maintenance of optimum water relations in containers and responsiveness of irrigation control systems need to be analyzed and modified in order to render automation and precise control feasible. Therefore, this thesis was designed to address the effects of container design and media on water relations and to address the feasibility of using a newly developed moisture controlling device to determine moisture levels in a container medium. If sufficiently reliable, this device could feasibly be used to control automatic irrigation systems, thereby optimizing plant growth by maintaining desirable water relations.

Irrigation is an essential requirements for the production of container nursery stock since container grown plants are strictly dependent upon a controlled supply of water (21). Container design and media influence water relations in a container (106). The composition of most potting mixes for container crops are designed to encourage good aeration and drainage because poor aeration of the growing medium has often been the limiting factor in growth and functioning of root systems in containers (68). Deep containers and coarse textured media improve aeration porosity and reduce water holding capacity. The opposite is true for shallow containers because the perched water table reduces the portion of the medium column with adequate aeration (88). The same perched water table exists in deep containers, but a greater portion of the medium column with adequate aeration is available to the root system of the plant.

Hand watering of container grown crops was the most widely used method of irrigation in wholesale nurseries for many years. However, reasons such as reliability and cost of labor, and improper irrigation techniques have led to the automation of irrigation systems (98). The purpose of good water management is to apply water at the frequency and in the amounts necessary to produce optimum growth (29). Excessive irrigation often results in poor aeration, waste of water and fertilizer, reduced plant growth, increased occurrences of root rot, and eventual death of plant material (42). Most irrigation or moisture sensing devices used for field soils are not suitable for container mixes. For example, tensiometers have been used successfully for container culture with some media but are inadequate in coarse or very porous media (38). Of the devices presently used for container irrigation control, few actually sense the moisture content of a medium, activate and control irrigation systems, and few are applicable to a wide range of soils and soilless media (100).

A new moisture controlling device developed at The University of Tennessee, Knoxville shows promise of overcoming these deficiencies. This series of experiments was designed to gain information on the effect of various edaphic parameters on the functioning and potential application of the device, and to study the effects of a new container design on water related edaphic factors.

CHAPTER II

EFFECT OF CONTAINER DESIGN ON THE PHYSICAL PARAMETERS OF MEDIA

Introduction

Growing media and container design are two factors which influence plant growth regardless of species when adequate water and air are present in the container medium (45). A problem associated with media and conventional container designs in nursery containers is decreased aeration due to development of a perched water table. The height of a container affects water distribution in a medium. Even when the container medium is fully drained or at container capacity, the bottom of the medium column is saturated. Water content of the medium decreases with increasing height above the bottom of the container (87). Characteristics such as porosity, bulk density, and water retention are different for deep, unconfined field soils compared to free draining potting mixtures (37). A new container bottom design utilizing a porous polyester fabric bottom has been shown to prevent development of the perched water table found in a conventional container. Thus, increased drainage and aeration can be achieved (82). Many researchers have reported physical parameters for a variety of media, but it has been suggested that air space values cannot be accurately reported for a given medium without regard for specific container size and shape, since drainage is influenced by container height (53). Therefore the purpose of this study was to determine the physical parameters of four media as influenced by container design.

Literature Review

The design of nursery containers has changed over the past forty years from clay pots and metal cans to the now common plastic and polyethylene containers. Modern plastic containers have numerous advantages over other types. They are sturdy, lightweight, reuseable, flexible, and require little storage space since they nest together (40).

In the 1960's, square and polyhedric containers were considered to have no advantages compared to the typical round container (67). Although square containers do not presently have large market acceptance, they are better suited for growing, lend themselves to mechanization, and should prove to be superior for over-wintering and various other production practices (20). Square containers have been shown to provide significant winter protection when bunched together for container grown nursery stock (81). Van de Werken (99) has designed a square container with numerous advantages such as winter protection, elimination of the perched water table, prevention of rooting-out, a low center of gravity, and a folding design which allows for compact packing.

Container design is known to affect the growth of plants. Growth is stimulated when there is a matching of container shape and the natural root growth pattern of the plant (10, 55). Top growth of plants often increases as container size increases (11, 96).

Poly bags have been promoted recently for use as containers (35). Advantages such as low cost, longevity, ease of storage, availability in many sizes, and availability with black or white outside surfaces have been noted (47). According to Whitcomb (107), plants grown in poly bags exhibit a 5 to 15% increase in growth, a sixfold increase of visible root tips, and greater braching of roots due to a root pruning effect.

The placement of a medium in a shallow container changes the air-water relationship because the medium column is not continuous as found in an unrestricted field soil. Therefore, a perched water table occurs at the bottom of the container (17, 106). Thus, more water is held in a container medium than in a similar medium in the field, especially in the lower portion of the container (112). This parameter has become known as container capacity and is expressed as the percent water by volume which is held by a medium in a container of a given depth with zero hydraulic head at its lower surface and in the absence of evapotranspiration (108).

In order for drainage to occur, the hydraulic pressure at the bottom of a container must be greater than zero. When drainage stops, suction at the bottom of the container will equal zero and the suction at the surface of the medium will be equal to the depth of the medium column (38). The retention of moisture in containers is a function of depth (73). As container height increases, air space increases and water-holding capacity decreases (5, 103). The placement of drainage holes can affect the physical properties of a medium, but the number and size of holes in plastic pots does not affect drainage (17). However, side holes are preferred to bottom holes which may become plugged and cause water logging of the root system or create rooting-out problems.

The function of a growing medium is to provide mechanical support, to supply water and essential nutrients, and to allow for the diffusion of oxygen to the roots (63). Reproducible growing media are necessary so standardized cultural practices can be utilized and consistent results obtained (49). The lack of standardization of growing media has been noted as one of the largest drawbacks in the nursery industry (23). Due to variability among media, individual management programs are necessary if comparable plant growth is to be realized (86).

Media components vary considerably in their texture and physical properties (64). Most container grown plants are produced in lightweight soilless media which are formulated to achieve desirable physical and chemical properties. Many media are a combination of two or more components (74). The pore size distribution of a medium influences water retention and drainage characteristics (71). As pore size decreases, water-holding capacity and capillary rise of water increase (106). Soil moisture which is available to plant roots is largely determined by pore size distribution and bulk density (94).

Physical and chemical properties of a medium are influenced by bulk density (93). Total porosity of media mixtures have been predicted by bulk density alone (39). When mineral soil particles are used, the influence of mixes on total porosity and water-holding capacity is not consistently predictable (29). Bulk densities of 0.75 g/cc or less are acceptable for container media (49), with a range of 0.4-0.5 g/cc being commonly recommended (16, 18). An average bulk density for a mineral loam soil having good physical properties is 1.1 to 1.4 g/cc (24). After irrigation, a medium must retain a sufficient quantity of water while still having adequate aeration.

Poor aeration of a growing medium is often the limiting factor in the growth and function of roots (68). Fluctuations in oxygen and carbon dioxide content of a medium are influenced by the moisture content, physical structure, management of the medium, and presence of roots and microorganisms (63). Total porosity is equal to the air space plus the water holding capacity at container capacity (32). A suggested acceptable value for total porosity is as high as 85% (22). Acceptable volumes of air space range from 1) 5% (29), 2) 10-20% (18), to 3) 20-35% (83). It has been suggested that air space should never go below 20% (57), while air space of 32-35% represents excessive drainage (106). If a medium has sufficient air space, the next most important parameter is the water holding capacity (4). On a volume basis, water holding capacity considered acceptable for container grown plants ranges from 1) 30-60% (73), or (2) 35-50% (18).

Two commonly used ingredients in container production are peat moss and sand (21). Peat moss is considered to be a standard component in nearly 90% of all mixes used in the nursery industry (51). Peat moss is a fairly uniform substrate which is relatively free of disease and nutrients. It generally has very high total porosity, high air space, and exceptional water-holding capacity (4) while having water release characteristics most suited for container plant production (41). However, peat moss in combination with pine bark and/or peanut hulls tends to reduce total porosity, air space, and decreased growth of some plant species (9).

Sand varies greatly in its physical and chemical properties. As a container mix component, the ideal particle size is 1/16 to 1/8" (65). Coarse sand was found to have no effect on air space, but fine sand decreased air space (76). Percolation rate was found to decrease in pine bark:sand mixes as percent sand increased (15) and total porosity was decreased in sand:soil mixtures because fine soil particles packed into the large sand pores (89). Addition of sand to container mixes was found to decrease total porosity, air space, and water available for plant usage (34).

Mineral or field soils can rarely be used as a growing medium in containers due to retention of excess water and reduced aeration

(38) caused by the small size of pores in clay substrates (63). After irrigation, the pores of field soils often remain filled with water thus restricting oxygen supply to the roots (38). Therefore it is often necessary to add large quantities of organic matter or coarse aggregrates in order to increase drainage and air space (63).

Pine bark has been used to a great extent in the formulation of nursery potting mixes in the southeastern U.S. because it is inexpensive, lightweight, uniform, reproducible, and generally available (69). Much work has been done on the development of pine bark: sand mixes based on screen analysis (72). Bark has been found to become waterlogged, especially in the lower part of a container, thus increasing moisture and causing a decrease in air space (78). Water is released by pine bark at low matrix suctions, thus a low water:air ratio occurs (33).

Pine and hardwood barks are common media components in many parts of the United States (7). Hardwood bark came into use during the 1970's because of its disease-suppressing properties (43, 62). Composting of hardwood bark is generally required before usage (44). Recent studies have shown that blending composted pine bark and hardwood bark produces pH, physical properties, and plant growth acceptable for container production (8). A 1:1 mixture of pine bark and hardwood bark resulted in increased air space and water holding capacity, thus providing better physical properties than either component alone (8).

Materials and Methods

The experiment was arranged as a completely randomized design with four media, four container types, and three replications. Four container designs were chosen to test various edaphic parameters. Each container was capable of holding 1 gallon or 3.8 liters of medium. The first container was a Zarn 400 (Z)(Zarn, Inc.), chosen to represent a conventional round polyethylene container. The second container was a black poly bag (PB) (Menne Nursery Corp.)

The next two square containers were designed and fabricated for this study. Both containers were made of 1/8" polyethylene sheeting which was cut in 6" by 24" strips and folded to make a cube 6" square. One container type (CS) had a solid black polyethylene film bottom (4 mil), attached to the container with Monsanto All-Purpose Tape. Two holes, 5 mm in diameter, were drilled at the base of each side, each two inches from the corner of the container. The fourth container (CF) was also a cube of 6", the bottom being made of porous Formax polyester fabric (0.01" by 0.005" mesh). The Formax fabric was attached to the bottom edge of the container by heat welding until the polyethylene melted and bonded with the fabric.

Four media were chosen to represent a wide spectrum of uses and bulk densities. The media were: Etowah loam, A-horizon mineral soil (EL); Pro-Mix BX, a commercially prepared floricultural mix (PM); a 3:1:1 mixture by volume of pine bark, sphagnum peat moss, and river sand (3-1-1); and a 1:1 mix by volume of pine bark and hardwood bark mixed before composting with nutrients added (1-1) (92).

Each medium was air dried for one week before the experiment was conducted. Each container was lined with a one gallon size (11 1/2" by 12 1/2") plastic food storage bag and weighed. 3000 cc of each medium was measured and placed in each container, with each container being tapped five times to allow for settling of the medium.

Then 1400 cc of water containing 0.1% Triton AG-98 (Rohm and Haas, Charlotte, NC) was added to each container. Triton AG-98 was added to aid in wetting the hydrophobic media particles. The plastic bags in the containers were sealed and the containers were allowed to equilibrate for twelve hours. At this time, the bags were opened and water was added to the media until the surfaces glistened of moisture. The amount of total water added (cc) determined the total porosity of each medium.

After sealing each bag, ten holes were punctured in the bottom of each bag. All containers were placed on an 18" column of sand and allowed to drain for twenty-four hours. After twenty-four hours of free drainage, the containers were at container capacity. Each container was then weighed using a Terraillon Manostat gram balance. Since one cc of water is equal to one gram, percent water-holding capacity and percent air space at container capacity were determined on a weight loss basis and expressed as percent of volume. The following formulas were used to determine the values present in this study:

BULK DENSITY (g/cc) = air dry weight/volume of medium

TOTAL POROSITY = WATER HOLDING CAPACITY + AIR SPACE

$$\text{TOTAL POROSITY (\%v)} = \frac{\text{cc of water needed to saturate a known of medium}}{\text{cc volume of medium}} \times 100$$

$$\text{WATER-HOLDING CAPACITY (\%v)} = \frac{\text{wt. of media at 24 hours} - \text{wt. of dry media}}{\text{1\% of volume of media}}$$

$$\text{AIR SPACE (\%v)} = \frac{\text{vol. of water at saturation} - \text{vol. of water held at 24 hours}}{\text{1\% of volume of media}}$$

Mechanical analysis to determine the % sand, % silt, and % clay for the EL medium was performed using the hydrometer method (12). Soil (EL) core samples were taken from the field and pore size distribution was determined using a tension table apparatus under 50 cm of water tension (79). The EL soil was also tested to determine low moisture tension release under 5 and 15 pounds of pressure using the porous plate method (79). Five and 15 pounds of pressure were used because 5 pounds = 1/3 bar = field capacity. Most container grown plants are irrigated before one bar of tension occurs, thus 15 pounds of pressure (1 bar) was used.

Results and Discussion

The data for the physical parameters of the Etowah loam, A-horizon soil are shown in Table 1. Using the hydrometer method, the textural category for the EL soil was determined to be a loam. Over one-third of the soil particles were classified as silt which is important because the silt fraction of most mineral soils

Table 1. Physical Parameters of an A-Horizon Etowah Soil

	Etowah A-Horizon Soil
Mechanical Analysis of Soil by the Hydrometer Method	
% Sand	42.3
% Silt	34.7
% Clay	23.0
Texture	Loam
Determination of Pore Size Distribution at 50 cm Tension	
% Macropores	9.0
% Micropores	50.2
Bulk Density	1.28
Determination of Moisture by the Porous Plate Method	
5 Pounds of Pressure	
% Moisture by Weight	21.6
% Moisture by Volume	27.6
15 Pounds of Pressure	
% Moisture by Weight	16.0
% Moisture by Volume	20.5

contributes greatly towards available water for plant usage. The bulk density (1.28 g/cc) was in the normal range for a productive loam soil.

The pore size distribution consisted of 9% macropores compared to 50.2% micropores measured at 50 cm water tension. Macropore water in container media is considered to be that which is held between 1-100 cm of water tension (14). Micropore water is that released at greater than 100 cm tension. Since the determinations were made at 50 cm of water tension, macropore space would be expected to increase if 100 cm tension had been used. Easily available water is that which is held between 10-50 cm water tension, which represents 75-90% of the total water available to plants (28). The parameters for testing mineral soils are different than for container media, thus 50 cm water tension was used as the standard for determining macro and micro pore space for the EL medium in this study. Percent moisture by volume was determine to be 27.6% and 20.5% at 5 and 15 pounds of pressure, respectively. Five pounds of pressure is equal to 1/3 bar, therefore being close to field capacity under natural conditions.

Bulk density for the four media used in this study was as follows: 0.19 (PM), 0.36 (1-1), 0.55 (3-1-1), and 1.24 (EL) g/cc, determined on an air dry basis. The bulk density of the air dry EL soil was very similar to that determined in the lab (1.28 g/cc). Total porosity for the different media was 73.3% (PM), 60.0% (1-1), 56.7% (3-1-1), and 53.3% (EL). Therefore, as bulk density increased, total porosity decreased for the media used in this study.

The influence of container design on water holding capacity and air space for all media is presented in Table 2. Removal of the perched water table in the container with the Formax bottom (CF) placed on sand was evident as it had the lowest percent water holding capacity and the highest air space, exactly the opposite of the CS container with the solid bottom. Table 3 shows the influence of media on water-holding capacity and air space for all container types at container capacity. The mean water-holding capacity and air space were within acceptable ranges for container production for the following media: PM, 3-1-1, and EL. The air space (32.9%) and water-holding capacity (27.1%) for the 1-1 medium were considered to be above and below the acceptable limits for these parameters, respectively. The mean water holding capacity for the EL medium (Table 3) was greater (36.2%) than the moisture retained at 5 pounds of pressure (27.6%, Table 1), indicating that the EL medium at container capacity was at a lesser tension and holding more water than at field capacity.

The media consisting of composted hardwood bark and pine bark had the greatest air space for the composite of all container types (Table 3). Pro-Mix BX had the greatest mean water-holding capacity and a high mean air space. The 3-1-1 media had an air space only 0.6% greater than the EL soil (Table 3). In all container

Table 2. Influence of Four Container Designs on Mean Percent Water Holding Capacity and Mean Percent Air Space Across all Media at Container Capacity

Container Type	Mean % WHC	Mean % Air Space
CS	42.0a	18.8d
Z	38.4b	22.5c
PB	37.5c	23.3b
CF	29.6d	31.2a

Duncan's New Multiple Range Test - means within columns with the same letter are not significantly different at the 5% level.

Table 3. Influence of Four Media on Mean Percent Water Holding Capacity and Mean Percent Air Space Across All Container Types at Container Capacity

Media Type	Mean % WHC	Mean % Air Space	Total Porosity
PM	45.4a	27.9b	73.3%
3-1-1	38.9b	17.8c	56.7%
EL	36.2c	17.2d	53.4%
1-1	27.1d	32.9a	60.0%

Duncan's New Multiple Range Test - means within columns with the same letter are not significantly different at the 5% level.

types except the CF, the EL medium had significantly greater air space than the 3-1-1 medium (Table 4). The overall mean for the 3-1-1 medium was greater than the EL medium (Table 3) because of the high percentage of air space (28.9%) found in the CF container compared to a high of 19.4% for the EL (Table 4). The 1-1 mix had the lowest water-holding capacity in all container types (Table 5). Tables 4 and 5 show significant differences for different media and container designs for air space and water-holding capacity.

This research demonstrates that for a variety of media of different bulk densities and consisting of different media components, air space and water-holding capacity can be manipulated by altering container design. The 1-1 medium appears to have excessive drainage and therefore increased air space which could be useful for crops requiring a high percentage of air space in the medium. Pro-Mix BX has very good physical properties whereas it is interesting to note the often low percentage of air space for the 3-1-1 medium compared to the EL field soil.

The study shows that air space can be greatly increased for different media by eliminating the perched water table. At container capacity, the CF container increased air space 77% to 137% in the often used 3-1-1 nursery mix and 29% to 94% in the PM mix, compared to other containers tested (Table 4). This research also shows that the amount of water held at container capacity is greatly affected by container design. For the 3-1-1 mix, the water retained

Table 4. Percent Air Space by Container Type and Media at Container Capacity

Container Type	Media 1-1	 PM	 3-1-1	 EL
CF	38.3a	38.2a	29.9d	19.4g
PB	34.7b	24.4f	16.3i	18.0h
Z	31.1c	29.5d	13.6j	15.6i
CS	27.6e	19.7g	12.2k	15.6i

Duncan's New Multiple Range Test - means within rows and columns with the same letter are not significantly different at the 5% level.

Table 5. Percent Water Holding Capacity by Container Type and Media at Container Capacity

Container Type	1-1	Media PM	 3-1-1	EL
CF	21.7l	35.1g	27.7j	33.9h
PB	25.3k	48.9b	40.4e	35.3g
Z	28.9j	43.8cd	43.1d	37.7f
CS	32.4i	53.6a	44.5c	37.7f

Duncan's New Multiple Range Test - means within rows and columns with the same letter are not significantly different at the 5% level.

at container capacity ranged from 44.5% to 27.7% while for the PM mix it ranged from 53.6% to 35.1% (Table 5). Air space for the 1-1 mix ranged from 38.3% to 27.6% and from 19.4% to 15.6% for the EL medium (Table 4). Less variation in air space for the EL medium can be accounted for by the greater amount of water held by micropores compared to the other media.

This study indicates that container design has a significant effect on physical parameters of a medium. Although physical parameters have often been reported without regard for container design, this study indicates that reporting these parameters without concern for container design may be less useful than once thought.

CHAPTER III

INFLUENCE OF SOLUBLE SALTS AND PERCENT MOISTURE CONTENT ON THE FUNCTIONING OF A NEW MOISTURE CONTROLLING DEVICE

Introduction

The ability to control soil moisture in a container at a uniform level is one of the problems associated with container plant production. The supply of water to plants has been noted to account for many of the problems associated with greenhouse culture (38). More precise irrigation indicators are necessary to prevent stress associated with fluctuations in moisture availability (36).

The following questions are often considered before applying water to container grown plants: 1) how much water to apply?, 2) when should plants be irrigated?, 3) what effect does moisture stress have on quantity and quality of plant growth?, and 4) what method or equipment should be used for irrigation? (63). Irrigation frequency is influenced by environmental parameters such as size of plants and containers, potting medium, media and air temperatures, solar radiation, humidity, and air movement (42). Integration of these factors is necessary to produce quality plants while minimizing water related stress.

A number of methods to control or measure soil moisture have been tested during the past ninety years. At the turn of the century, electrical resistance methods (31) and auto-irrigators (61) were being developed. It was noted in 1897 (110) that for the in situ measurement of soil moisture by electrical resistance, an instrument would have to be accurate over a wide range of moisture levels, portable, compact, and lightweight. Other considerations for the development of a soil moisture determining device are 1) independance of salt content to a large degree, 2) accurate over a complete range of moisture contents, 3) rapid and simple to operate, 4) applicable to soils in situ, and 5) not greatly influenced by temperature (26, 84).

Researchers at The University of Tennessee, Knoxville have recently developed a moisture sensing and irrigation controlling device suitable for a wide range of container media in which other methods fail (100). The purpose of this study was to determine the effects of soluble salt levels and moisture regimes in different media on the current flow (milliamperes) through these media using the newly developed moisture controlling device.

Literature Review

Two radiological methods are available for the measurement of soil water, these being neutron scattering and gamma ray attenuation (14). Both methods have advantages in that the equipment is portable, measurements can be taken at permanent observation sites, and the edaphic environment is not disturbed after initial installation (14).

Neutron scattering devices are based on the fact that hydrogen atoms have a greater ability to slow down and scatter fast neutrons than most other atoms; thus, counting slow neutrons in the vicinity of fast neutrons provides a means of estimating the hydrogen content of a medium, which is proportional to the amount of water present (24). Disadvantages of this method are 1) expense, 2) legal restrictions because of radioactivity, and 3) it must be calibrated for each soil texture (58). Neutron scattering measurements are not accurate in shallow soils and are affected by soil organic matter and certain mineral elements (29, 58).

Gamma ray attenuation or absorption is the measurement of changes in soil water content by the change in gamma radiation absorbed. The amount of radiation passing through a soil depends on its density, which changes with the moisture content (58). This method has many of the advantages of the neutron scattering method, but it is assumed the changes in density are due to changes in soil water content (14); therefore, it is only useful in soils where the change in bulk density is very small compared to the water content. Neutron scattering and gamma ray attenuation have not been adopted by commercial growers because the cost of equipment is too high and the radiation hazard in shallow growing media is too great (63).

Water has a higher dielectric constant than dry soil, therefore the value of the soil dielectric constant varies with changes in water content (58, 85). The major advantage of this method is that results are only slightly affected by the salt concentration in a soil solution (2). The disadvantages of the system are problems associated with electrode contact effects (101), temperature variation effects (58), and changes in bulk density related to moisture content (85).

Shaw and Baver (84) made use of the phenomenon that as the moisture content of a soil decreases, the conduction of heat also decreases. This is known as thermal conductivity. A heating element, usually copper, is placed in the soil, an electrical current passed through it, and the amount of heat dissipation or the change in current magnitude is measured (58, 85). The major advantage of this system is that salts in the soil solution have little effect on the results obtained. Problems encountered are lack of sensitivity at low matric potentials and problems with electrode contact because of shrinkage of media during drying cycles. Furuta (29) has suggested that this method should be useful for determining the moisture content of a container medium, although this method is not commonly in use.

Electrical resistance between two metal electrodes in the soil as a method of measuring soil moisture content was attempted in 1898 (110). Early attempts using this method were unsuccessful due to variations in soil salt solutions, but these problems were overcome by embedding the electrodes in plaster of paris blocks (13). Gypsum blocks are popular because they can be made cheaply and they mask the effects of high soluble salt concentrations. Problems associated with gypsum blocks are that they often deteriorate within one season, but they are effective over the range of soil moisture which is available to plants (0.5 to 15 bars). These blocks work best in dry soils and the effects of electrode contact, soil salt concentration, and temperature induced resistance are moderated (58). Nylon and fiberglass resistance blocks are available, and although they are longer lasting, they are affected by the soil salt concentration to a greater degree. One advantage of this system is that they can easily be attached to automatic irrigation equipment (85). Resistance blocks are not considered to be accurate or reliable within the moisture range found in container grown plants (29).

Tensiometers have been reported to be useful for the automatic irrigation control of greenhouse crops (75, 105). The first commercial installation of a completely automatic sprinkler system in a container nursery using tensiometers was reported in 1964 (98). Tensiometers allow for the direct measurement of the soil matric potential or suction (28, 58). Problems occur in porous media in containers due to poor contact between the medium and the porous ceramic tip of the tensiometer (29, 38). The tensiometer is very useful for measuring the matric potential of moist media, but air begins to enter the porous cup below 80 KPa (1 KPa=0.01 bar), thus making the tensiometer unreliable (58, 59). Tensiometers are made in different sizes suitable for small pots (38), and electrical switching devices can be purchased for automatic irrigation control (59). Tensiometers have been used successfully to determine the matric potentials for water release curves of container media (53). Gaggini (30) has suggested that one gallon containers be watered at 20 KPa and that irrigation of larger containers should be triggered at 30 KPa.

Early attempts to maintain a preset media matric potential involved the use of autoirrigators (66). Self-irrigating pots are variable in their ability to maintain uniform soil moisture (80) although successful maintenance of a matric potential of 50 cm water tension has been reported (77). A number of methods based on gravimetric loss have been proposed for laboratory studies (6, 60). White and Shaw developed a gravimetric device for controlling irrigation systems that integrated many of the factors affecting the edaphic regime which influence water loss and uptake of a container grown plant (109). Use of porous ceramic bulbs may have potential for controlling the moisture content of container media (54) but further research is needed with plants growing in containers.

Distilled or pure water is a poor conductor of electrical current; whereas, water containing dissolved salts or charged ions will conduct a current proportional to the amount of salt in solution (48). Since most media are a nonconducting porous matrix, their electrical resistance is a function of the electrolytic concentration and the moisture content of a given medium. Altering either parameter should allow for the measurement of electrical resistance between two electrodes. It has been noted that such methods appear unworkable (14).

Electrical resistance between two electrodes has never shown much promise as an indicator of soil moisture content. Erratic measurements often occur because electrical contact between a medium and the electrode is altered due to shrinking and swelling of the medium in relation to the moisture content (2). All electrical resistance units are affected by the electrolytic concentration of the soil solution (2, 14), therefore introducing error in measurements taken.

Total soluble salts in a growing medium can be determined with the use of a conductivity meter (102). Electrical resistance is defined as $E = IR$, where E = volts, I = current in amperes, and R = resistance in ohms. Electrical conductance, C, is the conductivity of a solution in mhos and is the reciprocal of resistance, R, expressed as $C = I/R$ (48). Specific conductance, L, of a solution is that measured between two electrodes one cm^2 in cross section and one cm apart at 25°C. From this, the following conversions are possible (50):

Osmotic Pressure (atm.) = 0.28 - 0.36 L mmhos/cm

Milliequivalents of salt/liter = 12.5 L mmhos/cm

Parts per Million of salts = 640 L mmhos/cm

The specific electrical conductance of a media extract is linearly related to the amount of salts in solution. This is important because soluble salts decrease the availability of water by increasing osomotic pressure (38, 59). This significance can be seen since the total water potential of a container medium is equal to the matrix potential (moisture tension) plus the osmotic potential (17).

When expressing electrical conductivity (EC), the term mho has been replaced by the term Siemen, with 1 Siemen = 1 mho. Thus current terminology for expressing EC in the USA is in dS/m which is equal to mmhos/cm.

Materials and Methods

The experiment was arranged as a nested design with six moisture levels, two soluble salt levels within each moisture level, four media within each soluble salt level, four different aliquot levels within each medium, and four samples per aliquot level. Each aliquot level was based on physical parameters of container design-media relationship determined in Chapter II.

The media used in this experiment were the same as previously described in Chapter II: 1-1, 3-1-1, EL, and PM. The container designs were also the same as described in Chapter II: Z, PB, CS, and CF. The six moisture levels were 0, 20, 40, 60, 80, and 100% of the water held by each container type at container capacity as determined in Chapter II. The milliliters of solution needed to increase the moisture content of each medium in 20% increments for each container design is presented in Table 6. The soluble salt solutions used were 50 ppm (0.28 dS/m) and 500 ppm (2.30 dS/m) based

Table 6. Milliliters of Soluble Salt Aliquot Treatment Necessary to Achieve 20% of Container Capacity for 3000 cc of Each Medium*

Aliquot Portion for Container Type		Media		
	PM	EL	3-1-1	1-1
Z	294	226	259	173
PB	263	212	242	152
CS	322	226	267	196
CF	211	204	167	130
MEAN	273	217	234	163

*- Media volume of 3000 cc.

on %N of 20-20-20 (Plant Marvel Laboratories, Inc., Chicago Heights, IL).

Eight experimental groupings were used, each group having sixteen experimental units (four samples x four container designs). Each main group was a soluble salt level (2) times medium (4) combination. Each soluble salt solution contained 0.1% Triton AG-98 surfactant (Rohm and Haas, Charlotte, NC).

Three thousand cc of air dry medium was placed into Rubbermaid pans (Rubbermaid, Inc., Chicago Heights, IL) having dimensions of 11 1/2" x 13 1/2" x 5 1/4". Each experimental unit was then wetted with the appropriate aliquot volume of soluble salt solution, covered with a plastic bag to prevent evaporation, and allowed to equilibrate for twelve hours before testing. At each application, the aliquot solution was added and mixed by hand for twenty turns. Data recorded at the 0% level was for air dry media. A 12 volt light bulb was attached to the MCD through the solenoid connector in order to determine if solenoid activation would have occurred. The MCD was set at 16.0 milliamps for solenoid activation, indicated by the turning on of the light bulb.

Milliamp readings and soluble salt measurements were taken for each experimental unit after equilibration at each moisture level (0-100% container capacity). Milliamp readings were taken utilizing a new moisture controlling device (MCD) developed at The University of Tennessee, Knoxville (100). A milliamp meter (Triplett

Corp., Model 310) was attached in-line between the MCD and the electrodes to increase the accuracy of readings. The electrodes used were stainless steel Scoopulas (Fisher Scientific Co.,Pittsburgh, PA) coated with Plasti Dip (PDI, Inc., St. Paul, MN), a flexible air dry plastic coating. A surface area of 2.25 cm^2 at the tapered end of the Scoopula was left uncoated, with this exposed end being inserted into the medium. The electrodes were placed 12 cm apart (parallel) and inserted to a depth of 9 cm in the medium being tested. Media conductivity levels were determined using a 1:2 (medium:water) by volume method (103) utilizing a Beckman Solu-bridge. A 50 cc sample of medium was diluted with 100 cc of distilled water, stirred, and allowed to set for one hour before testing. After filtering the sample, the 50 cc sample of medium was returned to its corresponding container. Solution temperatures were determined using an Omega 450 ATH Thermistor Thermometer (Omega Engineering, Inc., Stamford, CT).

Results and Discussion

As far as is known, there is no low voltage electronic solenoid controlling device based on current flow through a medium as influenced by the moisture content. The moisture controlling device (MCD) has a unique feature in that it can be set to maintain a medium moisture content above the preset level by allowing for the activation of an electronic solenoid when soil moisture reaches that level. Therefore this automatic irrigation control system is based on water content of the medium and maintenance of sufficient water to avoid water stress.

The MCD has a transistor which activates a relay to signal for irrigation of a crop. The transistor, which allows for electrical resistance to be amplified, is controlled by a voltage drop in the base to emitter circuit. The voltage drop varies proportionally to the resistance of the soil-water-electrolytic interactions of the medium. As moisture increases, the amount of resistance decreases. The potentiometer, which can be adjusted to provide a desired amount of capacitance, is in the base to emitter circuit and allows for relay activation at a predetermined moisture content. The relay closes the circuit which activates the solenoid valve. At present, the MCD has a 100 V input with a 25 V output transformer, thus making the system low voltage allowing for safe operation. Further description of the MCD is not possible at this time because a patent has been applied for through the University of Tennessee Research Corporation. Non-disclosure forms may be obtained from the U.T. Research Corporation or by contacting Professor Hendrik van de Werken in the Department of Ornamental Horticulture and Landscape Design at The University of Tennessee, Knoxville.

The MCD responds to the flow of current between two electrodes as governed by water content of the container medium. The principle is different from that of a conductivity meter which is based on conductivity as governed by the soluble salt content of a media extract. Conductivity (mhos) is the reciprocal of resistance (ohms) and a conductivity meter integrates this with compensation for temperature thereby giving readings in dS/m (mmhos/cm). The electrodes used in a conductivity meter are not designed to respond to soil moisture.

Data for milliamp readings and corresponding soluble salt levels are presented in Tables 7 through 11. The temperature of all solutions tested was 22°C. The 3-1-1 mix had the lowest initial soluble salt levels (Table 9) followed by the EL medium (Table 8). The readings for the 1-1 medium were greater because of the nutrients added during the composting process (92). PM had the greatest initial soluble salt levels (Table 10) because it comes amended with macro and micro nutrients.

The amount of change from the initial soluble salt level to the final soluble salt level at 100% container capacity varied for the four media at both soluble salt levels. At the 50 ppm level, the change in soluble salt levels from 0% to 100% container capacity was as follows: 0.14 (EL), 0.23 (3-1-1), 0.44 (PM), and 0.45 (1-1) dS/m, over all treatment levels (Tables 7-10). The change in dS/m for the 500 ppm level was as follows: 0.42 (EL), 0.83 (1-1), 1.52 (3-1-1), and 1.75 (PM). In all cases except for 3-1-1 and EL at the 50 ppm treatment, significant differences occurred at all levels of container capacity tested.

It is recommended (63) that for a 1:2 media to water extract, from a porous organic based medium, a level of 1.80 dS/m should not be exceeded or damage may occur. Only the PM medium at the high soluble salt rate exceeded this figure (Table 10).

Table 7. 1-1 Medium Effect of Percent Container Capacity Obtained through the Addition of 50 ppm (0.28 dS/m) and 500 ppm (2.30 dS/m) Nutrient Solutions upon Milliamp and Soluble Salt Readings*

Percent Container Capacity	Milliamp		SS Level	
	50	500	50	500
100	12.8a	19.1a	0.74a	1.13a
80	10.6b	16.5b	0.67b	1.00b
60	8.4c	12.5c	0.56c	0.92c
40	5.3d	7.3d	0.46d	0.80d
20	2.2e	2.2e	0.41e	0.49e
0	0.5f	0.5f	0.29f	0.30f

Duncan's New Multiple Range Test - means within columns with the same letter are not significantly different at the 5% level.

*- averaged across container types.

Table 8. EL Medium Effect of Percent Container Capacity Obtained through the Addition of 50 ppm (0.28 dS/m) and 500 ppm (2.30 dS/m) Nutrient Solutions upon Milliamp and Soluble Salt Readings*

Percent Container Capacity	Milliamp		SS Level	
	50	500	50	500
100	18.7a	23.8a	0.29a	0.54a
80	15.9b	20.3b	0.21b	0.39b
60	9.5c	14.0c	0.16c	0.26c
40	3.6d	5.3d	0.14d	0.21d
20	1.7e	1.7e	0.14d	0.16e
0	0.5f	0.5f	0.15cd	0.12f

Duncan's New Multiple Range Test - means within columns with the same letter are not significantly different at the 5% level.

* - averaged across container types.

Table 9. 3-1-1 Medium Effect of Percent Container Capacity Obtained through the Addition of 50 ppm (0.28 dS/m) and 500 ppm (2.30 dS/m) Nutrient Solutions upon Milliamp and Soluble Salt Readings*

Percent Container Capacity	Milliamp		SS Level	
	50	500	50	500
100	10.7a	29.2a	0.28a	1.57a
80	8.4b	25.0b	0.26b	1.12b
60	6.1c	17.9c	0.13c	0.88c
40	3.3d	9.0d	0.05d	0.65d
20	1.4e	2.0e	0.05e	0.21e
0	0.5f	0.5f	0.05d	0.05f

Duncan's New Multiple Range Test - means within columns with the same letter are not significantly different at the 5% level.

* - averaged across container types.

Table 10. PM Medium Effect of Percent Container Capacity Obtained through the Addition of 50 ppm (0.28 dS/m) and 500 ppm (2.30 dS/m) Nutrient Solutions upon Milliamp and Soluble Salt Readings*

Percent Container Capacity	Milliamp		SS Level	
	50	500	50	500
100	20.8a	30.6a	0.94a	2.26a
80	19.3b	27.4b	0.88b	1.60b
60	15.9c	23.1c	0.68b	1.40c
40	11.4d	14.7d	0.58d	0.90d
20	4.8e	4.2e	0.51e	0.63e
0	0.5f	0.5f	0.50e	0.51f

Duncan's New Multiple Range Test - means within columns with the same letter are not significantly different at the 5% level.

* - averaged across container types.

Table 11. Soluble Salt (dS/m) and Milliamp Means for Four Media as Influenced by Container Design

Container Design	50 ppm (0.28 dS/m) Soluble Salts	50 ppm (0.28 dS/m) Milliamps	500 ppm (2.30 dS/m) Soluble Salts	500 ppm (2.30 dS/m) Milliamps
EL				
CS	0.188a	8.85a	0.296a	10.77b
Z	0.187a	8.38b	0.280b	11.83a
PB	0.182a	8.48b	0.285b	10.90b
CF	0.165b	7.56c	0.267c	10.23c
PM				
CS	0.774a	13.58a	1.508a	18.21a
Z	0.664c	11.71b	1.116c	16.97b
PB	0.701b	13.46a	1.259b	18.21a
CF	0.588d	9.37c	0.989d	13.58c
1-1				
CS	0.578a	7.54a	0.938a	11.02a
Z	0.532b	6.91b	0.789b	10.27b
PB	0.509c	6.58b	0.718c	9.56c
CF	0.459d	5.54c	0.643d	7.83d
3-1-1				
CS	0.154a	6.23a	0.939a	15.54a
Z	0.139b	5.30b	0.812b	15.12b
PB	0.135b	5.10b	0.681c	14.56c
CF	0.128c	3.72c	0.552d	10.56d

Duncan's New Multiple Range Test - means within vertical columns and for individual media with the same letter are not significantly different at the 5% level.

The small difference between initial and final soluble salt levels for the EL medium may be explained in terms of cation exchange capacity (CEC), although the CEC of the various media used in this study was not determined. The cation exchange capacity of various media can be summarized as follows: mineral soils > aged pinebark > peat moss > vermiculite > perlite = sand. Therefore it would be expected that the EL medium, a mineral soil, would have a greater capacity to bind the cations added in the soluble salt treatments, thus having the least amount of change (Figure 1). The 1-1 medium had the greatest change at the low soluble salt level and had the second lowest change at the high soluble salt level. For the high soluble salt level, the media mixtures with more than one component had the greatest change in soluble salt levels. The inert ingredients such as sand in the 3-1-1 medium and the perlite in the PM medium do not contribute greatly to the CEC; therefore, at the higher soluble salt levels it would be expected that saturation of the binding sites would occur sooner, as was indicated in this study. It was also interesting to note that the medium with the greatest bulk density, EL, had the least amount of change in soluble salt levels at the high rate and that the PM medium, which had the lowest bulk density, had the greatest amount of change, possibly because many of the binding sites were already occupied by the original nutrient amendments of the PM medium.

The effects of soluble salt levels on milliamp readings can be seen in Figure 1. The 3-1-1 medium had the least amount of change

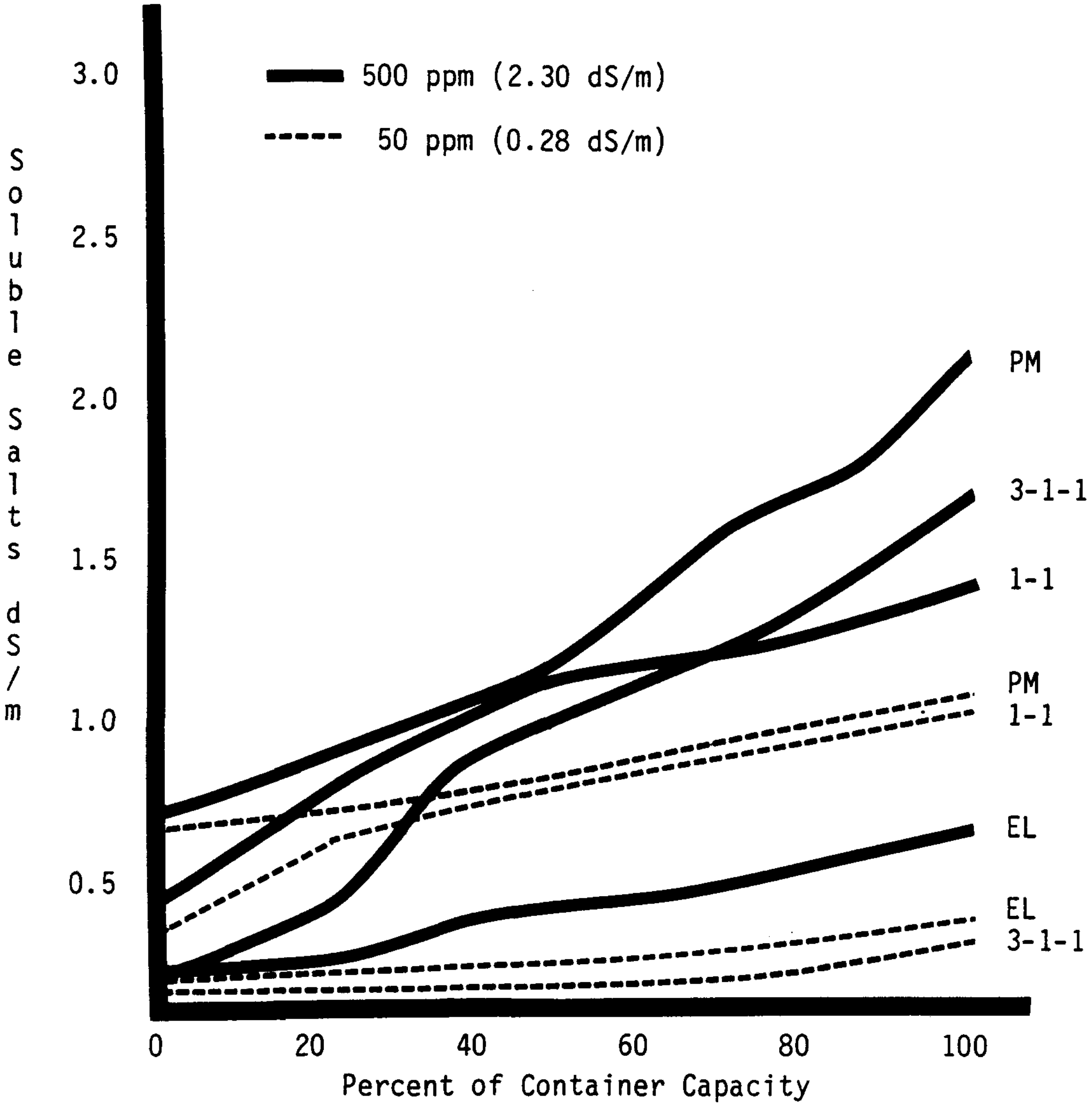

Figure 1. The influence of soluble salt treatments (50 and 500 ppm %N) in four media and six moisture levels on soluble salt readings in dS/m averaged across container types.

at the 500 ppm level. In general, the 1-1 medium had the lowest changes in milliamp readings between 0 and 100% container capacity, but also, because of its low water holding capacity, received the least amount of total soluble salts for all container types (Table 6, p. 32). The differences in soluble salt readings between the 50 ppm to 500 ppm treatments was the least for the 1-1 and EL media.

In all instances, the milliamp readings increased as the percent of container capacity increased, indicating the ability of the MCD to detect changes in the moisture content of the medium. Correlation coefficients are presented in Table 12. As the soluble salt level increased from 50 ppm to 500 ppm, a greater change in milliamp readings at the lower moisture contents can be seen (Figure 2). In all instances, the 500 ppm treatment gave greater milliamp readings than the 50 ppm treatment at the same moisture percentage, indicating that the electrolytic concentration of the soil solution indeed increased the number of charged ions in the soil solution and allowed for greater current flow between the electrodes of the MCD.

The purpose of the MCD is to allow growers and researchers who utilize container grown plants to monitor the edaphic environment and to allow for automated irrigation of crops based on water stress factors. The main factors involved in water stress of container grown plants are those related to water loss and corresponding increases in soluble salt levels in the container. The MCD responds to both of these parameters. Although responses of devices to

Table 12. Pearson Correlation Coefficients for Milliamps and Soluble Salts by Soluble Salt Treatment Level, Media, and Container Design Aliquot

Soluble Salt Level	Media	Container Design Aliquot	Correlation Coefficient
50	FS	CF	.82
50	FS	CS	.83
50	FS	PB	.85
50	FS	Z	.91
500	FS	CF	.94
500	FS	CS	.95
500	FS	PB	.96
500	FS	Z	.94
50	PM	CF	.87
50	PM	CS	.94
50	PM	PB	.89
50	PM	Z	.91
500	PM	CF	.92
500	PM	CS	.97
500	PM	PB	.91
500	PM	Z	.95
50	1-1	CF	.96
50	1-1	CS	.98
50	1-1	PB	.97
50	1-1	Z	.97
500	1-	CF	.95
500	1-1	CS	.95
500	1-1	PB	.95
500	1-1	Z	.97
50	3-1-1	CF	.94
50	3-1-1	CS	.95
50	3-1-1	PB	.95
50	3-1-1	Z	.96
500	3-1-1	CF	.96
500	3-1-1	CS	.99
500	3-1-1	PB	.95
500	3-1-1	Z	.96

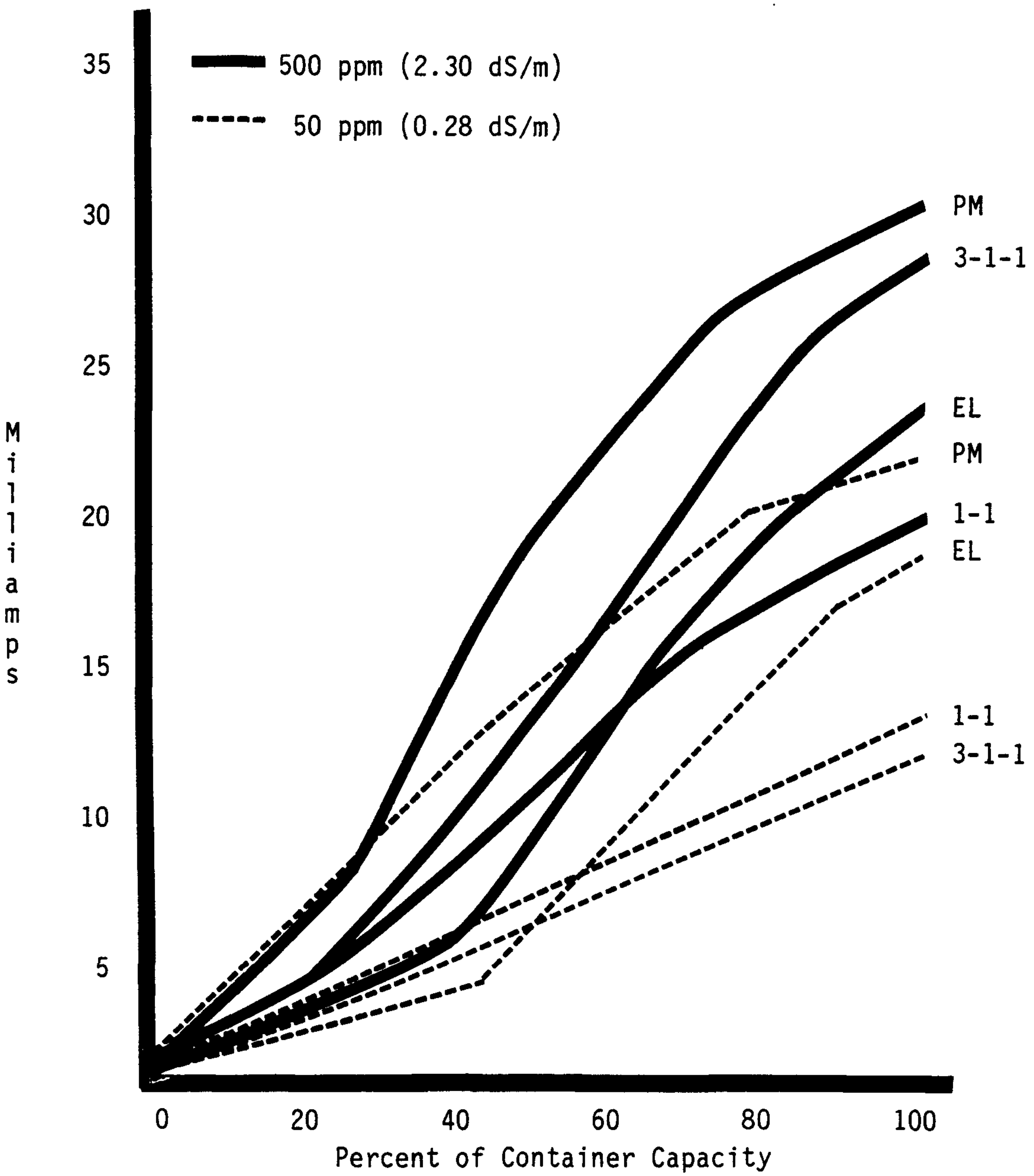

Figure 2. The influence of soluble salt treatments (50 and 500 ppm %N) in four media and six moisture levels on milliamperage readings averaged across container types.

soluble salt levels has been considered to be a disadvantage of this system since it is not intended to directly measure the matrix potential or to give readings of the soluble salt levels of the medium in which it is being used. With the MCD being influenced by moisture levels in a container and soluble salt levels or osmotic stress, the system integrates these parameters and responds to the combined effect of both edaphic factors causing water stress of plants.

Since most container crops are watered before 50% of container capacity is reached, a device such as the MCD needs to be accurate at higher soil moisture contents. The MCD has very good response characteristics throughout the entire range of moisture percentages tested. The similarity of responses at 0% container capacity can be accounted for since air dry media are not very good conductors of electrical current. The MCD also proved to be useful for a variety of media components and differing bulk densities in which other devices often fail. Small variations among the different readings within samples tested fell within acceptable ranges indicating that no problems occurred with electrode contact or soil hysteresis. This indicates that the MCD may have practical application for irrigation control of container grown nursery and floricultural plants.

CHAPTER IV

INFLUENCE OF FOUR MEDIA AND TWO NUTRIENT LEVELS ON WATER UTILIZATION OF CONTAINER GROWN COLEUS

Introduction

Availability of water to plants in container media is influenced by various physical and chemical properties of a medium. Two properties which are major factors in determining water availability are the matrix potential and the osmotic potential (17). The matrix potential is influenced by physical parameters such as bulk density, pore space, and particle size. The osmotic potential is directly related to the soluble salt concentration in the liquid phase of the medium. Increases in either potential decreases the availability of water for plant use.

Container grown plants should be irrigated before the soil moisture content reaches 50% of the total water holding capacity (63, 98). This will vary from medium to medium due to different edaphic regimes and cultural practices. The purpose of this study was to examine the influence of eight different media-soluble salt interactions on subsequent growth and water utilization of container grown *Coleus* employing the newly developed moisture sensing device (MCD) described in Chapter III.

Literature Review

A variety of techniques and instruments are available to determine the water status of plants. These devices can be placed into the following categories for the measurement of water potential, osmotic potential, turgor potential, stomatal resistance, and canopy temperature (56).

Environmental and plant-related factors affect leaf water potential (90). Environmental factors are solar radiation, temperature, humidity, wind, and soil moisture availability. Plant-related factors include plant age and growth stage, plant morphology, and stomatal resistance. Stanley et al. (90), using chrysanthemums, found that leaf water potential was difficult to interpret in terms of final plant characteristics. Plant growth parameters such as height and growth rate were found to be the best indicators of effects of water stress on final yield. Pan evaporation and plant height when used together have proven to be good indicators of daily water requirements of potted chrysanthemums (91).

The development of a healthy root system is essential for the growth of container plants. Distribution of roots in the soil is determined by genetic and environmental conditions (111). Size, number, and structural rigidity of soil pores influences the size and shape of root systems (52). Bulk density is an important physical property which influences other physical and chemical properties of a medium (93). The bulk density of a soil is known to affect root penetration; thus, media having lower bulk densities favor the penetration of roots (95). Tap roots of container grown pecan seedlings had much greater root penetration in a low bulk density medium (4:1 pinebark:sand) than in a higher bulk density (1:1 pinebark:sand) medium (1).

As bulk density increases, the soil becomes more compact, structure is less defined, and pore space decreases (97). The movement of water and gases is reduced and growth is inhibited as bulk density increases (27). Oxygen supply to a root system can be a growth rate limiting factor influenced by the physical structure of the root medium and its moisture content (37). Roots which receive adequate oxygen are long, white in color, and well supplied with root hairs. Lack of oxygen creates roots which are shorter, thicker, darker in color, and few root hairs are found (63). The oxygen content of a medium may range from 0-21%, but below 3% roots begin to die and decompose in container media (70). Extension of a root system into all areas of a medium is restricted by poor aeration (63).

Water consumption of woody plants in 3.8 L containers has been noted to be 300-500 ml/day while available water is often 700-1000 ml/container (19). Available water holding capacity varies with different media components (4). Bearce (3) has determined the practical available water content of media based on a percent volume basis by measuring the difference between a well watered container which was allowed to drain and the weight of the container at the first sign of wilting. It was found that a non-composted hardwood bark mix had a greater practical available water content than a peat-lite medium.

Permanent wilting point is the moisture content in the root zone at which a wilted plant can no longer recover turgidity, even when placed in a saturated atmosphere for 12 hours (25), but can recover if watered. A soil moisture tension of 15 atmospheres is usually associated with the permanent wilting point of plants, although most container crops are irrigated before 1 atmosphere tension occurs. Beardsell et al. (5) have described different stages of wilting, with stage 2 being when all leaves are wilted. They placed more emphasis on stage 2 wilting instead of stage 3 wilting (permanent wilting point) because plants reaching stage 3 will experience a reduction in growth.

It has been found that the time it takes for plants in a container to wilt is not always proportional to the amount of available water held (5). It was found that pinebark resists water loss by evaporation, and because its available water is not readily available to the plant, pinebark is able to maintain plants unwilted for a longer period of time even though it has less total available water holding capacity than peat moss. It was noted that standard techniques for measuring available water holding capacity do not give meaningful data and that the only meaningful measure of the available water holding capacity of a medium comes from the performance of plants grown in that medium.

Materials and Methods

The experimental design used in this study was a split-plot factorial arrangement of treatments. The main treatments were two nutrient salt levels, 50 ppm and 500 ppm. Three replications of each treatment were used with four different media per replication and four samples per media.

Tip cuttings of Coleus blumei were stuck directly in four inch pots and placed under mist on 10-21-85. These rooted cuttings were then shifted into 3.8 L (Zarn 400) containers and placed in a greenhouse on 11-15-85. The media used were an Etowah loam, A-horizon (EL), Pro-Mix BX, a commercially prepared floricultural mix (PM), a 3:1:1 mixture by volume of pinebark, spagnum peat moss, and river sand (3-1-1_, and a 1:1 mix by volume of pinebark and hardwood bark mixed before composting (1-1). Each container was weighed at the time of potting so that the same amount of medium was in each container. Knowing the bulk density of each medium and the weight of medium added, the volume of medium in each container was easily calculated.

After the containers were placed in the greenhouse, they were treated as follows: S.T.E.M. micronutrients (W. R. Grace & Co., Iron Run Industrial Park, Fogelsville, PA) 1 teaspoon per gallon, magnesium sulphate at 4 ounces per 1.5 gallons, and 100 ppm calcium nitrate. The plants were fertilized as needed with a 50 ppm liquid solution based on %N of Plant Marvel 20-20-20 until 12-08-85. After this point, the respective groups of plants were fertilized with either 50 ppm (0.28 dS/m) or 500 ppm (2.30 dS/m) as needed.

On 01-06-86, the plants were moved to a warmer greenhouse and liquid fertilized daily. On 01-12-86 the containers were watered several times to bring each to complete saturation. Each container was allowed to drain for 24 hours, therefore reaching a point below container capacity due to transpiration of the plants. At this time daily milliamp readings were recorded using the MCD, each container was weighed to track water utilization, and soluble salt measurements were taken using a 1:2 medium to water by volume method utilizing a Beckman Solu-bridge.

Data was recorded at 8:00 am each morning until wilting occurred for a particular container plant. The experiment was considered terminated for a particular plant if the plant remained wilted overnight. At this time, the plants were watered, allowed to regain turgor for 24 hours, and were then cut off at the soil line so fresh weights could be recorded. The plants received full solar exposure as no shading compound was on the glasshouse. Daily maximum temperatures were between 90-100°F.

Results and Discussion

Bulk density for the four media is as follows: 0.19 (PM), 0.36 (1-1), 0.55 (3-1-1), and 1.24 (EL) g/cc on an air dry basis. It was noted that the 1-1 mix produced the highest quality root systems with the 3-1-1 and the PM being similar to each other. The EL medium only had roots present in the upper one-half of the container. Total water consumption data is presented in Table 13.

Table 13. Water Consumption until Wilting of Coleus Grown at Two Nutrient Levels in Four Media

Media	Nutrient Level ppm	% WHC (% V)	Water Held at Container Capacity in cc	Water Utilized cc	Water Utilized %	Water Remaining cc	Water Remaining %	Days until Wilting
1-1	50	29	867	612	70.6	255	29.4	4
1-1	500	29	867	573	66.1	294	33.9	3
3-1-1	50	43	1293	1149	88.9	144	11.1	6
3-1-1	500	43	1293	1074	83.1	219	16.9	4
PM	50	44	1314	909	69.2	405	30.8	6
PM	500	44	1314	837	63.7	477	36.3	5
EL	50	38	1131	591	52.3	540	47.7	4
EL	500	38	1131	573	50.7	558	49.3	4

Daily water consumption for the 50 ppm treatment is shown in Figure 3 and the 500 ppm treatment is shown in Figure 4. No significant difference occurred between the two treatment levels for water utilization, indicating that the different media accounted for the differences in water utilization.

The greatest percentage of available water for utilization was found in the 3-1-1 mix, with 88.9% of container capacity for the 500 ppm treatment and 83.1% for the 500 ppm treatment being available for the plant to utilize. The 1-1 and PM media were very similar as to the percentage of water utilized, the 1-1 medium having 70.6% and 66.1% water utilized and the PM having 69.2% and 63.7% water utilized for the 50 ppm and 500 ppm treatments, respectively. Plants in the EL medium were only able to utilize just over 50% of the available water before wilting occurred. The similarity of percent water utilized in the 1-1 and PM media was interesting since at container capacity, the 1-1 medium held only two-thirds the volume of water held by the PM medium.

Significant differences occurred between the nutrient salt treatment levels in milliamp readings and soluble salt levels in the various media. The PM medium had the greatest mean milliamp readings (7.4) followed by EL (6.2) 3-1-1 (3.2), and 1-1 (2.6, respectively. The PM and EL media were significantly different from the two bark-based media. Milliamp data by treatment, media, and day is shown in Figures 5 and 6.

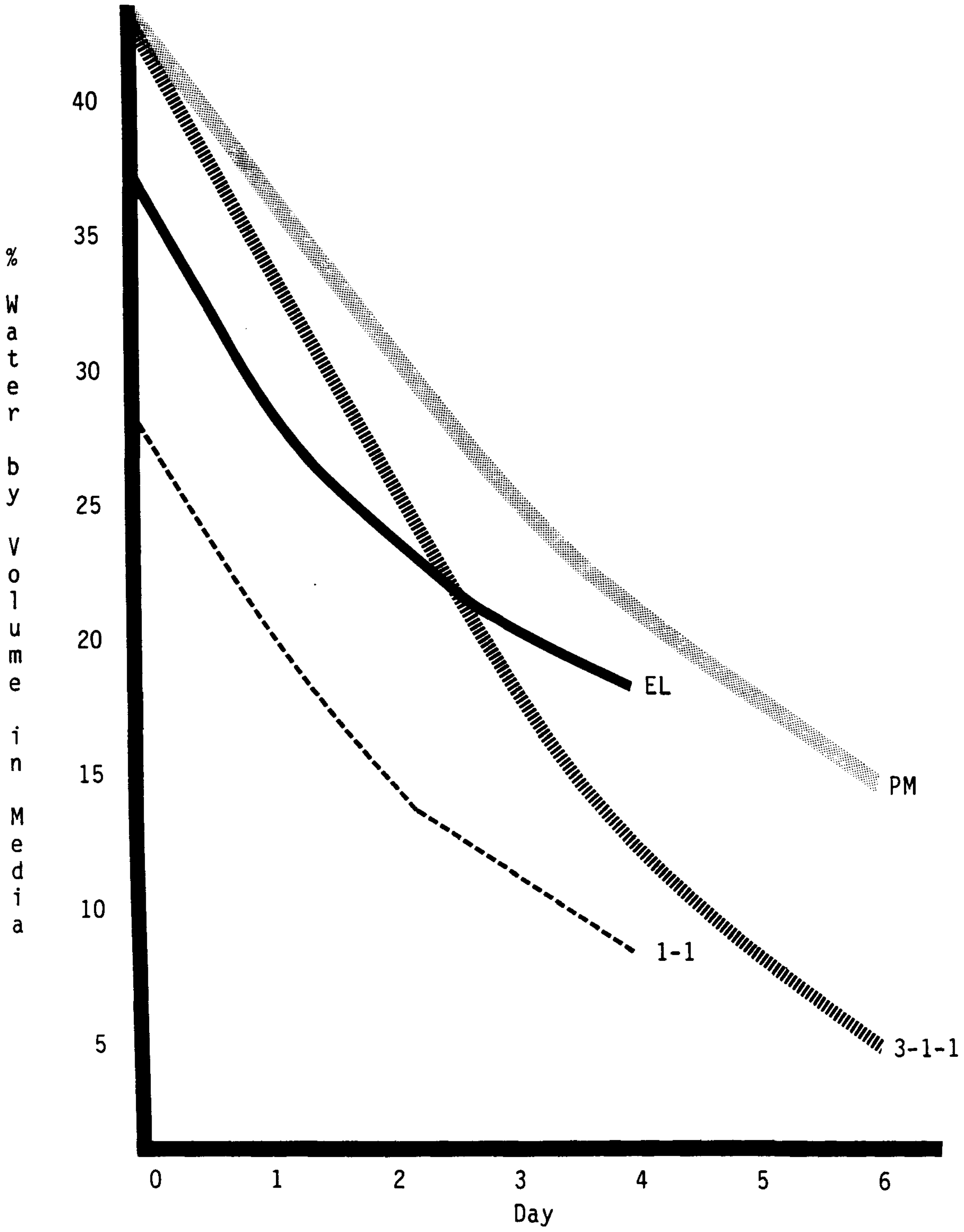

Figure 3. Water utilization by day until wilting for container grown Coleus in four media at the 50 ppm treatment level.

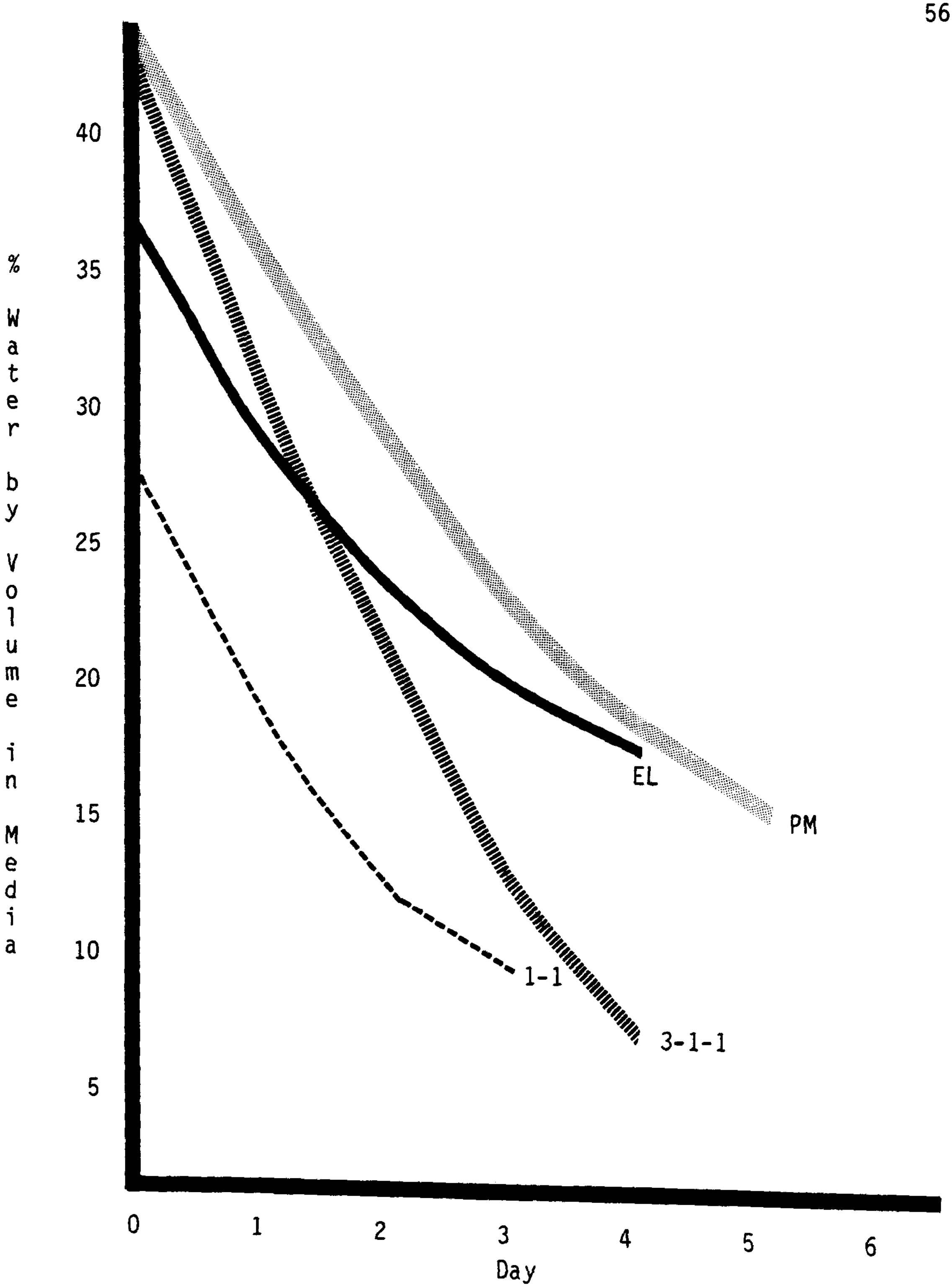

Figure 4. Water utilization by day until wilting for container grown Coleus in four media at the 500 ppm treatment level.

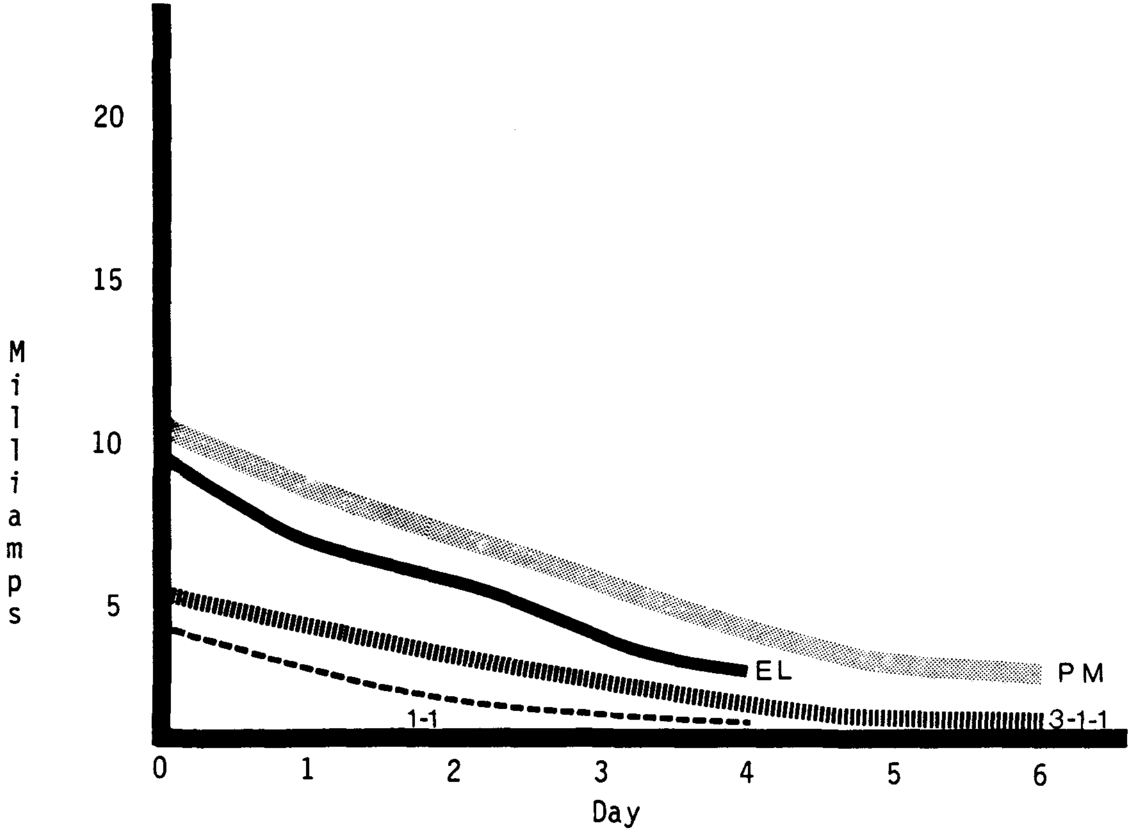

Figure 5. Milliamperage readings by day until wilting for container grown Coleus in four media at the 50 ppm treatment level.

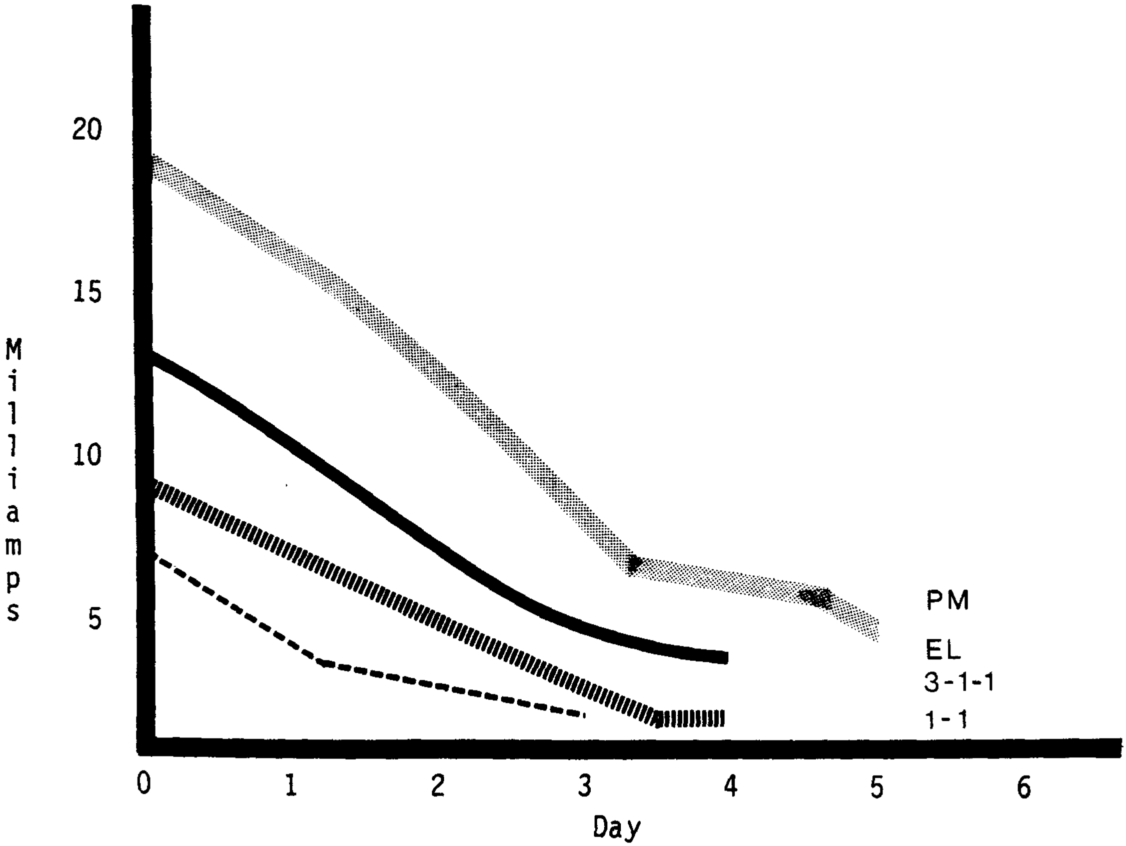

Figure 6. Milliamperage readings by day until wilting for container grown Coleus in four media at the 500 ppm treatment level.

Although a significant difference in soluble salt levels was detected between the two nutrient salt treatment levels, no difference could be detected by day, indicating that soluble salt levels did not significantly increase as the media became drier.

A significant difference occurred between treatment levels for fresh weight of Coleus, the mean for the 500 ppm treatment being 233.7 grams compared to 142.4 grams for the 50 ppm treatment (Table 14).

Differences between the 1-1 and PM media were evident in the number of days until wilting (Table 13) and the fresh weight of plants (Table 14). Plants in the 1-1 medium wilted after 4 and 3 days compared to 6 and 5 days for the PM medium. The 1-1 medium initially held less water at container capacity than the PM medium but the fresh weights were greater for both soluble salt levels. A significant difference was detected among treatment levels for soluble salts, the 500 ppm (0.40 dS/m) treatment plants wilted before the 50 ppm (0.25 dS/m) treatment plants in all media. This may be due to greater transpiration of the larger plants at the 500 ppm level or due to greater osmotic stress.

For all nutrient level-media interactions, 50% of the water in each container was utilized by the end of the third day, indicating the need for irrigation (Figures 3 and 4). High correlations were found for milliamp-percent water remaining by volume in container interactions (Table 15). This study shows that although the commonly

Table 14. Shoot Fresh Weight in Grams of Coleus Grown in Four Different Media at Two Nutrient Levels

Media	50 ppm	Nutrient Level	500 ppm
1-1	176.0a		311.4a
PM	153.4b		230.3b
3-1-1	117.3c		220.4b
EL	122.6c		172.8c
Mean	142.4b		233.7a

Duncan's New Multiple Range Test - means within columns with the same letter are not significantly different at the 5% level.

Table 15. Pearson Correlation Coefficients for Milliamps and Percent Water Remaining in the Container by Nutrient Level and Media Interactions

Nutrient Level	Media	Correlation Coefficient
50	FS	.95
50	PM	.97
50	1-1	.94
50	3-1-1	.96
500	FS	.94
500	PM	.98
500	1-1	.91
500	3-1-1	.95

used 3-1-1 medium may have quite a different set of physical parameters (Chapter II) compared to other media, it released most of its water for plant use, therefore the plants grown in this medium took the longest before reaching stage 2 wilting. This is in agreement with previous research (5).

The MCD appears to be adaptable to a variety of media under differing edaphic regimes. It appears from these studies that edaphic conditions are quite different in the greenhouse with plants growing in containers compared to studies done in the lab with media alone. The MCD appears to have potential for controlling the irrigation scheduling of container grown plants. Although further testing needs to be done, utilization of a device such as the MCD should provide plants with a more optimal edaphic regime, thus eliminating stress and increasing growth.

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VITA

The author, John Michael Ruter, was born in Los Angeles, California on September 18, 1962. He was graduated from Simi Valley High School in 1980. In 1984, he received his Bachelor of Science degree from California Polytechnic State University, San Luis Obispo with a major in Ornamental Horticulture.

In August 1986, he was granted the Master of Science degree from The University of Tennessee, Knoxville with a major in Ornamental Horticulture and Landscape Design. While working towards this degree, he was employed by the University of Tennessee Agricultural Experiment Station as a Graduate Research Assistant in the Department of Ornamental Horticulture and Landscape Design.

The author is a member of Alpha Zeta and Gamma Sigma Delta, the Agricultural Honor Society. He is a member and past president of the Alpha Beta Chapter of Pi Alpha Xi, the Floriculture and Ornamental Horticulture Honor Society.