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THE ROLE OF PEAT-BASED ROOT MEDIA IN WATER AND NUTRIENT EFFICIENCY OF GREENHOUSE CROPS

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William R. Argo

has been accepted towards fulfillment of the requirements for

Master of Science degree in Horticulture

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Major professor

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THE ROLE OF PEAT-BASED ROOT MEDIA IN WATER AND NUTRIENT EFFICIENCY OF GREENHOUSE CROPS

by

William R. Argo

A THESIS

Submitted to
Michigan State University
in partial fulfillment of the requirements
for the degree of

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ABSTRACT

THE ROLE OF PEAT-BASED ROOT MEDIA IN WATER AND NUTRIENT EFFICIENCY OF GREENHOUSE CROPS

by

William R. Argo

The efficient application of water and water soluble fertilizer is important to the greenhouse industry to prevent water and fertilizer runoff into the environment. One method of reducing runoff is through root media selection. Root media that hold more water and reduce the number of applications may reduce runoff if fertilizer concentrations and leaching levels are reduced. Other factors such as moisture release and rewettability were also important for extending the time between irrigations. In general, the root media tested had little effect on nutrient retention efficiency and media analysis values. Evaporation from the surface of the root media was found to be a significant source of water loss from peat-based root media and may account for as much as 50% of the water lost from the pot. The effect of an evaporation barrier on root media nutrient levels was also studied.

Guidance Committee:

The paper format was adopted for this dissertation in accordance with departmental and university regulations. Sections I and II are to submitted to the Journal of the American Society of Horticultural Science, and section III was prepared as a research report to be presented to the Bedding Plant Foundation.

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INTRODUCTION

INTRODUCTION

Historically, the switch from field soils to soilless root media in ornamental plant production occurred due to the difficulty in obtaining uncontaminated field soil with the proper balance of physical and chemical properties and the improved aeration and drainage provided by coarser soilless root media. Soilless root media were designed specifically for the automated irrigation system. These irrigation systems were very nonuniform in the application of both irrigation water and fertilizer salts. Due to this nonuniformity, high leaching rates were maintained to reduce the buildup of fertilizer salts. Thus, soilless root media were designed to be leached frequently and were difficult to over water.

Recently, there has been an emphasis on reducing water and fertilizer runoff from greenhouses into the environment to reduce the potential for ground water contamination. One method that has been suggested to reduce water and fertilizer runoff is through root media selection. Root media with a high water holding capacity may allow a longer period of time between each irrigation, thus requiring fewer irrigations to produce a crop. Fewer irrigations may reduce the amount of water and fertilizer runoff. However, little information exists on how extending the time between irrigations affects nutrient levels in root media with high water holding capacities. A better understanding of how root media components, amendments and different types and methods of applying fertilizer interact to affect root media nutrient levels will help greenhouse growers become more efficient in fertilizing greenhouse crops.

The objective of this research was to better understand how root media affect the water and fertilizer requirements of greenhouse crops during production and in the post-production environment. A further objective was to determine if root media could reduce the amount of maintenance required sustain the keeping quality of flowering plants in hanging baskets in a post-production environment.

LITERATURE REVIEW

Literature Review

Water and Fertilizer Efficiency of Peat-based Root Media

The application of water soluble fertilizer (WSF) is the most common method of fertilizer application in the greenhouse industry. However, with the high fertilizer concentrations and rates of leaching that can be found under commercial conditions (George, 1989), the application of WSF is not an efficient method of applying fertilizer. Large amount of nutrients can be lost from the pot due to leaching which is an important environmental issue (Furuta, 1976; Holcomb, 1980; Hershey and Paul, 1982; Biernbaum, 1992). Estimates of the amount of mineral nitrogen that can be applied to different container crops range from 2000 to 6000 kg N ha^{-1}, while the amount of mineral N required by those same plants was between 200 and 600 kg N ha^{-1} (Holcomb, 1980; Yelanich, 1991; Nelson, 1991).

The efficient application of water and water soluble fertilizer is important for the greenhouse industry to prevent water and fertilizer runoff into the environment (Biernbaum, 1992). One method of reducing water and fertilizer runoff from greenhouses is to reduce the amount of water leached from the root media during irrigation. George (1989) found that leaching fraction above 50% were not uncommon with automatic drip irrigation systems. Yelanich (1991) demonstrated that a reduction in applied nutrients was possible with a decrease in the leaching fraction and the concentration of the fertilizer solution. Hasek et al. (1986) determined that chrysanthemums could be grown without any leaching if fertilizer concentrations were reduced.

Another way to reduce water and fertilizer runoff may be through root media selection (Biernbaum et al., 1989). According to Nelson (1991), the four functions of a root media to support plant growth are: 1) serve as a reservoir for plant nutrients, 2) hold water that is available to the plant and at the same time, 3) provide sufficient air space for gas exchange between the roots and the air outside the pot and, 4) provide support for the plant. Root media with a high water holding capacity may provide these desired functions and also allow a longer period of time between each irrigation, thus requiring fewer irrigations to produce a crop. Fewer irrigations may reduce the amount of water and fertilizer runoff.

The switch from field soil to soilless mixes was due primarily to the difficulty in finding uncontaminated field soil with the proper balance of physical and chemical properties and the improved aeration and drainage provided by coarser root media (Nelson, 1991; Biernbaum, 1992). Because of the importance in maintaining root media uniformity, weed and pathogen free materials such as peat, bark, perlite and vermiculite tend to be the primary components of soilless mixes (Boodley and Sheldrake, 1972).

Efforts to provide for properties in a peat based root media necessary for the efficient application of nutrients and irrigation water can be broken down into six categories; 1) water holding capacity of the root media at any single irrigation, 2) moisture release characteristics of the root media, 3) rewettability or water absorption rate of the root media, 4) evaporation of water from the surface of the root media, 5) nutrient retention due to cation exchange capacity (CEC) and, 6) addition of resin coated fertilizers (RCF) to supplement root media CEC.

Water Holding Capacity

Water holding capacity is determined by the volume of the root media in a container occupied by either solid or pore space. The amount of total pore space (TPS) in a root media is inversely proportional to the bulk density (BD) (Beardsell et al., 1979a; Hanan et al., 1981; Bunt, 1983). As the BD decreases, TPS increases linearly.

Bunt (1983) tested 32 combinations of peat and either vermiculite, calcined clay or sand with BD's ranging from 90 to 1500 kg m^{-3}. Bunt obtained the following relationship between the BD of the root media combination and the TPS:

$$\text{Total Pore Space} = 98.39\ (\pm\ 0.26) - 0.03655\ (\pm\ 0.00036) * \text{Bulk Density}$$

Sphagnum peat and vermiculite, components of the Cornell Peat-lite A mix, would have a BD of approximately 125 kg m^{-3} or less. Using the above equation, the calculated TPS of the Peat-lite A mix would be approximately 93%. In comparison, a loam based soil can have a BD of 1400 kg m^{-3} and a calculated pore space of 47%. It is commonly reported that mineral soils contain about 50% solid and 50% pore space. In contrast, in a soilless peat-based root media, only 7%-15% of the volume may be solid with the remaining 85%-93% being occupied by pore space (DeBoodt and Verdonck, 1971; Blom, 1983: Fonteno, 1988).

For some components, such as perlite, large amounts of internal closed pore spaces may be present (Bunt, 1983). In the case of closed pores, there is a difference between the total and effective pore space. Effective pore space is the volume within the root media for exchange of gases and water. In root media containing perlite, total pore space remains constant at approximately 90% with increasing amounts of perlite but the

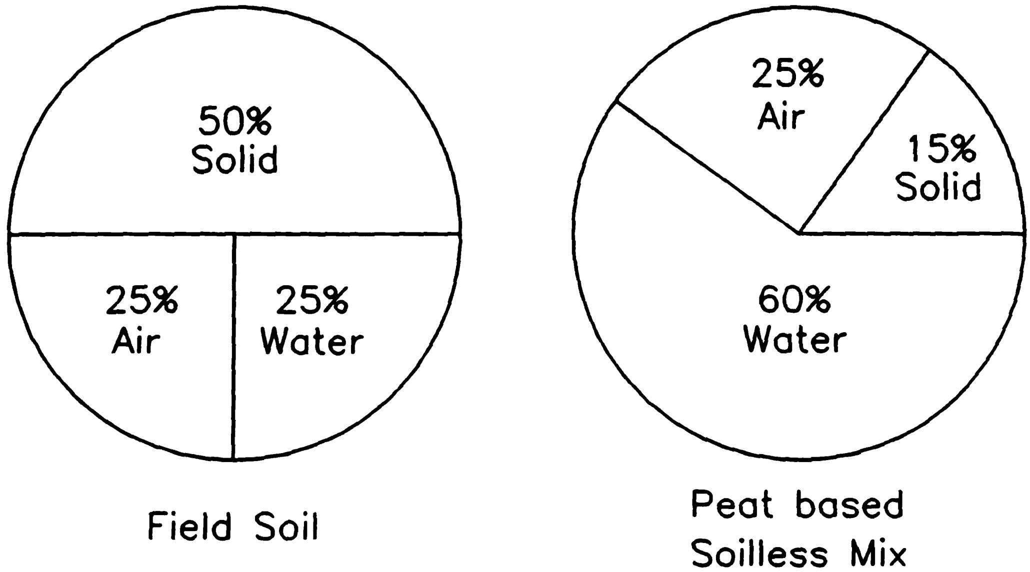

Figure 1. Ideal distribution between air, water, and solid in a field soil and a peat based root media (DeBoodt and Verdonck, 1972).

effective pore space decreases from 90% to 80% over the same ratios of perlite (Bunt, 1983).

Pore space is occupied by either air or water. For field soil with a column height of over 1 meter, pore space (50% of the total volume) after drainage is typically reported to be 50% air and 50% water (Figure 1). For a peat based container root media in a 15 cm (6 inch) tall pot at container capacity, the reported ideal pore space (85% of the total volume) is 30% air and 70% water (Deboodt and Verdonck, 1972). The distribution of air and water in a container root media is dependent on several factors including pore and particle size distribution, container height, and shrinkage or settling.

DeBoodt and Verdonck (1971) estimated that ideal container root media maintain 25% air space at container capacity. The problem with root media with low air space is that the root media can be difficult to manage due to the increased chance for over watering. Bunt (1988) found a decrease in the growth of tomatoes as the percent air space in a container decreased below 10% of the total volume of the pot. Fonteno (1988) found that the average air space in five commercially available root media to be 21% (percent air space ranged from 17% to 24% of the total volume of the pot) in a 15 cm pot at container capacity. Thus it appears that in commercially available root media, a relatively high air space is maintained. Porous root media most likely evolved in response to the development of automated irrigations systems developed in the 1960's (Biernbaum, 1992).

When the air and solid space are subtracted from the total volume of the pot, the amount of water held in the root media can be determined (White and Mastalerz, 1966). In the example from Fonteno (1988), if 10%-15% is solid space and 21% is air space, then the remaining 65%-70% of the 15 cm pots is occupied by water at container capacity. The amount of water held in a root media after an irrigation is dependent on the particle size and pore space distribution within the root media and gravitational forces pulling the water out of the pot as determined by container height (Nelson 1991).

Particle size and pore space distribution influence the ratio of water to air held in the root media. Two types of pores exist within a root media, capillary and non-capillary pores. Capillary pores are smaller (< 0.3 mm) and retain much of the water after an irrigation. Non-capillary pores are larger (> 0.3 mm) and provide the aeration for the roots. It is normally reported that the water held in a root media that is available to the plant is held at a tension between 1 and 10 kPa (DeBoodt and Verdonck, 1971) (see moisture release discussion, p. 11). This range of moisture tension corresponds to pore space diameters of between 0.3 and 0.03 mm (Bunt, 1988). Thus, the smaller the particle size, the greater percentage of smaller pore spaces and the greater amount of water held in the root media after an irrigation.

Puustjarvi and Robertson (1975) reported on the relationship of particle size and water holding capacity of peat. If particle size is less than 0.01 mm, the pore space diameter is so narrow that the water is held at tensions that make the water unavailable to the plant. Particle size between 0.01 mm and 0.8 mm retain most of the water applied and so most of the pore space within these particles would be termed capillary pores. Non-capillary pores may still contain water, but the water is held as a film along the sides of the pore space. Both water and air can exist in non-capillary pores at the same time. As particle size increases from 0.8 mm to 6.0 mm, the proportion of large non-capillary pores increases thus increasing the amount of space occupied by air after an irrigation. Above 6.0 mm, large non-capillary pores predominate (Puustjarvi and Robertson, 1975)

The type of peat used in a root media will greatly effect the physical properties. In general, the more degraded the peat, the greater the BD, which in turn reduces pore space (Puustjarvi and Robertson, 1975). More degraded types of peat also contain a greater percentage of fine particles which reduces the amount of large pore spaces (non-capillary pores) in the root media (Table 1). More degraded types of peats maintain a

Table 1. Percentage by volume of capillary and non-capillary pores in four different types of peat (Puustjarvi and Robertson, 1975).

Peat type	Capillary pores	Non-capillary pores
Coarse sphagnum peat	18	78
Medium-coarse sphagnum peat	29	66
Fine dark sphagnum peat	43	50
Black peat	50	39

lower percentage of air space in a root media due to the lower percentage of non-capillary pores.

The handling and preparation of peat based root media can have a great effect on the distribution between capillary and non-capillary pores (Milks et al., 1989). Excess shredding or mixing can break down the structure of peat by reducing particle size. In greenhouse operations where root media is prepared on site in batch mixers, it is not uncommon for the first bale of peat to be in the mixer for 20 to 30 minutes before the root media is ready for the pot filling machine. By reducing the particle size of the peat, the distribution between capillary pores and non-capillary pores is changed. Increasing the percentage of small pores will increase the water holding capacity but will decrease the air space (Bunt, 1988; Fonteno, 1988).

Due to peats high water holding capacity, materials are often added to peat to decrease the water holding capacity and thus increase air space (Spomer, 1974). Examples of these materials are perlite, polystyrene, and vermiculite. These materials are meant to increase the percentage of non-capillary pores within the root media thus decreasing the total amount of water held after an irrigation.

Other materials such as rockwool or water absorbent gel are added to a root media to increase the water holding capacity. Rockwool has been used as a substrate for hydroponics for several years. Recently, rockwool has been added to peat as a component to increase both the air and water holding capacity of peat.

Rockwool is an inert material with a very low BD and thus contains approximately 92% pore space or similar to the least degraded sphagnum peats (Fonteno and Nelson, 1990). Loose rockwool has been shown to produce plants of similar size and quality as peatlite mixes both when used as a single component or as a component in peat based root media (Hanan, 1983; Lee et al., 1987; Fonteno and Nelson, 1990; Blom and Piott, 1992).

Rockwool is added to a root media to increase both the water holding capacity and aeration. Fonteno and Nelson (1990) found the water holding capacity of a pinebark (45%)/rockwool (20%)/ vermiculite (20%)/ sphagnum peat (10%)/ perlite (5%) blend to be slightly less than two commercial root media but the aeration to be slightly greater.

Root media containing rockwool have been reported to be susceptible to shrinkage in excess of 30% of the total volume of the pot after planting (Hanan, 1983; Blom and Piott, 1992). It is recommended that additional root media be added to the pot to compensate for the shrinkage (Hanan, 1983).

Water absorbent gels are materials that absorb between 40 and 1000 times their own weight in pure water. Originally formulated in the early 1960's for water purification, these materials are available in horticultural grades and are marketed to increase the water holding capacity of the root media and therefore, extend the time between watering, decrease water and fertilizer runoff, increase plant quality and extend shelf life (Kuack, 1986; Sulecki, 1988; Fisons Postharvest Mix, 1990). In containerized root media, gels have been shown to increase the post production shelf life of chrysanthemums by up to 100% (Bearce and McCollum, 1977). However, while some research has shown a benefit from the gel, other research has shown no benefit at the recommended incorporation rates (James and Richards, 1986; Lamont and O'Connell, 1987).

Water absorbent gels may require up to 8 hours to fully absorb water (Wang and Gregg, 1990). Wang and Gregg (1990) found that one type of gel incorporated in a root media required 15 daily irrigations to fully hydrate. Fertilizer salts also decrease the amount of water absorbed by the gel. Specifically, divalent cations such as calcium, magnesium, and iron can irreversibly reduce the amount water held by the gel (James et al., 1986; Wang and Gregg, 1990; Bowman et al., 1990). Bowman et al. (1990) found that tap water with a EC of 0.5 mS cm^{-1} reduced the amount of water absorbed by the gel 25% of the water absorbed in deionized water. The long period of time for hydration and the effect of fertilizer salts on water absorption may explain why no consistent beneficial effect has been observed with water absorbent gels.

Container height also affects the ratio between air and water in a given root media. The greater the container height, the less water that will be held in a given root media. After saturation and drainage, a perched water table exists at the bottom of the pot (Spomer, 1975). For every 1 cm increase in height above the bottom of the pot, there is a 0.1 kPa increase in moisture tension and less water held. Milks et al. (1989) showed that the percent moisture held in a 17 cm tall pot decreased from 69% at the bottom of the pot to 32% at the top of the pot. The overall container capacity of the root media within the pot was the average water held by the root media throughout the column.

An illustration of how container height affects the water content of a root media is presented by Fonteno (1988). At container capacity, the average water content of 5 different commercially available root media in a 15 cm pot was 64%, in a 10 cm pot was 70%, a 48 cell bedding flat was 76%, and a 273 plug tray (5 cm tall) was 82% water by volume. The percentage of solid material in the root media remained relatively constant in the different container sizes. It was the ratio of air space to water space that changed with the different container heights.

Shrinkage or settling affects the physical properties of a root media by decreasing column height and changing the distribution between capillary and non-capillary pores (Nash and Pokorny, 1990). Settling occurs when the small particles settle into the large non-capillary pores located between the larger particles (Spomer, 1974). Nash and

Pokorny (1990) found that excess settling occurred in a two component root media when there was a large difference in the particle size of the two components. The greatest amount of settling occurred when the components were mixed in equal volumes (50% each by volume). Settling could be reduced or eliminated by using similar size components in the root media (Nash and Pokorny, 1990).

Blom and Piott (1992) found that peatwool (50% peat, 50% rockwool by volume) was susceptible to large loss in volume (> 30% of total volume) due to settling and occurred primarily during the first overhead irrigation. Compaction with 50 g cm^{-2} force and or increasing the preplant moisture content to 250% of dry weight decreased settling. However, while compaction reduced settling, it also increased the amount of root media required to fill the pot by 30% (Blom and Piott, 1992). Perhaps the formulation of peatwool using 50% fine peat and 50% medium grade rockwool made this type of root media particularly susceptible to settling, as predicted by Nash and Pokorny.

Moisture Release Characteristics

The amount of water held in the root media after an irrigation is not the only factor influencing the duration between irrigations. Equally important is the availability of the water in the root media.

The water held in the root media after an irrigation can be divided into water available to the plant (available water) and water that remains in the root media even when the plant is wilted (unavailable water). The available water is reportedly held at moisture tensions of between 1 and 1467 kPa, 1 kPa would be equivalent to a root media at container capacity and 1467 kPa would be the same root media at permanent wilt (Bunt, 1988; Milks et al., 1989) (1 kPa = 10 cm water = 10 mbars).

A reduction in plant growth is observed long before the moisture tension reaches 1467 kPa (Bunt, 1988). For example, Spomer and Langhans (1975) measured an increase

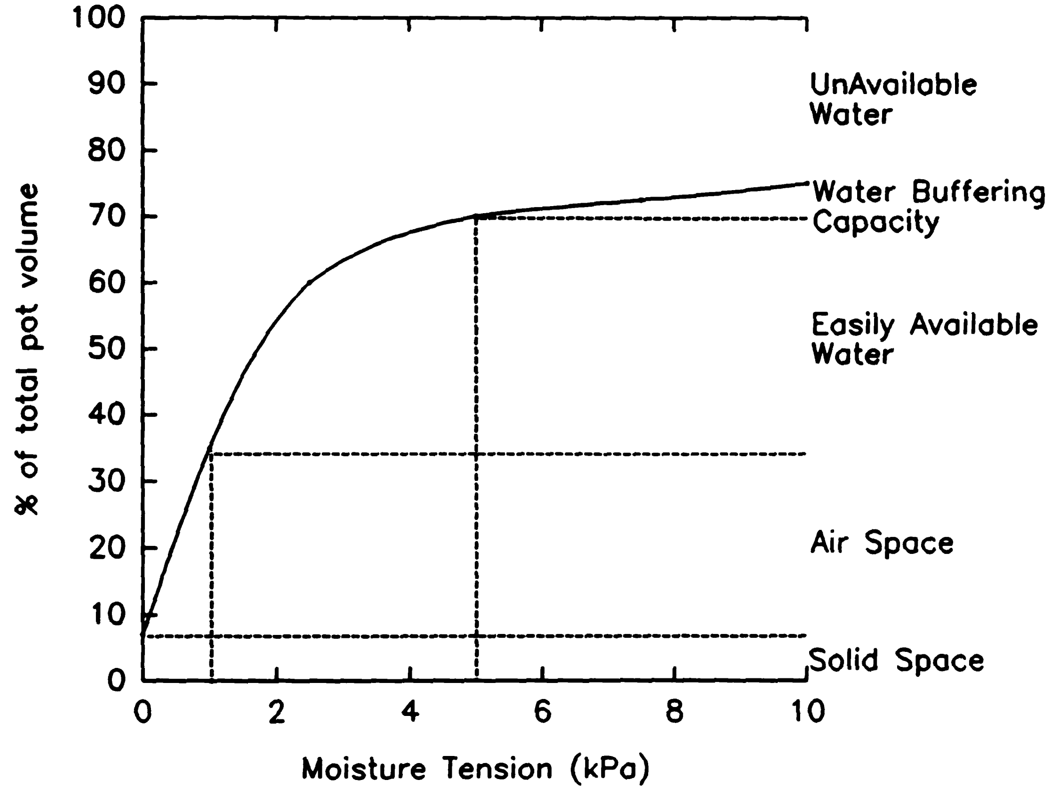

Figure 2. Moisture release characteristics of the ideal container root media (Verdonck et al., 1983).

in the growth of bench chrysanthemums as the water content of the root media was increased to approximately 90% of pore saturation. When Kiehl et al. (1992) grew chrysanthemums at different moisture tension levels, there was a decrease in fresh and dry weight as the constant moisture tension the plants were grown at increased from 0.8 to only 16 kPa.

Figure 2 illustrates the moisture release characteristics of the ideal container root media. Moisture tensions for container root media that are easily available to the plant are often reported between 1 and 5 kPa and moisture tensions between 5 and 10 kPa are termed water buffering capacity (DeBoodt and Verdonck, 1972). Milks et al. (1989) termed moisture tensions levels above 30 kPa as being unavailable water. Verdonck et al. (1983) recommend that for optimal growth conditions, 30-45% of the water held in a root media after an irrigation should be easily available water. Fonteno and Nelson (1990) found that two commercial root media (Metro Mix 350 and Ballmix #2) had available water contents of approximately 35%.

Peat type and particle size also affect moisture release. As with water holding capacity, the more degraded the peat, the greater the percentage of water held at higher moisture tensions (Table 2). The higher moisture tensions are due to the greater percentage of fine particles (<0.1 mm) and capillary pores small enough to retain water even at the high moisture tensions. Thus for more degraded peats, it may be necessary to maintain moisture levels closer to saturation than for less degraded peats in order to maintain optimal growth levels, similar to the results found by Spomer and Langhans

Table 2. Moisture release characteristics of different peats between moisture tensions of 0 and 10 kPa (Puustjarvi and Robertson, 1975).

Peat type	TPS	AS	EAW	WBC	UAW
Coarse sphagnum peat	95%	45%	25%	7%	18%
Medium coarse sphagnum peat	94%	24%	30%	10%	30%
Fine dark sphagnum peat	92%	10%	27%	12%	43%
Black peat	89%	0%	22%	7%	60%

Water held at tensions between 1 and 5 kPa is easily available water (EAW) and between 5 and 10 kPa is water buffering capacity (WBC) an is calculated as a percentage of total volume. Water held at greater moisture tensions than 10 kPa is assumed to unavailable water (UAW). The difference between total pore space (TSP) and the water held at 1 kPa is the air space (AS) of the peat at container capacity.

Table 3. The relationship between available water holding capacity (AWHC) and water release (Beardsell et al., 1979b)

	Peat	Pinebark	Sandy loam
AWHC (% by volume)	50.2	38.5	30.8
Days to visible wilt	5.7	10.1	6.5

(1975) for greenhouse bench soils.

Due to the large amount of easily available water, plants grown in peat and peat based root media maintain higher rates of transpiration than plants grown in other root media components (Beardsell et al. 1979b). However, with higher rates of transpiration, large amounts of water held in the peat are quickly used by the plant.

The difference between available water holding capacity (AWHC) and water release from a root media to the plant is illustrated in Table 3 (Beardsell et al., 1979b). In the experiment, different organic and inorganic root media components were evaluated for both water holding capacity and days to wilt (water release). Marigold seedlings were transplanted into the different components and allowed to acclimate. The components were then saturated with water and allowed to dry until wilt was observed. Of the organic materials, peat held the greatest amount of water after an irrigation but went the shortest period of time to wilt. Pinebark held 30% less available water but went 80% longer before wilt was observed. Transpiration rates (measured gravimetrically) for plants grown in peat were higher than for plants grown in the other materials tested. As available water became limiting in other materials, transpiration rates of the plants gradually decreased. This would indicate that for materials such as pinebark or sandy loam, there was a relatively small percentage of easily available water, but a large percentage of less available water (water buffering capacity) that could be absorbed by the plant, but not as quickly as easily available water. Peat contained a large percentage of easily available water but once used up, there was relatively little water buffering capacity and the plants wilted (Beardsell et al., 1979b)

Water absorption and rewettability

For irrigation water to be applied efficiently over the production of a greenhouse crop, it is important that a root media not only retains a large amount of water after one irrigation but also quickly absorbs water over an extended period of time. Relatively little research has been done on a root media's capability of quickly absorbing water under normal production conditions.

The currently used method of determining root media air and water space at container capacity (White and Mastalerz, 1966) has little relationship with a normal irrigation under commercial conditions. With current methods, the root media remain submerged in water for 24 hours. Following drainage, a perched water table is present at the bottom of the pot. Under production conditions, the root media is typically dry at the start of an irrigation and may be irrigated for a period of one to five minutes. Lateral distribution of the water is slow and saturation often does not occur (Biernbaum, personal communication).

Organic materials such as peat tend to be hydrophobic and may be difficult to rewet if allowed to become too dry. Airhart et al. (1978) and Beardsell and Nichols (1982) found that when the water content of pine bark was allowed to decrease below 35%, little of the water applied was retained. As moisture levels increased to 50%, the bark became progressively easier to rewet. Thus the greater the water content of a root media prior to an irrigation, the greater the amount of water held in the root media after an irrigation.

Other components can be added to a root media to increase water absorption. Beardsell and Nichols (1982) found that water absorption by coarse sand was not dependent on the moisture content prior to water being applied. This water absorption characteristic could be transferred to a root media in proportion to the amount of course sand used. Beardsell and Nichols concluded that a minimum of 30% of the volume of the root media be made up of coarse sand to achieve acceptable levels of rewettability (> 80% of initial container capacity). However, the large percentage of sand reduced the water holding capacity of the root media and, therefore, was less effective than preventing the root media from drying out (Beardsell and Nichols, 1982). Vermiculite and perlite may also improve the rewettability of root media (Bunt, 1988).

Much of the research on the rewettability of peat has dealt with the effect of wetting agents or surfactants. Many surfactants exist but relatively few are not phytotoxic to plants (Sheldrake and Matkin, 1969). Wetting agents are nonionic materials that bind to the surface of the root media particle and decrease the surface tension of the water, thus increasing the penetration of water into the root media which increases rewetting (Valoras et al., 1976; Templeton, 1987). Wetting agents are commonly added to commercial peat based root media to aid in rewetting (Templeton, 1987). One application of AquaGro L (1500 mg liter^{-1}) increased the amount of water absorbed by air dried peat (17% moisture content) by 90% at one irrigation (Aquatrols Corporation, 1992).

The effect of a wetting agent should be relatively long lasting. Valoras et al. (1976) found that a nonionic surfactant did not degrade quickly in sphagnum peat. After 270 days, only 30% of the surfactant had decomposed in the peat compared to 70% degradation in a water repellent sandy loam soil. However, some wetting agents can be applied frequently without phytotoxicity at low rates (Templeton, 1987).

The state of decomposition of the peat may also affect the ability to rewet after drying. Peats in a greater state of degradation also have a greater amount of humic acid. Humic acid plays an important role in cation exchange capacity of peat based root media (see CEC discussion). However, if peat is allowed to dry, the humic acid may form hard granules that have lost their initial capacity to absorb water and nutrients and may ultimately have an adverse affect on the structure of the peat (Puustjarvi and Robertson, 1975).

Evaporation of water from the surface of the root media

Laurie (1950) commented on the large amount of water lost by peat due to surface evaporation. The peat fibers act as a wick, moving the internal moisture by capillarity to the surface where evaporation is most rapid. The more fibrous the peat, the greater the wicking effect and the greater amount of water lost due to surface evaporation.

In a experiment by Beardsell et al. (1979b), different materials were placed in 13 cm pots and saturated with water. After draining, the pots were weighed to determine the amount of total water held in the pot. Weights were taken daily for the first 5 days and every other day for the remaining 8 days to determine the amount of water lost by evaporation from the surface of the media. Peat took seven days to loose 0.25 liters or 50% the water held at container capacity by evaporation. In comparison, pine bark lost 0.10 liters or 22% of the total water held at container capacity over the same time period. Thus, the high water holding capacity of peat compared with other types of material used as root media is offset in part by the large amount of water lost because of evaporation from the surface (Beardsell et al., 1979b).

Various researchers have estimated the amount of water lost from the pot due to evaporation from the surface of the root media during plant production to be 25%-30% of the total amount of water used by the plant on a per day basis (Furuta et al., 1977;

Van de Werken, 1989). Total plant water use can be reduced by simply placing a barrier over the surface of the root media to block evaporation. Furuta (1977) reduced evapotranspiration of Monteray pines grown in 3.8 liter containers by 26% with the use of a plastic disk placed over the surface of the root media.

One of the consequences of water evaporation from the surface of the root media is the concentrating of soluble fertilizer salts into the top 1-2 cm of the root media. As water evaporates, any fertilizer salts mixed with the water will be left on the surface of the root media. Top watering with leaching may leach the fertilizer salts back into the root zone and perhaps out of the pot. However, with subirrigation, fertilizer salts will remain at the root media surface and will continue to increase in the top layer of the pot throughout the production of the crop. With the accumulation of salts at the surface layer of the root media, nutrients may be unavailable to the plant, thus reducing the efficiency of fertilizer applications.

Guttormsen (1969) studied the accumulation of fertilizer salts in subirrigated pots. Lettuce plants were grown in 10 cm pots for ten weeks using either constant water level or ebb and flow subirrigation. Plants were fertilized with either 7, 14, or 28 mol m^{-3} N at every irrigation. Separate root media analysis was determined for the top half and bottom half of the pot. The difference in root media EC between the two layers within the same pot was much greater than over the three fertilization levels. After ten weeks, nutrient levels in the bottom half of the pot were approximately 1, 2, and 3 mS cm^{-1} for the respective fertilizer treatments. In the top half of the same pots, nutrient levels were 5, 9, and 20 mS cm^{-1} (Guttormsen, 1969).

If evaporation of water from the surface of the root media is reduced, fertilizer salts do not move to the top layer of the root media. Instead, fertilizer salts remain in the root zone. Havis (1982) conducted an experiment with RCF in which some of the containers were covered with a fiber glass disk. Root media was sectioned into 10 cm sections and tested separately. The treatment receiving the high rate of RCF (3.0 kg m^{-1}) and the surface covered with a barrier were lower in quality than the same plants without the barrier. In plants with the barrier, a lower EC was measured in the top 10 cm. The decrease in plant quality with the barrier was reportedly due to the higher EC levels measured in the root zone (Havis, 1982).

Nutrient retention

Cation exchange capacity (CEC) refers to the ability of a root media to retain positively charged nutrients against the leaching effects of water while still allowing the nutrients to be available to the plant (Conover and Poole, 1977; Nelson, 1985). The CEC of peat tends to be relatively high and is usually reported to be 100 to 130 meq $liter^{1}$ (1.0 to 1.3 meq g^{-1}, assumed BD = 100 kg m^{-3}) (Puustjarvi and Robertson, 1975; Nelson, 1991; Bunt, 1988). Conover and Poole (1977) tested twelve different peats and found the CEC to range from 120 to 760 meq $liter^{1}$ (by weight not possible, BD not available (NA)).

The CEC of peat is due to the presence of humic acid. Humic acid is made up of an amorphic hydrophobic interior with an exterior covered by a large amount of acidic carboxyl and phenolic groups. Humic acid is formed from the degradation of lignins from the cell wall of plants (Puustjarvi and Robertson, 1975). The more degraded the peat, the greater the amount of humic acid and the higher the CEC by both weight and volume.

The CEC of the humic acid is pH dependent and increases as the pH increases. Helling et al. (1964) found that the CEC of a sphagnum peat increased by 140 meq $liter^{1}$ (1.4 meq g^{-1}, assumed BD = 100 kg m^{-3}) as the pH increased from 3.5 to 8.0. In contrast, the CEC of montmorillonite clay increased 0.18 meq g^{-1} (by volume not possible, BD NA) over the same pH range.

Lucas et al. (1975) described a peat with a pH of 3.0 to 3.4 as being nearly hydrogen saturated. At a low pH, hydrogen ions are tightly bound to the organic acids (carboxyl and phenolic groups) and thus the overall CEC is low due to the absence of organic acid binding sites. As the pH increases, the hydrogen ions are removed from the organic acids. Once the hydrogen ion is removed from the organic acid, the acid has a net negative charge and can absorb a cation. The greater number of hydrogen ions removed, the greater number of cation binding sites available and the higher the CEC. At a pH of 7.6, a large percentage of the hydrogen ions have been removed from the organic acids and the peat described as being Ca/Mg saturated (Lucas et al., 1975).

The strength of retention of ions at the exchange sites is ion specific. Baes and Bloom (1988) found that peat preferentially absorbed Ca^{+2} over Mg^{+2}. Andre and Pijarowski (1977) found that the selectivity of sphagnum peat for either Ca^{+2} or K^{+1} was determined by the CEC (pH) of the peat and the H-Ca exchange site, even at relatively low concentrations of the divalent cation. These results would indicate order of strength of absorption would be Ca > Mg > K and would be similar to the ion absorption of soil colloids (Brady, 1974). Thus, the CEC of peat is largely an indication of the potential amount of exchangeable divalent ions, specifically Ca^{+2} and Mg^{+2}. The monovalent ions, NH_4^{+1} and K^{+1}, will mostly remain in solution as water soluble ions (Bunt, 1988).

When the hydrogens dissociate from humic acid, humate ions are formed. If the predominant cations are an alkali earth metal such as potassium, the humate complex will remain water soluble and the nutrients will be available to the plant. If the predominant cations are alkaline earth metals such as calcium or other diatomic ions, the humate complex is insoluble and the nutrients bound to the humate are less available to the plant

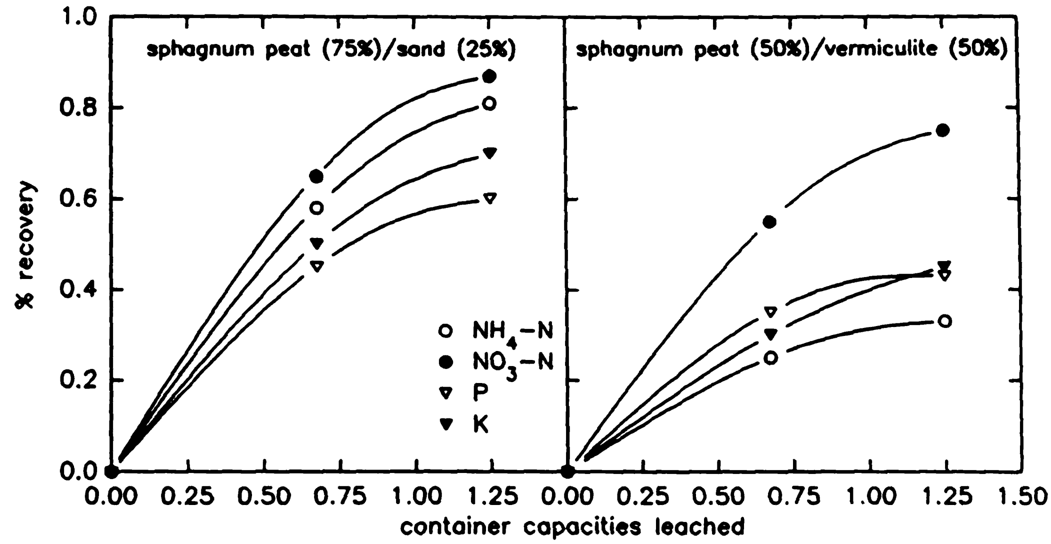

Figure 3. Percentage of nutrients leached from a sphagnum peat/sand and a sphagnum peat/vermiculite root media in 1 liter pot (Bunt, 1988).

(Puustjarvi and Robertson, 1975). Verloo (1980) reports that the water soluble humate complex may clog non-capillary pores and interfere with normal gas exchange. The addition of lime to peat is necessary for the conditioning of peat not only to raise the pH but also to provide sufficiently high amounts of Ca^{+2} to keep the humic acid flocculated.

Other material can also be added to peat base root media to increase CEC. Vermiculite has a CEC of 100 to 150 meq liter^{1} (1.0 to 1.5 meq g^{-1}, BD = 100 kg m^{-3}) or similar to that of peat in both weight and volume. Vermiculite will retain K^{+1} and NH_4^{+1} along with the divalent cations. The NH_4^{+1} is available to bacteria to convert into NO_3^{-1} (Bunt, 1988). In a controlled leaching experiment, Bunt (1974) found that a mixture of 75% sphagnum peat and 25% fine sand lost greater amounts of NH_4-N, K^{+1} and phosphorus at all leaching rates up to 1.25 container capacities leached compared with a mixture of 50% sphagnum peat and 50% vermiculite (Figure 3). Similar amounts of NO_3-N were lost from both root media.

Clinoptilolite Zeolites are silica based materials with a honeycomb type structure and a CEC of 3700 meq $liter^{-1}$ (1.85 meq g^{-1} , assumed BD = 2.0 g cm^{-3}). Much of the exchange capacity is located within the small pores. Due to the size of the pores (0.5 nm), K^{+1} and NH_4^{+1} are preferentially absorbed over diatomic cations. These pores are also small enough to exclude the bacteria that convert NH_4^{+1} to NO_3^{-1}. Bunt (1988) found that a mixture of 90% peat and 10% zeolite had a CEC of 290 meq $liters^{-1}$ (by weight not possible, BD NA) or double the CEC of the peat alone. Hershey et al. (1980) found that the incorporation of 33.3 kg m^{-3} potassium enriched zeolite as the only source of potassium produced pot chrysanthemums equal in quality as plants receiving a daily irrigation of a fertilizer solution containing 6 mol m^{-3} K. The release of the potassium from the zeolite was similar to the nutrient release of a slow release fertilizer (Hershey et al. 1980).

Root media components such as perlite, polystyrene, and rockwool have no significant CEC and thus have no effect on nutrient retention due to ionic factors if added to a root media. However, components increasing the water holding capacity of the root media and or reducing the amount of leaching may reduce the necessity for higher CEC.

The CEC of peat and vermiculite based on a weight basis is large compared to mineral soil. However, on a volume basis, the CEC can be quite low. An example from Foth and Ellis (1988) is to compare the CEC of peat (BD = 100 kg m^{-3}) and sandy loam mineral soil (BD = 1200 kg m^{-3}). On a weight basis, the CEC of peat is 1.2 meq g^{-1} and the CEC of the sandy loam was 0.12 meq g^{-1} or 10% of the CEC of peat. However, the BD of the sandy loam is twelve times that of peat. On a volume basis, the CEC of peat would be 120 meq $liter^{-1}$ and the CEC of sandy loam would be 140 meq $liter^{-1}$ or 17% greater than peat.

Compared to CEC, the anion exchange of peat is very low (Puustjarvi and Robertson, 1975). The major sources of ground and surface water contamination are the nitrate ($NO3^{-1}$) and the phosphate (PO_4^{-3}) anions. Most if not all of the nitrate and phosphate would remain in solution and could be easily leached from the pot.

Bunt (1988) mentions the experimental use of anion exchange resins in root media. No other previous research to increase anion exchange in container root media was found.

Resin coated fertilizers

In the absence of appreciable root media CEC, the use of resin coated fertilizers (RCF) may help retain nutrients within the root media. One advantage to RCF is the greater efficiency of nutrient recovery and the reduction of fertilizer runoff (Lunt and Oertli, 1962; Furuta, 1976; Holcomb, 1979; Shibata et al. 1979; Holcomb, 1980; Hershey and Paul, 1982). Holcomb (1979) estimated that 46% of the applied N would be absorbed by the plant with WSF while the calculated efficiency of RCF was 89%.

Hershey and Paul (1982) conducted a leaching study in which chrysanthemums were grown with different incorporated rates of RCF or different concentrations of WSF. Leaching fractions for all treatments averaged 27%. The percentage of the applied N lost due to leaching ranged from 12% to 23% with the RCF and 12% to 48% with the WSF. For the RCF, the majority of N lost due to leaching occurred during the first half of the crop. During the second half of the experiment, N losses due to leaching decreased to near 0%. With WSF, the N loss to leaching occurred throughout the experiment (Hershey and Paul, 1982).

The release of the nutrients in the RCF is based solely on temperature (Oertli and Lunt, 1962; Rutten, 1979; Shibata et al., 1979). For the two common types of RCF, Osmocote and other Sierra products have a release rate based on an average temperature of 21C while Nutricote has a release rate based on an average temperature of 25C. For both products, an increase in 5C will increase the amount of fertilizer released by the RCF by 25% (Osmocote - Rutten, 1979; Nutricote - Shibata et al., 1979).

The effect of temperature on release rate is illustrated in an experiment by Harbaugh and Wilfret (1982). Fixed amounts of Osmocote 14-14-14 (3-4 month release rate) were place in water and incubated for 96 days at a constant temperature of 16C, 23C, or 30C. Solutions were tested on a regular basis to determine the percentage of fertilizer salt released by the RCF. After 48 days, the RCF at 16C had released 50%, at 23C had released 70%, and at 30C had released 85% of the total salt held in the RCF.

Summary

Peat based root media hold a large amount of water at low moisture tensions. However, water holding capacity alone does not determine the length of time between irrigations. Water held at low moisture tensions is quickly used by plants and must be replaced frequently. The presence of less available water may increase the interval between irrigations but, a decrease in plant quality may be observed. Peat based root media are susceptible to large amounts of water being lost due to evaporation from the root media surface. Components can be selected for increased water holding capacity, reduced settling or shrinkage and for rapid rewetting to increase water absorption. Most commercially available root media contain some type of wetting agent to aid in the rewetting of the root media. CEC may play a role in nutrient retention but ultimately, the amount of water and fertilizer applied and leached from the pot will have a much greater effect on nutrient retention and possible fertilizer runoff. RCF provides a method of applying fertilizer more efficiently than WSF under leaching conditions.

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SECTION I

Comparison of Nutrient Levels and Irrigation Requirements of Five Root Media with Poinsettia and Easter Lily

Comparison of Nutrient Levels and Irrigation Requirements of Five Root Media with Poinsettia and Easter Lily.

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Subject Category: Soils, Nutrition and Fertilizers

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Abstract: Poinsettias irrigated by top watering with 20% leaching and Easter Lilies irrigated by subirrigation were grown with 5 root media. With top watering, root media with a high water holding capacity required fewer irrigations than root media with a lower water holding capacity. However, similar amounts of water were applied and leached with both types of root media. With subirrigation, the greatest amount of water was applied to a root media that absorbed the lowest amount of water at an irrigation. The other 4 root media received similar amounts of water. The greatest differences in root media nutrient levels were found between the top 2.5 cm (top layer) and the root media within the same pot. A top layer with nutrient levels 3 to 6 times greater than the root zone was measured with both methods of irrigation. When the root media surface was covered by an evaporation barrier in subirrigated Easter Lily pots, root zone nutrient concentrations were similar to the control plants even though 36% less water and N-fertilizer were applied to the covered plants. In a simulated post production environment, Easter lilies with the root media surface covered by a barrier lost 48% less water than the control plants.

The efficient application of water and water soluble fertilizer is important for the greenhouse industry to prevent water and fertilizer runoff into the environment (Biernbaum, 1992). One method of reducing water and fertilizer runoff from greenhouses is to reduce the amount of water leached from the root media during irrigation. George (1989) found that leaching fractions above 50% were not uncommon with automatic drip irrigation systems. Yelanich (1991) demonstrated that a reduction in applied nutrients was possible with a decrease in the leaching fraction and the concentration of the fertilizer solution. Hasek et al. (1986) determined that chrysanthemums could be grown without any leaching if fertilizer concentrations were reduced.

Another method of reducing water and fertilizer runoff may be through root media selection (Biernbaum et al., 1989). According to Nelson (1991), the four functions of a root media to support plant growth are: 1) serve as a reservoir for plant nutrients, 2) hold water that is available to the plant and at the same time, 3) provide sufficient air space for gas exchange between the roots and the air outside the pot and, 4) provide support for the plant. Root media with a high water holding capacity may provide these desired functions and also allow a longer period of time between each irrigation, thus requiring fewer irrigations to produce a crop. Fewer irrigations may reduce the amount of water and fertilizer runoff.

An adequate cation exchange capacity (CEC) is desired in a root media in order to retain nutrients and buffer the root media from a sudden change in nutrient concentration. Without an adequate CEC, the root media will not act as a suitable reservoir for nutrients and frequent fertilizer applications will be necessary (Nelson, 1991). Peat is the major component in many greenhouse root media, accounting for a minimum of 50% of the total volume. Peat has a CEC reported to be in a range of 100 to 130 meq liter^{-1} (1.0 to 1.3 meq g^{-1}, assumed bulk density (BD) = 100 kg m^{-3})

(Puustjarvi and Robertson, 1975; Bunt, 1988; Nelson, 1991). However, Conover and Poole (1977) found that the CEC of 12 different peats ranged from 120 to 760 meq $liter^{-1}$ (by weight not possible, BD NA). In general, the more degraded the peat, the higher the cation exchange capacity. For example, reed sedge peat has a higher CEC than sphagnum moss peat (Puustjarvi and Robertson, 1975).

Many of the remaining components used in peat based root media such as perlite, polystyrene, and rockwool are relatively inert and are added to increase aeration (Nelson, 1991). Rockwool is unique in that it can be added to a root media to increase both aeration and water holding capacity (Fonteno and Nelson, 1990). Vermiculite is added to a root media for aeration as well as nutrient retention. Vermiculite has a CEC of 100 to 150 meq $liter^{-1}$ (1.0 to 1.5 meq g^{-1}, assumed BD = 100 kg m^{-3}). In a controlled leaching experiment, Bunt (1974) found that a mixture of 75% sphagnum peat/25% fine sand lost greater amounts of ammonium-N (1.5 times), phosphorus (0.4 times), and potassium (0.56 times) than 50% sphagnum peat/50% vermiculite mixture with 1 liter of leachate.

Many experiments have been done to determine plant responses to root media with different physical and chemical properties. Often, the different root media are watered and fertilized the same (Brown and Emino, 1981; Fonteno et al., 1981; Bilderback et al., 1982). Differences in water absorption and water holding capacity could result in different levels of leaching. When root media are treated independently as in moisture tension experiments, leaching rates are also different for the different treatments (Karlovich and Fonteno, 1986; Kiehl et al., 1992). Root media nutrient levels are a function of both fertilizer concentration applied and the leaching fraction (Yelanich, 1991; Ku and Hershey, 1991). In order to compare root media nutrient levels in root media with different water holding capacities using top watering, the leaching fraction for each root media should be the same. With both top watering and subirrigation, the total water holding capacity and the amount of available water must be determined for each root media and irrigations scheduled accordingly. The objectives of these experiments were to monitor water use and leaching, track changes in root media EC, pH, and nutrient levels in root media of different peat types and components that varied in water holding capacity and cation exchange or buffering capacity, and to identify root media characteristics that influence fertilization practices and soil test interpretation for further study.

Materials and Methods

Experiment 1: The root media used in this experiment were as follows: 1) Al-par (Al-par Peat Co., Ovid MI). Commercially available root media (CARM) composed of field harvested muck soil containing highly degraded reed sedge peat, Canadian sphagnum peat, polystyrene and lime with a preplant nutrient charge. 2) Metro Mix 510 (Grace Sierra, Fogelsville, PA). CARM composed of Canadian sphagnum peat, #3 vermiculite, composted pine bark, bark ash, and sand with lime and a preplant nutrient charge. 3) Peat A/RW (Michigan Growers Products, Galesburg MI). CARM composed of Canadian sphagnum peat (60%), medium grind rockwool (30%) (Partek North American Inc., Brunswick OH) and, #3 vermiculite (10%) with lime and a preplant nutrient charge. 4) Peat A/VM. Canadian sphagnum peat (60%) and #2 vermiculite (40%) with lime and a preplant nutrient charge. 5) Peat B/VM. Michigan sphagnum peat (60%) and #2 vermiculite (40%) with lime and a preplant nutrient charge. Peat A was Fisons Professional Black Bale Canadian sphagnum moss peat (Fisons Western Corp. Downers Grove IL) and was a light color, long fibered peat with little dust. Peat B was a Michigan sphagnum moss peat (Michigan Peat Co., Houston TX) and was a darker, shorter fibered peat with a significant amount of peat dust. While CEC was not measured, the expected nutrient retention was Al-par > Peat B/VM > Peat A/VM = Metro Mix 510 > Peat A/RW.

The experiment was conducted in a well ventilated glass greenhouse with constant air circulation and cement floors located at Michigan State University, E. Lansing, Michigan. Rooted *Euphorbia pulcherrima* 'Gutbier V-14 Glory' cuttings were planted into 12 cm tall by 15 cm wide (volume=1.5 liter) plastic pots containing one of the 5 root media on 31 August 1989. A total of 24 plants were randomly assigned to each root media treatment. The experimental design was a randomized complete block with 3 replications per block. Plants were top watered with tap water (pH 8.3, electrical conductivity (EC) 0.70 dS m^{-1} and a HCO_3^- concentration of 5.6 mol m^{-3}) from planting until 11 September such that the root media remained moist without saturation or leaching.

The fertilizer solution used in this experiment had a concentration of 28.6-0-8.5 mol m^{-3} N-P-K from $Ca(NO_3)_2$ and KNO_3 and an EC of 3.3 dS m^{-1}. Fertilizer solution was applied with every irrigation between 12 September and 29 October. After 30 October, tap water was applied with every irrigation. The amount of water that remained in the pot after an irrigation was multiplied by the fertilizer concentration to determine the amount of N-fertilizer applied.

On 11 September 1989, root media were thoroughly watered with fertilizer solution and the pots were weighed. The weight was an estimate of the maximum amount of water that would be held in the root media after an irrigation. Thereafter, each root media was treated independently. Six plants from each root media were checked daily for watering. The time to water was determined gravimetrically when the average of the 6 plants reached a target weight based on a loss of 70% to 80% of the available water. The target weight for the root media was 650 g for plants grown in the Al-par and 600 g for all other root media. Sufficient water was applied for 20% leaching. Plants were weighed before and after each irrigation to determine the amount of water that remained in the root media. The amount of water leached from the pot was also collected and measured to determine the average leaching fraction at each irrigation. The EC of the leachate was tested after every other irrigation.

Root media samples were collected from 3 pots every 2 weeks after planting for 14 weeks. The top 2.5 cm was removed and discarded for the first 5 sampling dates. The top 2.5 cm was removed and sampled separately for the final 3 sampling dates. Nutrients in the root media were sampled using the saturated media extraction (SME) technique (Warncke and Krauskopf, 1986) using reverse osmosis (RO) water as the extracting solution. Root media pH was measured in the saturated media prior to extraction. EC was determined using a YSI model 32 conductance meter (Yellow Springs Instrument Co., Inc. Yellow Spring OH) at a standard temperature of 25C and Nitrate-N was determined with a Orion model 93-07 nitrate specific electrode (Orion Research Inc., Cambridge MA). Phosphorous, K, Ca, Mg, and Na were determined by the Michigan State University soil testing lab. Potassium, Ca, Mg, and Na were determined by flame emission and P was determined colorimetrically by the ascorbic acid method (Knudsen and Beegle, 1988).

Plant height, shoot fresh weight, leaf and bract area was measured at the final harvest. Leaf area was determined using a Delta-T area meter (Decagon Devices, Inc. Pullman, WA). Samples were dried in a forced draft oven at 60C and combined for total dry weight. Mature, fully expanded green leaves were collected for elemental analysis.

Experiment 2: The root media used in this experiment were as follows: 1) Al-Par. 2) Metro Mix 510. 3) Peat A/RW. 4) Postharvest Mix (Fisons Western Corp., Downers Grove IL). CARM composed of Canadian sphagnum peat, perlite, calcined clay and a superabsorbent gel with a preplant nutrient charge. 5) Baccto Professional Growers Mix (Michigan Peat Comp., Houston TX). CARM composed of Michigan sphagnum peat, vermiculite and, perlite with a preplant nutrient charge. Peat A was similar to the Canadian sphagnum peat used in Postharvest Mix and Peat B was the same peat used in the Baccto Professional Growers Mix. The expected nutrient retention was Al-par > Baccto > Postharvest Mix = Metro Mix 510 > Peat A/RW.

The other factor examined in this experiment was the effect of an evaporation barrier on the water and fertilizer requirements of Easter Lilies. The evaporation barrier was made from a 15 cm plastic saucer that was placed over the surface of the root media. When the plant emerged from the root media, a hole was placed in the saucer for the plant to grow up through. The barrier was placed on half the pots at planting, prior to any solution being applied.

The experiment was conducted in a well ventilated glass greenhouse with constant air circulation and cement floors located at Michigan State University, E. Lansing, Michigan. Case cooled bulbs of *Lilium longiflorum* 'Nellie White' were planted into 15 cm tall by 15 cm wide (volume=1.7 liter) plastic pots containing one of the 5 root media on 19 December 1989. A total of 20 bulbs were randomly assigned to each treatment for a total of 120 pots. Experimental design was a randomized complete block with 2 blocks for each media cover combination and 6 replications at each block. Plants were subirrigated with tap water from planting until 18 January 1990. Each root media was treated independently. Six plants from each root media were checked daily for watering. The time to water was determined gravimetrically when the average of the 6 plants reached a target weight based on a loss of 70% to 80% of the available water. This weight was 1100 g for plants grown in the Al-par and 800 g for all other root media. A plastic saucer was placed under each of the pots. Sufficient solution was placed in the saucer of the different root media such that all the solution was absorbed within 30 minutes. The amount applied was different for each root media, due to the different water holding capacities. At an irrigation, 0.45 liter was applied to the peat A/rockwool media, 0.35 liter was applied to the Metro Mix 510 and the Postharvest Mix and 0.30 liter was applied to the Baccto and Al-par media.

Starting 19 January, fertilizer solution with a concentration of 7.1-0-2.1 mol m^{-3} N-P-K from $Ca(NO_3)_2$ and KNO_3 plus a source of minor nutrients (Compound 111, Grace/Sierra) was applied at every irrigation. After 21 February, the concentration of the fertilizer solution was increased to 14.2-0.7-4.1 mol m^{-3} N-P-K plus minor nutrients. The phosphorous was supplied by the addition of 2.3 mol m^{-3} of phosphoric acid (85%) to the fertilizer solution to help reduce the pH of the root media.

Root media samples were collected from 2 pots approximately every 3 weeks starting 30 January. The top 2.5 cm was removed and sampled separately from the remainder of the pot. Nutrients in the root media were sampled as in Experiment 1.

Days to flower was calculated from time of planting until the opening of the first flower bud. Leaf height and bud height were measured from the rim of the pot. Final bud height was measured when the first bud opened.

On 14 April, six plants from each treatment were moved into a simulated post production environment which consisted of a laboratory with 24 hour fluorescent lighting and a constant temperature of 22C. The root media was saturated to close to container capacity and allowed to dry. Weights were taken every 2 days for 16 days to determine the total amount of water used by the plant over the time period. On 8 May, the top 10 leaves were removed from each plant to measure leaf area and for elemental analysis.

Results

Experiment 1

Root media nutrient levels: The initial pH was different for the different root media and ranged from 6.3 with the Metro Mix 510 and the Peat A/RW to 4.6 with the Peat B/VM (Figure 1). Peat A/VM and Peat B/VM had a similar amount of lime added prior to planting. At planting, there was a 2 unit difference in the pH of these two media. However, by week 6, there was no difference in pH between the 5 root media. Root media pH generally increased after week 8 when fertilizer solution was no longer applied. Metro Mix 510 had the greatest increase from a pH of 5.7 to 8.1 over the last 6 weeks of the experiment. Only the Peat B/VM maintained the pH once fertilizer solution was no longer applied.

Root zone EC, NO_3^{1-}-N, K^{1+}, and Ca^{2+} increased in four of the root media from planting until fertilization was stopped. In Metro Mix 510, EC and Ca^{2+} levels started at a greater level than the other root media and decreased over time. Nitrate-N and K^{1+} levels remained at or above optimum levels (Warncke and Krauskopf, 1983) in all root media during the final six weeks of the experiment while no fertilizer solution was being applied.

Phosphorous levels decreased from the first media analysis until the end of the experiment. Peat A/RW and Al-par were lower than the 3 other root media at planting but only Al-par was below the P level recommended for a SME. There was no difference in P levels for any root media during the final 2 media analyses.

While the plants were being fertilized, leachate EC was higher than root zone EC in 4 of the root media (Figure 2). In general, the difference between leachate EC and root zone EC was greater in root media that went longer between irrigations. In the Peat B/VM, leachate EC was lower than root zone EC over the same period of time. Once fertilization was stopped, leachate EC and root zone EC were similar in 3 of the root media. The leachate EC of the Peat A/RW and the Metro Mix 510 remained higher than the root zone EC until the end of the experiment.

When the top layers of the root media (top 2.5 cm) were tested 2 weeks after fertilization was stopped, EC levels were 2 to 3 times higher than either the root zone or leachate EC. In 4 of the root media, the top layer continued to have a higher EC than either the leachate or root zone for the remaining 4 weeks of the experiment. In general, the EC of the top layer was closer to the root zone EC in root media that received greater amounts of water at any 1 irrigation. In comparison, the Peat B/VM received the least amount of water at an irrigation and the top layer remained constant over the final weeks of the experiment. In the peat A/RW, the top layer and the root zone were similar for the final six weeks of the experiment.

Applied water and fertilizer: Selected plants from each root media were irrigated, allowed to dry to a wilt. The difference between the weight at the irrigation and the wilt weight was determined to be the available water held in the root media. Using this method, available water ranged from 0.44 liters in the Peat A/VM to 0.69 liters in the Peat A/rockwool. It was estimated that the plants were irrigated on average when between 75 and 85% of the available water was lost.

The total number of irrigations applied to the different root media ranged from 15 to 21 between 26 September and 6 December (Table 1). The Peat A/RW media held the greatest amount of water after a "normal" irrigation (0.59 liters), was watered the least number of times (15), and the plants received the greatest amount of water. The Peat A/VM had the greatest amount of water leached from the root media. Actual calculated leaching fractions ranged from 18% for the Peat A/RW and Metro Mix 510 to 22% for the Peat A/VM.

The number of fertilizer applications ranged from 9 in the Peat A/RW and Metro Mix 510 to 15 in the Peat A/VM (Table 1). The greatest difference in the amount of applied N-fertilizer was between the Peat A/VM and the Metro Mix 510. Plants grown in Peat A/VM received 0.4 grams N or 1.0 liter of the 28.6 mol m^{-3} N solutions more than Plants grown in the Metro Mix 510.

Plant growth and tissue analysis: Plants grown in the Peat A/RW had a greater plant height, shoot fresh and dry weight, bract number and bract leaf area compared to plants grown in the other root media (Table 2). Plants grown in Metro Mix 510 were similar in fresh weight to plants grown in the Peat B/VM but had a lower dry weight than plants grown in the Peat B/VM. Plants grown in Metro Mix 510 were shorter in height with a lower leaf number than plants grown in the other root media, but the bract leaf area was the second largest.

Leaf tissue N, Mn, Fe, and Na levels were not different at the final harvest (Table 3). Plants grown in Al-par showed lower levels of P, K and Cu and higher levels of B than plants grown in the other root media. In general, leaf tissue N, K, Ca, Mg, Mn, Fe, B, and Zn levels were within adequate levels for all the root media. Phosphorus and Cu levels were low in Al-par compared with the other 4 root media and lower than recommended for poinsettias (Ecke et al., 1990). The low leaf tissue P levels correspond to the low root media P levels measured in the Al-par.

Experiment 2

Root media nutrient levels: Root zone pH increased in all root media until day 63 at which time Phosphoric acid was added to the irrigation water (Figure 3). After the addition of acid into the fertilizer solution, root zone pH decreased until the end of the experiment.

In general, root zone EC, NO_3^{1-}-N, K^{1+}, Ca^{2+}, and Mg^{2+} decreased from the initial soil test until day 63 (third soil test). After this time, the fertilizer concentration was increased and root zone nutrient levels increased. Except for NO_3^{1-}-N and P, nutrient levels remained below the optimal level for a SME (Warncke and Krauskopf, 1983) during the remainder of the experiment in all root media. Nitrate-N levels remained below optimal levels in all root media until the final soil test at which time there was a large increase in the Postharvest mix and Al-par.

Initial root zone P levels varied by root media. The Al-par media had the lowest levels during the first half of the experiment. Once phosphoric acid was applied to the irrigation water, P levels quickly built up in the root zone of all the root media. Phosphorous levels remained lower in Al-par than the other root media despite Al-par receiving more irrigation water and thus more phosphorous from the phosphoric acid than the other root media.

Postharvest Mix had lower Mg^{2+} levels and higher Na^{1+} levels in the root zone than other root media at planting. However, Mg^{2+} levels were similar for all root media by 63 days after planting and remained similar for the final 65 days of the experiment. There was a decrease in Na^{1+} levels in the Postharvest Mix over the course of the experiment. By day 63, Na^{1+} levels were similar to the other root media.

When the surface of the root media was covered with a barrier, nutrient levels did not change as quickly as the control plants although similar trends were measured. Six weeks after planting, nutrient levels in pots covered with the barrier were similar or higher than the control pots. The covered pots had only been watered once with clear water while the uncovered pots had been watered twice with clear water and fertilized 3 times with the 7.2 mol m^{-3} N fertilizer solution.

A large difference in nutrient levels did not occur between the different root media tested. Instead, the greatest difference in nutrient levels occurred within the each pot due to stratification of fertilizer salts (Figure 4). In the control plants, much of the fertilizer salts had moved out of the root zone into the top layer of the pot. With the barrier, the stratification did not start occurring until after emergence when a whole was placed in the cover. While stratification did occur after day 40, the difference between the top layer and the root zone of covered plants was never greater than 1.5 dS m^{-1}. In the control pots, the average difference between the root zone and the top layer continued to increase over the length of the experiment and was greatest at the end of the experiment.

A lower pH was measured in the root zone of covered plant compared to the control plants. The greater change in pH of the root zone of uncovered plants was likely due to greater amounts of high alkalinity water that were applied to the uncovered pots. The pH of the top layer in both covered and uncovered pots remained stable over the length of the experiment.

Applied water and fertilizer: The number of irrigations ranged from 12 with the Peat A/RW to 20 with the Al-par (Table 4). The amount of N-fertilizer applied during the experiment was similar for 4 of the root media. Al-par received the greatest number of irrigations and also received the greatest amount of water and N-fertilizer compared with the other root media. Averaged over all root media, approximately 60% of the water and 85% of the fertilizer was applied during the last half of the experiment. The large amount of fertilizer applied during the last half of the experiment corresponds to the doubling of the fertilizer concentration at day 63.

With the covered pots, averaged over all root media there was a 35% reduction in number of irrigations and the total amount of applied water compared to the control.

Over the last 24 days of the experiment, 22% less water was applied to the covered pots (data not shown). The reduction in the amount of water applied to the plants was media dependent. The total amount of applied fertilizer was reduced by 25%. In the post-production environment, pots covered with an evaporation barrier used 49% less water than the control plants.

Plant growth and tissue analysis: Plants grown in Baccto had the smallest leaf area compared with plants grown in the other root media (Table 5). Plants grown in the Peat A/RW had the greatest leaf number but had the fewest flower buds, had the greatest days to flower and were the shortest plants at anthesis.

The plants grown with the evaporation barrier were shorter than control plants at anthesis. Leaf area decreased with the evaporation barrier in plants grown in Al-par, Peat A/ rockwool, and Postharvest Mix but increased in plants grown in Metro Mix 510 and Baccto.

Lily tissue N, K, Fe and Cu were not different for plants grown in the different root media (Table 6). Leaf P levels were lowest for plants grown in the Al-par which corresponds to the low levels of P measured in the root media analysis measured early in the crop. Plants grown in Postharvest Mix had higher leaf B, Zn and Na levels. High levels of leaf-Na were found in plants grown in the Postharvest Mix and were higher in the uncovered plants than in the control.

Discussion

The assumption made in this experiment was that differences between the container capacities and the target weights when the plants were irrigated were within moisture tension (MT) range of 5 to 30 kPa for all root media. A majority of the available water held in peat based root media is held a relatively low MT corresponding to 1 to 30 kPa (DeBoodt and Verdonck, 1972).

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A smaller leaf area was measured in lilies and poinsettias grown in the Al-par and Peat B/VM or Baccto media. Both of these media contain a large amount of fine peat particles and dust. Fine particles are known to increase the capillary pore space within a root media. Increasing the capillary pore space may increase the water holding capacity of the root media which in turn may decrease aeration. However, the methods of irrigation used in both experiments would have optimized aeration in all types of root media tested. Therefore, reduced aeration was probably not the cause of the reduction in leaf area measured in plants grown in the Al-par or the Peat B/VM or Baccto root media.

Fine particles and dust also increase the MT of the water held in the root media (Puustjarvi and Robertson, 1975). Kiehl et al. (1992) determined that chrysanthemums grown at higher constant MT had a lower fresh and dry weight but similar shoot height compared to plants grown at lower constant MT. Higher MT may have decreased leaf expansion in plants grown in Al-par and Peat B/VM or Baccto. However, there was no reduction in overall height of either poinsettias or lilies grown in these two root media. The reduction in leaf size was more pronounced with the poinsettias because leaf expansion directly effects plant size and floral display. Reduced leaf area did not effect the overall appearance of the lilies.

One of the primary interests of this experiment was if buffering capacity would have an effect on pH management (Biernbaum, 1992). Irrigation water in the Midwest often contains a high concentration of bicarbonate and must be treated with acid for root media pH control. In top watered poinsettias, Peat B/VM media did provide the smallest change in pH after fertilization ceased. However, the more degraded peat found in Al-par did not buffer the pH of the root media as well as expected.

There was a relationship between root zone EC and pH once fertilization ceased in Experiment 1. In general, the greater the decrease in root zone EC levels, the greater the increase in root zone pH. For example, the EC of Metro Mix 510 decreased from 5.1 dS m^{-1} to 1.7 dS m^{-1} and the pH increased from 5.6 to 8.0 over the last 6 weeks of the experiment. In contrast, the EC of the Peat B/VM decreased from 3.0 dS m^{-1} to 2.6 dS m^{-1} and the pH increased slightly from 5.9 to 6.0 over the same time period.

In top watered poinsettias, a 20% leaching fractions was not sufficient to maintain nutrient levels in the root zone within the optimal soil test levels while fertilizer was being applied in all root media tested. Either a reduction in the concentration or an increase in the leaching fraction would be necessary to maintain root zone nutrients within the recommended soil test levels similar to the conclusions of Yelanich (1991) and Ku and Hershey (1991).

Recommendations have been made to stop fertilization two to four weeks prior to shipping to reduce media fertilizer levels for improved post production keeping quality (Yelanich, 1991). With the high levels of fertilizer applied in Experiment 1, fertilization could have been stopped 6 weeks prior to finish. However, this recommendation can not be made without first measuring soil test levels. If fertilization would have been stopped four weeks prior to the end of Experiment 2, nutrient deficiencies may have occurred. Whether or not this recommendation is followed should be made based solely on soil test nutrient levels.

The greatest difference in nutrient levels did not occur between the different root media but instead were found within the pot itself. A layer of soluble salts was found in the top 2.5 cm of all root media several times higher than in the root zone in both top watered and subirrigated pots. Nutrient levels remained at or near levels normally considered optimal for a SME soil test after 6 weeks of receiving only tap water. Perhaps the high concentration of fertilizer salts in the top layer acted as a nutrient reservoir for the plant after fertilization was stopped. After fertilization was stopped, the 20% leaching fraction was not sufficient to remove the high concentration of fertilizer salts in the top layer of the root media at any one irrigation. Instead, nutrients were washed down from the top layer gradually.

With subirrigation, the top layer acted as a fertilizer sink similar to the removal of salts from the root zone by leaching with water. However, with subirrigation there was no force to wash the fertilizer salts back into the root zone. The result is that fertilizer salts continued to move from the root zone into the top layer even when root zone nutrient levels were below the optimal recommended levels (Warncke and Krauskopf, 1983).

When evaporation was reduced with a barrier, the stratification of fertilizer salts did not occur to the same extent as in the control pots. Less water and fertilizer were necessary to maintain similar root zone nutrient levels. However, if high levels of nutrients are present, a reduction in growth may be observed since the nutrient salt stratification could not occur. For example, higher root zone Na levels were found in the Postharvest Mix which may have been due to the acrylamide gel used in the mix. In the control plants, root zone Na levels decreased rapidly. In the covered pots, root zone Na levels remained higher until the last harvest. Leaf Na was 2 times higher in the plants from the covered pots compared to the control plants grown in Postharvest Mix. This would indicate that evaporation from the surface of the root media is the main driving force for the movement of fertilizer salts into the top layer of the root media.

Furuta et.al. (1977) found that total evapotranspiration could be reduced by 26% by placing a cover over the surface of the root media. In Experiment 2, the amount of water lost by evaporation from the surface of the root media accounted for 35% of the total water applied during production over the 106 days of Experiment 2. When the plants were moved to a post production environment, the amount of water lost by evaporation increased to 50% of the total water loss. This would indicate that evaporation from the surface of peat based root media is a major source of water loss in a non-production, low light environment.

One of the major concerns about root media that hold large amounts of water is the reduction in frequency of the fertilizer applications. If fertilizer is not applied frequently, nutrients will become limiting. However, the amount of fertilizer applied is a function of both the number of applications and the amount of solution that remains in the root media. In Experiment 1, for example, Peat A/VM was fertilized 14 times for a total of 2.8 grams N fertilizer and Peat A/RW was fertilized 9 times for a total of 2.7 grams N fertilizer.

However, there is an indication from Experiment 2 that root media that hold large amounts of water must be managed differently. For higher water holding capacity root media, one irrigation is a larger percentage of the total fertilizer applied compared to root media that hold less water. When low fertilizer concentrations are used, fertilizer solution must be applied at every irrigation or the plants will go a longer period of time before the next irrigation can occur resulting in less fertilizer being applied and perhaps deficiency problems.

Another possible assumption is that root media that hold large amounts of water will automatically reduce the amount of runoff. While it is true that high water holding capacity root media need to be irrigated less often, more water needs to be applied at every irrigation. If the leaching fraction is maintained constant compared to other media, more water is leached at any one irrigation. Over the entire production time, the total amount of irrigation water leached would be similar for similar size plants. Yelanich

(1991) concluded that the leaching fraction determined the amount of fertilizer removed from the root media. To reduce fertilizer runoff, the amount of leaching must also be controlled. If a root media with high water holding capacity are not leached, it is likely the concentration of fertilizer may also need to be reduced to prevent soluble salt buildup.

Literature

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Table 1. Water and fertilizer application for poinsettia grown in five root media in Experiment 1 from 26 September until 6 December, 1989. All reported values are on a per pot basis.

root media	Number of Irrigations	Average amount of water applied at each irrigation (liters)	Average amount of water remaining in root media after 1 irrigation (liters)	Total amount of applied water that remained in the root media (liters)	Total water leached (liters)	Total Number of Fertilizations[z]	Applied nitrogen fertilizer (g N)
Al-par	16	0.56	0.43 c[y]	6.9 c	1.9 ab	11	2.5
Metro Mix 510	15	0.67	0.54 b	8.0 b	1.8 ab	9	2.4
Peat A/rockwool	15	0.74	0.59 a	8.8 a	2.0 a	9	2.7
Peat A/vermiculite	21	0.47	0.36 d	7.5 b	2.1 a	15	2.8
Peat B/vermiculite	19	0.45	0.34 d	6.5 c	1.7 b	14	2.5

[z]Fertilizer was applied between September 12 and October 29, 1989.
[y]Mean separation by Duncan's multiple range test, 5% level.

Table 2. Plant characteristics of poinsettia at final harvest (week 14) in Experiment 1.

Root Media	Plant Height (cm)	Fresh Weight (g)	Dry Weight (g)	Leaf Number	Leaf Area (cm^2)	Bract Number	Bract Leaf Number	Bract Area (cm^2)
Al-par	22.3 cb[z]	67.8 c	10.9 cd	38 a	915 b	6.7 ab	57 b	1836 cd
Metro Mix 510	20.0 c	77.4 c	10.1 d	29 b	882 b	5.3 c	68 b	2457 b
Peat A/rockwool	29.3 a	116.7 a	16.3 a	41 a	1526 a	7.0 a	83 a	3250 a
Peat A/vermiculite	24.8 b	91.4 b	13.7 b	41 a	1423 a	5.7 cb	64 b	2299 cb
Peat B/vermiculite	24.0 cb	78.0 c	11.8 c	41 a	1358 a	6.3 abc	65 b	1636 d

[z]Mean separation by Duncan's multiple range test, 5% level.

Table 3. Poinsettia leaf tissue analysis at final harvest (week 14) in Experiment 1.

Root Media	N (%)[z]	P (%)	K (%)	Ca (%)	Mg (%)	Mn ($\mu g\ g^{-1}$)[y]	Fe ($\mu g\ g^{-1}$)	Cu ($\mu g\ g^{-1}$)	B ($\mu g\ g^{-1}$)	Zn ($\mu g\ g^{-1}$)	Na ($\mu g\ g^{-1}$)
Al-Par	4.50 a[x]	0.22 c	2.46 b	1.56 a	0.58 ab	77.8 a	116.2 a	2.5 c	59.7 a	40.4 b	243.0 a
Metro Mix 510	4.50 a	0.32 b	2.97 a	1.40 ab	0.53 b	110.0 a	110.7 a	3.3 b	44.0 bc	48.7 ab	204.0 a
Peat A/rockwool	4.50 a	0.30 b	3.19 a	1.21 ab	0.70 a	90.8 a	121.3 a	4.4 a	48.5 b	51.0 ab	205.7 a
Peat A/vermiculite	4.70 a	0.37 a	3.20 a	1.26 ab	0.60 a	79.9 a	113.3 a	3.6 ab	41.0 c	42.8 ab	217.0 a
Peat B/vermiculite	4.80 a	0.40 a	3.31 a	1.14 b	0.65 a	95.3 a	123.3 a	3.9 ab	40.5 c	64.1 a	223.3 a

[z]Percent of dry leaf tissue.
[y]Microgram of element per gram dry leaf tissue.
[x]Mean separation by Duncan's Multiple Range Test, 5% level.

Table 4. Applied water and fertilizer for Easter lily grown in 5 root media from 19 December 1989 to 14 April 1990. All reported values are on a per pot basis.

root media	Number of Irrigations	Total water applied (liters)	Total N-fertilizer applied (g)	Post-production wateruse (liters)[z]
Control				
Al-par	20	6.80	0.98	0.36
Metro Mix 510	15	5.92	0.87	0.40
Peat A/rockwool	12	5.83	0.84	0.39
Postharvest Mix	14	5.54	0.90	0.45
Baccto	16	5.32	0.95	0.35
Root Media Covered with an Evaporation Barrier				
Al-par	12	4.08	0.66	0.20
Metro Mix 510	10	3.76	0.52	0.22
Peat A/rockwool	6	2.93	0.47	0.17
Postharvest Mix	10	3.62	0.60	0.20
Baccto	12	4.15	0.71	0.22
Root Media (RM)	***	**	**	**
Evaporation Barrier (EB)	***	***	***	***
RM*EB	*	*	*	**

[z]Post production water use was calculated for the first 8 days.

[NS,*,**,***]Nonsignificant or significant at P=0.05, 0.01, or 0.001 respectively.

Table 5. Plant characteristics of Lily at final harvest (week 14) from Experiment 2.

Root Media	Leaf Number	Bud Number	Leaf Height (cm)[z]	Total Height (cm)[y]	Leaf Area (cm^2)[x]	Days to Flower[w]
control						
Al-par	86	5.9	28.6	48.7	225	109
Metro Mix 510	91	6.8	31.6	53.6	254	110
Peat A/rockwool	94	5.4	29.2	45.1	256	114
Postharvest Mix	82	6.0	26.6	48.3	242	111
Baccto	84	5.9	26.2	48.9	207	112
Root Media Covered with an Evaporation Barrier						
Al-par	88	6.3	27.5	46.8	212	110
Metro Mix 510	91	6.7	32.2	49.0	267	111
Peat A/rockwool	81	5.2	24.7	42.6	230	114
Postharvest Mix	82	5.7	24.5	44.3	213	112
Baccto	82	5.8	28.5	45.9	226	108
Root Media (RM)	*	**	***	***	***	***
Evaporation Barrier (EB)	NS	NS	NS	***	NS	NS
RM*EB	NS	NS	NS	NS	*	*

[z]Final leaf height was measured from the rim of the pot to the top leaf.
[y]Final bud height was measured from the rim of the pot to the top most flower bud at first flower.
[x]Leaf area was the sum of the top 10 leaves.
[w]Days to flower was calculated from planting until first flower.
[NS,*,**,***]Nonsignificant or significant at $P=0.05$, 0.01, or 0.001 respectively.

Table 6. Lily leaf tissue analysis at final harvest from Experiment 2.

Root Media	N (%)[z]	P (%)	K (%)	Ca (%)	Mg (%)	Mn ($\mu g\ g^{-1}$)[y]	Fe ($\mu g\ g^{-1}$)	Cu ($\mu g\ g^{-1}$)	B ($\mu g\ g^{-1}$)	Zn ($\mu g\ g^{-1}$)	Na ($\mu g\ g^{-1}$)
Control											
Al-Par	3.04	0.28	4.08	1.54	0.70	17.1	82.0	5.3	33.3	23.1	558.8
Metro Mix 510	3.12	0.54	4.21	1.36	0.69	42.7	76.3	6.8	29.4	26.4	474.9
Peat A/rockwool	3.08	0.46	4.32	1.10	0.73	18.3	78.7	6.9	34.4	31.9	500.7
Postharvest Mix	3.38	0.73	4.32	1.56	0.80	47.0	59.0	5.7	40.6	46.1	1698.3
Baccto	3.14	0.47	4.44	1.13	0.82	13.6	62.1	6.5	21.2	27.1	647.8
Plants Covered with an Evaporation Barrier											
Al-Par	3.26	0.32	3.62	1.69	0.73	19.2	77.8	5.4	30.6	24.3	449.2
Metro Mix 510	3.29	0.65	4.29	1.40	0.72	54.0	65.6	6.8	26.8	26.9	516.4
Peat A/rockwool	2.93	0.53	3.97	1.33	0.90	13.0	56.8	6.6	41.0	27.6	856.3
Postharvest Mix	3.14	0.66	4.04	1.40	0.67	39.4	67.5	6.0	43.2	43.3	3317.7
Baccto	3.19	0.58	4.28	1.20	0.93	13.8	62.5	4.3	20.6	25.2	535.2
Root Media (RM)	NS	***	NS	***	***	***	NS	NS	***	***	***
Evaporation Barrier (EB)	NS	NS	NS	NS	*	NS	NS	NS	NS	NS	***
RM*EB	NS	NS	NS	NS	**	***	NS	NS	NS	NS	***

[z]Percent of dry leaf tissue.

[y]Microgram of element per gram dry leaf tissue.

[NS,*,**,***]Nonsignificant or significant at $P=0.05$, 0.01, or 0.001 respectively.

Figure 1. Root media pH, EC, Nitrate-N, P, K, Ca, Mg, and Na levels for top w
poinsettias grown in five root media with 20% leaching. Samples were ta
two week intervals since planting. Dotted lines indicate the recommended o
range(s) for the SME (Warncke and Krauskopf, 1983).

p watered
e taken at
d optimal

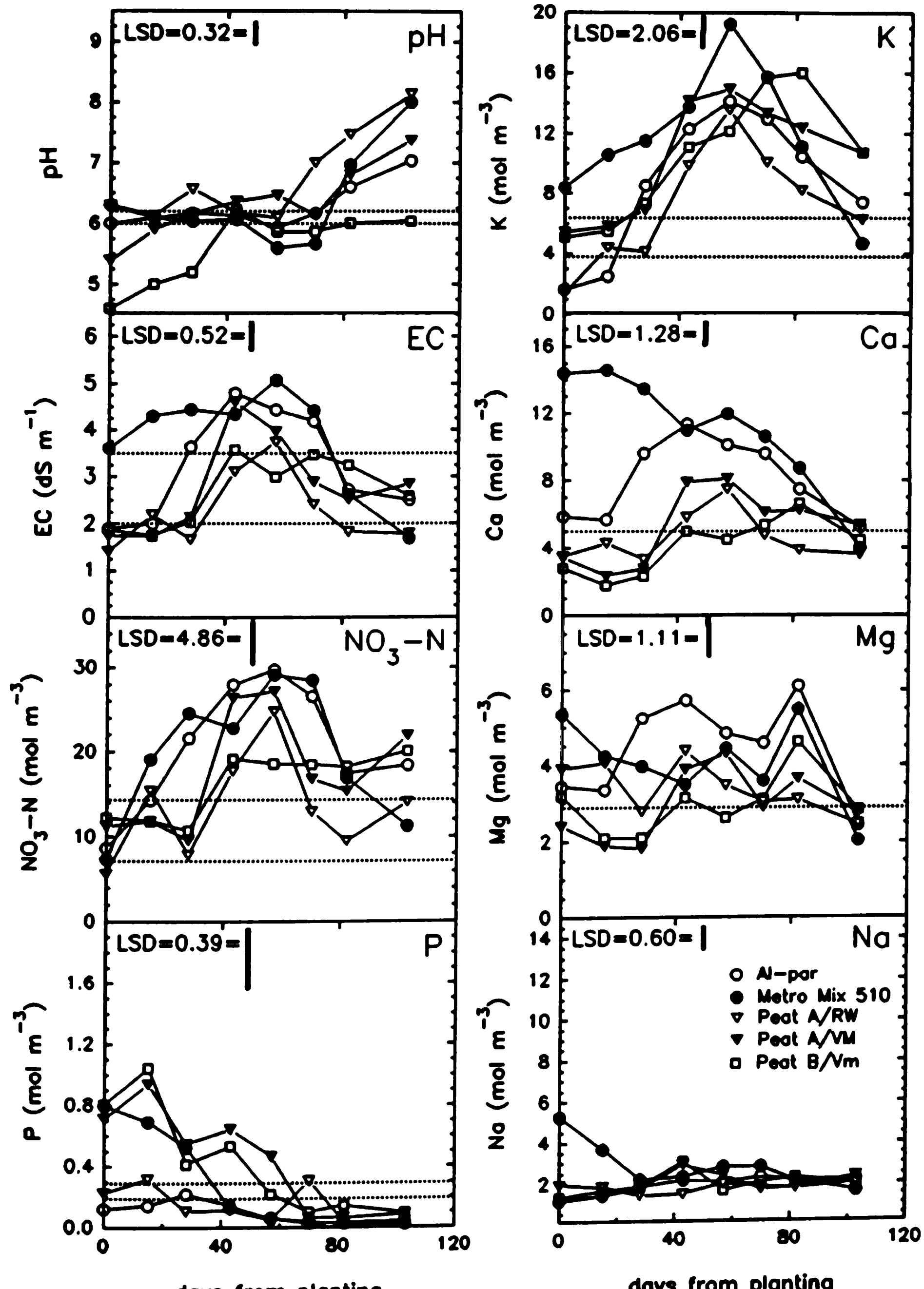


Figure 2. EC levels measured in the root zone, top layer, leachate, and applied solut five root media. Dotted lines indicate recommended optimal EC ranges f SME (Warncke and Krauskopf, 1983).

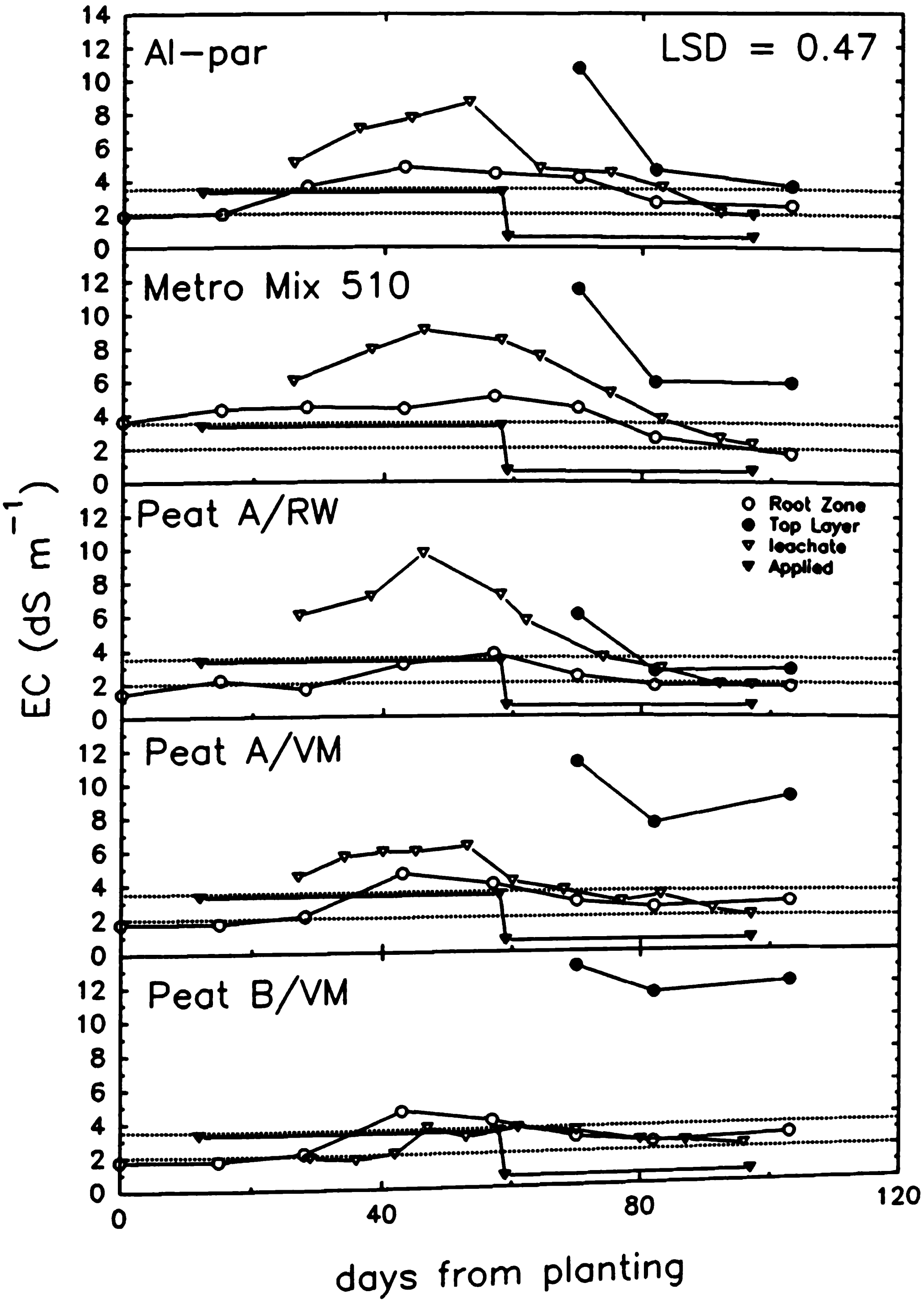
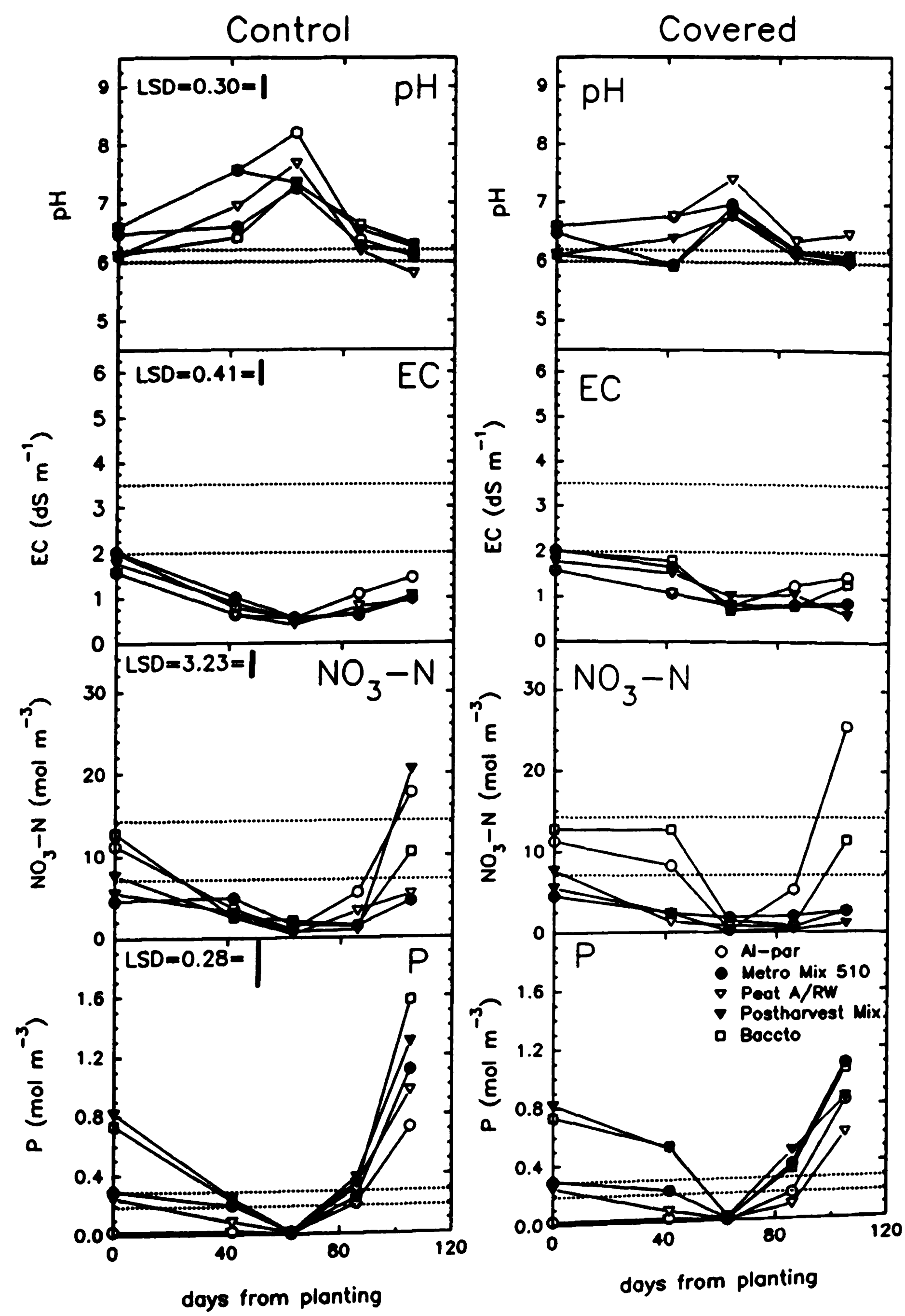

Al–par
LSD = 0.47
Metro Mix 510
Peat A/RW
Peat A/VM
Peat B/VM
Root Zone
Top Layer
leachate
Applied
EC (dS m^{-1})
days from planting
0
2
4
6
8
10
12
14
0
40
80
120

Figure 3. Root media pH, EC, Nitrate-N, P, K, Ca, Mg, and Na levels for subirrigated Easter Lilies grown in five root media. Effect of the evaporation barrier on root media nutrient levels is presented next to the graphs from the control plants. Dotted lines indicate the recommended optimal range(s) for the SME (Warncke and Krauskopf, 1983).



Control
Covered
LSD=0.30=
pH
LSD=0.41=
EC
EC (dS m^-1)
LSD=3.23=
NO3-N
NO3-N (mol m^-3)
LSD=0.28=
P
P (mol m^-3)
Al-par
Metro Mix 510
Peat A/RW
Postharvest Mix
Baccto
days from planting

Figure 3 (cont.)

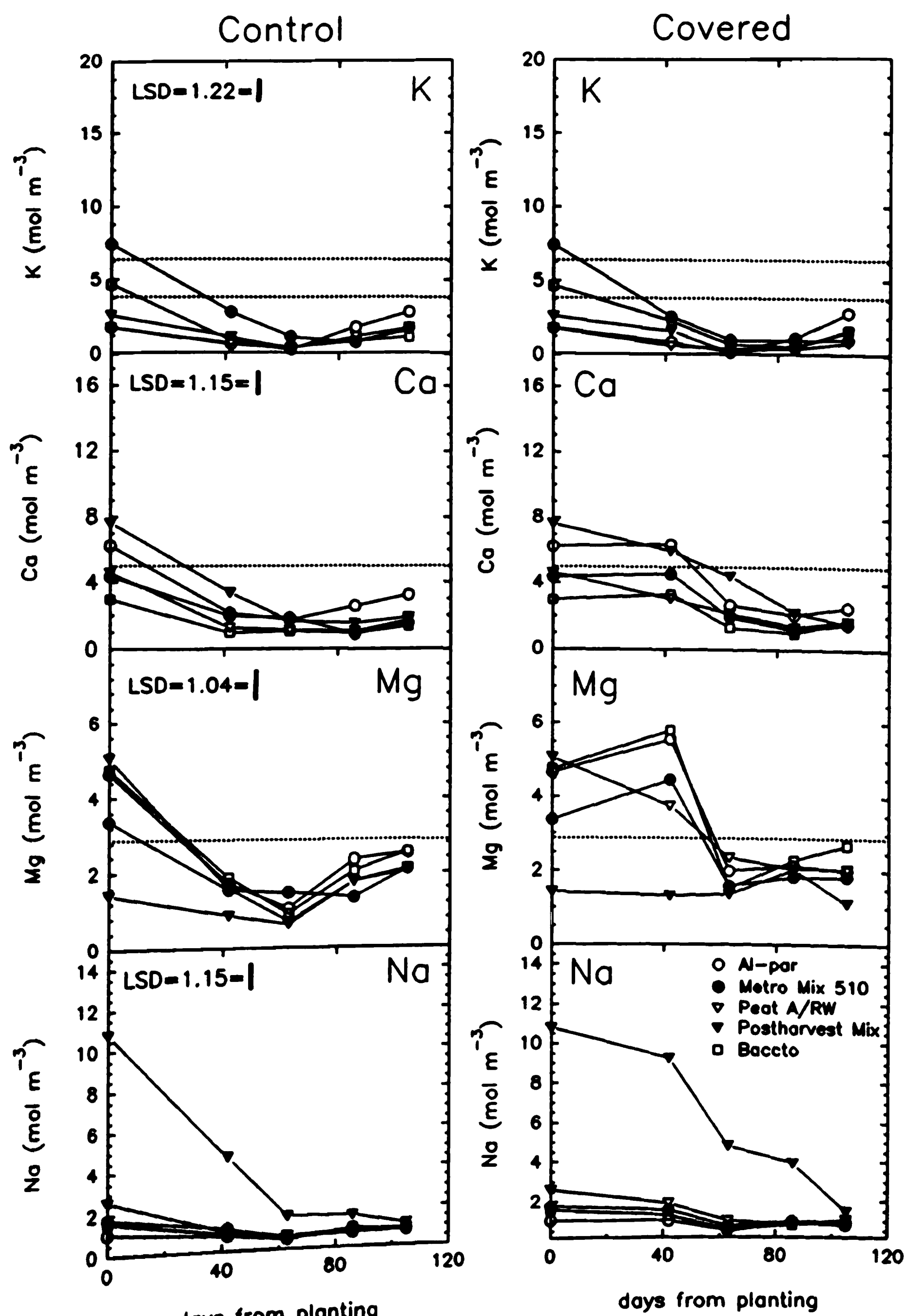
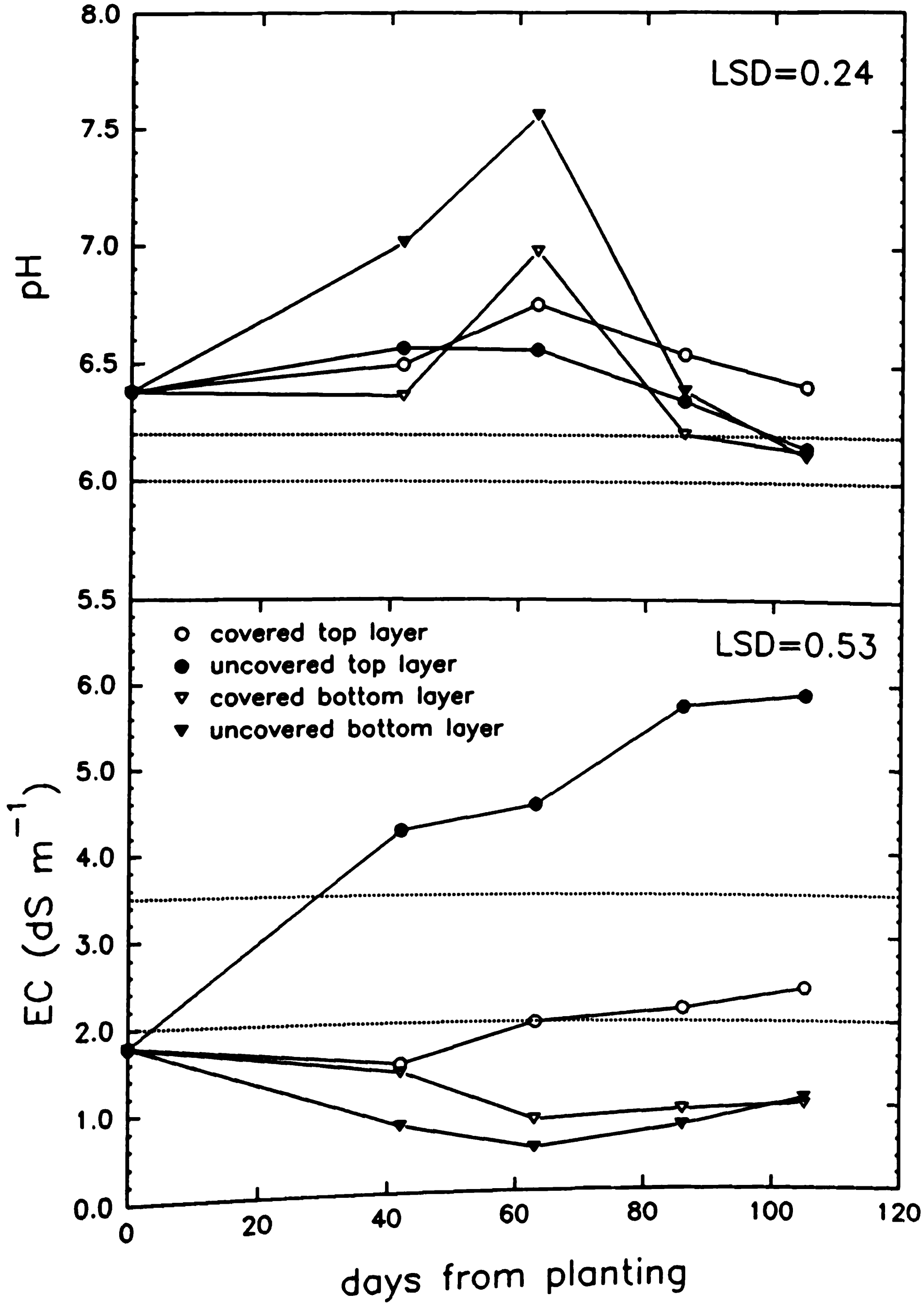


Figure 4: Comparison of root zone and top layer pH and EC levels in Easter lilies grown as a control or with the surface of the root media covered by an evaporation barrier. Values for each treatment are averaged over the 5 root media. Dotted lines indicate recommended optimal ranges for the SME. (Warncke and Krauskopf, 1986).



8.0
7.5
7.0
6.5
6.0
5.5
pH
LSD=0.24
o covered top layer
● uncovered top layer
▽ covered bottom layer
▼ uncovered bottom layer
LSD=0.53
6.0
5.0
4.0
3.0
2.0
1.0
0.0
EC (dS m⁻¹)
0
20
40
60
80
100
120
days from planting

SECTION II

Effect of Irrigation Method, Fertilization and Nutrient Charge on Early Vegetative and Root Growth of Poinsettia 'V-14 Glory'

The Effect of Irrigation Method, Fertilization and Nutrient Charge on Early Vegetative and Root Growth of Poinsettia 'V-14 Glory'

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Additional index words. Soluble salts, irrigation, evaporation, *Euphorbia pulcherrima*

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Subject Category: Soils, Nutrition and Fertilizers

The Effect of Irrigation Method, Fertilization and Nutrient Charge on Early Vegetative and Root Growth of Poinsettia 'V-14 Glory'

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Additional index words. Soluble salts, irrigation, surface evaporation, *Euphorbia pulcherrima*

Abstract. Rooted cuttings of poinsettia 'V-14 Glory' were grown in 15 cm pots using 2 methods of irrigation, 2 water soluble fertilization schedules, and 2 levels of pre-plant root media fertilization. There was no difference in shoot growth with either top watering with 33% leaching or subirrigation. With both types of irrigation, nutrients moved out of the root zone to the top 2.5 cm of the root media. With the constant application of 28 mol m^{-3} N water soluble fertilizer (WSF), there was a decrease in shoot and root growth after both 3 weeks and 8 weeks compared with a weekly increase in the concentration of WSF from 0 to 28 mol m^{-3} N in 7 mol m^{-3} N increments over a 5 week period. The additional incorporation of 0.27 kg m^{-3} mineral N to Metro Mix 510 containing a preplant nutrient charge prior to planting had no effect on fresh weight or dry weight accumulation. When the root media surface was covered by an evaporation barrier, 46% less water and 41% less N-fertilizer was applied to similar size plants, although higher root zone nutrient levels were maintained over the 8 weeks of the experiment. The evaporation barrier had the greatest effect on increasing root zone nutrient levels and reducing the growth of subirrigated plants.

Current recommendations for the fertilization of commercially produced poinsettias range from 18 mol m^{-3} nitrogen (N) to 28 mol m^{-3} N applied at every watering (Yelanich, 1991). Sheldrake (1987) and Berghage et al. (1987) recommend fertilization with 28.5 mol N m^{-3} for the first 3 weeks of production after which the concentration is reduced to 21.4 mol N m^{-3} for the remainder of the crop. This is also the common recommendation found on bags of commercially available water soluble fertilizer (WSF) designed specifically for poinsettia production. The high initial rate of fertilization is recommended to quickly build up the nutrient concentration in the root media to satisfy the high nitrogen requirement of poinsettias early in development (Berghage et al., 1987).

Another method of quickly increasing the nutrient concentration of a root media is to incorporate the nutrients prior to planting. Most commercially available root media contain some type of preplant nutrient charge including mineral nitrogen. However, Bunt (1988) recommends the addition of no more than 0.20 to 0.25 kg m^{-3} mineral N of root media prior to planting because higher nutrient levels may cause soluble salt damage to plants.

The maintenance of the nutrient concentration in the root media after planting is not only dependent on the concentration of the fertilizer solution applied but also the amount of water leached from the pot in top watered plants. It is commonly recommended to leach 10% of the applied water at every watering to reduce fertilizer salt buildup (Nelson, 1985). Yelanich (1991) found leaching fractions above 35% were required to maintain nutrient concentrations within acceptable soil test levels with either 14 or 28 mol m^{-3} N applied at every irrigation. Similar root media nutrient concentrations could be maintained when 28 mol m^{-3} N was applied with a 50% leaching fraction or 14 mol m^{-3} N applied with a 10% leaching fraction (Yelanich, 1991).

With flood subirrigation, fertilizer salts are not leached from the root media. Subirrigation has been shown to produce plants of equal quality as top watering with one half the concentration of WSF used for top watering (George, 1989). However, fertilizer salts tend to accumulate in the top 2-3 cm of the root media (Guttormsen, 1969; Havis, 1982; George, 1989; Molitor, 1990). The accumulation may prove harmful to the plants if water is applied from the top which washes the salts down into the root zone.

The accumulation of fertilizer salts in the top layer of subirrigated pots is due to evaporation of water from the surface of the root media (Guttormsen, 1969; Havis, 1982). Laurie (1950) commented on the large amount of water lost due to evaporation from sphagnum peat due to a wicking effect. Beardsell et al. (1979) found that sphagnum peat lost much greater amounts of water to evaporation compared with other organic and inorganic components. Furuta et al. (1977) reduced evapotranspiration by 26% by placing a plastic disk over the surface of the root media. Covering the surface of the root media with some type of barrier reduced the amount of water lost by evaporation from the surface of the root media.

Havis (1982) found that the distribution of fertilizer salts in the root media was different when the surface of the pot was covered with a barrier compared with pots left uncovered. In 12 cm tall pots, a higher electrical conductivity (EC) was measured in the top 4 cm of the root media compared to lower levels in the pot when the surface was uncovered. With the surface of the root media covered, a higher EC was measured at the 4 to 8 cm level of the root media. Rhododendrons grown in pots with the surface of the root media covered were lower in quality than rhododendrons grown in pots without a barrier when Osmocote 18-6-12 was incorporated at a rate of 3.8 kg m^{-3}. The reduction in plant quality was thought to be due to the higher EC measured at the 4 to 8 cm level in the covered pots.

The objective of this experiment was to investigate how irrigation method, early fertilization, and an evaporation barrier affect early vegetative growth of poinsettias and root media nutrient levels.

Materials and Methods

The four factors in this experiment were 1) method of irrigation, 2) water soluble fertilization strategies, 3) preplant nitrogen charge and, 4) the effect of an evaporation barrier. There were 2 levels for each factor. The experimental design was a split plot factorial with irrigation used as the main plot and the other 3 factors as sub-plots. Each treatment had 6 replications for two sampling dates. Data was analyzed using the analysis of variance (ANOVA) procedures of SAS (SAS Institute, Inc., 1982). Due to the differences in growth of plants grown with the root media surface covered with a barrier, statistical analysis was divided between treatments with and without the evaporation barrier to aid in data analysis and interpretation. Statistical analysis of the root to shoot ratio was determined by analysis of variance of the arc sine transformation of the ratio.

Top watering with 33% leaching was compared with subirrigation. Plants were initially irrigated with 0.3 liters using the irrigation and fertilization method for the particular treatment. Thereafter, each treatments was irrigated on an as needed basis which was determined to be when the average weight of three pots reached of 55 to 65 percent of the weight at container capacity (container capacity = 1250 g). Plants were weighed daily using a battery powered gram scale model no. L-01042 (Cole-Parmer, Chicago IL) to determine when plants needed water. For the top watered treatment, 0.75 liters of solution was applied to the surface of the root media and the pots were allowed to drain. Weights were taken before and after irrigations to determine the amount water held in the root media. Approximately 0.5 liters of the applied solution remained in the root media after irrigation. For the subirrigated treatments, 0.325 liter of water or fertilizer solution was placed into a plastic saucer and the root media was allowed to absorb the solution through the bottom of the pot. Subirrigated pots were not weighed after an irrigation.

The constant application of 28 mol m^{-3} N (CLF) was compared with the scheduled weekly increase of 7 mol m^{-3} N in applied fertilizer from 0 to 28 mol m^{-3} N over a 5 week period (SLF). A given concentration was applied for only 1 week. Treatments that did not get irrigated for that week, did not receive that particular concentration. After week 5, all treatments received the 28 mol m^{-3} N solution. The fertilizer used was a commercial WSF 15N-2.2P-20.1K Poinsettia Special (Grace/Sierra, Fogelsville PA) which contained 70% of the N in the nitrate form. The WSF supplied (mol m^{-3}) 28-1.9-14.1 mol m^{-3} (N-P-K) at the 28 mol m^{-3} N rate. All fertilizer applications were measured and recorded.

The base preplant nutrient charge (BPC) of Metro Mix 510 was determined to be EC 2.06 dS m^{-1} and 7.9 mol m^{-3} nitrate-N in a saturated media extract (SME) (Warncke, 1986). The higher preplant nutrient charge (HPC) was the same root media except amended with the addition of 0.6 kg m^{-3} KNO_3, 0.6 kg m^{-3} $Ca(NO_3)_2$, and 0.3 kg m^{-3} of NH_4NO_3. The additional fertilizer salts increased the nutrient levels of the root media to an EC of 3.51 dS m^{-1} and 34.3 mol m^{-3} nitrate-N.

The evaporation barrier was made from a 15 cm polystyrene plate that was placed over the surface of the root media. A hole was melted in the middle of the plate to allow for the plant stem and a cut was made from the perimeter to the center so the cover could be inserted after planting. Three smaller holes were also placed in the plate to allow surface applied water to drain into the root media below. The barrier was placed on half the pots at planting, prior to any solution application.

The experiment was conducted in a well ventilated glass greenhouse with constant air circulation and cement floors located at the Plant Science Greenhouses, Michigan State University. Rooted *Euphorbia pulcherrima* 'V-14 Glory' cuttings were planted into 15 cm by 15 cm (volume=1.7 liter) plastic pots containing Metro Mix 510 (Grace/Sierra) on 30 March 1990 and were grown with a day/night temperature set point of 24/21 C. Plants were kept vegetative by either a 4 hour night interruption (2200-0200 HR) from incandescent lights or normal day length. A total of 12 plants were randomly assigned to each treatment.

At planting, the location of the newest fully expanded leaf was marked on the stem with a permanent marker (approximately 1.5 to 2.0 cm above the soil line). All shoot data was from plant material above this mark. After 3 weeks, plant height, shoot fresh and dry weight, and leaf area was determined for 6 plants from each treatment. Leaf area was determined using a Delta-T area meter (Decagon Devices, Inc. Pullman, WA). Three of the 6 were used to determine root fresh and dry weight. The roots were separated from the root media by gently washing in tap water. Little root loss was apparent during separation. The root/shoot ratio was determined by only using the dry weight from the roots and shoots of plants in which both the roots and shoots were sampled. The remaining 3 pots were used for root media sampling. The top 2.5 cm of root media was removed and tested separately from the remaining root media using the SME technique using distilled water as the extracting solution. EC was determined using a YSI model 32 conductance meter (Yellow Springs Instrument Co., Inc. Yellow Spring OH) at a standard temperature of 25C and Nitrate-N was determined with a Orion model 93-07 nitrate specific electrode (Orion Research Inc., Cambridge MA).

The remaining six plants from each treatment were pinched using a soft pinch with leaf removal technique (Berghage et al. 1987) leaving 9-11 internodes on a plant. Plants were grown for another 5 weeks before sampling as for the first harvest.

Plant water use was calculated as the sum of the amount of water remaining in the pot after each irrigation. The total amount of applied nitrogen was calculated as the sum of the water applied multiplied by the concentration of the applied fertilizer solution and is only the amount of applied N-fertilizer from WSF.

Results

Plant Growth: Fertilization was the most important factor influencing plant growth for treatments with no evaporation barrier. At the first harvest, SLF plants had a greater shoot height, shoot fresh and dry weight, leaf area and root dry weight compared to CLF plants (Table 1). With the HPC media, root dry weight and root to shoot ratio were increased for top watered plants but decreased for subirrigated plants compared to the BPC media. The root to shoot ratio in top watered plants decreased with CLF compared to SLF while the ratio remained constant in subirrigated plants over the 2 fertilizer treatments.

At the second harvest, SLF plants had greater shoot height, shoot fresh and dry weight, leaf area and root dry weight compared to CLF plants. However, with subirrigation, shoot fresh and dry weight decreased with HPC compared to the BPC at both liquid fertilization levels. With top watering, shoot fresh and dry weight decreased for HPC media compared to the BPC media with CLF but increased with the HPC media compared to the BPC media with SLF.

Root dry weight and root to shoot ratio were also affected by irrigation method at the second harvest. Subirrigated plants had a greater root dry weight compared to top watered plants. The root to shoot ratio was greater in subirrigated plants compared to top

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watered plants. For top watered plants there was an increase in the ratio with SLF compared to the CLF while for subirrigated plants the ratio was similar for both liquid fertilization methods. With top watering, the root to shoot ratio decreased with the HPC media compared to the BPC media. With subirrigation, the ratio increased with the HPC media compared to the BPC media.

When evaporation of water from the surface of the root media was reduced, irrigation method and starting nutrient charge had the largest effect on plant growth. At the first harvest, shoot height, fresh and dry weight, leaf area, root dry weight and the root to shoot ratio decreased in plants grown in HPC media compared to BPC media. However, the decrease in the 4 shoot characteristics was greater with subirrigation than with top watering. The decrease in fresh and dry weight and leaf area was greater in the HPC media compared to BPC media in SLF plants compared to CLF plants.

At the second harvest, the response of the plants to fertilizer varied with the irrigation method. Overall, shoot height, shoot fresh and dry weight, leaf area, and root dry weight were greater with top watering compared to subirrigation. The decrease in these 5 characteristics for subirrigated plants was greater with HPC media compared to the BPC media. The 5 plant characteristics were greater for SLF plants than for CLF plants. Subirrigated plants had a greater root to shoot ratio than top watered plants.

Root Media Nutrient Levels: At the first harvest, soluble salt levels (EC) and nitrate-N concentrations in the top 2.5 cm of the root media were higher than in the remaining root media (root zone) in the pot with both top watering and subirrigation with no evaporation barrier (Table 3). On average, the top layer of top watered plants had an EC 3.9 times and a nitrate-N concentration 3.8 times higher than the levels found in the root zone. The top layer of subirrigated plants had an EC 7.1 times and a nitrate-N concentration 10.2 times the levels found in the root zone. In general, the greater amounts of fertilizer applied to the plant, the greater the soluble salt concentration in the top layer.

The root zone EC of subirrigated plants was lower than for top watered plants. With subirrigation, there was a greater difference in the EC between CLF and SLF than for top watered plants. With top watering, there was a greater difference in root zone EC between the BPC media and the HPC media than for subirrigation. Top watered plants had greater nitrate-N concentrations in the root zone than subirrigated plants. CLF plants had higher nitrate-N concentrations in the root zone than SLF plants.

By the second harvest, the top layer of top watered plants had an EC 2.3 times and a nitrate-N concentration 2.1 times the root zone. The top layer of subirrigated plants had an EC 7.2 times and a nitrate-N concentration 7.9 times the root zone. Irrigation and liquid fertilization method were the dominant factors influencing the accumulation of soluble salts in the top layer. Subirrigated plants had a higher EC and nitrate-N concentration in the top layer but lower root zone EC and nitrate-N concentrations than top watered plants. CLF plants had greater EC and nitrate-N concentrations in the top layer than SLF plants.

With the evaporation barrier, the large difference in soluble salts levels between the root zone and top layer did not occur (Table 4). Similar EC and nitrate N levels were measured in the top layer and root zone of top watered plants. However, top layer of subirrigated plants had EC levels 1.8 times and nitrate-N levels 1.6 higher than the root zone at the first harvest and was higher in HPC media than BPC media.

Root zone EC and nitrate-N levels were higher with CLF than SLF. Root zone EC and nitrate-N levels were similar for the different irrigation methods with the BPC media but higher with the HPC media for subirrigated plants.

At the second harvest, top layer soluble salt concentrations were lower than the root zone of top watered plants. In subirrigated plants, higher soluble salt levels were found in the top layer compared to the bottom layer and averaged 2 times the EC and 1.8 times the nitrate-N concentrations compared the top layer of top watered plants.

In the subirrigation root zone, EC and nitrate-N concentrations were higher than with top watering. With subirrigation, EC and nitrate-N root zone concentrations with the HPC media were lower compared to the BPC media, while with top watering, EC and nitrate-N concentration were similar between the 2 nutrient charges. There was a greater difference in the root zone nitrate-N concentration between the BPC media and the HPC media with SLF than with CLF.

Plant Water Use: Top watered plants used more water between planting and the first harvest compared to subirrigation (Table 5). For top watered plants, water use was similar between the nutrient charges at each fertilization levels. With subirrigation, water use was similar between the 2 nutrient charges with CLF while there was a decrease in water use with the HPC media for SLF plants.

Top watered plants and subirrigated plants used similar amounts of water during the 5 weeks between day 21 and day 54. For top watered plants, water use decreased between the BPC media and the HPC media with CLF while water use increased between the BPC media and the HPC media with SLF. In subirrigated plants, water use was similar between the 2 nutrient charges with CLF while there was an increase in water use of the HPC media over the BPC media with SLF.

With the evaporation barrier, averaged over all treatments, water use was decreased by 68% from planting until the first harvest and 43% between the first and second harvest. Over the 8 weeks of the experiment, water use was decreased by a total of 51%.

With a barrier, top watered plants used more water than subirrigated plants for the first 3 weeks. The difference in water use was due to the decrease in growth of the subirrigated plants due to higher soluble salts found in the root zone. A similar amount of water was applied to top watered plants at both liquid fertilization levels, while with subirrigated plants, more water was applied with SLF compared to CLF. SLF plants had more water applied and there was a greater decrease in the amount of water applied to SLF plants in the HPC media compared to CLF plants in the BPC media.

From day 21 to day 54, the water use of top watered plants decreased with the application of CLF compared to SLF at approximately the same rate over both nutrient charges. With subirrigation, the decrease in water use with CLF compared to SLF was greater at the lower nutrient charge compared to the higher nutrient charge.

Plants of similar size can be directly compared to determine the amount of water lost from evaporation compared to transpiration. Top watered plants were similar in fresh weight when averaged over all treatments. Water loss from evaporation of water from the surface of the root media accounted for approximately 60% of the total amount of water applied to the plant during the first 3 weeks after planting. For the remaining 5 weeks of the experiment, water loss of top watered plants from evaporation from the surface of the root media accounted for 33% of the water applied. Subirrigated plants were not similar in size at either harvest so a direct comparison could not be determined.

Applied Water Soluble Fertilizer: Subirrigated plants received 38% less N-fertilizer than top watered treatments although similar root zone nutrient levels were measured with both irrigation at week 8 (Table 5). Greater amounts of WSF were applied to the CLF plants that SLF plants. Within an irrigation treatment, the greatest difference in applied fertilizer was 1.27 g N (3.17 liters of the 28 mol m^{-3} N fertilizer solution) for the top watered plants and 0.47 g N (1.18 liters of the 28 mol m^{-3} N fertilizer solution) for subirrigated plants.

With the root media surface covered by a barrier, less N-fertilizer was applied. Averaged over all treatments, 41% less fertilizer was applied when the surface was covered by a barrier. With top watering, similar size plants and similar root nutrient levels were maintained with 37% less applied N-fertilizer. With subirrigation, 53% less fertilizer was applied to the covered plants. However, the difference in plant growth between the subirrigated controls and covered plants makes a direct comparison impossible.

Discussion

George (1989) determined that subirrigation produced plants of similar quality as top watering. However, a lower fertilizer concentration was used to reduce the chance of fertilizer buildup in the root media of subirrigated plants. In this experiment, the same high fertilizer concentrations and similar amounts of N-fertilizer were applied to both top watered and subirrigated plants without any detrimental effect to the subirrigated plants. After 8 weeks the root zone of the top watered plants had a higher EC and nitrate-N level.

High concentrations of WSF early in the crop reduced plant growth with both methods of irrigation contrary to the current recommendations for early poinsettia fertilization (Sheldrake, 1987; Berghage et al., 1987). Growth was less with CLF despite the fact that the nutrient levels of the root zone were in the desired optimal range for soil tests using the SME technique (Warncke and Krauskopf, 1983). Plants with the greatest shoot fresh and dry weight were grown with root media nutrient levels that would normally be considered low for high nitrogen requiring plants. This would indicate that the there was no benefit from the higher concentrations of nutrients during the first 3 weeks after planting.

It should be noted that the root media used contained a preplant nutrient charge. Increasing the preplant nutrient charge did not have a direct effect on shoot growth for plants without an evaporation barrier. Much of the excess nutrient charge did not remain in the root zone and either moved to the top layer or was leached from the pot. Current preplant nutrient levels of approximately 0.6 kg m^{-3} KNO_3 and 0.6 kg m^{-3} $Ca(NO_3)_2$ are probably adequate.

By the second harvest, root media nutrient levels in all the treatments were above 3.5 dS m^{-1} or above the optimal nutrient level (Warncke and Krauskopf, 1983) even with leaching levels 2 to 3 times the recommended level (Nelson, 1985). Yelanich (1991) also determined that higher fertilizer concentrations required higher leaching fractions to maintain root media nutrient levels at or below 3.5 dS m^{-1}. Leaching fractions greater than 30% would be necessary to maintain root media nutrient levels in the recommended range with liquid fertilizer concentration of 28 mol m^{-3} N.

One of the major concerns with subirrigation is the formation of the high soluble salt layer at the top of the pot. However, the presence of a high soluble salt layer in the top 2 to 3 cm of top watered pots has also been reported previously (Molitor, 1990; Yelanich, 1991). Yelanich (1991) found 30% greater amounts of nitrate-N in the top layer of top watered pots with leaching fractions up to 50%. However, Ku and Hershey (1991) found lower EC levels in the top layer of top watered plants at all leaching fractions ranging from 0 to 40%. In this experiment, nutrient concentrations up to 3 times greater than found in the root zone were present at three and eight weeks even though plants were top watered at every irrigation with 33% leaching. Perhaps higher levels of evaporative water loss from the root media surface than previously reported

(Furuta et al., 1977) may have contributed to the to the higher nutrient levels measured in the top layer of this experiment.

The formation of the high salt layer was due primarily to evaporation from the surface of the root media (Guttormsen 1969, Havis 1982). When water evaporates from the surface of the root media, there is a pull on the water contained in the root media to the surface were it is lost to the air. Any fertilizer salt that moved with the water would be left at the surface of the root media when the water evaporated. The amount of fertilizer salt that remains on the top layer can be a large percentage of the total amount of fertilizer applied to the plant. The accumulation of the fertilizer salts at the surface of the root media can be a sink for excess fertilizer similar to leaching water from the bottom of the container.

If evaporation is reduced, fertilizer salts that are placed in the root zone tend to remain in the root zone. With top watering, fertilizer salts can still be removed from the root zone with leaching. However, with subirrigation or top watering with little leaching, any fertilizer salt that is placed in the root zone will tend to stay in the root zone. If high levels of fertilizer salt are applied soon after planting under these conditions, a reduction in plant growth may be observed due to salt stress. A reduction in evaporation would have a similar effect to the reduction in leaching reported by Yelanich (1991) in that lower concentrations of WSF would be necessary to maintain root zone nutrient concentrations in a specific range.

In some cases, it is recommended to avoid the top layer when root media is sampled due to the presence of high levels of fertilizer salts (Nelson, 1985). However, other literature recommends taking root media samples from a complete profile of the root media (Bethke, 1985). Yelanich (1991) removed the top layer in subirrigated plants but used the a combination of the whole pot in top watered plants for soil tests. The presence of the top layer in a root media sample could significantly alter the concentration of any nutrient tested. Commercial greenhouse operators switching from sampling the entire profile to sampling only the bottom layer measured a significant reduction in root media nutrient levels (personal communication, Kalamazoo Valley Coop. Kalamazoo, MI).

Optimal EC levels in the root media are currently recommended to be between 2.0 - 3.5 dS m^{-1} for established plants (Warncke and Krauskopf, 1983) but, it is not clear if these recommendations include the top layer in the sample. An emphasis should be placed on the consistency of sampling method and refining recommended nutrient levels.

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Table 1. Plant characteristics of poinsettias in harvest 1 and harvest 2. Control plants with no cover on the surface of the root media.

Treatments		Harvest 1						Harvest 2					
Fert.	Charge	Plant Height (cm)	Fresh Weight (g)	Dry Weight (g)	Leaf Area (cm^2)	Root Dry Weight (g)	Root/ Shoot Ratio	Plant Height (cm)	Fresh Weight (g)	Dry Weight (g)	Leaf Area (cm^2)	Root Dry Weight (g)	Root/ Shoot Ratio
Top Watered													
CLF	BPC	9.1	7.19	1.19	272	0.26	0.202	17.0	54.00	7.98	1869	0.89	0.119
CLF	HPC	9.5	7.45	1.18	288	0.40	0.393	14.8	44.94	6.91	1608	0.66	0.104
SLF	BPC	10.2	8.56	1.29	309	0.53	0.479	19.6	70.57	10.24	2483	1.60	0.166
SLF	HPC	9.3	8.42	1.32	304	0.62	0.505	21.2	78.13	11.65	2636	1.54	0.144
Subirrigated													
CLF	BPC	8.3	6.97	1.10	265	0.49	0.462	18.7	56.49	8.32	2055	1.63	0.190
CLF	HPC	9.0	6.84	1.10	276	0.31	0.266	17.1	52.10	7.79	1917	1.85	0.248
SLF	BPC	10.0	8.82	1.44	327	0.64	0.450	20.3	73.74	10.62	2678	2.14	0.205
SLF	HPC	9.3	7.72	1.25	312	0.32	0.241	20.6	69.89	10.43	2472	2.28	0.224
irrigation (I)		NS	NS	NS	NS	NS	NS	*	NS	NS	NS	*	*
error (a)													
fertilizer (F)		*	**	**	**	**	*	***	***	***	***	***	*
charge (C)		NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
I*F		NS	NS	NS	NS	NS	**	*	*	*	NS	NS	*
I*C		NS	NS	NS	NS	***	***	NS	NS	NS	NS	NS	*
F*C		NS	NS	NS	NS	NS	NS	**	*	**	NS	NS	NS
I*F*C		NS	NS	NS	NS	NS	NS	NS	*	*	NS	NS	NS

NS,*,**,*** Nonsignificant or significant at P = 0.05, 0.01, 0.001 respectively. CLF=constant liquid fertilizer. SLF=schedule increasing liquid fertilizer. BPC=base preplant nutrient charge. HPC=High Preplant Nutrient Charge.

Table 2. Plant characteristics of poinsettias in harvest 1 and harvest 2 grown with pots covered with an evaporation barrier.

Treatments		Harvest 1						Harvest 2					
Fert.	Charge	Plant Height (cm)	Fresh Weight (g)	Dry Weight (g)	Leaf Area (cm^2)	Root Dry Weight (g)	Root/ Shoot Ratio	Plant Height (cm)	Fresh Weight (g)	Dry Weight (g)	Leaf Area (cm^2)	Root Dry Weight (g)	Root/ Shoot Ratio
Top Watered													
CLF	BPC	8.7	8.45	1.38	304	0.46	0.341	19.6	58.32	10.27	2539	1.39	0.129
CLF	HPC	8.0	6.88	1.15	260	0.22	0.167	16.5	52.26	7.67	1916	1.02	0.141
SLF	BPC	9.3	9.63	1.54	341	0.49	0.300	20.8	77.49	11.03	2721	1.41	0.143
SLF	HPC	7.7	6.14	0.97	234	0.29	0.281	18.2	59.92	8.55	2198	1.20	0.144
Subirrigated													
CLF	BPC	8.3	6.58	1.12	261	0.29	0.245	15.8	39.30	6.10	1454	1.38	0.226
CLF	HPC	4.8	3.36	0.54	135	0.07	0.146	9.6	12.42	2.17	464	0.39	0.200
SLF	BPC	10.7	10.88	1.80	410	0.50	0.255	20.4	62.15	9.39	2260	1.92	0.214
SLF	HPC	6.4	4.23	0.69	174	0.08	0.111	12.8	19.60	3.16	768	0.70	0.227
irrigation (I)		NS	*	*	*	NS	NS	***	***	***	***	NS	*
error (a)													
fertilizer (F)		**	***	***	***	NS	NS	***	***	***	***	**	NS
charge (C)		***	***	***	***	***	***	***	***	***	***	***	NS
I*F		**	***	***	**	NS	NS	**	NS	*	*	NS	NS
I*C		***	***	***	***	NS	NS	***	***	***	***	***	NS
F*C		NS	***	***	**	NS	NS	NS	**	NS	NS	NS	NS
I*F*C		NS	NS	NS	NS	NS	NS	NS	NS	*	*	NS	NS

NS,*,**,*** Nonsignificant or significant at $P = 0.05, 0.01, 0.001$ respectively. CLF=constant liquid fertilizer. SLF=schedule increasing liquid fertilizer. BPC=base preplant nutrient charge. HPC=High Preplant Nutrient Charge.

Table 3. Root media EC and Nitrate-N concentrations from harvest 1 and 2. Control plants with no cover on the surface of the root media.

Treatments		EC (dS m^{-1})				Nitrate-N (mol m^{-3})			
		Harvest 1		Harvest 2		Harvest 1		Harvest 2	
Fert.	Charge	top layer	root zone	top layer	root zone	top layer	root zone	top layer	root zone
Top Watered									
CLF	BPC	11.71	2.75	12.24	4.86	99.1	23.7	107.0	46.3
CLF	HPC	14.40	3.63	12.53	4.16	128.9	32.4	113.4	39.0
SLF	BPC	5.99	1.61	8.81	4.75	41.2	12.1	74.9	45.9
SLF	HPC	6.82	1.91	9.09	4.80	52.7	16.4	80.9	47.7
Subirrigated									
CLF	BPC	15.50	2.82	32.83	4.19	129.6	23.8	338.2	38.6
CLF	HPC	20.11	3.30	36.32	3.87	185.6	29.3	374.9	34.3
SLF	BPC	8.97	1.17	24.22	4.27	47.9	9.2	241.3	41.0
SLF	HPC	17.70	1.44	29.66	4.67	155.5	13.2	297.5	44.3
irrigation (I)		*	NS	***	**	NS	NS	***	*
error (a)									
fertilizer (F)		***	***	***	*	***	***	***	***
charge (C)		***	***	NS	NS	***	***	NS	NS
I*F		NS	*	NS	NS	NS	NS	*	NS
I*C		*	*	NS	NS	**	NS	NS	NS
F*C		NS	**	NS	*	NS	NS	NS	NS
I*F*C		NS	NS	NS	NS	NS	NS	NS	NS

Top layer=top 2.5 cm of the root media. Root zone=remaining root media in the pot. NS,*,**,*** Nonsignificant or significant at $P = 0.05$, 0.01, 0.001 respectively. CLF=constant liquid fertilizer. SLF=schedule increasing liquid fertilizer. BPC=base preplant nutrient charge. HPC=High Preplant Nutrient Charge.

Table 4. Root media EC and Nitrate-N concentrations from harvest 1 and 2 in pots with an evaporation barrier.

Treatments		EC ($dS\ m^{-1}$)				Nitrate-N ($mol\ m^{-3}$)			
		Harvest 1		Harvest 2		Harvest 1		Harvest 2	
Charge	Fert.	top layer	root zone	top layer	root zone	top layer	root zone	top layer	root zone
Top Watered									
CLF	BPC	3.61	3.19	4.47	4.95	26.1	20.7	39.7	44.9
CLF	HPC	4.48	4.54	4.23	4.94	36.1	38.0	37.3	43.1
SLF	BPC	1.79	1.76	4.21	5.00	10.3	10.3	37.1	45.5
SLF	HPC	2.70	2.78	3.90	4.69	21.1	21.2	36.4	42.1
Subirrigated									
CLF	BPC	4.33	3.09	9.31	5.88	19.3	21.5	71.2	54.0
CLF	HPC	8.74	5.14	8.78	5.21	73.7	44.3	78.1	49.1
SLF	BPC	4.10	1.78	8.13	6.93	14.2	8.6	57.3	65.2
SLF	HPC	8.18	3.85	8.27	5.00	67.0	32.2	76.4	46.1
irrigation (I)		**	NS	**	*	**	NS	**	**
error (a)									
fertilizer (F)		***	***	NS	NS	***	***	NS	NS
charge (C)		***	***	NS	**	***	***	NS	***
I*F		***	NS	NS	NS	***	NS	NS	NS
I*C		***	**	NS	**	***	***	*	**
F*C		NS	NS	NS	NS	NS	NS	NS	*
I*F*C		NS	NS	NS	NS	NS	*	NS	NS

Top layer=top 2.5 cm of the root media. Root zone=remaining root media in the pot. NS,*,**,*** Nonsignificant or significant at P = 0.05, 0.01, 0.001 respectively. CLF=constant liquid fertilizer. SLF=schedule increasing liquid fertilizer. BPC=base preplant nutrient charge. HPC=High Preplant Nutrient Charge.

Table 5. Poinsettia water and WSF use over the 8 week time period for both control and pots covered with an evaporation barrier.

Treatments		Control					Pots covered with an evaporation barrier				
		Day 0 to 21		Day 21 to 54		Total	Day 0 to 21		Day 21 to 54		Total
Charge	Fert.	No. of Irr.	Plant Water Use (liters)	No. of Irr.	Plant Water Use (liters)	Applied WSF-N (g N)	No. of Irr.	Plant Water use (liters)	No. of Irr.	Plant Water Use (liters)	Applied WSF-N (g N)
Top Watered											
CLF	BPC	5	2.22	7	3.63	3.60	3	0.84	5	2.75	2.40
CLF	HPC	5	2.08	6	3.26	3.30	2	0.55	4	1.75	1.80
SLF	BPC	5	2.31	7	3.51	2.33	3	0.87	7	3.32	2.03
SLF	HPC	5	2.29	10	4.80	3.08	2	0.52	5	2.40	1.58
Subirrigated											
CLF	BPC	5	1.49	11	3.62	2.08	3	0.56	6	2.20	1.17
CLF	HPC	5	1.48	11	3.59	2.08	2	0.27	3	0.85	0.65
SLF	BPC	6	1.81	12	3.70	1.66	4	0.85	9	3.03	1.20
SLF	HPC	5	1.32	14	4.52	1.95	2	0.37	4	1.10	0.59
irrigation (I)			***		NS			***		***	
error (a)											
fertilizer (F)			***		***			***		***	
charge (C)			***		***			***		***	
I*F			NS		NS			***		NS	
I*C			***		NS			NS		***	
F*C			***		***			*		**	
I*F*C			***		**			NS		***	

NS,*,**,*** Nonsignificant or significant at $P = 0.05, 0.01, 0.001$ respectively. CLF=constant liquid fertilizer. SLF=schedule increasing liquid fertilizer. BPC=Base preplant nutrient charge. HPC=High Preplant Nutrient Charge.

SECTION III

Factors Affecting the Garden Performance
of Flowering Plants in Hanging Baskets

Factors Affecting Garden Performance of Flowering Plants in Hanging Baskets

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Introduction

This research was undertaken to generate information needed to help bedding plant producers make informed decisions about different methods and materials that may help improve and extend the lasting quality of flowering plants in hanging baskets. The approach was to investigate both root media and fertilization methods used for hanging basket production.

The objectives of this research were:

1. Investigate the effect of root media on the maintenance required to sustain growth and flowering.
2. Determine the water and fertilizer requirements of several different plant species used in hanging basket production.
3. Investigate the use of resin coated fertilizers (RCF) as a method of supplying nutrients during production and through the summer.

Background

Flowering plants in hanging baskets play an important role in greenhouse bedding plant production. In 1990, 21 million flowering hanging baskets were produced in the United States. The wholesale value of flowering hanging baskets accounted for $112 million or 13% of the wholesale value of all bedding plants produced (USDA Floriculture Crops Statistics, 1990). Since 1988, the number of baskets produced has increased by

34% with an additional 7% increase projected for 1991 and a 6% increase projected for 1992.

Consumers buy flowering hanging baskets with the intent of the plants lasting throughout the summer. Based on a survey of consumer satisfaction of flowering hanging baskets (Zehner and Krauskopf, 1990), the greatest problem was keeping the plants in the baskets adequately watered (between 18% - 42%, depending on the species). Between 22% and 44% of the respondents indicated that the baskets had to be watered daily. While low fertility was not specifically mentioned, yellowing with loss of foliage and discontinued flowering were both listed as problems. Forty three percent of the respondents reported never fertilizing the hanging baskets during the summer.

From a production perspective, hanging baskets can be a potential source of fertilizer runoff. Flowering hanging baskets tend to be shipped as color develops which may not be uniform for an entire irrigation line. Hanging baskets that remain on the irrigation line still may be receiving water soluble fertilizer (WSF). The empty spaces along the irrigation line may leave drip tubes to drain WSF directly onto the greenhouse floor. The use of RCF during production may reduce the possibility of fertilizer runoff.

RCF may also help the consumer maintain fertility throughout the summer. Recommendations exist for the use of RCF in the production of floriculture crops such as chrysanthemums and poinsettias. However, most of the floriculture research on RCF has been limited to 8 - 12 weeks of fertilization. Flowering plants in hanging baskets are unique in that the plants are expected to remain flowering and actively growing throughout the summer, which may be up to 20 additional weeks after production. Nutritional levels must be maintained in the root media throughout the post production period or plants will become chlorotic and stop blooming.

Implications for the grower

The bedding plant producer will obtain several benefits from this research. First, independent evaluation of root media in controlled experiments has provided information that will allow growers to justify selection of root media without unnecessary specifications or directions from retailers. Second, minimum fertilizer requirements for several hanging basket crops have been identified, which could lead to a reduction in fertilizer use. The results of these experiments are also applicable to other landscape container crops such as patio planters. Finally, consumers may be more successful in growing and maintaining flowering hanging baskets throughout the summer. This success should maintain or increase the potential for future consumer purchases and therefore production.

General Methodology

All root media were mixed in a small batch mixer with a volume of 0.09 m^3 (3 ft^3). Water was added during mixing to increase the moisture level of the root media prior to planting to 40 - 50% of the container capacity of the root media in a 15 cm (6 inch) standard pot. Baskets were filled at a rate of 6 baskets/0.03 m^3 (6 baskets/ft^3).

The water used in all experiments (unless otherwise indicated) had an alkalinity of 320 mg $liter^{-1}$ (ppm), a pH of 8.3 and electrical conductivity (EC) of 0.65 mS cm^{-1}. Irrigation water was applied without saturation for the first 2-3 weeks after planting. Watering frequently without saturation was considered necessary to promote root growth and uniformly establish plants grown in root media with different water holding capacities.

Plants were checked daily to determine if irrigation was necessary. In experiments with impatiens as the test plant (Experiments 1, 2, 3, 4, and 7), plants were irrigated at visible wilt. Impatiens foliage was found to be tolerant to wilting and normally recovered fully after watering. In experiments with multiple species (Experiments 5 and 6), plants were also checked daily for watering. A weight was determined when the plant would wilt. Water or fertilizer solution was applied when the weight of the baskets was close to the wilt weight. For treatments without RCF, WSF was applied as a normal irrigation when leaves began to turn chlorotic and flowering was reduced.

There was a difference between a normal irrigation and uniformly saturating the root media. During a normal irrigation, water was applied with methods selected to approximate watering by a consumer. Saturation of the root media was accomplished by applying water until drainage occurred and again after 30 minutes. The saturation method allowed for better uniformity and reproducibility.

The outdoor evaluation area (OEA) was a structure specifically built for the purpose of testing the garden performance of the hanging baskets. The structure consisted of wooden framework with hooks placed every 0.6x0.9 m (2x3 ft), at 2.4 m (8 ft) off the ground. Final basket height was 2 m (6.5 ft) above the ground. Snow fence with a 2.5 cm (1 in) lath placed every 7.5 cm (3 in) was placed over the top of the framework to provide some shade. The indoor evaluation area (IEA) consisted of 2 parallel pipes, 2.6 m (8.5 ft) off the ground located inside a glass greenhouse hallway (3 m (10 ft) wide by 46 m (150 ft) long). Baskets were placed every 0.6 m (2 ft). Final basket height was 2.1 m (7 ft) above the ground. Both evaluation areas had conditions of bright light and high air movement.

When possible, the data was statistically analyzed to determine significant treatment differences. Only differences that were statistically different are discussed.

Terminology

Several terms are used to describe the water holding capacity of the different root media. *Available water holding capacity (AWHC)* was the amount of water held in a root media between watering and wilt. A gram scale was used to weigh the baskets after irrigation and at wilt (1000 grams of water = 1 liter of water = 34 fl.oz. of water). AWHC was determined on fully developed and thoroughly rooted plants. However, plant size did not have to be identical for this comparison. The amount of fertilizer applied to the plants was calculated by determining the amount of solution applied to the pot (based on weight) and multiplying by the fertilizer concentration.

Average days between irrigation (ADI) was the frequency of irrigation over a specified number of days and was calculated by dividing the number of days by the number of times the baskets were watered. *Minimum days between irrigation (MDI)* was the shortest interval between irrigation over the same specified number of days. MDI was a measure of the amount of maintenance required for plant survival during periods of hot, dry conditions. Both ADI and MDI were dependent to some extent on plant size. Unless otherwise indicated, only plants of similar size were used for comparisons.

Experiment One: Effect of root media components and amendments on improving the garden performance of flowering hanging baskets.

Introduction

Considerable interest has been shown in root media that can reduce the amount of plant maintenance required after production. Root media that hold a large amount of available water are also desired to increase the time between irrigations during production to reduce the potential for water and fertilizer runoff from greenhouses.

One of the primary elements of many greenhouse container root media is peat. Several types and grades of peat are available, but in general, peat tends to have a large water and nutrient holding capacity (Puustjarvi and Robertson, 1975). The amount of non-capillary or air space can vary dramatically due to either the state of degradation of the peat or a reduction in particle size as a result of over mixing or improper handling. For these reasons, course components are blended with peat to provide aeration. The most common components used in soilless media are perlite, polystyrene, #2 or #3 vermiculite, rockwool and bark. When added to peat, the air space and AWHC of the resulting root media can vary significantly depending upon the type and particle size of the component used.

Other materials have been advertized to increase root media water holding capacity and reduce fertilizer requirements. Since these materials are added to root media at rates making up less than 10% of the total volume, they are referred to as amendments.

Water absorbent gels can absorb between 40 and 1000 times their own weight in pure water. Gels are marketed to increase the water holding capacity of the root media and thus extend the time between watering, decrease water and fertilizer runoff, increase plant quality and extend shelf life (Kuack, 1986; Sulecki, 1988; Fisons Postharvest Mix, 1990). In containerized root media, gels have been shown to increase the post production shelf life of chrysanthemums by up to 100% (Bearce and McCollum, 1977). However, while some research has shown a benefit from the gel, other research has shown no benefit at the recommended rates (James and Richards, 1986; Lamont and O'Connell, 1987).

Wetting agents can be applied to a root media to increase water absorption. Sphagnum peat is normally shipped dry to save on shipping costs. Most commercial media contain some type of wetting agent in the mix for quick and uniform rewetting (Templeton, 1987). Reapplying a wetting agent on a regular basis throughout production is recommended for some products. The constant application of Aquagro L^{R} during production has been shown to extend the time to wilt for chrysanthemums by 3.3 days in a post production environment (Bhat et al., 1991). Bhat et al. (1989) determined that at the recommended application rate, Aquagro L^R had no phytotoxic effects on a variety of species. However, at twice the recommended application rate, some phytotoxic effects were observed that were both species and cultivar dependent.

Maintaining nutrient levels in root media after production is also important for hanging basket performance. Cation exchange capacity (CEC) refers to the ability of a root media to retain positively charged ions against the leaching effects of water while still allowing the nutrients to be available to the plant (Conover and Poole, 1977). The CEC of peat can vary dramatically but is generally reported to be in the range of 1.0 to 1.2 meq g^{-1} (Bunt, 1988; Nelson, 1991) which is considered high on a weight basis. However, the actual CEC of peat in container root media on a volume basis can be low due to the low weight per unit volume.

Zeolite is a fine powdered natural silica material with a CEC between 1.4 and 2.0 meq g^{-1}. These materials also have the ability to selectively absorb specific monovalent cations such as ammonium (NH_4^{+1}) and potassium (K^{+1}) ions. Due to its high bulk density, relatively small amounts of this material can greatly increase the CEC of a root media. Bunt (1988) found that a mixture of 90% sphagnum peat and 10% zeolite had a CEC double that of the sphagnum peat alone. The incorporation of 33.2 kg m^{-3} (56 lbs yd^{-3}) of K^{+1} enriched zeolite was able to supply all the K^{+1} needed for chrysanthemums grown in 15 cm (6 inch) pots (Hershey et al., 1980). The release of the K^{+1} by the zeolite was similar to a slow release fertilizer.

Another method of chemically amending root media is with the use of RCF. It has been reported that plants grown in root media containing RCF are much more efficient in the use of fertilizer compared with plants grown with water soluble fertilizer

(Holcomb, 1979; Hershey and Paul, 1982). RCF also provides a nutrient reserve that can provide for extended periods of time.

The objective of this experiment was to look at a variety of root media components and amendments either singularly or in combination that could reduce the amount of maintenance required to keep flowering plants in hanging baskets blooming and actively growing through the summer.

Materials and Methods

Root Media Components: The basic components tested were polystyrene, #2 perlite, #2 vermiculite, and medium grade granular rockwool (Partek, Englewood CO) along with 100% peat. The peat used was Fisons Sunshine Grower Grade Canadian sphagnum peat. Peat and components were mixed in a 60:40 blend.

Water absorbent Gel: Supersorb C^R (Aquatrols, Penn Sauken NJ) is a coarse (1-2 mm in size when dry) superabsorbent polyacrylamide gel capable of holding up to 400 times its weight in pure water. Supersorb C^R was incorporated prior to planting at the recommended rate of 0.9 kg m^{-3} (1.5 lbs yd^{-3}) into 4 of the original root media blends (polystyrene, #2 vermiculite, rockwool and 100% peat).

Zeolite: Clinoptilolite zeolite is a fine powdered natural silica material with a cation exchange capacity (CEC) of 1.4 to 2.0 meq g^{-1}. The zeolite (East West Minerals, San Salita, CA) used in this experiment was ground to 35 mesh or less and was incorporated prior to planting at a rate of 30 kg m^{-3} (50 lbs yd^{-3}) in 3 of the root media blends (polystyrene, rockwool and 100% peat/gel).

Wetting Agent: The wetting agent used in the above treatments was Aquagro L^R (Aquatrols, Penn Sauken NJ). Aquagro L^R was incorporated prior to planting at the recommended rate of 0.35 liters m^{-3} (9 fl.oz. yd^{-3}). In the wetting agent comparison, 100% peat with no wetting agent was compared to 100% peat +1 Aquagro L^R and 100%

peat +1 AC160. AC160 was an experimental wetting agent also by Aquatrols (now available as Aquagro 2000[R]). AC160 was incorporated at mixing at the recommended rate 0.12 liters m^{-3} (3 fl.oz. yd^{-3}).

Fertilization: Plants grown in each of the 14 root media treatments described above were grown with both WSF or RCF. Peters 20-10-20 Peatlite (Grace/Sierra, Fogelsville, PA) was applied at a rate of 300 mg $liter^{1}$ (ppm) to half the plants. The RCF, Osmocote[R] 13-13-13, 8-9 month release rate (Grace/Sierra, Fogelville, PA), was incorporated prior to planting at a rate of 4.2 kg m^{-3} (7 lbs yd^{-3}) for the remaining plants. RCF was incorporated into 0.03 m^3 (1 ft^3) of each of the root media blends prior to planting with an additional 60 seconds of mixing in the cement mixer. The remaining 0.03 m^3 (1 ft^3) of each of the root media blends with no RCF was also mixed for an additional 60 seconds to maintain uniformity.

While the plants were being grown in the greenhouse, treatments that received WSF had the solution applied at every watering after the initial saturation on May 5. After the baskets were moved to the OEA, WSF was applied on an as needed basis. The RCF treatments only received tap water at every irrigation. Six baskets were planted for each root media/fertilizer combination for a total of 198 baskets.

Each root media blend was mixed in 0.06 m^3 (2 ft^3) batches for 2 minutes to incorporate a starting preplant nutrient charge of 0.6 kg (1 lb) $Ca(NO_3)_2$, 0.6 kg (1 lb) KNO_3, 0.3 kg (0.5 lb) $MgSO_4$ per cubic meter (yd^{-3}). Dolomitic lime was added to bring the pH of the root media to the range of 5.8 to 6.0. The amount of lime added was 5.3 kg m^{-3} (9 lbs yd^{-3}) for the 100% peat, 3.0 kg m^{-3} (5 lbs yd^{-3}) for the rockwool blends and 4.2 kg m^{-3} (7 lbs yd^{-3}) for all the other blends. Wetting agent (if applicable) was also incorporated as the root media was moistened.

General Methods: The basket used was a 25.4 cm (10 inch) fluted saucerless basket with a total volume of 4.9 liters (1.3 gallons) and an internal reservoir volume of 0.3 liters (10 fl.oz.). A root media capillary column allowed for direct contact with the water in the internal reservoir. Impatiens (orange hybrid) grown in a 32 cell bedding flat were planted 3 plants/basket on April 17, 1990.

On May 5, all the baskets were watered to container capacity with tap water and the weight recorded. From that point, baskets were watered again at visible wilt with a beaker using sufficient water for 10% leaching (1.0 to 2.0 liters (34 - 68 fl.oz.)). AWHC was determined by weighing for each drying cycle in the greenhouse.

On June 21, half the baskets from each treatment were sampled for shoot fresh and dry weight. Root media settling or shrinkage was determined by placing a sheet of plastic wrap over the top of the basket and adding water up to the rim of the pot. The volume of the water was determined by weighing and equaled the shrinkage volume. Root media samples were tested for pH, EC and nitrate-N levels using the saturated media extract technique (Warncke, 1986). The remaining baskets were saturated with either water or fertilizer solution and moved to the OEA.

While outside, plants were checked daily for visible wilt. If visible wilt was observed in one plant, all three plants from that treatment were watered. Water was applied with a beaker to determine the exact amount of water applied to each basket. Sufficient water was applied for approximately 10% leaching (1 to 2 liters (34 - 68 fl.oz.)). AWHC was determined by weighing for each drying cycle.

On September 5, the baskets were brought back inside the greenhouse, saturated thoroughly, and a final controlled dry-down was completed. On September 20, shoot fresh and dry weight and root media settling were determined. Root media pH, EC, and nitrate-N concentrations were determined for samples collected after mixing the entire content of the basket.

Results

Due to the plant response of the different fertilization methods, all discussions dealing with root media are for plants fertilized with WSF. The difference in the fertilizer treatments is discussed in the RCF section.

Components: All plants grown in the 5 root media blends were visually similar in size and quality at the end of production (June 10). The plants grown in peat/vermiculite had a greater fresh weight compared to the other 4 peat/component blends (Figure 1).

At the end of the garden performance phase (September 10), plants grown in peat/polystyrene, peat/vermiculite and peat/rockwool were similar in fresh weight and visually similar in size and quality. The plants grown in peat/perlite had a lower fresh weight and were visually smaller but were still high quality. Plants grown in 100% peat were smaller and of reduced quality (see wetting agent discussion).

During the garden performance phase (June 21 - September 20), AWHC varied from 1 liter (34 fl.oz.) with the peat/polystyrene media to 1.7 liters (58 fl.oz.) with the peat/rockwool media (Figure 2). The amount of available water retained in the different peat/component blends was consistent with the water holding properties of the components alone. The ADI almost doubled from the plants grown in the peat/polystyrene media (3.5 days) to the peat/rockwool media (6.1 days). The MDI was extended from 1 day with the peat/polystyrene media to 3 days with the peat/rockwool media (Figure 3). Statistical comparisons were not appropriate because the 3 plants in each treatment were not irrigated independently in this experiment.

The settling or shrinkage volume was different at both harvests. The shrinkage volume ranged from 0.65 liters for the peat/perlite media to 0.86 liters for the peat/rockwool. The shrinkage reduced root media volume by 13% for the peat/perlite media and 18% for the peat/rockwool media (basket volume of 4.9 liters (1.3 gallons)). The increase in the settling between the 2 harvests averaged 0.12 liters or 2% of the total volume.

Superabsorbent Gel: The incorporation of Supersorb C^R had no significant effect on plant size in either the production or the garden performance phase of the experiment. Supersorb C^R did not increase the amount of water held by the root media (Figure 4). The ADI was increased by an average of 25% (approximately 1 day) over the same root media without gel. There was no increase over the MDI (Figure 5). There was no difference in the amount of settling at either harvest in root media containing gel compared with the same media without gel.

In a laboratory experiment, 1 gram of Supersorb C^R was placed in a container with either Reverse Osmosis (RO) water or tap water (approximately 80 mg liter^{-1} Ca^{+2}, 40 mg liter^{-1} Mg^{+2}) containing one of three fertilizers (KNO_3, $Ca(NO_3)_2$ or Peters 20-10-20) at 4 different rates (0, 50, 150 or 350 mg liter^{-1} N). The gel was allowed to hydrate for a 24 hour period and then weighed to determine water absorption.

Supersorb C^R absorbed 330 times its own weight in RO water and 75 times its own weight in tap water (Figure 6). Increasing levels of fertilizer decreased the amount of water absorbed by the gel, particularly in RO water. The greatest reduction in water absorption due to fertilizer was from increasing levels of $Ca(NO_3)_2$. With 350 mg N liter^{-1} from $Ca(NO_3)_2$ in the water, water absorption by the gel was similar in both types of water (RO = 39 times, tap = 31 times).

Zeolites: The incorporation of zeolite had no significant effect on plant fresh weight. The addition of zeolite did not increase the AWHC. However, there was an increase 25% in the ADI in the root media containing zeolite compared to plants grown in the same root media without zeolite. There was no increase in the MDI. In treatments receiving WSF, similar amounts of nitrate-N were applied to plants grown in root media containing zeolite compared to plants in the same root media without zeolite.

Wetting Agent: Plant size was different between each of the three wetting agent treatments. Peat + AC160 produced the largest plant (fresh weight = 874 grams) while the peat + Aquagro L^R produced the smallest plant (fresh weight 542 grams).

Both wetting agents (Aquagro^R and AC160) allowed the 100% peat media to absorb more water (10% and 17% respectively) than the 100% peat with no applied wetting agent. The peat + Aquagro^R averaged longer (7.9 days) between watering than either the peat + no wetting agent (5.6 days) or the peat + AC160 (5.5 days).

Fertilization: At the first harvest (June 20), plants fertilized with RCF had a fresh weight of 302 g (11.1 oz.) while plants fertilized with WSF which had an average fresh weight of 257 g (9.4 oz.). Average soil test values for root media fertilized with RCF were pH=6.58, EC=0.81 mS cm^{-1} and 9 mg $liter^{-1}$ nitrate-N. Average soil test values for the same root media fertilized with WSF were pH=6.01, EC=2.07 mS cm^{-1} and 153 mg $liter^{-1}$ nitrate-N.

When the baskets were returned to the greenhouse on September 4, the average temperature was held at a constant 27°C (77°F). During the 2 weeks the plants were in the greenhouse, plants grown in root media containing RCF became noticeably darker green in color.

At the second harvest (September 20), the average fresh weight of the plants fertilized with RCF was 426 g (15.6 oz.). The average fresh weight of the plants fertilized with WSF was 779 g (28.5 oz.) (Figure 7). Average soil test values for root media blends fertilized with RCF were pH=6.67, EC=1.08 mS cm^{-1} and 58 mg $liter^{-1}$ nitrate-N. The same root media fertilized with WSF were pH=7.59, EC=0.41 mS cm^{-1} and 2 mg $liter^{-1}$ nitrate-N.

The starting preplant nutrient charged incorporated in the root media prior to planting was 0.8 g nitrogen fertilizer per basket. The additional nitrogen fertilizer applied with RCF was 2.6 g N per basket for a total of 3.4 g N per basket. The plants receiving WSF had solution applied on average 7 times. The average amount of nitrogen fertilizer applied with the WSF was 2.7 g N for a total of 3.5 g N per basket.

Discussion

Components: High quality plants could be produced and maintained in all root media tested (Except for the 100% peat + Aquagro L^R treatment - see wetting agent discussion). However, the amount of maintenance required to sustain plant growth varied dramatically for the different root media. In general, increased amounts of available water increased both the ADI and the MDI.

One common perception of root media that hold large amounts of water is that it is difficult to apply sufficient fertilizer early in the crop because the root media is not irrigated as often. However, the amount of fertilizer applied is not only a function of the number of applications but also the amount applied at any one time. The greater the water holding capacity of the root media, the greater the amount of fertilizer that can be applied at any one time.

This can be illustrated by comparing the fertilization of the peat/rockwool media and the peat/polystyrene media. During the garden performance phase of the experiment, the peat/polystyrene media held 1.0 liter (34.0 fl.oz.) of available water after an irrigation. When the plants were irrigated with a fertilizer solution at a concentration of

300 mg liter^{-1}, 0.3 g nitrogen fertilizer was applied to the peat/polystyrene media. The peat/rockwool media held 1.7 liter (57.5 fl.oz.) of available water. When plants grown in the peat/rockwool media were irrigated with the same fertilizer concentration, 0.51 g nitrogen fertilizer was applied. In this case, 70% more nitrogen fertilizer was applied to the peat/rockwool media compared to the peat/polystyrene media.

Between April 17 and September 20, 1990, plants grown in the peat/polystyrene media were fertilized 7 times for a total fertilizer application of 2.4 grams nitrogen from WSF. Over the same time period, plants grown in the peat/rockwool media were fertilized 6 times and received a total of 2.9 grams nitrogen or 20% more nitrogen fertilizer from WSF. If converted to dry fertilizer with 20% nitrogen, plants grown in the peat/polystyrene media received 12 g (0.43 oz.) per basket while the peat/rockwool media received 15 g (0.52 oz.) per basket.

Root media that hold large amounts of water after an irrigation may require different management. For these types of root media, a greater percentage of the total amount of fertilizer applied to the crop is applied at a single irrigation. A missed fertilization becomes greater in importance because of the longer period of time root media that hold large amounts of water may go between irrigations, especially at the beginning of the crop.

An adequate cation exchange capacity (CEC) has been reported to be desirable in container root media in order to buffer media pH and help retain positively charge nutrients (Bunt 1988). Vermiculite is often added for this purpose. Since there was no difference in growth or the fertilizer requirement of plants grown in root media containing vermiculite verses polystyrene, rockwool, or perlite with low CEC, the importance of CEC was not validated in this case.

The amount of leaching also affects how nutrients remain in the root media. Similar root media nutrient concentrations were maintained with 200 mg $liter^{-1}$ N applied with 15% leaching compared with 400 mg $liter^{-1}$ N applied with 50% leaching using a constant liquid fertilization program (Yelanich 1991). Low leaching levels may also help a root media to retain nutrients using an intermittent liquid fertilization program. The low levels of leaching used in the experiment (approximately 10%) may not have tested the ability of root media with different CEC to retain nutrients.

Superabsorbent Gel: The gel did not increase the AWHC of the root media. However, the ADI was increased compared to the same root media without gel. If the water held by the gel was similar to the water held in the root media, then there would not have been an increase in the time between irrigations. Thus, the water held by the gel may have been less available to the plant compared to the water being held by the root media and the plant may have therefore used less water. With high transpiration rates, the gel did not increase the time between irrigations, possibly because the plant was not able to absorb the water in the gel fast enough.

Supersorb C^R may require up to 8 hours to fully hydrate in RO water (Wang and Gregg, 1990). Thus, during one irrigation, the application of water occurs over too short a time period to fully hydrate the gel. Wang and Gregg (1990) found that Supersorb C^R required 15 daily irrigations in pots without plants to fully hydrate the gel. For some commercially available root media which contain gel (Fisons Postharvest Mix), the manufacture recommends multiple irrigations to allow for maximum water absorption by the gel. In this experiment, the plants grown in root media containing gel were never irrigated specifically to allow the gel to absorb water. Other evidence to indicate that the gel in the root media was not fully saturated was that the root media never significantly increased in volume as previously reported (Sulecki, 1988). For example, Fisons Postharvest Mix is expected to expand by 15-20% in volume after thorough watering.

Without frequent multiple irrigations, the easily available water contained in root media after irrigation is the sole source of water for the gel to absorb. The greater the amount of available water contained in a root media, the more water that can be absorbed by the gel. The peat/vermiculite and peat/rockwool media have a large AWHC and the addition of Supersorb C^R increased the ADI by 3 days and 2 days respectively. The peat/polystyrene media has a lower AWHC and the addition of Supersorb C^R increased the ADI by less than 1 day.

The hydration of a gel may be decreased by soluble salts dissolved in the water, specifically, divalent cations such as calcium (Ca^{+2}), magnesium (Mg^{+2}), or iron (Fe^{+12}) (James et al., 1986; Wang and Gregg, 1990). Increasing levels of fertilizer salts decreased the hydration of the gel. Increasing Ca^{+2} levels caused a greater decreased in the hydration of the gel than with the other fertilizer salts tested which are consistent with the findings of other researchers (Wang and Gregg, 1990; Bowman et al., 1990). Bowman et al. (1990) also found that the effect of Ca^{+2} on gel hydration was not reversible with subsequent rinses with RO water. Thus, the presence of Ca^{+2} in the irrigation water may have reduced the effectiveness of the gel.

On a practical basis, healthy mature impatiens grown in a 25.5 cm (10 inch) basket use approximately 0.5 liter (16 fl.oz.) of water per day. Under conditions of high light and temperature, the amount of water used can increase to 1 liter (34 fl.oz.) per day. Under the conditions of maximum water saturation with MSU water, 4.2 g of Supersorb C^R (4.2 g/basket = 0.9 kg m^{-3} (1.5 lbs yd^{-3})) could only absorb 0.32 liters (11.5 fl.oz.) of water.

Water quality, fertilizer type and concentration, and irrigation method effect gel hydration. Perhaps this may help explain why some growers obtain a benefit from water absorbent gels while others do not.

Zeolite: One objective of this experiment was to test the effect increased exchange capacity in different root media. The intent was that if fertility levels became too high, from excess release from RCF for example, the nutrients would be held by the root media instead of contributing to high soluble salt levels or being leached from the pot.

Most of the exchange sites in zeolite are located in 'holes' within the crystal structure that allow for the exchange of only specific size ions. Naturally occurring zeolite tends to absorb K^{+1} and ammonium (NH_4^{+1}) ions. If zeolite has been saturated with K^{+1} for example, the addition of NH_4^{+1} will cause a release of K^{+1} into solution that is available to the plant. The NH_4^{+1} will replace the K^{+1} in the exchange sites. Divalent cations such as Ca^{+2} or Mg^{+2} are too large to replace monovalent cations such as NH_4^{+1} or K^{+1} in the exchange sites.

The material used was not a K^{+1} or NH_4^{+1} saturated zeolite. Perhaps the fertility levels used in this experiment were not sufficient to fill the exchange sites. If the exchange sites were full, the low levels of nutrition used during the garden performance phase of the experiment did not allow for the replacement of one ion with another. At the second harvest, there was no difference in the shoot fresh weight of plants grown in root media containing zeolite compared to plants grown in the same root media without zeolite with either method of fertilization.

It has been reported that materials such as sand, calcined clay and perhaps zeolite may be added to a root media to increase water absorption. Beardsell and Nichols (1982) found that water absorption by coarse sand was not dependent on the moisture content prior to water being applied. This water absorption characteristic could be transferred to a root media in proportion to the amount of coarse sand or calcined clay used. Beardsell and Nichols concluded that a minimum of 30% of the volume of the root media be made up of coarse sand to achieve acceptable levels of rewettability (> 80% of initial container capacity). In commercial root media such as Fisons Postharvest Mix, calcined clay is added for this purpose.

The AWHC of the root media was not increased with the incorporation of zeolite. Incorporation levels (< 2% of the total volume) may not have been sufficient to affect rewetting. However, the average number of days between irrigation was increased by 1 day over the same root media without zeolite. This could indicate that the zeolite changed the way water was released by the root media back to the plant.

Wetting Agent: Aquagro L[R] has been shown to be phytotoxic to impatiens (Bhat et al., 1989). Plants grown in the 100% peat + Aquagro L[R] were significantly smaller than all other treatments. Since the decrease in growth was not observed in any other root media treated with Aquagro L[R] as the wetting agent, including 2 other treatments that were 100% peat, the basis for the problem was not clear.

The use of both wetting agents did increase the amount of water absorbed by the 100% peat. A comparison of the time between irrigations can not be made for Aquagro L[R] due to the difference in plant fresh weight. There was no increase for plants grown in the root media containing AC160. The additional 0.2 liters (7 fl.oz.) of water absorbed by the root media with AC160 may not have been sufficient to affect the time between irrigations. Peats differ in rewetting characteristics and results may have been different with other types of peats.

Fertilization: The slow start of the plants fertilized with WSF may have been due to the decision to use tap water in the initial saturating irrigation (May 5). Because of the large volume of water applied, some treatments were not fertilized for 4 weeks after the saturation. One application of the 300 mg liter^{-1} N fertilizer solution was equal to approximately 33% of the total amount of nitrogen fertilizer applied during production. If fertilizer solution was applied at the time when the baskets were first saturated, the problem with the WSF plants may not have occurred.

Plants with the incorporated RCF quickly began to grow after becoming established, approximately 2 weeks after planting. Plants fertilized with RCF were consistently larger than the plants grown with WSF while in the greenhouse. The difference in fresh weight at the first harvest between the 2 fertilizer treatments was 50 g (0.12 lb) or 20% greater fresh weight in the plants fertilized with RCF. However, both methods of fertilization produced acceptable plants by the end of the production phase.

Upon being placed outside, plants fertilized with RCF quickly began to show signs of low nutrition such as yellowing leaves and understory leaf drop. Very little new growth was observed. As the summer progressed, these symptoms became more pronounced (Figure 8). Yellowing leaves and understory leaf drop were kept to a minimum with plants fertilized with WSF since fertilizer solution was applied if these symptoms were to appear. The fresh weight of plants grown with RCF had increased by one third from the end of the greenhouse phase to the end of the garden performance phase (June 21 - September 4, 1990). Plant fresh weight tripled in some case with plants fertilized with WSF over the same time period.

Soil test nutrient levels at harvest 1 (June 20) in root media containing RCF were EC=0.81 mS cm^{-1} and 9 mg liter^{-1} nitrate-N. While the EC was in the acceptable range for a SME, the nitrate-N concentration would be considered very low (Warncke and Krauskopf, 1983). It has been reported that the amount of nitrogen lost to leaching was reduced to near 0 mg liter^{-1} in chrysanthemums fertilized with Osmocote^{R} 14-14-14, by 6 weeks after planting (Hershey and Paul, 1982). The assumption was that nutrient concentration in the leachate was similar to the nutrient levels in the root media. The low nutrient levels are said to be due to the higher efficiency of RCF in supplying nutrients to the plant (Holcomb, 1979, Hershey and Paul, 1982). However, from the appearance of plants fertilized with RCF, nutrients were not being released in sufficient quantities to maintain flowering and active growth.

Similar amounts of nitrogen fertilizer were applied using either WSF or RCF. Therefore, a sufficient quantity of nitrogen fertilizer was incorporated with the RCF prior to planting to maintain the plant over the 6 months of the experiment if 100% of the nutrients were released at the proper time. It is possible that the nutrients contained in the Osmocote[R] were released at a higher than expected rates inside the greenhouse leaving inadequate nutrient levels through the garden performance phase. Since little leaching occurred while the plants were in the greenhouse, high levels of nutrients would have been expected in the soil tests at the end of the production phase. This was not the case.

The release from Osmocote[R] 13-13-13 is based on 80% of the nutrients being released over 8-9 months at 20°C (68°F) (Rutten, 1980). If only 80% of the nutrients were released by the RCF, a total of 2.1 g N would have been applied to the RCF treatments. This may have been a sufficient amount to sustain the plants through the summer. However, the actual time period (5 months) was shorter than the optimal 80% release duration of the RCF. The conclusion therefore is that sufficient amounts of RCF were not incorporated into the root media for the duration of the experiment.

Since the release of the fertilizer salts in the RCF is based solely on temperature, a decrease in the average temperature by 5°C (9°F) will decrease the release rate by 25% (Rutten, 1980). The average air temperature for the month of July 1990 was 23/19°C (73/66°F) day/night. When the plants were returned to the greenhouse (September 4 -

September 20), the average day/night temperature inside the greenhouse was approximately 27°C (80°F). The plants grown in root media containing RCF responded by increased growth and darker foliage. Soil test nutrient levels at harvest 2 (Sept. 20) were an EC of 1.08 mS cm^{-1} and 58 mg N $liter^{-1}$. These nutrient levels were considerably higher than in the root media of plants fertilized with WSF although the plants fertilized with RCF were considerably smaller in size and much lower in quality.

Summary

Acceptable garden performance was maintained in all the media treatments. There were significant differences in the water holding capacity of the media tested. The amount of available water held in the media after watering ranged from 1.0 to 1.7 liters (34 - 57 ounces). The peat/rockwool blend held the greatest amount of available water. There was a difference in the average days between watering ranging from 3.5 to 8.1 days and there was a difference in the minimum number of days between watering ranging from 1 to 3 days.

The addition of Supersorb C^{R} polyacrylamide gel and zeolite did not improve plant quality under the conditions of the test. These amendments did extend the average period between watering by approximately one day. However, these amendments did not increase the minimum days between watering. Wetting agents allowed the 100% peat to absorb slightly more water than 100% peat with no applied wetting agent. Aquagro L^{R} had what appeared to be some detrimental effects in one case.

Plants fertilized with RCF were slightly larger plants at the end of the production phase then the plants grown with water soluble fertilizer. Once outside, the RCF plants could not maintain the rate of growth and quickly declined in quality. The plants fertilized with WSF continued to grow through the end of the experiment. On average, equal amounts of fertilizer (3.4 gms N) were applied to both the resin coated and water soluble fertilizer treatments. The long term release rate of the 8-9 month RCF at the incorporated rate (4.1 kg m^{-3} (7 lbs yd^{-3})) did not adequately supply nitrogen.

Experiment Two: Effect of the release rate of resin coated fertilizer on the garden performance of impatiens hanging baskets.

Introduction

RCFs are sold by the NPK ratio and the release time. Release rates for greenhouse crops are typically selected based on the 8-16 week production phase. Since less material is applied with the 3-4 month release products compared to the 8-9 month release rate materials, the cost per unit is lower. In the case of hanging baskets, the additional cost of an 8-9 month release rate material is significant ($0.05 per basket for the 3-4 month material compared to $0.08 per basket for the 8-9 month material), but perhaps can be justified by improved garden performance. The objective of this experiment was to compare the effect of RCF release rates on plant growth during both production and garden performance.

Materials and Methods

The 2 types of RCF tested were Osmocote^{R} 14-14-14 (3-4 month release rate) and Osmocote^{R} 13-13-13 (8-9 month release rate). Both were incorporated prior to planting at either 1.8 kg m^{-3} (3 lbs yd^{-3}) or 3.6 kg m^{-3} (6 lbs yd^{-3}). The 4 RCF treatments were compared to the application of either no additional fertilizer or WSF applied at the first signs of leaf chlorosis. These rates were selected based on previous research by Yelanich and Biernbaum (1992) but were well below the manufactures recommended incorporation rates of 5.3 kg m^{-3} (9 lb yd^{-3}) for the Osmocote^{R} 14-14-14 and 7.7 kg m^{-3} (13 lb yd^{-3}) for the Osmocote 13-13-13 in greenhouse crops.

The type of basket used was a 25.4 cm (10 inch) round bottom basket with a volume of 4.9 liters (1.3 gallons) and an external reservoir. The root media was a commercially available canadian sphagnum peat/polystyrene/vermiculite #3 mix (Suremix, Michigan Grower Products, Galesburg MI). RCF was incorporated into 0.03 m^3 (1 ft^3) of the root media with 60 seconds of mixing in 0.09 m^3 (3 ft^3) cement mixer. Root media for treatments that did not receive RCF were also mixed for 60 seconds to maintain uniformity. Impatiens (orange hybrid) from a 32 cell bedding flat were planted 3 plants/basket on April 17, 1990.

On May 5, the root media was saturated with tap water in all treatments and the weight recorded. Water was applied with a beaker using a sufficient amount of water for approximately 10% leaching (1 to 1.5 liters (34 to 51 fl.oz.)) at every irrigation. The WSF treatment received the fertilizer solution (Peters 20-10-20 Peatlite at 300 mg $liter^{-1}$ N) at every irrigation.

On June 28, three uniform baskets from each treatment were saturated with water or fertilizer solution and moved to the OEA. The root media from the remaining plants were sampled for pH and EC using the SME technique.

While outside, plants were checked daily and irrigated at visible wilt with approximately 10% leaching. The WSF treatment received Peters 20-10-20 Peatlite at 300 mg $liter^{-1}$ when needed as a normal irrigation

On September 4, 1990, 20 grams (3 1/3 tsp.) of Osmocote^R 14-14-14 was surface applied ("top dressing") to each of the basket's that originally received Osmocote^R 13-13-13 (3-4 month) incorporated at a rate of 1.8 kg m^{-3} (3 lbs yd^{-3}). The plants had stopped flowering and had very little foliage due to lack of sufficient fertilizer. The plants from this treatment was maintained for another 10 weeks until November 20, 1990. All other plants were discarded.

Results

Prior to the plants being placed outside, the was little visual difference in the quality of any of the treatments receiving some type of fertilizer. The plants that received no additional fertilizer were smaller in size and chlorotic but were still blooming. At the June 28 sampling date, the root media EC averaged 1.2 mS cm^{-1} for all treatments receiving fertilizer. The treatment that did not receive fertilizer had an EC of 0.9 mS cm^{-1}.

Within 2 to 3 weeks of being placed outside, all plants with either rate of the 8-9 month Osmocote^R or the 3-4 Osmocote^R incorporated at 1.8 kg m^{-3} (3 lbs yd^{-3}) rapidly became chlorotic with reduced flowering. Plants fertilized with 3-4 month Osmocote^R incorporated at 3.6 kg m^{-3} (6 lbs yd^{-3}) maintained their leaf mass and dark green color for 2 to 3 weeks longer (Figure 9). There was no visual difference in quality between the plants fertilized with WSF and the 3-4 month Osmocote^R at 3.6 kg m^{-3} (6 lb yd^{-3}) except the RCF plants were shorter than the WSF plants. However, after 2-3 weeks outside (approximately 12 weeks after planting), plants fertilized with the 3-4 month Osmocote^R incorporated at 3.6 kg m^{-3} (6 lbs yd^{-3}) also became chlorotic and lost much of the leaf mass. By early September, there was no noticeable difference for the 2 RCF's at the high incorporation rate.

For the plants that received the top dressed RCF on September 4, the few remaining leaves turned darker green within 1 week. After 2 weeks, rapid leaf growth was apparent. After sixty days when the plants were discarded, there was a full flowering leaf canopy (Figure 10).

Discussion

There were possibly several reasons why the fertilizers did not sustain plant growth through the summer. The release rate of the 3-4 month RCF was sufficient to initially sustain growth upon being placed outside but the duration was not great enough to maintain growth. Greater incorporation rates of the 3-4 month RCF would probably not have affected plant growth through the summer. The 8-9 month RCF had a sufficient release duration to last through the summer but there was not a large enough release rate to sustain growth once the plants were placed outside. With Osmocote[R] fertilizer, there typically is a higher initial release rate due to imperfections in the prill coat (Harbaugh and Wilfret, 1982). This early release may have provided adequate nutrition in the greenhouse but was probably depleted by the time the plants were moved outside. Greater incorporation rates for the 8-9 month RCF may have been sufficient for continued plant growth though the summer.

From the small test at the end of the experiment, it could be concluded that the decrease in quality seen in the RCF baskets upon being taken outside was probably due to macronutrient deficiencies (probably nitrogen). Growth and greening occurred with additional Osmocote[R] 14-14-14, which did not contain micronutrients.

No recommendations for RCF incorporation could be made based on Experiments 1 and 2.

Experiment Three: Effect of commercial root media on the garden quality of flowering hanging baskets.

Introduction

Experiment 1 was designed to characterize the water holding characteristics of root media components when mixed with one type of peat. However, there also was a need to investigate the AWHC of commercially available root media. The first objective of this experiment was to quantify the water holding capacity of commercially available root media. A second objective was to test the effect of a wetting agent on the water holding capacity of the root media.

Materials and Methods

The commercially available root media used in this experiment are presented in Table 1. The basket used was a 25.4 cm (10 inch) saucerless basket with a total volume of 4.9 liters (1.3 gallons) and an internal reservoir volume of 0.3 liters (10 fl.oz.). In this type of basket, there was no root media capillary column to allow for direct contact with the water in the reservoir. Four impatiens plugs (Shady Lady Pastel Mix) from a 406 plug tray were directly planted into each basket on March 15, 1991. Plants were lightly watered without saturation or leaching. While not common commercial practice, it was necessary for uniformly establishing plants in a wide variety of root media. This method of watering was used from the time of planting until May 10.

One liter of fertilizer solution (Peters 20-10-20 Peatlite, 300 mg liter^{-1}) was applied on April 8 with the addition of acid (0.5 mls H_2SO_4 (93%) per 3.8 liters (1.8 oz. per 100 gallons)) to lower the root media pH. From 8 April until May 10, fertilizer/acid solution was applied two more times to all the baskets for a total fertilizer application of 0.9 g N per basket.

On May 10, the baskets were moved to the IEA, watered twice using a hose and breaker to thoroughly saturated the root media, and the weights were recorded. For all later irrigations, water was applied with a hose and breaker until drainage occurred. WSF (Peters 20-20-20 Peatlite, 300 mg liter^{-1}) was applied as a normal irrigation when leaves in the plant canopy became chlorotic. Peters 20-20-20 was selected because this formulation is more commonly available to the consumer then 20-10-20. Plants were checked daily and watered at visible wilt. AWHC was determined at each irrigation. On 6 June, half the baskets were saturated with tap water containing the wetting agent

Aquagro 2000^{R} (Aquatrols, Pennsauken NJ) at a rate of 556 mg liter^{1}. The remaining baskets were saturated with only tap water. On 11 July, a hole was placed in the bottom of the basket to determine the effect of the internal reservoir on available water. The hole was placed so that no water would remain in the reservoir after watering but could be plugged when needed.

On 17 September, baskets were watered twice to saturate the root media and weighed. After 1 day in the evaluation area, the baskets were placed in a room under constant temperature and 24 hours of light from cool white fluorescent lamps. The baskets were allowed to dry down until the plants began to wilt. The degree of wilt was separated into 3 categories; initial wilt, obvious wilt, and hard wilt. Initial wilt was when the leaves became dull and began to droop. An obvious wilt was when the understory leaves had a considerable droop but the leaves around the growing tip had not yet begun to droop. A hard wilt was when the leaves around the growing tip drooped. The time and weight was first recorded when a slight wilt was observed. Weights were recorded every six hours until the basket reached a hard wilt. Once the baskets reached a hard wilt, water was applied and the baskets were moved back to the greenhouse.

Shoot fresh weight and root media shrinkage was determined on 30 September. Root media samples were collected to determine final pH (1:1 water to media; v:v) and EC (2:1 water to media; v:v) measurements.

Root media physical properties were determined with the method outlined by White and Mastalerz (1966). A 15 cm (6 inch) standard pot containing root media was placed into a water tight container. Water was slowly added so it entered the bottom of the pot and was applied until it reached a height similar to the container height. The root media was allowed to saturate for 24 hours. The saturated root media was weighed, allowed to drain for 1 hour and weighed again. The weight after 1 hour was considered the container capacity weight. The root media was then placed into a drying oven at 70°C (160°F) until the pot reached a constant weight. The difference between the saturation weight and the container capacity weight was used to calculate percent air space. The difference between the container capacity and the oven dried weight was the percent total water and the remainder calculated by subtraction was the percent solid. This procedure was done for each root media three separate times.

Results

Root Media: During production, plants grown in 8 of the 10 root media were of similar visual size and flowering quality. Plants grown in the Peatwool and the Baccto Rockwool Blend were smaller in size but were still high in flowering quality. Once moved to the IEA, plants grown in the Peatwool quickly grew in size so that there was no visual difference compared to the other root media. Throughout the summer, the plants grown in the Baccto Rockwool Blend maintained a more compact growing habit and remained smaller in size compared with plants grown in the other root media.

At the final harvest, the average plant fresh weight was 2 kg (4.4 lbs) and ranged between 1.6 kg (3.5 lbs) and 2.5 kg (5.5 lbs). While there was a visual difference in plant size over the course of the experiment, plants grown in all 10 root media maintained adequate green foliage and flowering.

Between May 11 and June 5, the ADI ranged from 7.2 days (Baccto Rockwool Blend) to 4.5 days (LC 1) (Table 2). The MDI ranged from 6.2 days (Baccto Rockwool Blend) to 3.5 days (Pro-mix BX). Over the same time period, the AWHC of the root media averaged 2.0 liters (67.6 fl.oz.) with the type of irrigation used in the experiment. AWHC in the 10 root media ranged from 2.3 liters (77.8 fl.oz.) (Pro-mix BX) to 1.6 liters (54 fl.oz.) (Baccto Rockwool Blend) (Table 3).

Placing a hole in the bottom of the reservoir decreased the amount of available water by approximately 0.25 liters (8.4 fl.oz). In the style of basket used, the root media was not in contact with the water held in the reservoir. However, at the time when the hole was placed in the reservoir, roots were visible in the reservoir.

In the determination of root media physical properties, container height is one of the main controlling factor (Bilderback and Fonteno, 1987). A 15 cm (6 inch) standard pot and the 24.5 cm (10 inch) saucerless basket used in the experiment have a similar height. The determination of the physical properties of the different root media was completed in 15 cm (6 inch) standard pots and is presented in Table 4. The physical properties at container capacity averaged over all root media were 21% air space, 58% total water space and 21% solid space. In general, the addition of rockwool decreased solid space and increased air and water space.

The amount of available water measured in a low light environment was 1.9 liters averaged over all root media. This was an increase in available water of 0.2 liters over the measured available water determined in high light without the reservoir. The difference in available water between stage 1 and stage 3 of visible wilt averaged only 0.1 liters or 5.4% of the total amount of available water. The average amount of time required to go from stage 1 to stage 3 of visible wilt was 12 hours.

The amount of settling or shrinkage in volume ranged from 0.55 liters with the Pro-mix BX to 1.2 liters with the Peatwool. This change corresponds to a root media volume reduction of 11% for the Pro-mix BX and 24% for the Peatwool assuming a basket volume of 4.9 liters (1.3 gallons). The majority of the changes in volume was due to settling that occurred with the first irrigation.

Wetting agent: The application of Aquagro 2000[R] had no effect on the visual quality or the final plant fresh weight except for plants grown in the Baccto Rockwool

Blend. In this case, there was a 30% decrease in shoot fresh weight without the wetting agent application.

There was no effect on the ADI or MDI. The effect of Aquagro 2000[R] on the AWHC was not consistent across all root media. In general, the AWHC of the root media with a wetting agent application was similar to same root media without the wetting agent. However, for Baccto and the Baccto Rockwool Blend, the application of a wetting agent increased AWHC by 50%.

Discussion

There are 2 main properties of a root media that will determine how long similar size plants will go between irrigations. The first is the amount of water held in the root media after an irrigation and the second is the relative availability of the water to the plant.

The amount of water held in a root media is based on physical properties. The ideal container root media will contain only 10 to 15% solid. The remaining volume is occupied by pore space that contains either air or water (DeBoote and Verdonck, 1972). The ratio of air space to water is based on the particle size of the root media and the height of the container (Bilderback and Fonteno, 1987). The physical properties of an ideal peat based container root media in a 15 cm (6 inch) standard pot is reported to be 20% to 25% air space, 60% to 70% water, and the remaining 10% to 15% being solid (DeBoote and Verdonck, 1972). The average physical properties of the commercial root media tested indicate a lower water holding capacity and a greater percentage of air and solid space than the proposed ideal root media.

The amount of settling or shrinkage reduced the volume of the root media and thus the pore space. Based on results from Experiment 1, we concluded that the greatest amount of shrinkage occurred during production and may have occurred during the first irrigation. This observation is supported by other researchers (Blom and Piott, 1992). Averaged over all root media, the amount of settling that occurred between planting and the final harvest (28 weeks) was 0.9 liters (30 fl.oz.).

The average measured AWHC of the root media without the effect of the reservoir (1.7 liters (57 fl.oz.)) divided by the water holding capacity from the physical property data (59%) multiplied by the volume of the container (4.9 liters (166 fl.oz.)) minus the shrinkage (0.9 liters (30 fl.oz.)) is an estimate of the percent of water that was available to the plant. Using this method, 73% of the total calculated volume of water held in the root media was available to the plant. Fonteno and Nelson (1990) determined that the amount of available water held in 2 commercial root media was 80% of the total water held at container capacity. Either a lower percentage of the total water was available to the plant than is determined using laboratory methods or our normal irrigation was not sufficient to bring the root media up to container capacity. We concluded that the method used for irrigation in this experiment was not sufficient to rehydrate the root media to the same water holding capacity as when container capacity was determined in the laboratory.

Another factor that can influence the amount of available water held in a root media is how easily or efficiently water is absorbed by the root media. Water absorption efficiency can influence the amount of water that is required to be applied at an irrigation and can be illustrated with an example using two root media. When high volumes of water (1.8 - 2.0 times AWHC) were applied to both root media A and B , the amount of available water which remained in the root media was 1.8 liters (60 fl.oz.). When low volumes of water (1.0 - 1.2 times AWHC) were applied to the same root media , root media A held 1.5 liters (51 fl.oz.) of available water while root media B held 0.95 liters

(32 fl.oz.) of available water. Thus root media A was more efficient at absorbing water at low applied volumes of irrigation water.

The water absorption efficiency of the two root media may also be due to shrinkage that occurs during a drying cycle. As some root media dry, there is a tendency for shrinkage away from the sides of the growing container. The gap that forms may allow irrigation water to run down the sides of the container and leach out the bottom of the pot without rewetting the root media. This would give the perception that the basket was adequately watered when in fact very little of the applied water entered the root media. It may be necessary to apply high volumes of water to sufficiently rewet some root media.

During this experiment, high volumes of water were normally applied. In comparison, relatively low volumes of water were applied to the root media blends in Experiment 1. Perhaps this could explain why there was a large difference in the AWHC of the commercial root media (average 2.0 liters (69 fl.oz.) compared with the root media blends used in Experiment 1 (average 1.3 liters (44 fl.oz.)). With the exception of the Baccto Rockwool Blend, the difference between the highest and lowest AWHC of the commercial root media (0.5 liters (17 fl.oz.) was less than the difference found in Experiment 1 for blends of components mixed at MSU (0.8 liters (27 fl.oz.)).

The second property of a root media that determines how long similar size plants go between irrigation is the availability of the water or the moisture release characteristics of the root media. In a comparison of 2 of the root media, there was a 0.47 liter (16 fl.oz.) difference in the amount of available water but there was no difference in the ADI or MDI. Root media C held more water but this water may have been easily available to the plant and was used rapidly. Root media D held less water but it was less available to the plant so it was used more slowly by the plant. The result was that the time between irrigations was similar for both root media. The regulatory role of moisture availability and the plant must be considered when comparing root media.

When AWHC was determined in a low light environment for mature plants with thorough root penetration of the root media, the difference from the start of visible wilt to severe wilt was only 5% of the total amount of available water and may have been due in part to water lost from the impatiens foliage. Plants went through the 3 stages of wilt very quickly. This would indicate that the amount of readily available water held by the root media was large compared with the less available water. Other researchers have come to a similar conclusion (DeBoodt and Verdonck, 1972; Beardsell et al., 1979; Fonteno and Nelson, 1990). When visible wilt is observed in a plant grown in a peat-lite mix, there is very little less available water for the plant to use and permanent wilt will occur unless water is applied rapidly.

It is important to note that the baskets in these experiments were being grown inside a greenhouse. The question must be asked if these baskets were under similar conditions as those found outside. Impatiens baskets produced for Experiment 5 were placed outside under either full sun or partial shade (25% full sun). The plants outside used an average of 0.53 liters (18 fl.oz.) of water per day and went an average of 4.3 days between irrigation (June 3 - September 12). Plants used in Experiment 3 in the same root media (Suremix RW blend) used an average of 0.51 liters (18 fl.oz.) per day and went an average of 4.3 days between irrigations (June 6 - June 25). This would indicate that there was not a large difference in the two locations.

The greatest complaint consumers had with hanging baskets was keeping them adequately watered (Zehner and Krauskopf, 1991). Non of the plants grown in the commercial root media tested averaged less than 4 days between irrigation. Only LC1 and Suremix went a minimum of 2 days between watering. This would indicate that the root media being used in the baskets are not the problem. Perhaps the retailer/consumer is not applying a sufficient amount of water at each irrigation to get the full benefit of the root media's water holding capabilities.

Wetting Agent: Sphagnum peat is normally shipped as dry as possible to save on shipping cost. Most commercial root media companies place some type of wetting agent in the mix to assist in quick and uniform rewetting (Templeton 1987). Once the root media is in use, further applications of wetting agent are often not made, but are recommended to maintain the benefit of the wetting agent in the root media. In the directions for the use of Aquagro[R], multiple applications on a regular basis are recommended during production.

Perhaps in this experiment, a sufficient amount of wetting agent remained in the root media though the summer so that the root media rewet easily. In one reported experiment, only 30% of a wetting agent applied to peat had degraded after 280 days (Valoras et al, 1976). It is also possible that with the high volumes of water applied to the root media in this experiment, the additional rewettability of the root media with the wetting agent may not have been tested.

The effect of the wetting agent was dependent primarily on the type of peat used in the root media. In this experiment, the wetting agent had the greatest effect on the Baccto Rockwool Blend that contained a more degraded Michigan sphagnum peat with short fiber and a large amount of peat dust compared to long fibered Canadian sphagnum peats used in most of the other root media. We concluded that the need for additional wetting agent applications should be determined for each root media independently. The grower should use the method for determining the AWHC used in these experiments on baskets that are almost ready for ship.

Experiment Four: Effect of commercial production on the garden quality of flowering hanging baskets.

Introduction

This experiment was a continuation of Experiment 3 in that commercially available root media were evaluated for AWHC. Since the baskets evaluated came from 10 different commercial greenhouses, basket style, impatiens cultivar, and production method were also variables.

Materials and methods

Twenty five centimeter (10 inch) impatiens baskets were obtained from 10 different wholesale and retail commercial greenhouse growers throughout the state of Michigan between April 23 and May 14, 1991. The basket internal volume varied from 4.9 to 6.8 liters (1.3 to 1.8 gallons). Baskets were maintained inside a MSU greenhouse until May 30, at which time they were placed in the IEA. Water and fertilizer methods were the same as Experiment 3. On June 28, half the baskets were saturated with tap water containing the wetting agent Aquagro 2000^R at a rate of 1400 mg liter^{-1}. The remaining baskets were saturated with only tap water. On September 23, plants were sampled to determine shoot fresh weight.

Empty baskets were also collected from the different commercial growers to determine the volume of the different styles. Volume was determined by taping the drainage holes and filling the basket with water to the rim or 2 cm (0.8 in) below the rim. The volume of the reservoir was measured separately by filling until water drained from the basket.

Results

Root Media: Throughout the summer, there was a difference in the visual size of the grower produced plants (Figure 11). Shoot fresh weight at the end of the experiment ranged from 1.0 kg (2.2 lbs) to 2.2 kg (4.9 lbs).

Between May 30 and July 26, the average AWHC was 2.0 liters (67.6 fl.oz.) and ranged from 2.5 liters (84.5 fl.oz.) to 1.8 liters (60.8 fl.oz.). The ADI was 4.2 days and ranged from 5.9 days to 2.4 days. The MDI ranged from 1 to 3 days (Table 4).

Total basket volume was 4.8 liters (1.3 gallons) in 8 of the 10 baskets used by the commercial growers. The volume of the basket determined 2 cm (0.75 inches) below the rim was reduced by an average of 1 liter (0.26 gallons). Two growers used baskets with a volume of 6.4 liters (1.8 gallons) or 5.5 liters (1.5 gallons) respectively. The volume of these baskets determined 2 cm (0.75 inches) below the rim was 5.3 liters and 4.7 liters. The volume of the reservoir ranged from 0.70 liters (23 fl.oz.) to 0.06 liters (2 fl.oz.). In general, saucerless baskets had a 50% greater reservoir volumes than baskets with external saucer reservoirs.

Wetting agent: The application of Aquagro 2000^R had no effect on the final plant fresh weight compared with plants that received a tap water application. Wetting agent had no effect on the AWHC averaged over all root media. There was no effect on the ADI or MDI.

Discussion

Root media characteristics in this experiment were similar to Experiment 3. However, there were several other differences worth noting. There were extreme differences in the plant size of the baskets produced by commercial growers. These differences were due either to cultivar or cultural practices. Figure 11 illustrates impatiens baskets from 2 different commercial growers. In both cases, the plants would have been acceptable to the consumer. Both of the plants were grown in root media containing a peat/rockwool blend that held approximately 1.9 liters (64 fl.oz.) of available water. The larger plant used an average of 0.74 liters (25.0 fl.oz) of water per day between May 30 and June 27 in the IEA compared to an average of 0.36 liters (12.1 fl.oz.) per day for the smaller plants. The larger plants were watered twice as often as the smaller plants. It can be concluded large plants may be more susceptible to drying out and a smaller plant will require less maintenance during the first few weeks after sale.

The other difference in commercial baskets was basket style. When asked, many growers said that there was a difference in volume between the various styles of 25 cm (10 inch) hanging baskets but non had made any measurements. Eight of the 10 different basket styles collected had similar volumes. When the largest style basket was compared with the "standard" baskets using the same root media (Metro Mix 360; Experiment 3), the larger basket contained an extra 0.27 liters (9.1 fl.oz.) of available water. Between May 30 and June 27, the average plant used 0.49 liters (16.6 fl.oz.) of water per day. This means the larger basket might provide an extra half day between irrigations.

Smaller diameter baskets, 20 cm (8 inch) or even 15 cm (6 inch), are still sometimes sold by retailers. However, baskets that have diameters smaller than 25 cm (10 inch) may not be good investments for the consumer. The smaller the diameter, the less root media can be placed into the basket. In general, a 20 cm (8 inch) basket holds only 42% and a 15 cm (6 inch) basket holds 14% of the root media contained in a 25 cm (10 inch) basket (Potting guide, Michigan Peat Co., Houston TX). The less root media contained in a basket, the less available water and the greater frequency the plants may require water. Recent trends in Michigan appear to be for increasing availability of 30 cm (12 inch) baskets. These baskets have a volume of approximately 9 liters (2.3 gallons).

Wetting Agent: See wetting agent discussion in Experiment 3.

Experiment Five: Water and fertilizer requirements of six species at 2 outdoor light levels.

Introduction

The main source of information the consumer has about the cultural need of flowering hanging baskets comes from plant care tags (Zehner and Krauskopf, 1991). The information consumers want on the plant care tags are preferred plant location, watering, and fertilization instructions. Most consumers do consider the specific location where the hanging basket is to be placed before it is purchased.

Plant species and location may have an important effect on both the water and fertilizer requirements. In plants that are similar in size, increased transpiration rates are normally observed at higher light levels as long as water is not limiting. Stanhill and Albers (1974) found increased water loss by greenhouse roses with increase light levels.

It has also been reported that plants grown under higher light levels also require greater amounts of nitrogen fertilizer to maintain growth. Knight and Mitchell (1983) determined that the dry weight of lettuce grown at higher light levels was increased with higher concentrations of nitrogen fertilizer. Bunt (1988) reported that chrysanthemum grown in the summer require 80% more nitrogen fertilizer than chrysanthemums grown during the winter time. The difference was due in part to the greater dry weight accumulation of the chrysanthemums grown during the summer, presumably due to the higher light levels.

There is little or no published information about differences in water or fertilizer requirements of species used in hanging basket production. The objective of this experiment was to determine the water and fertilizer requirements of 6 different basket species grown at 2 different light levels.

Materials and Methods

Six different species (impatiens 'Accent White'; New Guinea impatiens 'Aglia'; ivy geranium; zonal geranium 'Pinto Red'; non-stop begonia 'Orange'; and fuchsia 'Marinka') were planted on March 7, 1991. The fuchsia, New Guinea impatiens and the non-stop begonias were rooted cuttings in 72 count cell flats and were planted 4 plants per basket. The ivy and zonal geranium transplants were in 9 cm (3.5 inch) standard pots and planted 3 per basket. The impatiens transplants were from 32 count cell bedding flats and were planted 3 per basket. Loose root media was removed from the larger transplants when possible before planting into the baskets. Nine baskets of each species were planted.

The basket was a 25.4 cm (10 inch) saucerless basket with a total volume of 4.9 liters (1.3 gallons) and an internal reservoir volume of 0.3 liters (10 fl.oz.). In this particular brand of basket, there was no root media capillary column to allow for direct contact with the water in the reservoir. The root media was a commercially available peat/rockwool/perlite mix (Suremix Rockwool Blend, Michigan Growers Products, Galesburg MI).

For the first 3 weeks, all the plants were watered without saturation with tap water. On March 15, each basket received 1 liter (34 fl.oz.) of fertilizer solution (Peters 20-10-20 peatlite, 300 mg liter^{-1}). While the plants were in the greenhouse, water or fertilizer solution was not applied in great enough quantities for leaching to occur. Water and fertilizer solution were treated with acid (0.5 mls H_2SO_4 per 3.8 liters (1.7 oz./100 gallon)) to reduce the alkalinity of the water to 80 mg liter^{-1} $CaCO_3$.

Six baskets from each species were moved to the OEA on June 3. For the high level light treatment, baskets were placed on the south side of the structure and the snow fence was removed from over the top of the row. For the low light level treatment, baskets were placed on the north side of the structure under a double layer of shade cloth which reduced light levels to 25% of full sun.

The method used to determine when to water was based on the weight of the pot at wilt. Plants were checked daily by lifting the baskets to determine if the pots were close to the wilt weight. At that point, tap water was applied with a hose and breaker until it began to drain from the basket. Fertilizer solution (Peters 20-20-20 Peatlite, 300 mg liter^{-1}) was applied to each species (3 baskets) within a light level treatment as needed. AWHC was measured by weighing at each irrigation to determine the amount of water and or fertilizer that remained in the root media. The ivy and zonal geraniums, begonias and fuchsia had dead flowers removed on a continuous basis while the plants were outside.

On August 29, thermocouples were inserted into the center of the root mass from a hole in the side of the basket. Temperatures from 4 different species in either full sun or partial shade were recorded along with ambient air temperature and light levels in full sun and partial shade. The species tested were impatiens, ivy and zonal geraniums and fuchsia. Data was recorded every 30 minutes, 24 hours a day for 10 days.

On September 17, the baskets were brought back into the greenhouse. They were maintained inside the greenhouse until October 16, at which time the plants were sampled to determine shoot fresh weight. Baskets were maintained inside the greenhouse for 4 weeks because we wanted the experiment to last until mid October and with the low

outdoor air temperatures after September 17, the plants could not survive outdoors. No WSF was applied during this time.

Results

Averaged over all species, the amount of water used per day was 0.56 liters (19 fl.oz.) in plants grown in full sun while in partial shade the plants used 0.51 liter (17 fl.oz.) of water per day. Between June 3 and September 17, plants grown in full sun averaged 4.0 days between irrigations while the plants grown in shade averaged 4.3 days. The difference in the amount of fertilizer applied to the baskets in the 2 locations was 0.48 grams N or 1.6 liters (54 fl.oz.) more fertilizer solution applied to the plants grown in full sun.

For the species tested, the greatest difference in water and fertilizer use occurred between the ivy geraniums and the non-stop begonia (Table 5). Between June 3 and September 17, water use ranged from 0.73 liters (25 fl.oz.) per day for the ivy geraniums to 0.22 liters (7 fl.oz.) per day for the non-stop begonias. The ivy geraniums averaged 2.8 days between irrigation while the non-stop begonia went 8.4 days between irrigation. The amount of N-fertilizer applied ranged from 8.2 grams N for the ivy geraniums to 4.3 grams N for the non-stop begonias.

The average temperature of the root media in the baskets averaged 21°C (70°F) in both full sun and partial shade between August 29 and September 7. The outside air temperature averaged 22°C (71°F) over the same time period. When the day and night temperatures were separated, the root media in the baskets averaged 1.4°C (2.5°F) lower than the average air temperature during the day and 1.1°C (2.0°F) higher than the average air temperature during the night. The temperature of the root media in the fuchsia basket in full sun averaged 3.1°C (5.7°F) higher during the day and 1.7°C (3.0°F) lower during the night compared with the root media of the other basket species. The highest media temperature recorded in the fuchsia was 42°C (108°F) while the highest temperature in any of the other species was 34°C (94°F).

Plants grown in full sun were visually smaller through most of the summer. However, by the end of the experiment, there was no difference in fresh weight from the different species from the 2 locations except for the non-stop begonias. Non-stop begonias grown in partial shade were 2 times greater in fresh weight compared with plants grown in full sun. New Guinea impatiens died due to stem rot prior to plant sampling.

Discussion

Plant tolerances: All six species performed well in partial shade (25% full sun) but did not perform equally well in full sun. The tolerance to growing in full sun ranged from no difference in the visual quality of plants in either full sun and partial shade (sun tolerant plants) to a reduction in overall plant size and chlorotic leaves compared to plants grown in partial shade (sun sensitive plants). Ivy and zonal geraniums were examples of sun tolerant plants and non-stop begonias were examples of sun sensitive plants. The tolerance to growing in full sun in decreasing order were ivy geranium = zonal geranium > fuchsia > New Guinea impatiens > impatiens > > > non-stop begonias.

Based on pictures and observations (Figure 12), the growth of sun sensitive plants was greater in partial shade during most of the summer. The leaf size of both sun sensitive and sun tolerant plants was reduced in plants grown in full sun compared to partial shade. However, there was no difference in shoot fresh weight between those baskets grown in full sun compared to the baskets grown under partial shade for impatiens, fuchsia, ivy geraniums, and zonal geraniums when the plants were harvested on October 16. There was a flush of new growth observed in all the plants during the end of August to the middle of September. Perhaps the optimal growth conditions had shifted from partial shade to full sun at this time allowing for a quicker growth rate of the sun sensitive plants in full sun.

Evapotranspiration rates are normally expected to be higher with higher light levels. Both water used per day and days between irrigation were not significantly different between light levels. The similarity in water use between the 2 light levels may have been due in part to the smaller physical size of the plants grown in full sun during much of the experiment. Fully expanded leaves from all species (except New Guinea impatiens) were sampled to determine leaf area on October 17. The average area per leaf was 30% less from plants grown in full sun compared with the same species grown in partial shade. The smaller physical size and smaller leaf area may have reduced the higher evapotranspiration rates of plants grown in full sun.

Fertilizer requirements: Plants grown in full sun did receive an additional amount of nitrogen fertilizer compared with the same species grown in partial shade. This additional amount of nitrogen fertilizer amounted to an application of 1.6 liters (52 fl.oz.) of the fertilizer solution or approximately one irrigation if converted into the concentration of WSF used in the experiment. Additional fertilizer requirements for plants grown in higher light are normally associated with an increase in shoot fresh and dry weight accumulation. Since the plants grown in this experiment were similar in fresh weight over the 2 locations, it could also be expected that fertilizer requirements would be similar.

Temperature: The average outside air temperature was a good indicator of the average root media temperatures over the short time it was measured. In general, the temperature fluctuations were much less in the root media compared with the air temperature.

The greater fluctuation in root media temperature in the fuchsia baskets may have been due to the open leaf canopy habit of this species. The leaf canopy of all the other species covered the top of the root media. The shading effect of the leaves would have kept the day temperature of the root media lower during the day. At night, the leaves would have reduced the radiant heat loss.

Experiment Six: Effect of 2 resin coated fertilizers on the production and garden quality of six flowering hanging basket species.

Introduction

Currently, there are 2 main sources of RCF for the greenhouse industry: Sierra^R Controlled Release Nutrients (CRN) or Osmocote^R, and Nutricote^R. One of the largest differences between the products manufactured by the 2 companies is the average release temperature. For Sierra CRN/Osmocote^R materials, the rate of release is based on an average temperature of 21°C (70°F) (Rutten, 1980). For Nutricote^R materials, the rate of release is based on an average temperature of 25°C (77°F) (Shibata et al., 1979).

Another difference between the Sierra^R and Nutricote^R materials are in the resin coating used to control the release rate of the fertilizer salts. The release rate of Sierra/Osmocote^R products are altered by changing the number of coatings of resin. It has been reported that imperfections in the coating may allow for 10 to 20% of the fertilizer to be released in the first week after incorporation (Harbaugh and Wilfret, 1982). The release rate of Nutricote^R products are dependent on a property of the resin coating. The release characteristics are reported to have a gradual initial release rate (Shibata et al., 1979).

In Experiment 1, the low recommended rate of incorporation for Osmocote^R (13-13-13, 8-9 month) was not sufficient to keep impatiens actively growing over a six month period. It was concluded that higher levels RCF must be incorporated prior to planting to maintain nutrient levels through the 4 to 5 months of the summer.

Current recommendations for the incorporation of these 2 products prior to planting do not differentiate between different species used for flowering hanging basket production. The highest rate of incorporation is normally recommended for these "greenhouse crops". For Nutricote[R] with a release rate based on 140 days, the rate recommended is 7.1 kg m^{-3} (12 lb yd^{-3}) and for Sierra CRN[R] with a release rate based on 8-9 months, the recommended rate is 7.7 kg m^{-3} (13 lb yd^{-3}).

Materials and Methods

The 2 types of RCF tested were Sierra[R] CRN 17-6-10 plus minors, 8-9 month release rate (Grace/Sierra, Fogelsville, PA) and Nutricote[R] 18-6-8 plus minors, type 140 (Plantco Inc., Brampton, Ontario). The rates of incorporation were: 5.0, 5.9, 6.8, 7.7 kg m^{-3} for Sierra CRN[R] (8.5, 10, 11.5, 13 lb yd^{-3}) and 3.6, 4.7, 5.9, 7.1 kg m^{-3} for Nutricote[R] (6, 8, 10, 12 lb yd^{-3}). The experiment consisted of 8 fertilizer treatments and 6 species for a total of 48 baskets. There was no true experimental replication since replication of the different fertilizer treatments was made across species.

The root media and fertilization for each basket were individually placed into a 0.03 m^3 (1 ft^3) batch mixer and mixed for 1 minute. The baskets were refilled and planted with one of the same 6 species from Experiment 5. This time consuming method of mixing was used to guarantee exact fertilizer rate. No additional fertilizer was applied to the plants for the remainder of the experiment. Plants were watered in without leaching.

Between March 15 and June 3, all the baskets were leached heavily 3 times to reduce high soluble salts. The reason for leaching was the severely stunted appearance of the New Guinea impatiens and non-stop begonias. Root and stem rot severely affected the non-stop begonias so that this species was dropped from the experiment. After leaching, a combination of Subdue - 15 mls per 380 liters (100 gallons) and Benlate - 0.9 kg per 380 liters (2 lbs/100 gallons) was applied to control root rot. No other leaching occurred while the plants were in the greenhouse.

The baskets were moved to the OEA on June 4, 1991. Plants were maintained and irrigated with the same method used in Experiment 5 except that AWHC was not determined at each irrigation.

On September 17, the baskets were brought back into the greenhouse. They were maintained inside the greenhouse until October 14, at which time shoot fresh weight was determined. Root media samples were collected to determine final pH (1:1 (v:v)) and EC (2:1 (v:v)). Baskets were maintained inside the greenhouse for 4 weeks because we wanted the experiment to last until mid October and with the low outdoor air temperatures after September 17, the plants could not survive outdoors.

Results

During production, the effect of the different fertilizers was both species dependent and brand dependent (Figure 13). There was no difference in the visual quality of the ivy or zonal geraniums at the different incorporation rates and for either fertilizer. The growth of the New Guinea impatiens and non-stop begonias were stunted at the higher incorporation rates of both products. At the low incorporation rates, plants grown in root media containing the Nutricote[R] showed no signs of stunting. Plants grown in root media containing Sierra CRN[R] were stunted with downward curling leaves.

There was a shift in the effect of the different fertilizer treatments outside. By 19 weeks after planting (7 weeks outside), there was no difference in the visual quality of the New Guinea impatiens or zonal geraniums at any of the 4 rates or between the 2 products. The fuchsia were still stunted at the high rates of incorporation of both products. Impatiens and ivy geraniums were showing signs of low nutrition at the low incorporation rate of Nutricote[R].

By 24 weeks after planting (12 weeks outside), impatiens and zonal geraniums were chlorotic with all RCF treatments. Ivy geraniums and fuchsia were showing low nutrition at the 2 lowest rates in Nutricote[R] and the lowest rate of Sierra CRN[R]. Stem rot was observed in the New Guinea impatiens. By the time the plants were brought inside the greenhouse at the end of the experiment, all the New Guinea impatiens had died.

The average pH measured in the root media at the end of the experiment or 8 months after planting was 8.3 for the Sierra CRN[R] fertilizer and 8.2 for the Nutricote[R] fertilizer. Similar pH levels were measured over the different incorporation rates for each product. Soluble salt levels measured with the 2:1 (v:v) testing method in the same sample was 0.38 mS cm^{-1} for the Sierra CRN[R] fertilizer and 0.37 mS cm^{-1} for the Nutricote[R] fertilizer. The range of EC levels for the different RCF over the incorporation rates were 0.32 to 0.43 mS cm^{-1} in the Sierra CRN[R] and 0.34 to 0.40 mS cm^{-1} for the Nutricote[R].

Table 6 is a comparison of the shoot fresh weight from the largest treatment fertilized with incorporated RCF (Sierra CRN[R] at 7.7 kg m^{-3} (13 lbs yd^{-3}) from this experiment compared with the fresh weight of the average plant fertilized with WSF (Experiment 5). The difference in the fresh weight ranged from 1.4 to 2.4 times greater in plants fertilized with WSF.

Greater amounts of N-fertilizer were applied to different species used in Experiment 5 receiving WSF compared to highest rate of either Sierra CRN[R] (6.2 g N) or Nutricote[R] (6.1 g N) and ranged from 6.8 g N for the zonal geraniums to 8.7 g N for the ivy geraniums. The equivalent amount Sierra CRN[R] containing 17% N ranged from

8.4 to 10.8 kg m^{-3} (14.2 to 18.1 lbs yd^{-3}). The equivalent amount of Nutricote[R] containing 18% N ranged from 7.9 to 10.2 kg m^{-3} (13.4 to 17.2 lbs yd^{-3}).

Discussion

From results of this experiment, we concluded that the species tolerance of high root media nutrient levels due to the increasing rates of incorporation of RCF varied dramatically. At one extreme were the fertilizer tolerant plants, ivy and zonal geraniums. Increasing levels of fertilizer did not effect early growth. At the other extreme were the fertilizer sensitive plants, New Guinea impatiens and non-stop begonias. At the high rates of incorporation, both species had stunted shoot growth with leaves curling downwards which is an indication of high soluble salts. Fuchsia and impatiens were moderately tolerant of high root media nutrient levels.

For the fertilizer sensitive plants, the degree of stunting was also brand dependent. New Guinea impatiens grown in root media containing Sierra CRN[R] were stunted at all incorporation rates. This stunting may have been due to the high initial release of fertilizer salts that is reported for Sierra[R] products (Harbaugh and Wilfret, 1982). New Guinea impatiens grown in root media containing Nutricote[R] were stunted at the two high incorporation rates but grew normally at the two low incorporation rates. However, a direct comparison between the 2 products is difficult since the low rates of incorporation of the 2 products was not similar.

The rate at which the fertilizer salts are released for both types of fertilizer is solely dependent on temperature (Shibata et al., 1979; Rutten, 1979). The release rate is based on an average temperature of 21°C (70°F) for Sierra CRN[R] and 25°C (77°F) for Nutricote[R]. For every increase of 5°C, there is a 25% increase in the rate of release for both these products. During April and May of 1991, there were periods of 90°F (32°C) temperatures inside the greenhouse which may have caused excessive release of fertilizer salts. Most of the baskets produced in Michigan are scheduled for a late April ship date. The baskets produced at MSU in 1991 were scheduled to be placed outside on June 1. The later in the season, the higher temperatures that can be expected inside the greenhouse which may have contributed to the high fertilizer salt problem.

When high fertilizer salts become a problem, leaching with clear water is the normal recommendation. However, for many greenhouse bedding plant operations, leaching is not an option. Many commercial operations place hanging baskets directly over bedding flats. If baskets are leached, flats may be overwatered, washed out, or fertilized excessively by the leachate from the baskets.

When the fertilizer was applied may be as important as how much fertilizer was applied. From Experiment 5, New Guinea impatiens and zonal geraniums required similar amounts of nitrogen fertilizer between March 7 and September 17. However, New Guinea impatiens go through a period after planting when no new foliar growth is observed and appear to be sensitive to high root media nutrient levels at this time. Konjonian (1991) recommends waiting for 1 or 2 weeks before applying the first WSF and other growers wait until the plants begin to actively grow or roots reach the outside of the soil mass.

Zonal geraniums are normally much larger with a more developed root system early in production and may start growing almost immediately after planting. Zonal geraniums appear to be tolerant of high nutrient levels early after planting. Perhaps the time difference as to when active growth is observed could account for the differences in early fertilizer sensitivity between New Guinea impatiens and zonal geraniums.

Once the baskets were placed outside, leaching occurred and the stunted New Guinea impatiens began to grow. Perhaps lower temperatures outside also reduced the amount of fertilizer salts being released. By the beginning of August (19 weeks after planting), there was no visual difference in the quality of the baskets at any incorporation rate except for the lower rate of Nutricote[R] in the New Guinea impatiens.

At the end of August, increased growth was observed in the plants fertilized with WSF (Experiment 5). During this same period of time, symptoms of low nutrition were observed in all RCF incorporation rates. Plants fertilized with WSF were on average 2 times larger than the largest plant fertilized with RCF. This could have been due, in part, to the stunting observed during the production part of Experiment 6. However, from the middle of August until the plants were brought inside the greenhouse in September, plants fertilized with RCF decreased in quality. The baskets were beyond the release time for the Nutricote[R] (20 weeks at 77°F (25°F)) but was still within the release time for the Sierra[R] (32-36 weeks at 70°F (21°C)). The average temperature of the root media may have decreased below that needed for the projected release rate. Between August 22 and September 3, the average outside air temperature was 71°F (22°C) but temperature data was not available after September 3.

Finally, only 80% of the salts are expected to be released over the predicted time period. Therefore, only the amount of nitrogen from 80% of the incorporated RCF can be compared to the amount of nitrogen applied to the same plants fertilized with WSF. There was no practical way to determine the amount of fertilizer that was still left in the RCF.

Experiment Seven: Surface application of resin coated fertilizer as a method of improving the garden performance.

Introduction

RCF can be applied to the surface of the root media at any time during the growing period or at shipping. Surface application or top dressing could also be a method of fertilization that a retailer could apply to a flowering hanging basket prior to being sold to a consumer. Another possibility is that a small package of RCF could be sold along with the hanging basket for the customer to apply to the basket.

Materials and Methods

Twenty five centimeter (10 inch) impatiens baskets were obtained from 2 producers in the state of Michigan between May 1 and May 7, 1991. Two liters of fertilizer solution (Peters 20-10-20 peatlite, 300 mg liter^{-1}) were applied to each basket to maintain quality. Water was applied at all other times at visible wilt.

On June 5, RCF treatments were applied to the baskets as they were moved to the OEA. Treatments consisted of 1) No fertilizer, 2) WSF, 3) 12 g (2 tsp) RCF "top dressed", 4) 18 g (3 tsp) RCF "top dressed", 5) 24 g (4 tsp) RCF "top dressed", 6) 2 RCF plugs (15 g) and 7) 3 RCF plugs (22.5 g). The WSF used was Peters 20-20-20 Peatlite at a concentration of 300 mg liter^{-1} applied as needed. The "top dressed" RCF was Sierra^{R} 17-6-10 plus minors with a release rate of 8-9 months. The RCF plug was Sierra Tablets^{R} 16-8-12 plus minors with a release rate of 8-9 months (Grace/Sierra, Fogelsville, PA). Plants were checked daily and irrigated at visible wilt. Between September 17 and October 20, all the baskets were watered with tap water. On October 20, plants were sampled to determine fresh weight. Soil samples were collected to determine root media pH and EC.

Results

Plants with no additional applied fertilizer quickly decreased in quality and after 2 weeks were noticeably chlorotic with a decreased number of blooms. After 7 weeks, the low rate of RCF became noticeably chlorotic. After 12 weeks, the medium rate of RCF and the 2 RCF plugs became chlorotic. Plants fertilized with the highest rates of RCF continued to flower and grow normally until the end of August (Figure 14). At the end of August, all plants fertilized with RCF began to show symptoms of leaf chlorosis and abscission.

At the end of the experiment, plants grown with RCF were of smaller size and lower visual quality compared with plants fertilized with WSF. Averaged over the plants from both growers, the fresh weight of the plants fertilized with RCF ranged from 800 g (1.7 lb) from plants fertilized with 12 g (2 tsp) RCF to 1000 g (2.2 lb) from plants fertilized with 3 RCF tablets (data not shown). Plants fertilized with WSF had an average fresh weight of 1480 g (3.3 lb) or were 50% larger than the largest plant fertilized with RCF.

Discussion

Decline in quality was related to the amount of fertilizer applied. The greater the amount of RCF applied initially, the longer the period of active growth. As with Experiment #6, plants that were fertilized with RCF were not able to sustain the flush of growth at the end of the summer even at the high top dressed rate. If RCF is applied to a basket, consumers may need to apply WSF once or twice at the end of the summer to maintain adequate nutrient levels in the root media for the new growth. An alternative may be to provide a RCF with a delayed release pattern.

Summary of All Experiments

An increase in AWHC increased the time between irrigations when a single component was mixed with one type of canadian sphagnum peat. The AWHC of the 60% peat/40% component blends in decreasing order were rockwool > #2 vermiculite > perlite > polystyrene. The peat/rockwool blend had the greatest AWHC and the plants grown in the peat/rockwool blend went the greatest length of time between irrigations.

Water absorbent gel or zeolite did not effect the AWHC of the root media. The water absorbent gel Supersorb C[R] increased the ADI by 25% or 1 day compared to the same root media without gel but did not effect the MDI. In a laboratory experiment, the hydration of the gel decreased as soluble salts increased. The decrease in the hydration of the gel was greatest when calcium and magnesium were present. The incorporation of zeolite at 30 kg m^{-3} (50 lbs yd^{-3}) had no effect on the amount of fertilizer applied or plant growth but did increase the ADI by 1 day over plants grown in the same root media without zeolite. A wetting agent increased the amount of water held in 100% peat by 17% but did not increase the AWHC of commercial root media under the conditions of the tests. This may have been an effect of how the baskets were watered or from the fact that commercial root media were already treated with a wetting agent.

There was a difference in the AWHC of impatiens baskets produced in commercial root media ranging from 1.5 to 2.3 liters (51 to 77 fl.oz.). However, there was little difference in the average time between watering. We concluded that this was due, in part, to the way the water was released by the root media to the plant. The greatest difference in commercially produced impatiens baskets was in the size of the plant. The range in the daily water use of the largest and smallest plant was 0.32 to 0.75 liters (11 to 22 fl.oz) of water per day. In general, the larger the plant in a hanging basket, the more water that plant used per day. Another difference was in the volume of the 10-inch baskets. The majority of 10-inch baskets used had a volume of 4.9 liters (1.3 gallons). Only 2 commercial growers used 10-inch baskets with larger volumes. The greatest volume for a 10-inch basket was 6.8 liters (1.8 gallons). The greater root media volume in the 6.8 liter (1.8 gallon) basket increased the AWHC of Metro Mix by 25%.

Based on comparisons of water soluble fertilizer (WSF) or resin coated fertilizer (RCF) either incorporated prior to planting or surface applied at some later time, we concluded that incorporated levels of RCF that produce the largest growth in the greenhouse are not sufficient for active growth outside during the summer. At high levels of incorporated RCF, the growth of some species such as New Guinea impatiens were stunted due to high soluble salts. Other species such as ivy geraniums showed no sign of stress at these same high incorporation rates.

Most commercial root media have a starting nutrient charge roughly equal to 0.6 kg (1 lb) $Ca(NO_3)_2$, 0.6 kg (1 lb) KNO_3, and 1.2 kg (2 lbs) 0-20-0 per cubic meter (yd^{-3}) plus some form of trace elements. This starting charge is equivalent to approximately 0.78 grams N per basket. This is a sufficient amount of fertilizer to keep a mature basket growing for a minimum of 2 weeks. This should be a sufficient amount of fertilizer for 2 to 4 weeks with a newly planted rooted cutting or seedling if no leaching occurs. From Experiment 5, we concluded that an additional 1.5 grams N would be required to produce a salable plant in a basket over 12 - 14 weeks. The majority of nitrogen fertilizer (5 to 6 grams N) is required after production.

If RCF were to be specifically designed for basket production, the duration of release would be approximately 7 to 8 month duration. The RCF should have very little release during the first 2 week of production. After the initial 2 week period, 1.5 grams N would release over 10 weeks. After production, 5 - 6 grams N would release over a 20 week period for a total release of 6.5 - 7.5 grams N. More nutrients should be released later in the summer when the temperatures are lower and plant growth is increased. If this fertilizer were 20% nitrogen and 80% of the fertilizer salts were to be released over the specified time period, 8.6 - 9.8 kg m^{-3} (14.5 - 16.5 lbs yd^{-3}) of the fertilizer would need to be incorporated prior to planting.

The main hanging basket species grown are fuchsia, ivy and zonal geranium, impatiens, New Guinea impatiens and non-stop begonias. All the species tested grew well in partial shade (25% full). There was a difference in how the species grew in full sun ranging from sun tolerant plants, such as ivy geraniums, that grew equally well in full sun and partial shade to sun sensitive plants, such as impatiens, that were visually smaller and chlorotic during most of the summer compared to the impatiens grown in partial shade. Non-stop begonias grown in full sun were severally stunted and therefore we conclude that they should not be grown in full sun. When the plants were harvested, there was no difference in shoot fresh weight between the 2 light locations except for the Non-stop begonias. However, since only one cultivar of each species was tested, more cultural testing in full sun and shade should be completed before categories such as these are widely applied.

There was not a significant difference in the amount of water used per day by the different species in full sun compared to partial shade. The water use of the species ranged from 0.74 liters (25 fl.oz.) per day for the ivy geranium to 0.21 liters (7 fl.oz.) per day for the non-stop begonia. There was difference in the amount of fertilizer applied to species in the different light levels was less than the amount of fertilizer applied at 1 normal fertilization. However, the difference between the species ranged from 8.2 grams N for the ivy geraniums to 4.3 grams N for the non-stop begonias.

Main Conclusion

Flowering plants in hanging baskets produced under generally accepted management practices lasted through the summer and continued to flower and actively grow. The best methods of improving garden performance of flowering hanging baskets is to continue good production practices and to educate the consumer about how to maintain hanging baskets through the summer. Recommendations for the hanging basket producer are presented in Appendix A. Information generated to help educate the consumer based on this research is presented in Appendix B.

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Table 1. Commercial root media used in Experiment 3.

Root media	Components
Baccto	Michigan sphagnum peat, perlite, #3 vermiculite
Baccto Rockwool Blend	Michigan sphagnum peat, Bacctite, rockwool
LC1	Canadian sphagnum peat, perlite
Metro Mix 360	Canadian sphagnum peat, #3 vermiculite, bark ash, sand
OPM #8	Canadian sphagnum peat, rockwool, perlite
Peatwool	Canadian sphagnum peat, rockwool
Postharvest Mix	Canadian sphagnum peat, perlite, gel, calcined clay
Pro-Mix BX	Canadian sphagnum peat, perlite, #3 vermiculite
Suremix	Canadian sphagnum peat, polystyrene, #3 vermiculite
Suremix Rockwool Blend	Canadian sphagnum peat, rockwool, #3 vermiculite, perlite

Table 2. Available water holding capacity (AWHC), average days between irrigation (ADI) and minimum days between irrigation (MDI) of 10 commercial root media in Experiment 3 between May 10 and June 6. Root media are listed in alphabetical order. Value takes into account the water reservoir in the basket.

root media	AWHC liters (fl.oz.)	ADI	MDI
Baccto	1.80 (61)	4.7	3.0
Baccto Rockwool Blend	1.51 (51)	6.3	4.0
LC1	1.89 (64)	4.5	2.0
Metro Mix 360	2.13 (72)	4.8	3.0
OPM #8	1.95 (66)	4.9	4.0
Peatwool	2.10 (71)	6.3	4.0
Postharvest Mix	2.04 (69)	4.6	3.0
Pro-Mix BX	2.28 (77)	4.7	3.0
Suremix	1.86 (63)	4.3	2.0
Suremix Rockwool Blend	2.16 (73)	5.0	4.0
Average	1.98 (67)	5.0	3.2
LSD[z]	0.13 (4.4)	0.7	1.0

[z]Least significant difference between any two means that in different at a 95% level of confidence statistically.

Table 3. Percent air space, total water space, and solid for ten commercial root media in a 15 cm (6 inch) standard pot. Each value is the mean of 3 determinations completed at different times. Root media are listed in alphabetical order. Values are the percent of the total volume of the pot (volume 1.7 liters (57 fl.oz.)).

root media	% air	% total water	% solid
Baccto	16	55	29
Baccto Rockwool Blend	18	61	21
LC1	21	55	24
Metro Mix 360	20	63	18
OPM #8	25	53	23
Peatwool	24	62	14
Postharvest Mix	22	64	14
Pro-Mix BX	21	57	22
Suremix	17	54	29
Suremix Rockwool Blend	22	59	19
Average	21%	58%	21%
LSD[z]	4%	4%	4%

[z]Least significant difference between any two means that in different at a 95% level of confidence statistically.

Table 4. Available water holding capacity (AWHC), average days between irrigation (ADI) and minimum days between irrigation (MDI) of impatiens hanging baskets from 10 commercial growers in Experiment 4 between May 30 and June 27. ADI and MDI are an average from 6 baskets. Growers were arbitrarily numbered 1 - 10.

grower	Basket Volume liters (gallons)	AWHC liters (fl.oz.)	ADI	MDI
1	4.8 (1.3)	1.86 (63)	5.1	4.0
2	4.8 (1.3)	2.00 (68)	4.7	4.0
3	4.8 (1.3)	1.84 (62)	3.9	2.8
4	6.4 (1.8)	2.75 (93)	4.0	3.0
5	4.8 (1.3)	1.89 (64)	2.5	1.7
6	4.8 (1.3)	1.81 (61)	4.0	3.2
7	4.8 (1.3)	2.01 (68)	4.0	3.2
8	5.5 (1.5)	2.49 (84)	4.6	3.0
9	4.8 (1.3)	2.19 (74)	5.8	4.5
10	4.8 (1.3)	2.10 (71)	3.7	2.7
Average		2.09 (71)	4.2	3.2
LSD		0.19 (7)	0.8	1.1

[z]Least significant difference between any two means that in different at a 95% level of confidence statistically.

Table 5. Shoot fresh weight taken October, 16, 1991 or 8 months after planting in Experiment 5. Applied nitrogen in the total amount applied over the 8 months of the experiment. Average days between irrigation (ADI) and amount of water used per day are both calculated from the data collected between June 3 and September 12 or the period of time the baskets were outside.

Full sun	Shoot Fresh Weight (g)	Nitrogen-N Applied (g)	ADI	Water Use per Day (liters (fl.oz.))
Fuchsia	517	7.08	3.0	0.64 (22)
Ivy Geranium	1516	9.19	2.8	0.73 (25)
Impatiens	1387	7.46	3.6	0.59 (20)
N.G. Impatiens	NA[z]	6.67	3.3	0.56 (19)
N.S. Begonia	672	4.78	8.4	0.24 (8)
Zonal Geranium	888	7.33	3.2	0.60 (20)
Average		7.09	4.0	0.56 (19)
Partial Shade (25% full sun)				
Fuchsia	505	6.68	3.3	0.58 (20)
Ivy Geranium	1526	8.10	3.1	0.70 (23)
Impatiens	1488	7.38	4.3	0.48 (16)
N.G. Impatiens	NA	6.42	3.3	0.61 (20)
N.S. Begonia	1260	4.61	8.2	0.22 (7)
Zonal Geranium	823	6.17	3.7	0.49 (16)
Average		6.56	4.3	0.51 (17)
LSD[y]		1.02	0.8	0.10 (3.5)
Species		***	***	***
Light		*	*	NS
Species*Light		NS	NS	NS

[z]NA (not available). New Guinea impatiens died prior to fresh weights being recorded.
[y]Least significant difference between any two means that in different at a 95% level of confidence statistically.

Table 6. Comparison of the average shoot fresh weight of plants fertilized with water soluble fertilizer from Experiment 5 and the shoot fresh weight of the largest plant from the different RCF treatments in Experiment 6. Applied N from WSF is the average amount of fertilizer applied to both light treatments from Experiment 5. Equivalent amounts of Sierra CRN® and Nutricote® are calculated using 17% N and 18% N respectively and assume 100% release rate. Recommended incorporation rates for Sierra CRN® is 7.7 kg m^{-3} (13 lb yd^{-3}) and for Nutricote® is 7.1 kg m^{-3} (12 lb yd^{-3}).

species	Shoot Fresh weight WSF plants (g)	Shoot Fresh weight RCF plant (g)	Applied grams N from WSF (20-20-20)	equivalent Sierra CRN® kg m^{-3} (lb yd^{-3})	equivalent Nutricote® kg m^{-3} (lb yd^{-3})
Fuchsia	511	253	6.88	8.6 (14.5)	8.1 (13.7)
Ivy geranium	1521	699	8.65	10.7 (18.1)	10.2 (17.2)
Impatiens	1438	1013	7.42	9.3 (15.6)	8.7 (14.7)
Zonal Geranium	855	357	6.75	8.4 (14.2)	7.9 (13.4)

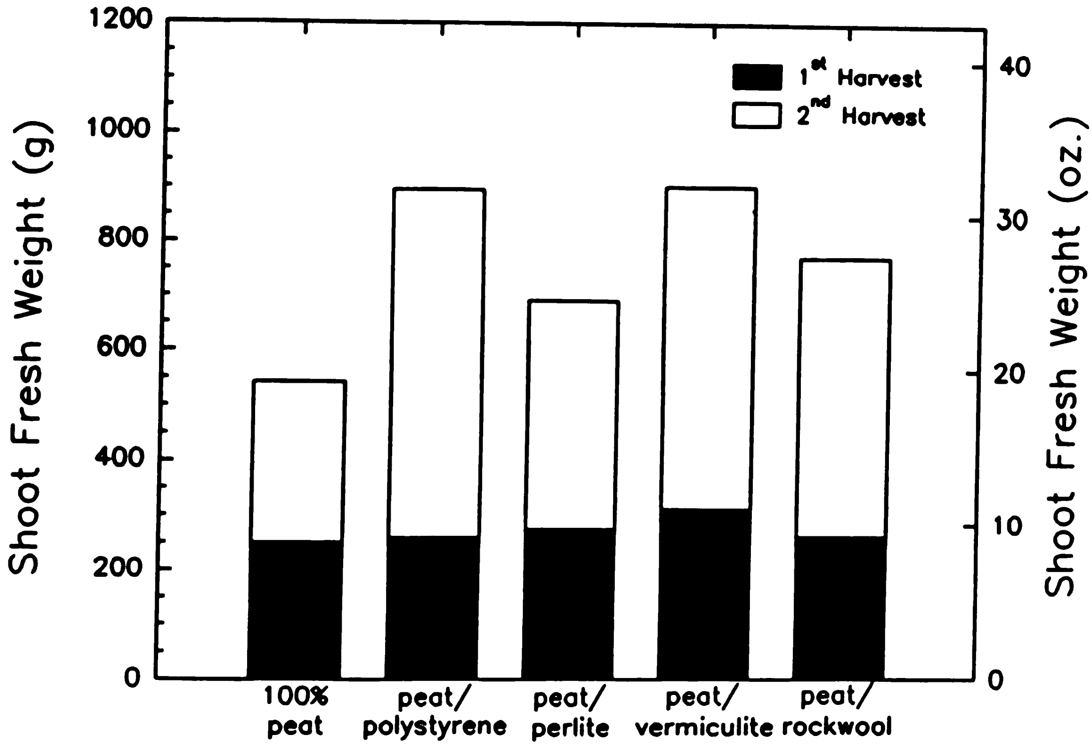


Figure 1. Shoot fresh weight from Experiment 1. Component blends were 60% sphagnum peat and 40% component by volume. The 1st harvest was the end of the production phase (June 20) and the 2nd harvest was the end of the garden quality phase (September 20).

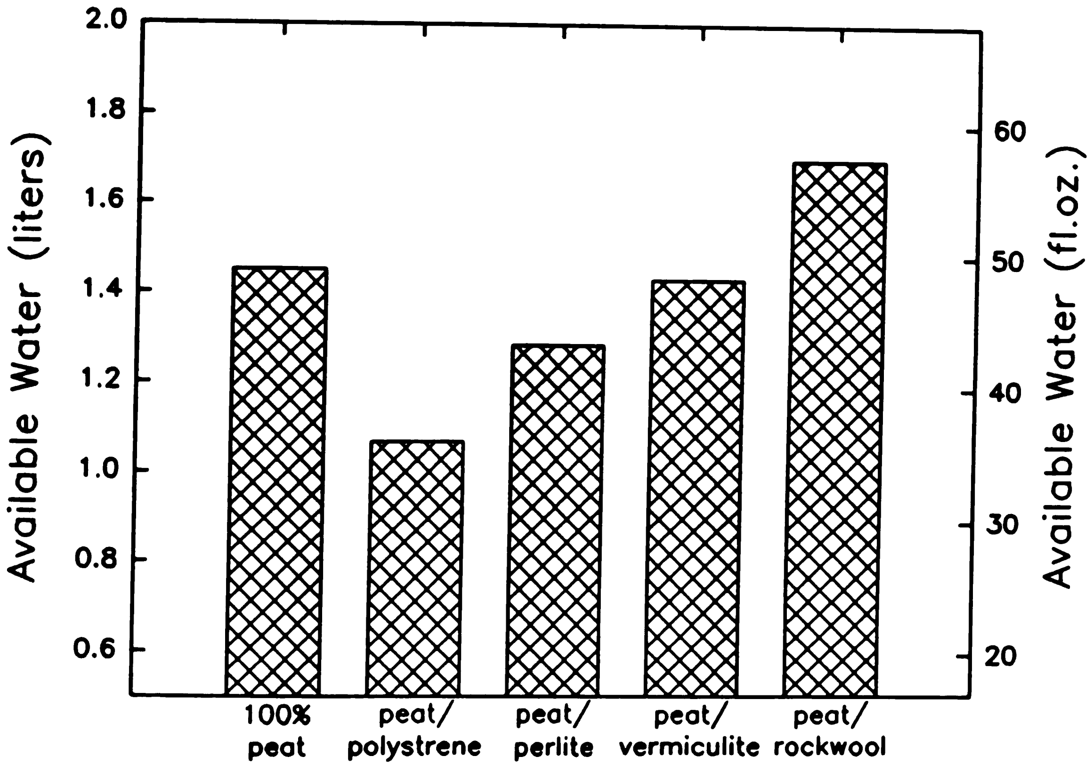


Figure 2. Average available water holding capacity (AWHC) of the base root media during the garden quality phase (June 21 to September 5) in Experiment 1.

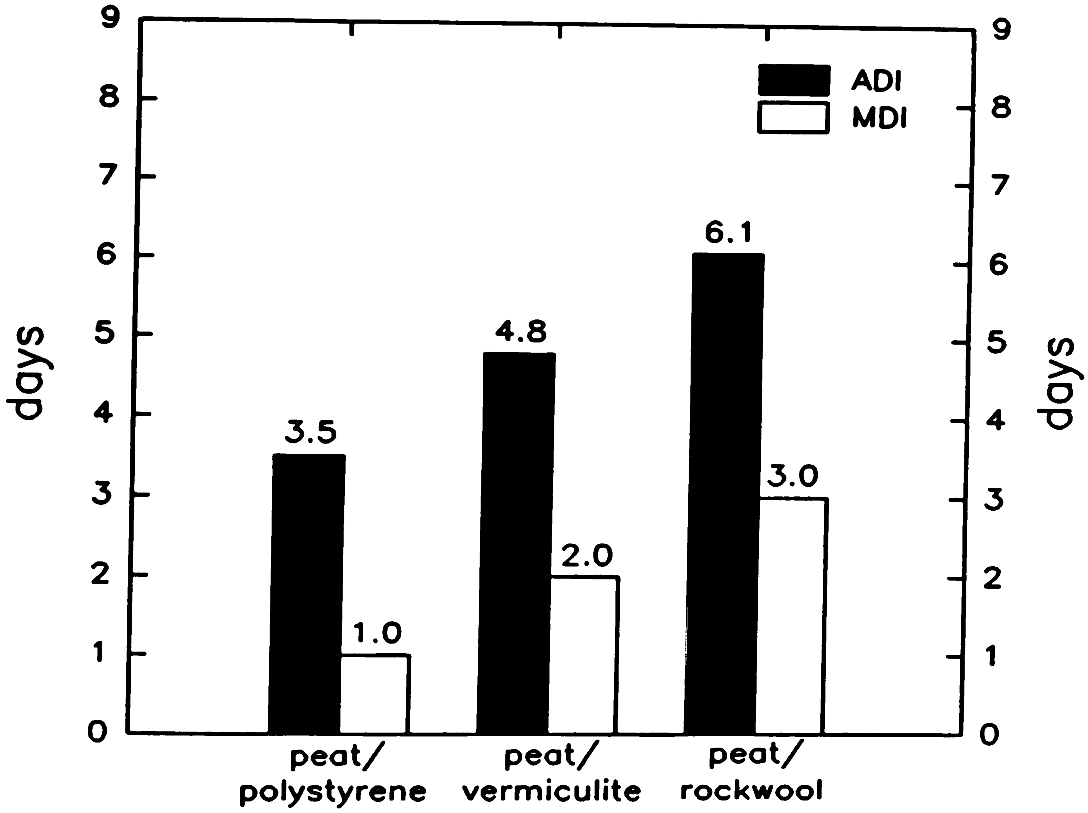


Figure 3. Average days between irrigations (ADI) and minimum days between irrigation (MDI) for plants of similar size determined during the garden quality phase in Experiment 1.

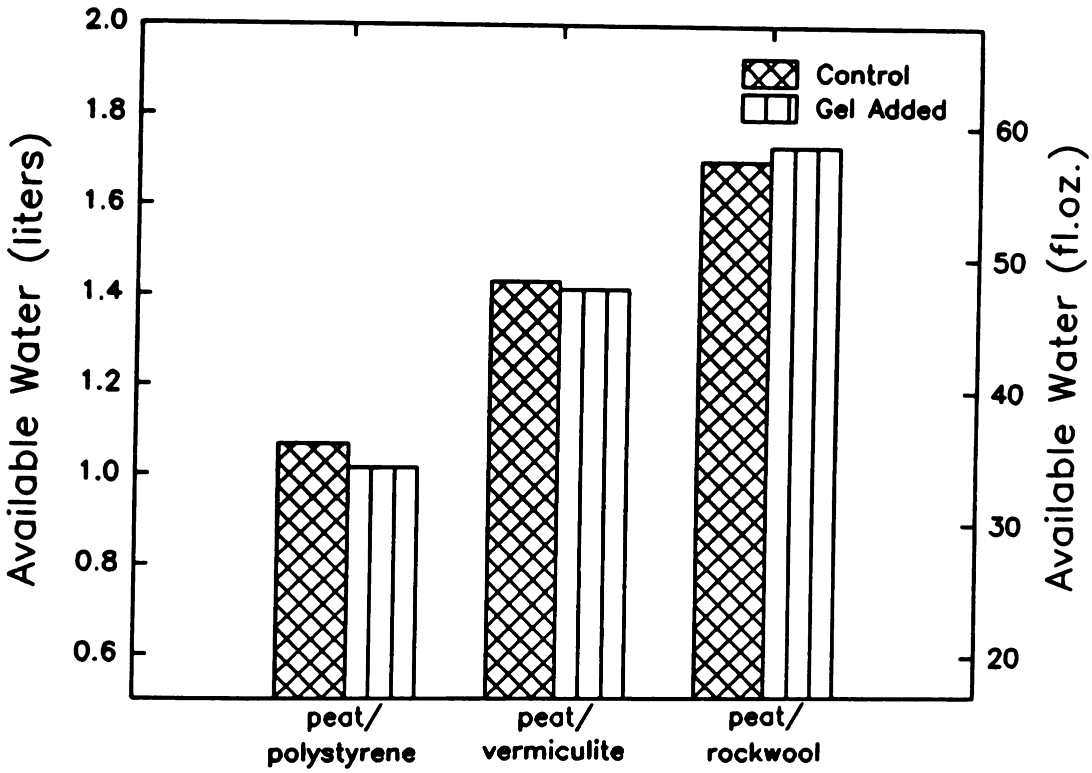


Figure 4. Effect of Supersorb C[R] on the AWHC of three sphagnum peat and component blends during the garden quality phase of Experiment 1.

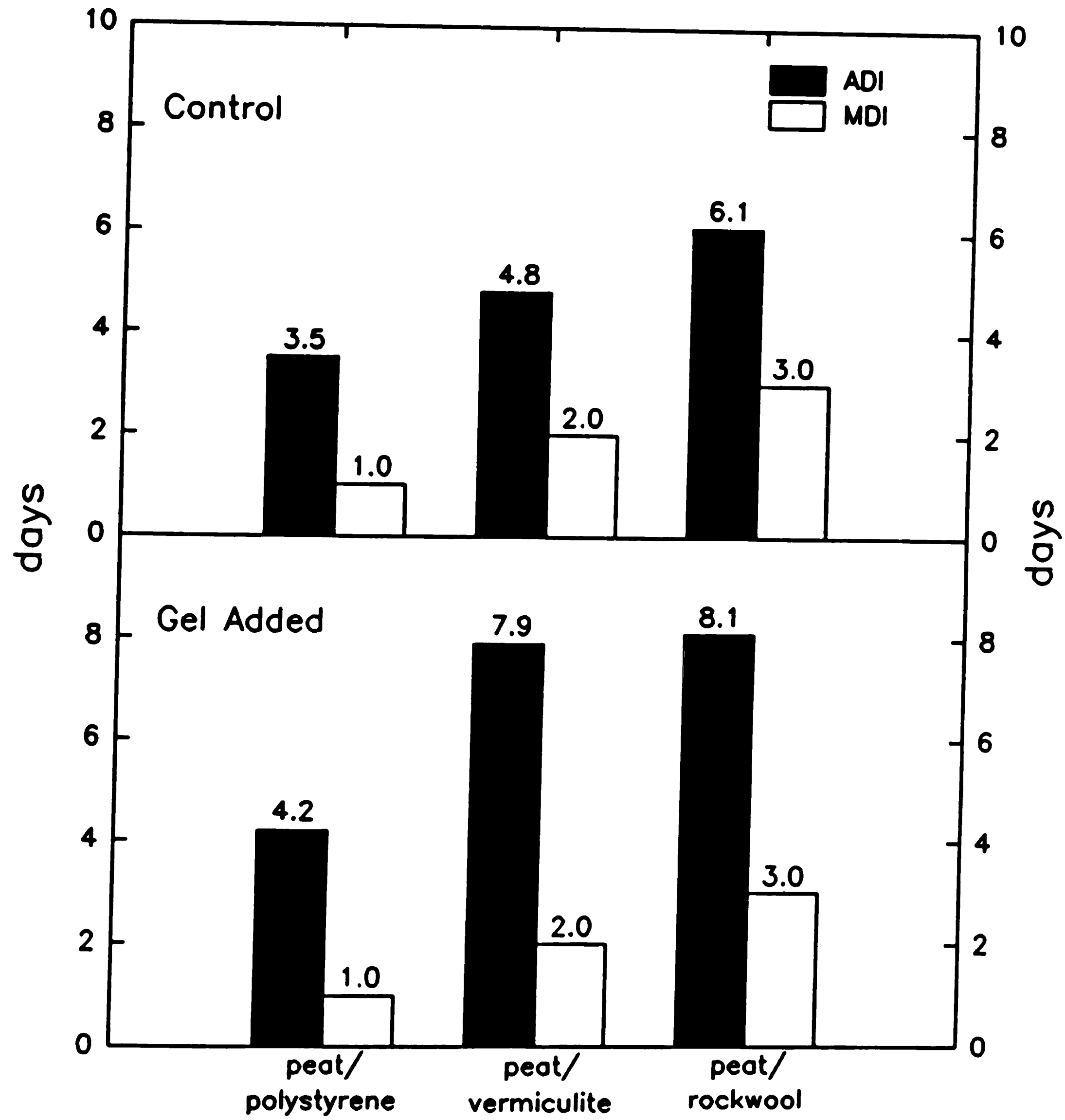


Figure 5. Effect of Supersorb C^R on the ADI and MDI of three sphagnum peat and component blends during the garden quality phase of Experiment 1.

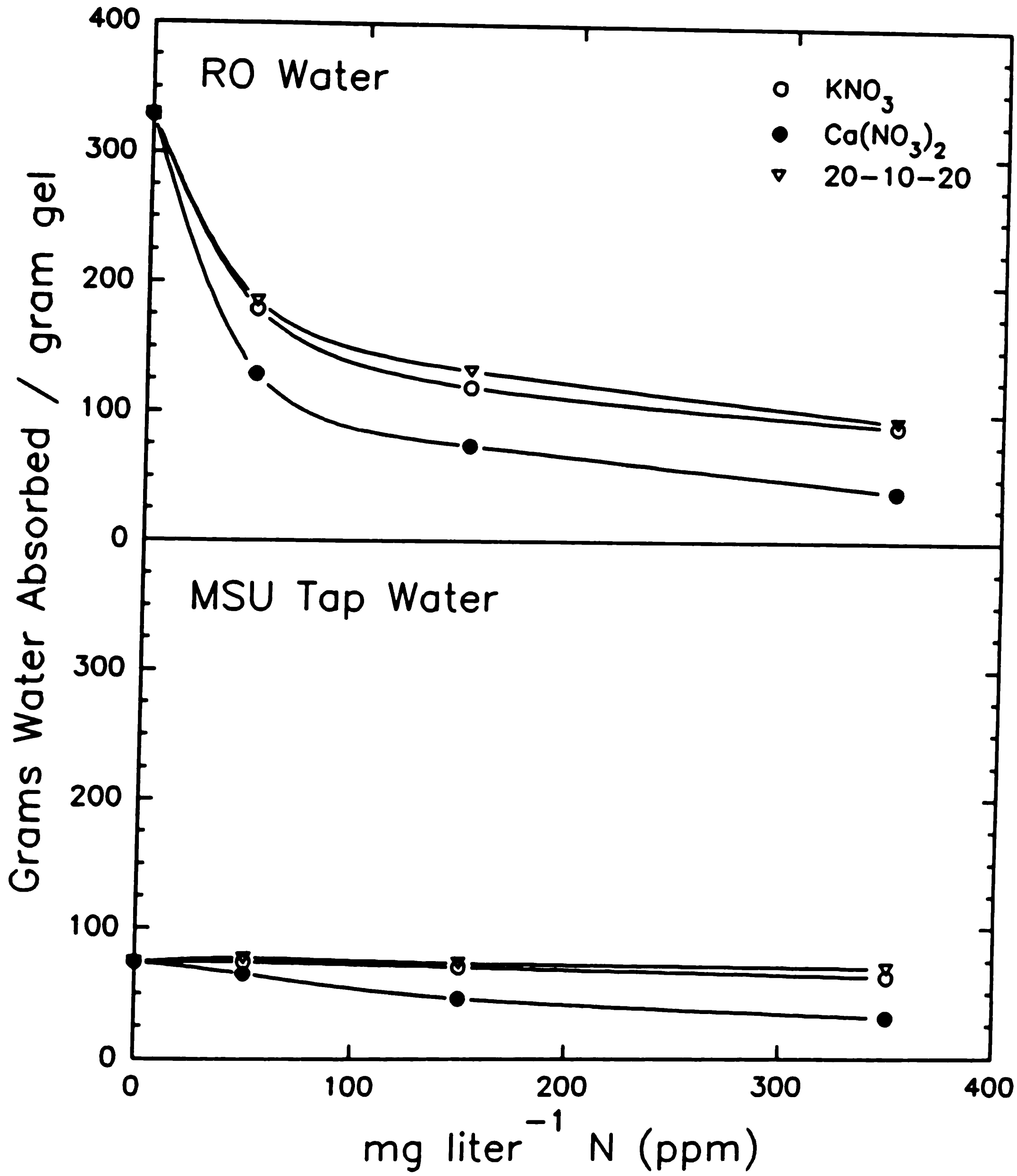


Figure 6. Effect of water quality and fertilizer salt type and concentration on the absorption of water by Supersorb C[R].

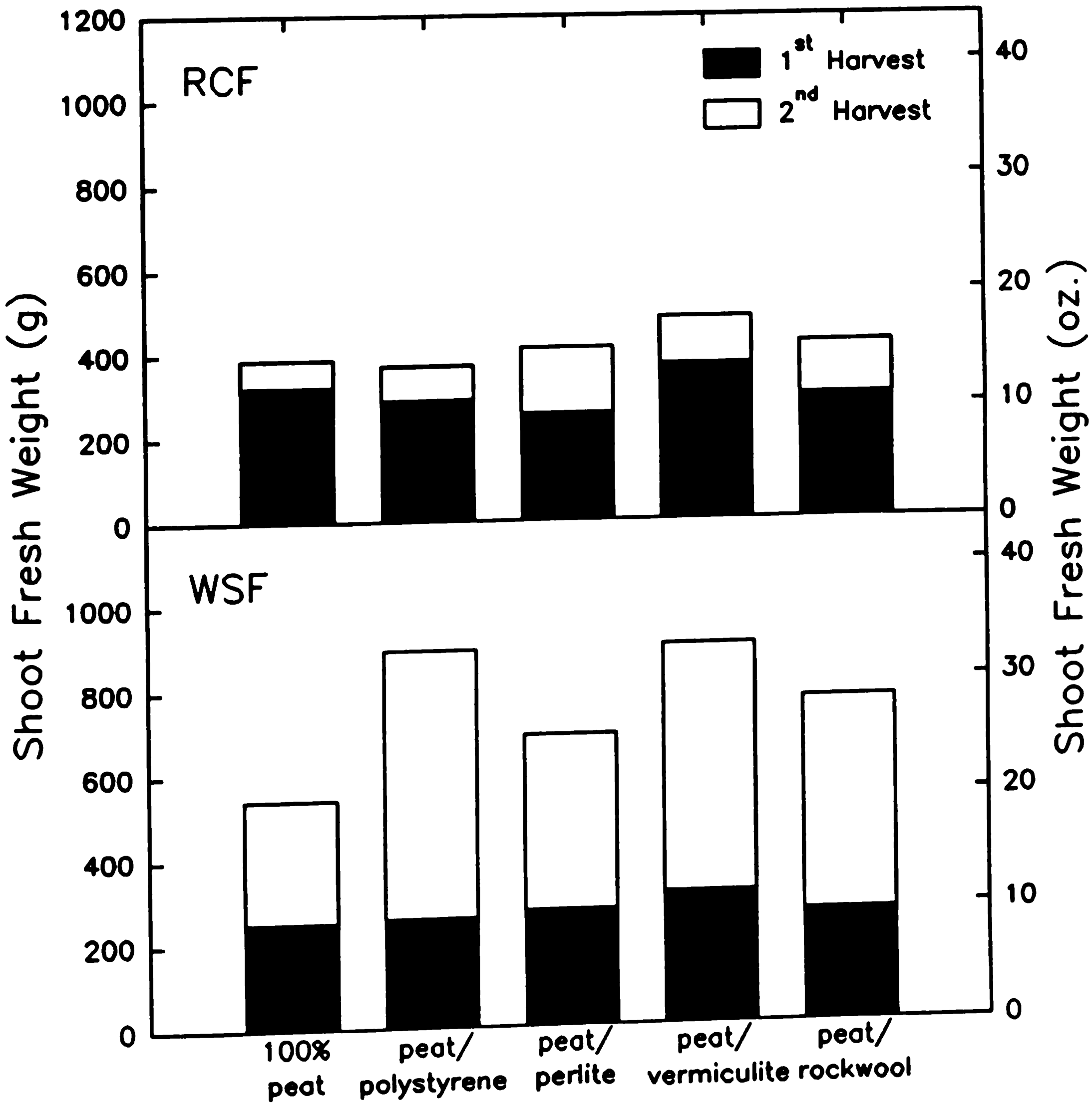
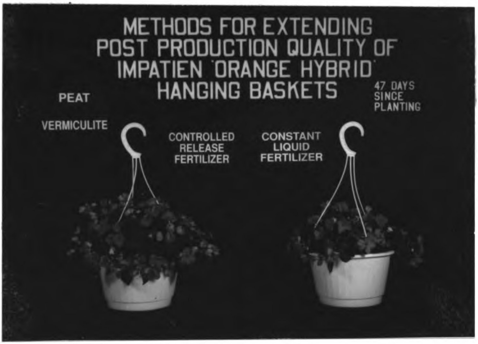


Figure 7. Shoot fresh weight of plants fertilized with RCF or WSF at the 1st and 2nd harvest in Experiment 1.

Figure 8. Comparison of RCF and WSF in peat/vermiculite blend from Experiment 1. Picture A was prior to the plants being placed outside (7 weeks from planting). Picture B was two weeks after being placed outside (9 weeks from planting). Picture C was eight weeks outside (18 weeks from planting).

A.


METHODS FOR EXTENDING
POST PRODUCTION QUALITY OF
IMPATIEN 'ORANGE HYBRID'
HANGING BASKETS
47 DAYS
SINCE
PLANTING
PEAT
VERMICULITE
CONTROLLED
RELEASE
FERTILIZER
CONSTANT
LIQUID
FERTILIZER

B.

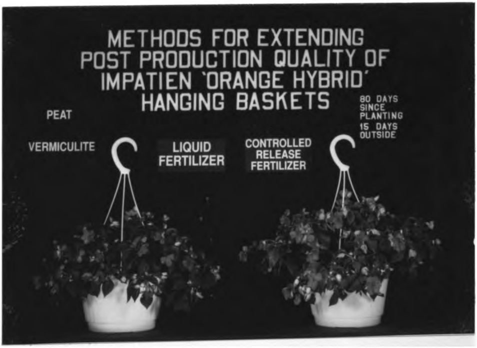

METHODS FOR EXTENDING
POST PRODUCTION QUALITY OF
IMPATIEN 'ORANGE HYBRID'
HANGING BASKETS
80 DAYS
SINCE
PLANTING
15 DAYS
OUTSIDE
PEAT
VERMICULITE
LIQUID
FERTILIZER
CONTROLLED
RELEASE
FERTILIZER

Figure 8. (cont.)
C.

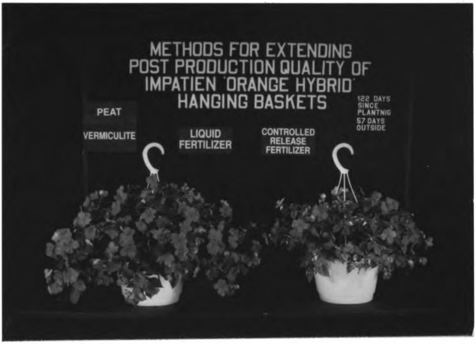
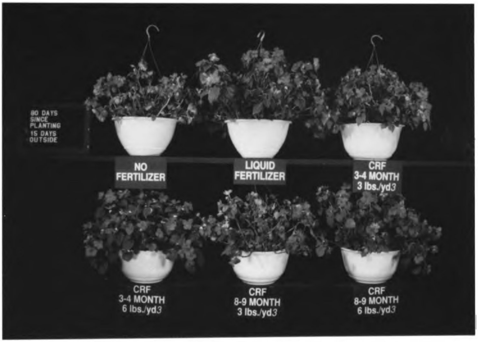


Figure 9. Effect of RCF release rate on the garden quality of impatiens in Experiment 2. Picture A was taken two weeks after being placed outside (11 weeks from planting) and Picture B was taken eight weeks after being placed outside (17 weeks from planting).

A.


80 DAYS SINCE PLANTING
15 DAYS OUTSIDE
NO FERTILIZER
LIQUID FERTILIZER
CRF 3-4 MONTH 3 lbs./yd3
CRF 3-4 MONTH 6 lbs./yd3
CRF 8-9 MONTH 3 lbs./yd3
CRF 8-9 MONTH 6 lbs./yd3

B.

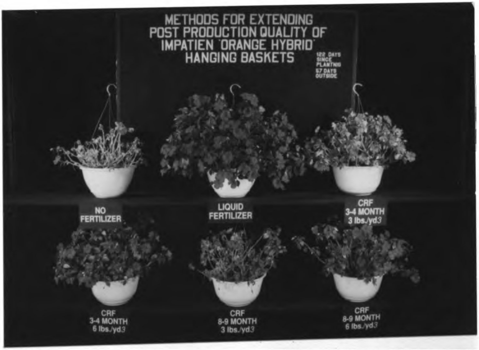

METHODS FOR EXTENDING POST PRODUCTION QUALITY OF IMPATIEN 'ORANGE HYBRID' HANGING BASKETS
122 DAYS SINCE PLANTING
57 DAYS OUTSIDE
NO FERTILIZER
LIQUID FERTILIZER
CRF 3-4 MONTH 3 lbs./yd3
CRF 3-4 MONTH 6 lbs./yd3
CRF 8-9 MONTH 3 lbs./yd3
CRF 8-9 MONTH 6 lbs./yd3

Figure 10. Effect of surface application of Osmocote® 14-14-14 applied at the end Experiment 2. Picture A is plant prior to application and Picture B is the same plant nine weeks after RCF application.

A.


122 DAYS
SINCE
PLANTING
57 DAYS
OUTSIDE
CRF
8-9 MONTH
3 lbs./yd3

B.


202 DAYS SINCE
PLANTING
60 DAYS SINCE
'CRF' APPLIED
CRF
8-9 MONTH
3 lbs./yd3

Figure 11. Example of the difference in plant size from different commercial growers in Experiment 4.

Figure 12. Examples of sun sensitive plants (non-stop begonia) and sun tolerant plants (Ivy Geraniums) from Experiment 5. Pictures were taken twelve weeks after being placed outside.

Non-stop Begonia.

Ivy Geranium.

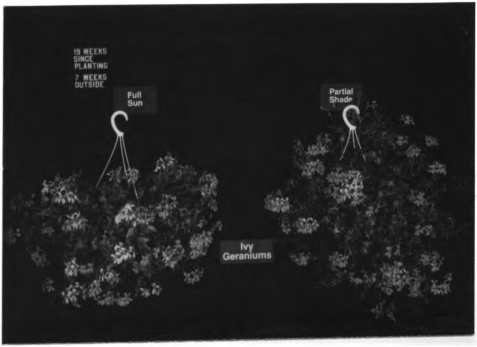
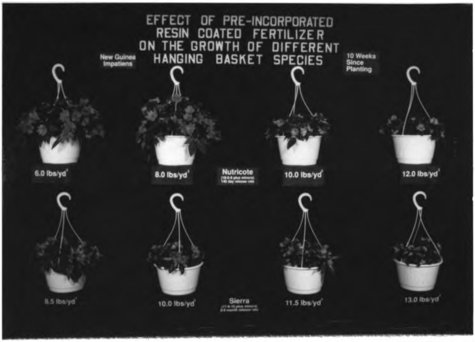


Figure 13. Example of fertilizer sensitive plants (New Guinea impatiens) and fertilizer tolerant plants (ivy geraniums) from Experiment 6. Pictures A and B were taken 10 weeks after planting. Pictures C and D were taken 19 weeks after planting or 7 weeks after being placed outside.

Ten weeks after planting

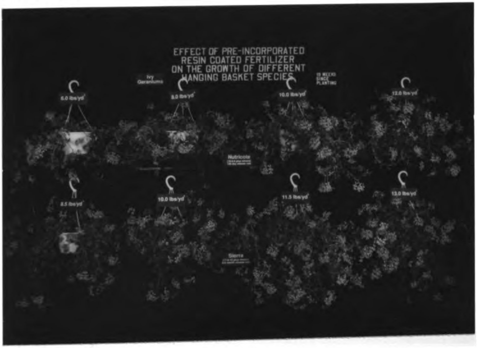
A. New Guinea Impatiens.



B. Ivy Geraniums

Figure 13 (cont.). Nineteen weeks after planting.
C. New Guinea Impatiens

D. Ivy Geraniums



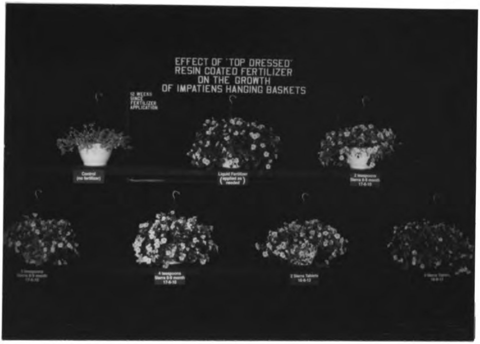


Figure 14. Effect of surface applied RCF on lasting quality of impatiens in Experiment 7. Picture taken 12 weeks after surface application.

APPENDICES

APPENDIX A

Recommendations to the Consumer
on the Care of Flowering Plants in Hanging Baskets

APPENDIX A

Hanging Basket Production Guidelines For Good Garden Performance

Flowering plants in hanging baskets account for 13% of the wholesale value of all bedding plants produced. However, there is a perception among consumers that hanging baskets are difficult to maintain. Consumers listed frequent watering, leaf yellowing with loss of foliage, and discontinued flowering as problems with flowering hanging baskets (Zehner and Krauskopf, 1990). The following production guidelines for garden performance are based on two years of research investigating the effects of root media, basket type, water absorbent gels, wetting agents, and resin coated fertilizer as well as interviews with over 25 wholesale and retail hanging basket producers.

Root Media Selection

Root media selection is the start of a good hanging basket program. The cost of the root media per basket may range from \$0.25 to \$0.62 assuming 162, 10-inch baskets/yd^3 and \$40 to \$100/yd^3 for the media. This cost is 10 to 45% of the materials cost of a hanging basket with \$0.50 to \$0.75 for the basket and \$0.25 to \$2.00 for the plant material.

Besides economics, an obvious criteria when selecting media for hanging basket production is the need to have enough air holding capacity so newly transplanted plugs or cuttings are not over watered in February while providing enough water holding capacity so the mature basket can go several days between waterings in August. While aeration and preventing over watering during production has been the primary selection criteria in the past, available water holding capacity (AWHC) is a key selection criteria for garden performance. AWHC is the amount of water held in a root media that is available to the plant between a normal watering and the time the plant wilts.

Polystyrene is the one component that should definitely be avoided when trying to increase AWHC. In evaluations of other components blended with peat, AWHC increased in the order perlite < vermiculite < rockwool. Of the 10 commercial media and 5 grower media evaluated, AWHC ranged from 51 to 84 fl.oz. Root media in a 10-inch basket should have about 64 fl.oz. AWHC. With water use per day averaging between 16 and 32 fl.oz., this will provide 2 to 4 days between irrigations.

All that is needed to determine the AWHC in a root media is a scale and a thoroughly rooted impatiens basket (4-6 weeks after planting). Impatiens work best since the foliage quickly wilts when the available water is gone and the foliage is remarkable tolerant to wilting. First, water the basket the way you think it will be watered or with a hose until water starts draining. Wait until drainage stops and weigh the basket. Allow the basket to dry until you observe wilting and weigh the basket again. The difference between the weight after watering and at wilt is AWHC. (1 gram equals 1 milliliter; 1lb is approximately 16 fl.oz. of water)

With high AWHC media, there are several management strategies to prevent over watering early in production: 1) transplanting larger plant material with a more developed root system into the basket; 2) more controlled watering during the first weeks after transplanting to prevent over watering of the root media; 3) maintaining the baskets on a bench initially rather than hung up overhead so watering can be more controlled and possibly done by hand; 4) production in baskets with external saucers that can be left off to provide drainage during production but attached prior to shipping to increase the amount of water retained; and 5) instructing growers to weigh baskets and not to water until they reach a predetermined weight. These methods may not be practical due to scheduling and labor concerns but should be considered.

Another factor that will effect the amount of available water held after an irrigation is how easily or efficiently water is reabsorbed by very dry root media. High AWHC does not guarantee rapid absorption. To test rewetting, take a wilted basket with dry root media, water until the first signs of leaching, and weigh the basket. Water the basket using the same method 2-3 times over a 30 minute period and reweigh the basket. If the increase in the weight after multiple irrigations is greater than 25%, wetting agent may be needed.

Based on our research to date, nutrient retention of the media as determined by cation exchange capacity (CEC) appears to have very little influence on garden performance. While buffering capacity of some peats can influence pH, selection of course components to be blended with the peat such as perlite, vermiculite, bark, or rockwool seem to have minimal influence on fertilization practices.

Basket Size/Style

Most growers interviewed had an opinion about whether an internal or external reservoir or vertical versus rounded side baskets held more media or water but none had made any measurements or comparisons. We tested the volume of 10 different styles of 10-inch baskets and found the volume to be similar (approximately 1.3 gallons) for 8 of the 10 baskets regardless of the type of reservoir. For the one comparison of a 10-inch basket with a volume of 1.3 gallons and a 10-inch basket with 1.8 gallons, the AWHC increased 15 to 25% without an increase in price. The main difference was the more vertical basket sides. At a root media cost of $50 per yd^3, the additional root media will add about $0.06 per basket.

Water absorbent Gels

Gels are marketed to increase AWHC and extend the time between watering. The cost of incorporating a water absorbent gel such as Supersorb C at the recommended rate of 1.5 lbs/yd^3 adds \$0.06 to \$0.07 per basket to the cost of the root media.

In our experiments, the addition of Supersorb C did not increase the available water held in the root media. We concluded that with our method of watering, the gel would not absorb water fast enough which agrees with results presented by other researchers.

Without multiple irrigations, the only water for the gel to absorb was the water that remained in the root media after an irrigation.

There was an increase in days between watering by 25% or 1 day for plants grown in root media with gel averaged over a two month period. However, there was no effect on the time to wilt under conditions of high water loss. We concluded that the gel changed the way the water held in the root media was released to the plant.

The hydration of water absorbent gels is reduced by increasing concentrations of fertilizer salts. In a laboratory experiment, 1 gram of Supersorb C absorbed 11 fl.oz. of RO water but only 2.5 fl.oz. of well water containing 80 ppm Ca and 40 ppm Mg. At a concentration of 350 ppm N and 500 ppm Ca from $Ca(NO_3)_2$ in RO water, 1 gram of Supersorb C absorbed about 1.1 fl.oz. of water. Thus, water quality, fertilizer type and concentration, and irrigation frequency effect hydration and may explain why some growers obtain a benefit from gels while other do not.

Wetting Agents

Most commercially available root media contain some type of wetting agent to increase rewetting. It is often recommended to reapply wetting agent during production or at ship to maintain uniform rewetting. The reapplication of a wetting agent costs \$0.01

to $0.02 per basket assuming 64 fl.oz. applied to each basket (Aquagro 2000[R] at $27/gal at a rate of 700 to 1400 ppm). In our experiments, the benefit of reapplying a wetting agent were apparent for some root media but not for others. The need for additional wetting agent should be determined for each root media using the previously presented method of measuring available water.

Fertilizer Requirements

In root media containing a preplant nutrient charge of 1 lb $Ca(NO_3)_2$ and 1 lb KNO_3 per yd^3 and a saturated media extract (SME) nitrate-N level of 75 to 100 ppm N, an additional 1.5 grams N or 5 quarts of a 300 ppm N fertilizer solution is required to produce a 10-inch hanging basket assuming 12 weeks production and little or no leaching. If soil test nutrient levels are measured maintain the EC of the root zone between 1 to 2 mS cm^{-1} from a SME test or 0.3 to 0.75 mS cm^{-1} on a 2:1 (V:V) water to media testing method for all species.

Different species used in hanging basket production vary in the sensitivity or tolerance to high fertilizer salt in the root media. An example of a fertilizer sensitive plant would be New Guinea impatiens. High root media fertility levels, especially in the first 3-4 weeks after planting will reduce shoot growth. On the other extreme are fertilizer tolerant plants such as ivy geraniums. Higher root media fertility levels probably are not necessary but will not reduce growth.

Five to six grams of N are required by plants in hanging baskets to maintain growth and flowering for about 20 weeks outside. This amount corresponds to 64 fl.oz. of 300 ppm N fertilizer solution applied every 2 weeks over a 20 week time period. However, consumers do not realize that hanging baskets need to be fertilized. In one survey on consumer satisfaction of hanging baskets by Zehner and Krauskopf (1990), 43% reported never fertilizing the basket during the summer.

Resin Coated Fertilizers

One way to maintain fertility through the summer is with the use of resin coated fertilizers (RCF). Two methods we tested in applying RCF were incorporation prior to planting and top dressing prior to ship.

Incorporation prior to planting is probably the simplest method of applying RCF. If RCF is to be of long term benefit to the consumer, it should have a release rate of at least 5 to 6 months. If a 3-4 month material is used, most of the fertilizer is released during production.

We have not identified a material that works both for production and for the entire summer outdoors. The problem is that the high incorporation rates required to sustain growth outside are too high for production for fertilizer sensitive plants such as New Guinea impatiens. Based on research finished to date, we would incorporate a rate of 6 to 7 lbs/yd^3 of an 8-9 month material with 17 or 18% N. This rate will be sufficient to produce the plant and still maintain a low level of fertility for the consumer. The consumer will still have to apply some liquid fertilizer to the plant. Research is continuing in this area.

Another method of applying RCF is to top dress prior to ship. With this method, a release duration of at least 4 to 5 months is desired. One to two tablespoons per basket will maintain fertility through a majority of the summer. The consumer may still have to apply some liquid fertilizer to the basket in the late summer and early fall to sustain the flush of new growth at that time.

Conclusion

Most commercial media without polystyrene and 10" plastic baskets can be used to produce a quality flowering basket with good garden performance. The cost of a super absorbent gel could not be justified under our conditions but the addition of wetting

agent may be beneficial. Addition of RCF could have the greatest impact on garden performance and should be either incorporated or top-dressed. With a well produced basket and adequate care instructions, consumers should be more successful in growing and maintaining flowering plants in hanging baskets through the summer. This success should maintain or increase future production.

Condensed from the complete research report by Bill Argo and John Biernbaum, Dept. of Horticulture, Michigan State University.

APPENDIX B

Recommendations to the Commercial Grower
on the Production of Flowering Plants in Hanging Baskets

APPENDIX B

Keep Your Baskets Blooming

Keys to success for maintaining flowering plants in hanging baskets

Flowering plants in hanging baskets are an eye catching part of both large and small outdoor landscapes. However, flowering hanging baskets need to be watered and fertilized more often compared to the same plants grown in the garden. Without proper care, plant quality is lost and flowering may stop. There are five key steps to keeping a hanging basket in flower.

Selecting the Right Plant

Before selecting hanging baskets, you should decide where the baskets will be located. Although most common basket plants can survive anywhere with proper care, not all plants will perform equally well in all locations.

Locations vary in the amount of exposure to light and high temperature. In general, southern exposures receive the most light and have the highest temperatures. Ivy and zonal geraniums will best tolerate high light conditions.

Eastern and western exposures get about the same number of hours of sunlight but a western exposure has higher temperatures because it receives the sunlight in the afternoon. Impatiens, New Guinea impatiens, begonias and fuchsia will tolerate an east or west exposure but may flower and perform better with the eastern exposure because of the lower temperatures.

The northern exposure has the lowest temperatures but also receives the least amount of light. Impatiens and begonias will tolerate conditions of very low light best, but all the species listed in the table below will continue to flower in shady conditions.

Most Common Plant Type	Maximum Light Tolerance	Tolerance to Wilting
Ivy Geranium	High	High
Geranium	High	High
Petunia	High	Medium
Fuchsia	Medium	Low
Impatiens	Medium	Medium
New Guinea Impatiens	Medium	Medium
Tuberous Begonia	Medium	Medium
Fibrous Begonia	Medium	Medium

Table 1. The tolerances of different species used in hanging basket production to high light and drought stress.

The common basket plants also differ in their ability to tolerate a lack of water. Impatiens and fuchsia can lose flowers and buds from wilting. Impatiens foliage is remarkably tolerant of wilting and will usually recover after watering. Fuchsia foliage is very sensitive to wilting and can turn yellow and drop. Ivy and zonal geraniums can tolerate dry conditions for several days without damage to the foliage or a reduction in flowering. Begonias do not tolerate wilting but like the geraniums, a wilted appearance does not rapidly develop. Petunias will wilt rather dramatically and leaves may turn yellow, but flowering will continue.

If you tend to neglect watering, choose a plant that can tolerate wilting, like a geranium. By matching plant tolerance to watering habits, you can increase the plant's chance of survival and flowering.

Finally, plant and container size should be considered. Hanging baskets are available in 6, 8, 10, and 12 inch diameters. In general, the larger the basket the better the investment and the less maintenance needed. Ten inch hanging baskets are most common.

The plant size should be in proportion to the basket size. A very large, plant in a small basket may not be a good investment. A large, showy plant may require twice as much water as a smaller plant in the same size basket and will be more susceptible to drying out the first few weeks until a watering schedule is developed.

Water is Essential

Once the right plants are selected, the next challenge is keeping them watered. If watered properly, most flowering plants in 10 inch diameter baskets should last 2 to 4 days between waterings. If watered thoroughly, the soil in a 10 inch hanging basket will hold about 64 fl.oz. (one-half gallon) of water that can be used by the plant. A medium size plant in a 10 inch hanging basket may use an average of about 16 fl.oz. (one pint) of water per day. The amount of water used by the plant may double under bright, hot conditions.

The key is to water *thoroughly*. Dry soil containing peat takes time to rewet and absorb water. Water draining out the hole in the bottom of the basket does not mean the soil is thoroughly watered. After watering, the basket should be heavy, about 7-9 lbs. If the plant has wilted and the root media is shrunken from the sides of the basket, water the basket once and then again about 15 to 30 minutes later. Another method is to place the basket into a bucket of water for about 10 minutes. To extend the time between watering, its important to have the soil absorb the maximum amount of water.

Perhaps the easiest way to tell when to water a plant is when wilting is observed. However, this method can damage the plant and reduce flowering.

A better method is to water by weight. Learn how heavy the basket feels like it is wilted and water it before it gets that light. Keep in mind that it is very difficult to over water hanging basket plants in medium and high light. If you are not sure, water every other day with a quart or more of water. In shady conditions, the soil should be allowed to dry between watering.

Plants Need to be Fertilized

Now that your baskets are alive and thriving into the summer, the next step to keep them flowering is fertilization. During production, hanging baskets are often fertilized with every watering. However, during the summer they may be only fertilized occasionally or not at all. Lack of fertilizer can cause a rapid decrease in plant quality.

Growing a flowering plant in a hanging basket is not the same as growing the same plant in the garden. The small volume of soil in a basket is the only available source of nutrients for the plant compared to the much larger volume of soil available to the plants in the garden. Another problem is that frequent watering can cause much of the fertilizer to be washed out.

There are at least two methods of keeping basket plants fertilized. The first method is to use complete water soluble fertilizers that can be purchased in most retail stores and garden centers. Look for products that contain between 15 and 25% nitrogen (the first number). The second and third number (phosphorus and potassium) should be at least 5 to 10%.

For a fertilizer containing 20% nitrogen, 1 or 2 level teaspoons per gallon of water will give an adequate concentration of nutrients. The fertilizer solution should be applied as a normal watering about every two weeks. Make it a regular activity throughout the summer. If the plants begin to show signs of yellowing leaves or decreased flowering, and wilting has not been occurring, you may need to increase the frequency or the concentration of the fertilizations.

Fertilizer can also be bought as plastic or resin coated beads. These coated materials will gradually release the fertilizer over a period of several months. One example found in stores is Osmocote[R] 14-14-14. This material is 14% nitrogen and will release fertilizer over a 3-4 month period. One to two tablespoons spread over the surface of the soil may be enough for the entire summer.

Sometimes a resin coated fertilizer is added during production. The beads should be visible in or on top of the soil. When this is the case, less fertilization may be needed during the summer.

Keep in mind that some plants in baskets tend to produce new growth and more flowers when temperatures drop at the end of the summer. Additional water soluble fertilizer at this time, even when resin coated fertilizers have been used, can help keep plants blooming right up to frost.

Removing Dead Flowers Helps

With proper watering and fertilization, hanging baskets may last so long and flower so well that regular grooming may be needed. Occasional pruning and removing dead flowers or seed pods will improve the appearance of the plant and may help many plants bloom better. Geraniums and fuchsia are two cases where the formation of seeds may reduce flowering. When the large showy flowers of tuberous begonias die, fungal diseases may get started. Occasionally removing old flowers is the best preventative.

Vacations Can Ruin It All

Your baskets are going to look so good that come vacation time, you will want to make sure they are watered. You may be able to ask the neighbors or hire the neighborhood entrepreneur to water the plants. Another method that may help keep the plants alive is to move them to a shady area on the ground. Water the plants thoroughly and place them under a tree or a bush. If all you have is a hot sunny balcony, put the plants on the floor behind a chair or move them inside. Flowering may be reduced when the plants are first returned to higher light, but they will still be alive and will recover.

Summary

Matching the right plant to the location can increase the chances for success from the start. With proper watering and fertilization, the plants will continue to grow and flower. There is no reason that your hanging baskets can not last through the summer and die with the frost instead of with the fireworks of the fourth of July.

APPENDIX C

Experimental Treatments from:
SECTION III
Factors Affecting the Garden Performance
of Flowering Plants in Hanging Baskets

APPENDIX C

Treatments used in the 1990 and 1991 experiments on improving the garden performance of flowering plants in hanging baskets.

1990 Experiments:

Experiment #1: Root media components and amendments.

Fertilizer was applied as either resin coated fertilizer (Osmocote[R] 13-13-13, 8-9 month, incorporation rate=7 lbs./yd^3 or as a solution (20-10-20 peatlite, rate=300 ppm N) applied as needed. Impatiens were the test crop. Fourteen different root media combinations, with 2 fertilizer treatments and 6 replications-168 baskets total.

Root Media	Comparisons
1) peat[Z]/polystyrene (60%/40%) + WA A[Y]	Root media component comparisons (media 1 - 5)
2) peat (100%)	
3) peat/perlite (60%/40%)	
4) peat/vermiculite #2[X] (60%/20%)	
5) peat/rockwool[W] (60%/40%)	
6) peat (100%) + gel[V]	Gel comparisons (media 2,6,1,7,4,8,5,9)
7) peat/polystyrene + gel	
8) peat/vermiculite #2 + gel	
9) peat/rockwool + gel	
10) peat/polystyrene + zeolite[U]	Zeolite comparisons (media 1,10,5,11,6,12)
11) peat/rockwool + zeolite	
12) peat (100%) + gel + zeolite	
113) peat (100%) + NO WA	Wetting agent comparisons (media 13,2,14)
14) peat (100%) + WA B[T]	

[Z]Fisons professional canadian sphagnum peat (Black Bale).

[Y]WA A (wetting agent A) was Aquagro[R] from Aquatrols. It was the standard wetting agent added to all the root media unless otherwise indicated.

[X]Coarse, horticultural vermiculite from W.R. Grace.

[W]Medium grind, loose rockwool from Partek.

[V]Supersorb C[R] from Aquatrols was a super absorbent polyacrylamide gel. It was incorporated into the root media prior to planting at the recommended rate of 0.9 kg m^{-3} (1.5 lbs yd^{-3}).

[U]The zeolite used in the experiment was a fine powdered material that can absorb NH_4^{1+} and K^{1+} ions. It was incorporated into the root media prior to planting at a rate of 30 kg m^{-3} (50 lbs yd^{-3}).

[T]WA B (wetting agent B) was an experimental wetting agent currently available as Aquagro 2000[R] from Aquatrols.

Experiment #2: Release rate of different RCF.

Amounts equivalent to the different rates of each RCF were incorporated prior to planting. The root media used in the experiment was a commercially available peat / polystyrene / vermiculite #3 blend (Suremix from Michigan Grower Products). Six fertilizer treatments with 6 replications-36 baskets total.

1) Control - No fertilizer applied
2) liquid fertilizer[z] applied as needed
3) Osmocote[R] 14-14-14, 3-4 month, 1.8 kg m^{-3} (3 lbs yd^{-3})
4) Osmocote[R] 14-14-14, 3-4 month, 3.6 kg m^{-3} (6 lbs yd^{-3})
5) Osmocote[R] 13-13-13, 8-9 month, 1.8 kg m^{-3} (3 lbs yd^{-3})
6) Osmocote[R] 13-13-13, 8-9 month, 3.6 kg m^{-3} (6 lbs yd^{-3})

[z]Peters 20-10-20 peatlite special applied at a rate of 300 mg $liter^{-1}$ N.

__1991 Experiments:__

Experiment #1: Commercially available root media.

Impatiens were the test crop. Eleven different commercially available root media, with 2 wetting agent[z] treatments and 3 replications-66 baskets total.

1) Michigan Grower Products-Suremix	6) Grace/Sierra-Metro Mix 360
2) Michigan Grower Products-Rockwool blend	7) Michigan Peat-Baccto
3) Fisons-Sunshine LC1	8) Michigan Peat-Rockwool blend
4) Fisons-Postharvest Mix	9) Ogilvie-OPM #8
5) Premier Brands-Pro-mix BX	10) Partek-Peatwool

[z]The wetting agent used in both Experiments #1 and #2 was Aquagro 2000[R] by Aquatrols. The rate of application was 550 mg $liter^{-1}$ (recommended low application rate) in Experiment 1 and 1400 mg $liter^{-1}$ (recommended high application rate) in Experiment #2.

Experiment #2: Commercially produced 10 inch baskets.

Impatiens were the test crop. Eleven different commercial growers, with 2 wetting agent treatments and 3 replications-66 baskets total.

Experiment #3: Different hanging baskets species.

Six species grown under 2 light levels and 3 replications. The commercial root media used in the experiment was a peat/rockwool/vermiculite #3 blend (Suremix rockwool blend)-36 baskets total.

__Species tested:__

Impatiens, New Guinea Impatiens, Ivy Geranium, Fuchsia, Zonal Geranium and Non-stop Begonia.

Experiment #4: Different species with different rates of incorporated RCF.

Six species with 8 fertilizer treatments. Replication made across species. The commercial root media used in the experiment was a peat/rockwool/vermiculite #3 blend (Suremix rockwool blend)-48 baskets total.

Species tested:

Impatiens, New Guinea Impatiens, Ivy Geranium, Fuchsia, Zonal Geranium and Non-stop Begonia.

RCF incorporation rates.

Sierra[R] RCF[Z]	Nutricote[R] RCF[Y]
5.1 kg m^{-3} (8.5 lb yd^{-3})	3.6 kg m^{-3} (6.0 lb yd^{-3})
6.0 kg m^{-3} (10.0 lb yd^{-3})	4.8 kg m^{-3} (8.0 lb yd^{-3})
6.9 kg m^{-3} (11.5 lb yd^{-3})	6.0 kg m^{-3} (10.0 lb yd^{-3})
7.8 kg m^{-3} (13.0 lb yd^{-3})	7.2 kg m^{-3} (12.0 lb yd^{-3})

[Z]Sierra 17-6-10 plus minors, 8-9 month release rate.
[Y]Nutricote 18-6-8 plus minors, 140 day release rate.

Experiment #5: Post production application of RCF.

Baskets were collected from 2 different growers. Seven treatments with 3 replications for each treatment-42 baskets total.

1) Control - No fertilizer applied
2) Liquid fertilizer applied as needed
3) Sierra[R], 2 tsp. (12 grams), "top dressed"
4) Sierra[R], 3 tsp. (18 grams), "top dressed"
5) Sierra[R], 4 tsp. (24 grams) "top dressed"
6) Sierra Tablets[R], 2/basket pushed into root media[X]
7) Sierra Tablets[R], 3/basket pushed into root media

[X]Sierra Tablets 16-8-12 plus minors, 8-9 month release rate (7.5 grams/tablet). Suggested application rate - 2 to 3 tablets per basket.

APPENDIX D

Cost of Components and Amendments

APPENDIX D

The cost of root media components and amendments and estimated cost per basket based on 10 inch hanging baskets filled at a rate of 6 baskets per ft^3 or 162 baskets per yd^3. Actual prices of components and amendments may vary. This for comparison purposes only.

Components	$/$yd^3$	$/$ft^3$
canadian sphagnum peat	$28-$37	$1.00-$1.36
perlite	$38-$51	$1.40-$1.90
vermiculite #2	$49-$57	$1.80-$2.10
polystyrene	$5-$6	$0.19-$0.23
rockwool	$38-$48	$1.40-$1.80
commercial root media	$54-$108	$2.00-$4.00

Amendments	$/lb.	$/$yd^3$	$/basket
calcined clay (50 lbs./yd^3)	$0.11-$0.12	$5.35-$5.70	$0.033-$0.035
zeolite (50 lbs./yd^3)	$0.10-$0.12	$5.00-$5.70	$0.031-$0.035
Supersorb C[R] (1.5 lbs./yd^3)	$6.23-$7.60	$9.35-$11.40	$0.058-$0.070
Aquagro L[R] (9 fl.oz./yd^3)		$1.62-$2.25	$0.010-$0.014
(1000 ppm drench)[Z]		$1.87-$2.60	$0.012-$0.016
(2500 ppm drench)		$4.68-$6.50	$0.029-$0.040
Sierra[R] RCF	$1.00-$1.40		
<u>incorporated</u>			
4.2 kg m^{-3} (7 lb yd^{-3})		$7.00-$9.80	$0.043-$0.060
5.1 kg m^{-3} (8.5 lb yd^{-3})		$8.50-$11.90	$0.052-$0.073
6.0 kg m^{-3} (10 lb yd^{-3})		$10.00-$14.00	$0.062-$0.086
6.9 kg m^{-3} (11.5 lb yd^{-3})		$11.50-$16.10	$0.071-$0.099
7.8 kg m^{-3} (13 lb yd^{-3})		$13.00-$18.20	$0.080-$0.112
<u>top dressed</u>			
12 grams (2 tsp) per basket		$4.21-$6.00	$0.026-$0.037
18 grams (3 tsp) per basket		$6.48-$9.07	$0.040-$0.056
24 grams (4 tsp) per basket		$8.59-$12.00	$0.053-$0.074
Sierra[R] tablets	$1.94-$2.18		
2 tablets (15 grams) per basket		$10.37-$11.66	$0.064-$0.072
3 tablets (22.5 grams) per basket		$15.55-$17.50	$0.096-$0.108
Nutricote[R] RCF	$1.20-$1.50		
<u>incorporated</u>			
3.6 kg m^{-3} (6 lb yd^{-3})		$7.20-$9.00	$0.044-$0.056
4.8 kg m^{-3} (8 lb yd^{-3})		$9.60-$12.00	$0.059-$0.074
6.0 kg m^{-3} (10 lb yd^{-3})		$12.00-$15.00	$0.074-$0.093
7.2 kg m^{-3} (12 lb yd^{-3})		$14.40-$18.00	$0.089-$0.111
Liquid Fertilizer	$0.40-$0.50		

[Z]Assume 1 drench application would be 1.9 liters (64 fl.oz.) per basket.

Other Costs			
baskets		$81.00-$121.50	$0.50-$0.75
plant material	$0.05-$0.80/plant		
(3 plants/basket)		$24.30-$388.80	$0.15-$2.40
(4 plants/basket)		$32.40-$518.40	$0.20-$3.20
(5 plants/basket)		$40.50-$648.00	$0.25-$4.00

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