

# **Greenhouse production of *Rosmarinus officinalis* L.**

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**Challenges in the Greenhouse Production of Rosemary (*Rosmarinus officinalis*  
L.)**

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(ABSTRACT)

*Rosmarinus officinalis* L. (rosemary) is popular as a culinary herb, landscape plant, and potted florist's crop. Little research has been reported on the greenhouse production of this plant. Effects of irrigation rate, fertilizer concentration, and growing media on root and shoot growth were investigated for *R. officinalis* 'Athens Blue Spires'.

In the first experiment, rooted cuttings were potted and received fertilizer treatments of 100, 200, or 300 mg·L<sup>-1</sup> nitrogen (N) from 15N-2.2P-12.2K water-soluble fertilizer for twelve weeks. Two irrigation regimes were imposed - plants were irrigated with fertilizer solution when the growing media dried down to less than 30% or 20% volumetric soil moisture content. Root and shoot dry weights showed irrigation rate did not effect roots, but the higher irrigation rate produced larger shoots at all fertilizer concentrations. The largest roots and shoots were a product of the lowest fertilizer concentration.

In the second experiment, rooted cuttings of the same cultivar were potted and received fertilizer treatments of 50, 100, 150, or 200 mg·L<sup>-1</sup> N from 15N-2.2P-12.2K water-soluble fertilizer for 2, 4, 6, or 8 weeks. Plants were harvested at the end of each treatment. A third irrigation regime was imposed – plants were irrigated with fertilizer solution when the growing media dried down to less than 40%, 30%, or 20% volumetric soil moisture content. Root and shoot dry weights showed neither irrigation nor fertilizer were significant at week two, six, or eight. Dry weights showed irrigation was significant for roots at week four with the lowest irrigation rate producing the largest

roots at all fertilizer concentrations except  $100 \text{ mg}\cdot\text{L}^{-1}$  at the less than 30% irrigation rate. Irrigation was also significant at week four for shoots with the lowest irrigation rate producing the largest shoots at all fertilizer concentrations except  $100 \text{ mg}\cdot\text{L}^{-1}$  at the less than 30% irrigation rate.

In the third experiment ‘Athens Blue Spires’ rooted cuttings were potted in five different soilless media [Fafard 52 (24% peat, 60% bark, 8% perlite, 8% vermiculite); Fafard 3B (45% peat, 25% bark, 15% perlite, 15% vermiculite); Scott’s Sierra Perennial Mix (25% peat, 65% bark, 10% perlite); Scott’s Metro Mix 700 with Coir (25% coir, 50% bark, 10% perlite, 15% vermiculite); and a nursery mix (89% pine bark, 11% sand)]. Plants were irrigated for fourteen weeks with  $150 \text{ mg}\cdot\text{L}^{-1}\text{N}$  fertilizer solution when the growing media dried down to less than 30% or  $<20\%$  volumetric soil moisture content. Growing media affected shoot dry weight with the highest-percentage peat media (Fafard 3B) producing the largest plants. All were of marketable quality. Irrigation rate did not affect root dry weight, but the higher rate produced larger shoots in each of the five media.

The fourth experiment examined the growth of *R. officinalis* ‘Tuscan Blue’ rooted cuttings when planted in five different growing media [Fafard 52, Fafard 3B, Scott’s Perennial, Metro Mix 560 with coir (30% coir, 15% peat, 40% bark, and 15% perlite), and 100% pine bark]. A third irrigation regime was imposed – plants were irrigated with  $150 \text{ mg}\cdot\text{L}^{-1}\text{N}$  fertilizer solution when the growing media dried down to less than 40%, 30%, or 20% volumetric soil moisture content. Treatments lasted for 2, 4, 6, or 8 weeks and plants were harvested at the end of each treatment. Dry weights showed neither media nor irrigation was significant for roots or shoots at weeks four or eight. However, at week two, media significantly affected root dry weight with the heaviest roots produced by the two perennial mixes (Scott’s perennial and Fafard 52). Growing media affected shoot dry weight at week six with the highest-percentage peat media (Fafard 3B) producing the largest plants at the low and high irrigation rate. Irrigation also affected root dry weight at week six with the two lowest irrigation rates producing the heaviest roots in all media.

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# LITERATURE REVIEW

## INTRODUCTION

Rosemary (*Rosmarinus officinalis* L.) has long been considered an important plant for its essential oil used in perfumes and medicine (Liberty Hyde Bailey Hortorium, 1976) as well as an important spice and antioxidant in processed foods (Chipault et al., 1952, 1955, 1956). It is also a delightful herb that's ornamental value may stretch beyond the herb garden, either as a standard (Armitage, 1997) or used as a holiday pot plant at Christmas (DeBaggio, 1987). For these reasons and others, it has been grown since ancient times (Simon et al., 1984). Even Shakespeare's Ophelia pays tribute to rosemary in Hamlet.

Rosemary is a member of the mint family, Lamiaceae. It has opposite, simple, entire, evergreen leaves up to two inches long and an eighth of an inch wide. The leaf margins are revolute and the leaves are a shiny green on top and whitish beneath due to a dense collection of very fine hairs (Dirr, 1990). Native to the Mediterranean, Portugal, and northwestern Spain (Kowalchik and Hylton, 1987), the plant begins to flower in late winter and continues through spring. Flowers are normally blue, but cultivars can be found with pink or white blooms (Armitage, 1997).

Despite its popularity and its many uses, there is very limited published research on growing criteria. Boyle et al. (1991) found rosemary does not respond well to high levels of fertilizer, but they did not determine the ideal fertilization concentration. Boyle et al. (1991) also found larger rosemary plants could be grown in soilless media than a field soil based mix, but they did not explore variations in soilless medias. No research has been found indicating the best management practices for field or greenhouse grown rosemary.

Table 1.1. Cold hardiness and descriptions of common cultivars of *Rosmarinus officinalis* L.  
(Armitage, 1997)

| <b>Rosemary species &amp; cultivars</b> | <b>Hardiness °F</b> | <b>Description</b>  |
|---|---------------------|---|
| <i>Rosmarinus officinalis</i>           | 0° F                | Wide and irregular habit<br>Up to 7' tall   |
| 'Arp'                                   | -10° F              | Dull gray green leaves.<br>Sprawling habit, up to 5' tall.                                    |
| 'Athens Blue Spires'                    | 10° F               | Thin gray green leaves<br>Upright and vigorous, profuse bloomer                               |
| 'Beneden Blue'                          | 20° F               | Very narrow, needle-like leaves.<br>Twisted, windswept look. Very strong aroma<br>To 5' tall. |
| 'Blue Boy'                              | 15° F               | Small, light green leaves.<br>Compact habit, heavy bloomer, to 2' tall                        |
| 'Blue Spires'                           | 0° F                | Shiny green leaves<br>Open upright habit, up to 3' tall                                       |
| 'Nancy Howard'                          | 15° F               | Large, narrow, dark green leaves.<br>White blooms   |
| 'Prostratus'                            | 20° F               | Short, narrow, green leaves.<br>Spreading habit, to 3' tall                                   |
| 'Majorica Pink'                         | 15° F               | Small, dull, green leaves.<br>Stiffly upright. Pink blooms. To 5' tall                        |
| 'Tuscan Blue'                           | 5° F                | Short, wide, glossy, green leaves.<br>Very upright with few branches. Up to 8' tall           |

## **MEDIA**

Soilless media is commonly used for growing greenhouse crops. Research of growing media is crucial due to the continuous introduction of new components (Fonteno, 1996). As

percentages of different components change, so might physical and chemical properties of the growing media (Fonteno, 1996).

### **Physical Properties:**

**Bulk Density:** Bulk density is defined as the dry weight of the media per unit volume. Media with a low bulk density will be lighter than that with a high bulk density and has many associated benefits including less physical strain on workers, more affordable shipping costs, and less stress on the greenhouse frame when used in hanging baskets. Crops prone to tipping over like Easter lilies and poinsettias may require a media with a slightly higher bulk density in order to stabilize the plant (Fonteno, 1996).

**Texture:** Texture is defined as the size and distribution of particles in the mix. It affects porosity and the water holding capacity of a given medium (Dole and Wilkins, 1999).

**Porosity:** Total porosity is the percentage of the media (or component) made up of pore space. Pore space is divided into two categories, macropores and micropores. During irrigation, most pores are full of water. After irrigation, water will drain from the macropores due to gravity and be replaced by air. Water that drains from the pot after irrigation is called gravitational water. When the container of a freshly irrigated media finishes dripping, it is said to be at container capacity. The adhesive and cohesive properties of water allows the micropores to retain water. Good pore space is essential for both air and water to be available to roots. Total media porosity is determined by the relative percentages of the chosen media components, handling of the media, irrigation practices, and pot size (Fonteno, 1996).

**Unavailable plant water:** As the media dries down, eventually a point will be reached where the media can hold onto the water so tightly that it is unavailable to plant roots. This point is the permanent wilting point (PWP). All the water between field capacity and the PWP is plant available water.

## **Chemical Properties:**

**pH:** pH is a measure of the acidity or alkalinity of a growing medium by measuring the relative amount of hydrogen ions in the media solution. On a scale of 1.0 – 14.0, a pH of 7 is neutral, below 7 is acidic, and above 7 is basic (alkaline). The pH of a given media regulates the availability of plant nutrients and pH requirements can vary within plant species (Reed, 1996). The pH of a soilless media should range from 5.4 to 6.0 (Reed, 1996). For media with more than 20% soil, pH should range from 6.2 to 6.8 (Fonteno, 1996). Media pH can change in response to fertilizers, water alkalinity, and the break down of organic matter, and can even be altered by the plant.

**CEC:** Cation Exchange Capacity (CEC) is a measure of the nutrient holding capacity of a given medium. The higher CEC a growing medium has the more nutrients it can hold so a high CEC is desirable in soilless media. Components with a high CEC are peat, bark, and vermiculite. Components with a low CEC are perlite, Styrofoam, and sand (Fonteno, 1996).

**EC:** All the nutrients in the soil solution are considered soluble salts. Electrical Conductivity (EC) is a measure of the total amount of soluble salts in a media not levels of individual nutrients. In greenhouse production using soilless media, salts come from fertilizer, so EC is used to track fertilizer levels in growing media. Soluble salts may also be a result of the break down of organic components in the media or impurities in the irrigation water (Dole and Wilkins, 1999).

## **COMPONENTS**

Soilless growing media is usually composed of two or more standard components: peat moss, composted pine bark, perlite, vermiculite, and sand (Fonteno, 1996).

**Peat:** Sphagnum peat moss is the one of the most common growing medium components. The peat we use in the United States comes mainly from Canada, but also Florida. Peat is very lightweight when dry, has a high CEC, adequate aeration, and excellent water holding capacity (Dole and Wilkins, 1999).

**Bark:** While many types of composted bark are available, pine bark is what we primarily use in the southeastern United States. Composted pine bark has a high CEC, is relatively lightweight, and provides excellent aeration and drainage. There are many producers of composted pine bark so quality can vary. Bark is used extensively in nursery production (Fonteno, 1996). Poorly or incompletely aged or composted pine bark based media is known to cause nitrogen depletion (Handrek, 1993). Microorganisms immobilize nitrogen as they consume carbon. The rate at which nitrogen is immobilized is directly proportional to microbial activity.

**Perlite:** Perlite is volcanic rock heated to a very high temperature (1,800F) until it expands into a very lightweight aggregate. Because of its much lighter weight, perlite is often used as a substitute for sand and can increase aeration. It has a pH slightly above 7, almost no CEC, and is used to increase drainage and aeration in the growing medium (Fonteno, 1996).

**Vermiculite:** Vermiculite is a mined silica that is heated, much like perlite, quickly turning water trapped between the layers to steam and expanding the silica 15 to 20 times its original size. The result is stacks of tiny layers. Vermiculite has a high CEC, is very lightweight, and has an excellent water holding capacity. It can be easily compressed and therefore it is easy to destroy the beneficial structure by excessively handling or mixing. Vermiculite is available in several particle sizes, the smallest sizes are commonly used as a seed-germinating medium (Dole and Wilkins, 1996).

New components are also being introduced into the mix. Coir, a coconut processing byproduct and renewable substitute for peat (Prasad, 1997), has proven a suitable growing media component through numerous production trials (Stamps and Evans, 1997; Evans and Stamps, 1996; Meerow, 1994, 1995). Coir has physical properties similar to peat (Fonteno, 1996), doesn't break down as quickly (Meerow, 1994), and has a lower CEC (Evans et al., 1996; Prasad, 1997). However, physical and chemical properties can vary significantly among husk sources (Konduru et al., 1999; Evans et al., 1996). While no literature was found on the suitability of coir dust as a growing media component for the production of rosemary or any other herb, coir based medias have successfully been used to grow several foliage plants

including, but not limited to *Spathiphyllum* (Mak and Yeh, 2001), *Dracaena* (Stamps and Evans, 1999), *Dieffenbachia* (Stamps and Evans, 1997), and *Anthurim* (Meerow, 1995).

While Rodale's Encyclopedia of Herbs (Kowalchik and Hylton, 1987) suggests rosemary requires good drainage and recommends a cactus media for container production, the only published research on growing media as it pertains to rosemary was done by Boyle et al. (1991). They compared the growth of rosemary grown in a soilless media to that grown in a soil-based media and found the soilless media produced taller plants with a greater dry weight. Bell and Courts (1979) found similar results with the herbs lemon balm, peppermint, and sage.

Plants may grow better in one growing media than another due to differences in CEC, water holding capacity, porosity, etc. Broschat and Moore (2001) found *Salvia splendens* 'Red Vista' or 'Purple Vista', *Tagetes patula* 'Little Hero Orange', *Capsicum annuum* 'Better Bell', *Impatiens wallerana* 'Accent White', and *Begonia x semperflorens-cultorum* 'Cocktail Vodka' grown in a peat-based media (Pro Mix BX) were larger than plants grown in pine bark.

Handling of the growing medium is also very important. Fonteno et al. (1981) found media compaction (due to overhead watering in this case, but arguably settling, improper handling, or improper planting would cause the same effect) reduced the volume of the media without changing the total pore space potentially causing a decrease in the plant available water crucial for optimal growth.

Meerow (1994) found shoot dry weight of *Ixora* was much smaller in the coir-based media than the two peat-based media without a corresponding impact to the root dry weight. He surmised the cause to be a nitrogen drawdown in the coir-based mix.

## CONTAINER

Fonteno (1996) reports the height of a media column impacts the available water and air space - the taller the column, the smaller the ratio of water to airspace. At field capacity, after all gravitational water has drained out, a six-inch pot may have 20% air space in the growing medium while a one-inch plug cell of the same media may have only 2.8% air space. The rest of the pore space is filled with water. The part of the media that remains saturated after all

gravitational water has drained through is called the perched water table and is an important consideration with small containers (Fonteno, 1996).

## IRRIGATION

Considering that a plant is mostly water and almost all essential plant nutrients enter the plant in an aqueous solution, proper crop irrigation is crucial. Also, different growing media have different water holding capacities (Fonteno, 1996) compounding irrigation concerns. Soil moisture retention is considered a key factor in irrigation management (Bruce et al., 1980). The challenge is to produce the best crop with minimal water (Sinclair et al., 1984). Over-watering can lead to higher irrigation costs, increased investment in developing water supplies, chemical contamination of ground water from run off, and reduced plant quality (Welsh and Zajicek, 1993). Studies of growth responses of plants to reduced irrigation volume have found all possible outcomes; decreased growth of *Ligustrum texanum* (Jarrell et al., 1983) and *Acer rubrum* (Martin et al., 1989), increased growth of *Azalea* (Ingram and Yeager, 1986) and no change with *Acer rubrum* (Ponder et al., 1984), *Boltonia*, *Eupatorium*, or *Rudbeckia* (Prevete et al., 2000). Rosemary is reportedly easy to over-water (DeBaggio, 1987) potentially killing the plant (DeBaggio, 1990), but growth also suffers if the media is too dry. Munne-Bosch et al. (1999a) found rosemary shoot growth stunted under typical Mediterranean drought conditions. Studies examining irrigation and effects on rosemary are limited to the effects of drought on photosynthesis (Nogues and Baker, 2000), whole-shoot gas exchange (Nogues et al., 2001), and antioxidant content (Munne-Bosch et al., 1999b).

Munne-Bosch et al. (1999b) investigated the water relations, stomatal conductance, dew absorption, and CO<sub>2</sub> assimilation rate of rosemary and lavender under drought conditions. They found rosemary is very well suited to surviving drought, but not thriving in it. Stomatal conductance can drop by 50% during drought periods without any damage or adverse effects to the plant other than reduced growth. Nogues et al. (2001) found drought stressed rosemary caused a significant reduction in the CO<sub>2</sub> assimilation rates of shoots without permanently damaging the photosynthetic ability of the plant. Other plants in the Lamiaceae family have also been subjects of drought tolerance research. Munne-Bosch et al. (2001) found *Salvia officinalis*, like rosemary, protects itself against drought damage through use of its antioxidants thereby

avoiding permanent damage. Kyparissis et al. (1995) found *Phlomis* responds to drought by decreasing the amount of chlorophyll. When the drought period ends, *Phlomis* photosynthesis recovers similar to rosemary.

### **Irrigation Methods:**

**Hand watering** is common, but it is also expensive and unreliable. Generally, a worker with a hose delivers water to the crop. The high cost is attributed to the experienced and skilled labor associated with growing a uniform crop under this irrigation method. Improper irrigation can lead to dry spots in the media (Lieth, 1996).

**Sprinkler** systems spray water onto a crop from above. It is difficult to uniformly irrigate a crop without over-watering some plants. Much of the applied water misses the crop altogether and falls to the ground increasing nutrient runoff to the potential detriment of the environment. Finally, water droplets on the leaves can leave a residue (Lieth, 1996) or in some cases, burn the leaves.

**Boom irrigation** consists of a mechanical watering arm passing over the crop and is a way to uniformly irrigate a crop from above. However, these systems are very expensive and usually require some labor to move from crop to crop. Again, much of the irrigation volume is wasted by not hitting the growing medium (Lieth, 1996).

**Drip irrigation** commonly has leaching fractions as high as 40-50% (Reed, 1996), but works well in a zero leaching fraction growth regime as has been proven with poinsettias by Ku and Hershey (1996). Benefits of a drip system include better disease control, flexibility in application timing, and improved water and fertilizer use efficiency (Reed, 1996). Problems include detached or clogged emitters, the labor associated with initial set up, and the inflexibility of the system when facing several crops with different spacing requirements (Lieth, 1996).

**Ebb & flow** is a system designed to have no runoff at all. Plants are grown in large watertight trays that are flooded with a nutrient solution to about an inch, and then drained, after several



minutes, into a storage tank to be reused (Reed, 1996). While high quality plants can be produced, salt buildup in the growing medium can be a problem as can the spread of disease through the community system (Lieth, 1996).

The **trough system**, another form of subirrigation, is very similar in that it uses the same irrigation technique as ebb & flow with the difference being plants are grown in a trough running the length of the bench and not in a large watertight tray (Reed, 1996). High quality plants can be produced with this system, but it faces the same potential problems as the ebb & flow system (Lieth, 1996).

**Flooded floors** are another subirrigation system utilizing recycled water. It is very similar to the ebb & flow and trough systems, but on a much larger scale. For this system, a concrete slab must be poured with a slight angle so that once flooded, the irrigation water can drain away. As with all irrigation recirculatory systems, much less water and fertilizer are needed to produce a high quality marketable crop and foliage diseases are less likely since the foliage is not wet (Dole and Wilkins, 1999). However, while very environmentally friendly, there are many potential problems including, puddles, cracks in the concrete, a build up of soluble salts in the growing medium, and the difficulty involved with properly constructing the slab. The spread of root pathogens with this system is also a concern because workers may carry them throughout the greenhouse on their shoes (Lieth, 1996).

Drip irrigation and the sub-irrigation systems listed above cite the build up of soluble salts in the growing medium as a potential problem. Leaching fraction (LF), described by Hershey and Paul (1982) as the volume of solution leached from the pot divided by the total solution applied, is often used to lower salt concentrations in the growing medium (Reed, 1996). According to Kerr and Hanan (1985) the fertilizer concentration of the leaching water does not affect the amount of salts leached, but it does affect the concentration of salts remaining. While working with poinsettia, Ku and Hershey (1991) found an LF of 10-20% caused media EC to rise over time while an LF of 40% kept the growing media EC stable. Some plants, like poinsettia (Ku and Hershey, 1996) can be grown at a 0% leaching fraction if the fertilizer concentration is reduced from 300 to 100 mg·L<sup>-1</sup>. Conover and Poole (1981) found using less water and watering more

often, essentially eliminating leaching, produces the same quality plants as those grown at higher leaching fractions. McAvoy (1994) found a high leaching fraction produced a significantly larger chrysanthemum crop, but at a serious expense to the soil under his greenhouse bench. After only two weeks, nitrate concentration in the top 15 cm of soil was 3.4 times higher under the high leaching fraction than the low. At ten weeks, the nitrate concentration in the top 40 cm of soil was almost twice as high under the high leaching fraction than the low. McAvoy et al. (1992) found a higher leaching fraction moved nitrate deeper into the soil profile and at higher accumulations than a lower leaching fraction. For these reasons, it is important for researchers to determine minimal leaching fractions that will produce acceptable plants.

## NUTRITION

Little of the nutrition required to produce marketable plants is available from soilless growing media alone (Fonteno, 1996). In addition, nutrient deficient plants may be more susceptible to damage from stresses (Jones, 1998). Concerns of excess fertilizer contaminating the environment are also being raised (McAvoy, 1994; McAvoy et al. 1992). For these reasons, it is important for growers to provide as little fertilizer as possible while still providing adequate nutrition to produce marketable plants.

Growth response to irrigation volume may vary with fertilization rate (Yelanich and Biernbaum, 1990, 1993) and plant growth stage [chrysanthemum (King and Stimart, 1990) and poinsettia (Argo and Biernbaum, 1991; Rose et al., 1999)]. Furthermore, to economically produce high quality crops, it is important to use no more fertilizer than necessary (Broschat and Moore 2001). Many studies have been conducted to determine optimal growth with minimal fertilization [*X Cupressocyparis leylandii* (Bilderback, 1985), *Cryptomeria japonica* ‘Elegans Aurea’ (Jull et al., 1994), *Cupressus arizonica* var. *glabra* ‘Carolina Sapphire’ (Stubbs et al., 1997), and *Euphorbia pulcherrima* (Ku and Hershey, 1997; Yelanich and Biernbaum, 1993, 1994)].

A variety of fertilizer forms are available to growers. Controlled release fertilizer (CRF) is a one-time application fertilizer that will release nutrients slowly into the growing medium over the course of the crop cycle (Dole and Wilkins, 1999). It may be incorporated into the medium or used as a top dress. Reed (1996) reports controlled release fertilizers have the major

disadvantage of having the release rate fixed until the time release finishes therefore not allowing the grower to adjust the rate of fertilization. Water-soluble fertilizer offers much more flexibility as it can be added as often as necessary. Constant Liquid Feed (CLF) or fertigation (Dole and Wilkins, 1999) is the practice of adding fertilizer at each watering.

Yelanich and Biernbaum (1993) found of three fertilizer concentrations (7, 14, or 28 mol N/m<sup>3</sup>) and four leaching fractions (0, 15, 30 and 55%), the largest poinsettias were grown at the lowest fertilizer rate and lowest leaching fraction (15%). Similarly, Ku and Hershey (1996) found poinsettias could be successfully grown at a 0% leaching fraction, but bigger plants were grown at higher fertilization rates (100 to 300 mg·L<sup>-1</sup> N).

Boyle et al. (1991) investigated the effect of controlled release fertilizer, liquid feed, and various combinations of the two on growth of rosemary finding the treatment with the most fertilizer (4.5 g/pot Sierra 12N-5.2P-12.5K controlled release plus 150 mg·L<sup>-1</sup> N Peters 20N-4.3P-16.7K constant liquid feed) produced the smallest plants. They did not report which fertilizer concentration used in constant liquid feed resulted in the largest plants. Bell and Courts (1979) found just the opposite for lemon balm, peppermint, and sage - all in the same family as rosemary – finding all three taller and with a greater fresh weight at 300 mg·L<sup>-1</sup> N weekly than 50, 100, or 200 mg·L<sup>-1</sup> N weekly.

## **MEDIA MOISTURE MEASUREMENT TECHNIQUE**

According to Rose et al. (1999) much of the published research involving nutrition of container grown plants based irrigation on the number of days between watering without regard to the moisture status of the growing medium. This can result in under-watering or over-watering depending on the environmental conditions. For this reason, we based our irrigation treatment on soil moisture percentage determined by a Theta Probe moisture meter.

Several methods have been developed to measure soil moisture. The lysimeter or other gravimetric methods are the most accurate as they directly measure soil moisture (Kramer and Boyer, 1995) however they are often large and measurements can be very time consuming. Other direct measurement techniques require growing media be removed from the container thus

lessening the potential rooting volume of the plant. For this reason, measuring soil moisture without disturbing the soil is important if measurements are to be repeated daily over the course of several months. Several indirect measurement techniques have been developed.

**Tensiometers** measure soil water by measuring the matric potential ( $\Psi_m$ ). A water filled tube with a porous ceramic tip on one end and a vacuum gauge on the other is inserted into the soil. As the soil dries down, the tension on the water column inside the tube increases and is measured by the vacuum gauge. In very dry soils, the tension may be so great as to cause air bubbles to pull through the ceramic tip thereby altering the accuracy of the measurement (Kramer and Boyer, 1995).

**Neutron scattering** is a technique used for mineral soils that takes advantage of the ability of hydrogen to slow down fast moving neutrons. A probe with a source of fast moving neutrons and a counter to keep track of slow moving neutrons is inserted in the soil. Since water is the major source of hydrogen ions in the soil, a measure of the hydrogen ion concentration is in effect a measure of the soil moisture. Other sources of hydrogen in the soil, such as organic matter, may alter the accuracy of the reading (Kramer and Boyer, 1995).

**Gamma ray attenuation** is another method used for mineral soils and utilizes the ability of water to impede radiation. A frame with a radiation source on one side and a gamma ray receptor on the other can measure the amount of water in the soil by measuring the percentage of radiation received minus the amount of radiation sent (Kramer and Boyer, 1995).

The **Time Domain Reflectometer** (TDR) takes advantage of the di-electric constant of water (~81) being so much higher than that of dry soil (~5) and air (~1). For this reason, the di-electric constant of moist soil is almost entirely determined by the amount of water it holds. The TDR probe sends an electric charge down metal rods that extend into the soil and measures the fraction reflected. Water is the primary impediment so by measuring the reflected charge, it effectively measures the amount of water in the sample area (Kramer and Boyer, 1995). Richardson et al. (1992) proved this technique is acceptable to determine the volumetric moisture percentage of soil in containers.

We used a ThetaProbe (ML2x; Delta-T Devices Ltd, Cambridge, U.K.) that utilizes the TDR method for determining soil moisture because of the speed and accuracy provided by the system.

## MEDIA TESTING

To ensure the optimum growth of a crop, it is advised to monitor plant roots as well as the above ground portion of the plant (Dole and Wilkins, 1999). Whipker and Hammer (1992) suggest thinking of it as an insurance policy for the crop. Visually monitoring the crop is the simplest, but it is also unreliable in the long run. By the time above ground symptoms are noticed on leaves or stems, damage has already been done to the plant potentially reducing the quality of the crop (Dole and Wilkins, 1999). Monitoring pH and EC with a portable pH/EC meter like the Hanna 9811 (Hanna Instruments, Inc. Woonsocket, RI) is a quick and inexpensive way to track the changes in the growing medium of a plant over the crop cycle and therefore allows adjustments to be made before any damage has been done to the crop.

Saturated Media Extract (SME), the 1:2 ratio media:water (v/v), the 1:5 ratio, and the pour through method are all established methods for monitoring the pH and EC of your soil solution. SME requires growing media sit in just enough distilled water to cover the soil sample for 30 minutes to come into equilibrium with the soil solution. After the equilibrium has been established, the solution is filtered and pH/EC tests are performed on the extract (Lang, 1996)

The 1:2 and 1:5 ratio are very similar to each other and to the SME method. One quarter to one half a cup of media is mixed with either two parts or five parts distilled water. After being allowed to sit for fifteen to thirty minutes to reach equilibrium with the soil, the solution is filtered and pH/EC tests are performed on the filtered solution (Lang, 1996).

These three systems require a portion of the growing medium be removed from an actively growing plant. To minimize the impact on the plant and to maximize the usefulness of the results, it is recommended that the tested media come from many plants in the crop.

The pour through method (Wright, 1986) does not require a disturbance to the root zone of a crop. An hour after irrigation, while the media is still close to saturated, a known volume of distilled water is poured onto the growing medium. The volume varies depending on the size of the pot. The idea is to displace the solution already in equilibrium with the growing medium without watering down the collected sample. The displaced water is collected in a tray or saucer under the pot and the pH/EC tests are then conducted using the leachate (Lang, 1996).

## TISSUE TESTING

If a grower’s routine media tests reveal a pH approaching the outer limits of acceptability or if they observe what appear to be nutrient deficiencies in the foliage, they may opt for a foliar tissue test. Directly measuring the concentration of nutrients in the plant gives tissue testing an advantage over media testing. However, tissue tests do not include pH and EC, so media tests should be included in addition to the tissue sample sent for testing (Dole and Wilkins, 1999). Established sufficiency ranges exist for a wide variety of crops (Mills and Jones, 1996). Table 1.2 lists the sufficiency ranges for tissue nutrient content.

Table 1.2. Sufficiency ranges of essential nutrient levels in leaf tissue of rosemary (*Rosmarinus officinalis* L.) ‘Arp’ and ‘Tuscan Blue’ grown from cuttings (Mills and Jones, 1996)

| Macronutrients<br>% dry weight |             | Micronutrients<br>ppm |             |
|--------------------------------|-------------|-----------------------|-------------|
| N                              | 1.64 – 1.96 | Fe                    | 41 – 109    |
| P                              | 0.19 – 0.29 | Mn                    | 19 – 92     |
| K                              | 1.84 – 2.08 | B                     | 21 – 27     |
| Ca                             | 0.43 – 0.55 | Cu                    | 3 – 6       |
| Mg                             | 0.16 – 0.17 | Zn                    | 30 – 36     |
| S                              | 0.16 – 0.18 | Mo                    | 0.33 – 0.89 |

## KNOWN CULTURAL PRACTICES FOR ROSEMARY

**Propagation:** DeBaggio (1990) reports rosemary is difficult to grow from seed due to sporadic germination, so propagation is almost exclusively from rotted cuttings. The recommended technique is to strip leaves from the lower half of a four inch cutting, dip the stripped end in a rooting hormone, and stick it in a peat-based rooting medium with bottom heat around 75-80° F (DeBaggio, 1990). Rooting should occur within two weeks though Long (1998) noted a delayed rooting time during the hottest part of the summer. Transplant the rooted cutting into a larger container being careful to not plant it deeper than it was planted before. Pinching the new plant immediately after transplanting will to increase branching (DeBaggio, 1990).

**Growing media and fertilizer:** Boyle et al. (1991) recommend a soilless or soil based growing medium with control of irrigation and fertilization. They also found low rates of fertilizer (12N-5.2P-12.5K controlled release fertilizer or 20N-4.3P-16.7K liquid feed once a week at a concentration of 150 mg·L<sup>-1</sup> N) produced larger plants than higher fertilizer rates.

**Stress Symptoms** include gray, upward turned leaf tips indicating a lack of water, yellow leaves at the plant base indicating nutrition problems or restricted rooting area, and brown leaf tips progressing to dead brown leaves indicating over-watering. Rosemary is especially sensitive to over-watering immediately after transplanting (DeBaggio, 1987).

## PESTS AND PATHOGENS

Pest problems are uncommon for this plant. *Rhizoctonia solani* is known to cause a foliar blight and root rot on rosemary. Kalra et al. (1993) describe the foliar blight of *R. s.* AG-1 as necrotic lesions normally found at the tips of leaves. This strain has been found to have a larger detrimental affect on the prostrate forms of rosemary (Holcomb, 1992). Conway et al. (1997) document *R. s.* AG-4 as a potential problem for rosemary cuttings under mist systems and suggest a combination of the biological control *Laetisaria arvalis* and the experimental fungicide CGA 173506 as an effective control. Holcomb (1992) also lists powdery mildew caused by *Sphaerotheca fuliginea* as a minor pathogenic problem. Finally, DeBaggio (1987) states *Botrytis* can be a problem if plants do not have adequate air circulation, but suggests proper spacing as a simple solution.

Insect pests are equally infrequent. DeBaggio (1990) lists mealy bugs, white flies, and spider mites as the major offenders suggesting a regular spray program with insecticidal soap for control.

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## **EFFECT OF FERTILIZER CONCENTRATION AND IRRIGATION RATE ON GROWTH OF *ROSMARINUS OFFICINALIS***

***Abstract.* *Rosmarinus officinalis* L. (rosemary) is popular as a culinary herb, landscape plant, and potted florist crop. Little research has been reported on the greenhouse production of this plant. Effects of fertilizer concentration and irrigation rate on root and shoot growth were investigated for *R. officinalis* ‘Athens Blue Spires’. In the first experiment, rooted cuttings were potted and received fertilizer treatments of 100, 200, or 300 mg·L<sup>-1</sup> nitrogen (N) from 15N-2.2P-12.2K water-soluble fertilizer for twelve weeks. Two irrigation regimes were imposed - plants were irrigated with fertilizer solution when the growing media dried down to less than 30% or 20% volumetric soil moisture content. Irrigation rate did not affect root growth, but the higher irrigation rate produced larger shoots at all fertilizer concentrations. The largest roots and shoots were produced at the lowest fertilizer concentration. In the second experiment, rooted cuttings of the same cultivar were potted and received fertilizer treatments of 50, 100, 150, or 200 mg·L<sup>-1</sup> N from 15N-2.2P-12.2K water-soluble fertilizer. Plants were irrigated with fertilizer solution when the growing media dried down to less than 40%, 30%, or 20% volumetric soil moisture content. Plants were harvested at two, four, six, or eight weeks. Neither irrigation nor fertilizer affected root or shoot dry weight at week two, six, or eight. Irrigation affected roots at week four with the lowest irrigation rate producing the largest roots at all fertilizer concentrations except 100 mg·L<sup>-1</sup> at the less than 30% irrigation rate. Irrigation also affected shoots at week four with the lowest irrigation rate producing the largest shoots at all fertilizer concentrations except 100 mg·L<sup>-1</sup> at the less than 30% irrigation rate. Our results indicate rosemary can be grown successfully at low fertilizer concentrations and at any of the irrigation rates tested.**

## Introduction

Native to the Mediterranean region, Portugal, and northwestern Spain (Kowalchik and Hylton, 1987), rosemary (*Rosmarinus officinalis* L.) is popular as a culinary herb, landscape plant, and potted florist's crop (DeBaggio, 1987,1990) and is also an important spice and antioxidant in processed foods (Chipault et al., 1952, 1956).

Very little research is published regarding the greenhouse production of rosemary or any other herb. Boyle et al. (1991) found rosemary does not respond well to high levels of fertilizer, but they did not determine the ideal fertilizer concentration for a plant produced under a constant liquid feed (CLF) fertigation regime. Bell and Courts (1979) found just the opposite for lemon balm, peppermint, and sage- all in the same family as rosemary – finding all three taller and with a greater fresh and dry weight at 300 mg·L<sup>-1</sup> N weekly than 50, 100, or 200 mg·L<sup>-1</sup> N weekly. Research validating concerns of excess fertilizer contaminating the environment (McAvoy 1994; McAvoy et al, 1992) make it important for growers to use as little fertilizer as possible while still providing adequate nutrition to produce marketable plants.

Growth information regarding the irrigation of rosemary is also lacking. While over-watering can potentially kill the plant (DeBaggio, 1990), growth rate is also reduced if the media is too dry (Munne-Bosch et al., 1999). According to Rose et al. (1999) much of the published research involving nutrition of container grown plants based irrigation on the number of days between watering without regard to the moisture status of the growing medium. This can result in under-watering or over-watering depending on environmental conditions. For this reason, we based our irrigation treatment on volumetric soil moisture content.

The objective of the following experiments was to determine the fertilizer concentration and irrigation regime that most promoted the growth of greenhouse grown rosemary.

## Materials and Methods

### *Experiment 1.*

On 2 Nov. 2001, rooted rosemary 'Athens Blue Spires' cuttings (82 per flat) from Yoder Greenleaf (Lancaster, PA) were transplanted individually into 15.2 cm pots (Dillen Products Middlefield, OH) using Fafard 3B [(45% peat moss, 25% pinebark, 15% perlite, and 15% vermiculite) (Conrad Fafard, Inc. Agawam, MA)] soil-less media. The plants were grown in a glass house located on the Virginia Tech campus in Blacksburg, VA with a daytime temperature of 24 to 29°C (75 to 84°F) and a nighttime temperature of 18 to 21°C (64 to 70°F).

Six treatments – three fertilizer concentrations each at two irrigation rates – began two weeks after planting (WAP) and continued for fourteen weeks until termination. 15N-2.2P-12.5K (15-5-15) Cal-Mag fertilizer (Miracle Gro Professional EXCEL; The Scotts Co. Marysville, OH) was mixed into irrigation water at concentrations of 100, 200, and 300 mg·L<sup>-1</sup> N. Media pH and electrical conductivity (EC) were monitored every two weeks using the Virginia Tech Extraction Method (Wright, 1986).

Irrigation treatments consisted of 250 ml aliquots of the fertilizer treatment when the media averaged below high or low volumetric soil moisture content (VSMC) percentages, less than 30% and 20% respectively. Growing media VSMC was determined daily for each plant with a ThetaProbe soil moisture meter (ML2x; Delta-T Devices Ltd, Cambridge, U.K.). All plants of a treatment were irrigated when the average moisture percentage for that treatment fell below the VSMC threshold. Fertigation volume was increased to 350 ml at the end of week six to maintain the leaching fraction (LF) of 20 to 30%. Leaching fraction was determined by dividing the volume of solution leached from the pot by the total solution applied.

On week fourteen, the plant shoot was cut at the soil line and roots removed and hand-washed. Root and shoot dry weight was determined following drying at 66°C (150°F).

The experiment was arranged in a completely randomized design with ten replicates. The treatment design was a 3 x 2 factorial with three fertilizer



concentrations and two irrigation rates for a total of six treatments. Data were analyzed by ANOVA and regressions performed on significant effects using SAS Version 8 (SAS Institute, Inc., Cary, N.C.).

### *Experiment 2.*

On 2 Dec. 2002, rooted rosemary 'Blue Spires' cuttings (82 per flat) from Yoder Greenleaf (Lancaster, PA) were potted individually into 10.2 cm pots (T.O. Plastics, Inc. Bloomington, MN) using Fafard 3B soilless media. The plants were grown in a glass house located on the Virginia Tech campus Blacksburg, VA at a daytime temperature of 24 to 29°C (75 to 84°F) and a nighttime temperature of 18 to 21°C (64 to 70°F).

Twelve treatments – four fertilizer concentrations each at three irrigation levels – began immediately after planting and continued for 2, 4, 6, 8 weeks depending on harvest date. 15N-2.2P-12.5K (15-5-15) CalMag fertilizer was mixed into the irrigation water at concentrations of 50, 100, 150, and 200 mg·L<sup>-1</sup> N. Media pH and electrical conductivity (EC) were collected, using the Virginia Tech Extraction Method (Wright: 1986), from each plant at harvest.

An additional irrigation regime was imposed relative to the previous experiment. Plants were irrigated with 350 ml of 50, 100, 150, or 200 mg·L<sup>-1</sup>N fertilizer solution when the growing media for the treatment averaged less than 40%, 30%, or 20% volumetric soil moisture content as determined by the Theta probe. At the end of week six, the fertigation volume increased to 450 ml to maintain the leaching fraction of 30 to 40%.

At each harvest date, the plant shoot was cut at the soil line and roots removed and hand-washed. Root and shoot dry weight was determined following drying at 66°C (151°F).

The experiment design was a randomized complete block with four blocks. The treatment design was a 4 x 3 factorial with four fertilizer concentrations by three irrigation levels for a total of 12 treatments. Each block contained four of each

treatment – one for each harvest. Data were analyzed by ANOVA and regressions performed on significant using SAS Version 8 (SAS Institute, Inc., Cary, N.C.).

## Results and Discussion

### *Fertilizer:*

Fertilizer concentration significantly affected both roots and shoots in experiment one (Table 2.1). At both irrigation rates, the lower fertilizer concentrations (100 and 200 mg·L<sup>-1</sup> N) produced the largest shoot dry weights and the 100 mg·L<sup>-1</sup> N treatment produced the largest root dry weights (Table 2.2). In experiment two, fertilizer had no effect on either shoots or roots (Table 2.3). Boyle et al. (1991) found low levels of fertilizer promoted the growth of rosemary more than high levels. Our results support these findings. The steady rise of EC (Figure 2.1) and pH (2.3) near the conclusion of the first experiment in the higher fertilizer treatments may have caused the depressed root and shoot dry weights. The lower fertilizer concentrations and the increased leaching fraction utilized in the second experiment reduced EC (Figure 2.2) and raised pH (Figure 2.4) and may have helped avoid the detrimental impact of the high fertilizer concentrations seen in the first experiment.

Mak and Yeh (2001) found maximum root dry weights at the lowest fertilizer concentration (4 mM N) with *Spathiphyllum*. They thought it may be a measure of the salinity sensitivity of the plant. Rosemary is thought to be very salt tolerant (Dirr, 1990), but our largest shoot dry weights were a product of the lowest fertilizer concentration (100 mg·L<sup>-1</sup> N). Our results indicate rosemary can successfully be grown at a fertilizer rate as low as 50 mg·L<sup>-1</sup> N constant liquid feed.

### *Irrigation:*

Irrigation rate significantly impacted shoots in experiment one with the highest irrigation rate (less than 30 % SVMC) producing the largest shoots at all fertilizer concentrations (Table 2.2). Irrigation treatments did not affect root growth in this

experiment. There were no significant fertilizer x irrigation interactions for either experiment.

Irrigation rate was not significant for shoot or root growth at week two, six, or eight in experiment two (Table 2.3). In week four however, shoot and root growth were significantly greater at the lowest irrigation rate (less than 20% SVMC) at all fertilizer concentrations except 100 mg·L<sup>-1</sup> N where the middle irrigation rate (less than 30% SVMC) produced the largest RDWs and SDWs. This may support DeBaggio's claim that rosemary is particularly sensitive to over-watering after transplant.

While rosemary is reportedly easy to over-water (DeBaggio, 1990), the greater SDWs produced by the higher irrigation rate in experiment one may be explained by Munne-Bosch et al. (1999) who found whole shoot CO<sub>2</sub> assimilation rates of drought stressed rosemary decreased by 75% and accompanied a substantial reduction in photosynthetic rate. A temporary growth slow down was the only detrimental effect.

In the first experiment, shoot dry weight was negatively correlated with EC ( $r = -0.41$ ) as was root dry weight ( $r = -0.57$ ), indicating growth of rosemary is promoted by lower levels of soluble salts in the growing medium. PH was positively correlated with shoot dry weight ( $r = 0.45$ ) and root dry weight ( $r = 0.57$ ) indicating a higher pH is more conducive to the growth of rosemary.

In the second experiment, EC was slightly positively correlated to root growth ( $r = 0.24$ ) indicating the roots of rosemary are more sensitive to soluble salt levels than the shoots. In both experiments, EC was strongly negatively correlated with pH ( $r = -0.87$ ) which is common for acidifying fertilizers.

Our results indicate rosemary is a very salt tolerant plant. It can successfully be grown at a range of fertilizer concentrations though the lower concentrations produce larger plants. It can also be produced at a range of irrigation rates though the higher rates may produce larger plants.

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Table 2.1. Analysis of variance summary for fertilizer concentration and irrigation rate effect on shoot dry weight (SDW) and root dry weight (RDW) of *Rosmarinus officinalis* L. ‘Athens Blue Spires’ over time in experiment 1.

| Source         | DF | SDW         |         | RDW         |         |
|----------------|----|-------------|---------|-------------|---------|
|                |    | Mean Square | P-value | Mean Square | P-value |
| Fertilizer (F) | 2  | 7.98        | 0.0003* | 2.55        | <.0001* |
| Irrigation (I) | 1  | 20.9        | <.0001* | 0.13        | 0.3090  |
| F x I          | 2  | 1.84        | 0.1283  | 0.23        | 0.1594  |

\*Significant at  $P \leq 0.05$

Table 2.2. Effect of fertilizer concentration and irrigation on main effects of shoot dry weight (SDW) and root dry weight (RDW) of *Rosmarinus officinalis* L. ‘Athens Blue Spires’ over time in experiment 1.

|                          | SDW (g)             | RDW(g) |
|--------------------------|---------------------|--------|
| Irrigation               |                     |        |
| < 30%                    | 9.50 a <sup>z</sup> | 1.55 a |
| < 20%                    | 8.32 b              | 1.46 a |
| Fertilizer               |                     |        |
| 100 mg·L <sup>-1</sup> N | 9.46 a              | 1.91 a |
| 200 mg·L <sup>-1</sup> N | 9.05 a              | 1.39 b |
| 300 mg·L <sup>-1</sup> N | 8.22 b              | 1.24 b |

<sup>z</sup>Mean separation within a column by the LSD *t* test.

Table 2.3. Analysis of variance summary for fertilizer concentration and irrigation effect on shoot dry weight (SDW) and root dry weight (RDW) of *Rosmarinus officinalis* L. ‘Blue Spires’ over time in experiment 2.

| Source         | DF | SDW p values   |        |       |       | RDW p values |        |       |       |
|----------------|----|----------------|--------|-------|-------|--------------|--------|-------|-------|
|                |    | 2 <sup>z</sup> | 4      | 6     | 8     | 2            | 4      | 6     | 8     |
| Block          | 4  | 0.860          | 0.375  | 0.639 | 0.797 | 0.067        | 0.471  | 0.235 | 0.998 |
| Fertilizer (F) | 3  | 0.944          | 0.076  | 0.974 | 0.647 | 0.852        | 0.071  | 0.404 | 0.574 |
| Irrigation (I) | 2  | 0.753          | 0.043* | 0.079 | 0.169 | 0.661        | 0.048* | 0.910 | 0.574 |
| F x I          | 6  | 0.667          | 0.095  | 0.137 | 0.961 | 0.446        | 0.202  | 0.060 | 0.662 |

\*Significant at  $P \leq 0.05$

<sup>z</sup>Weeks after planting



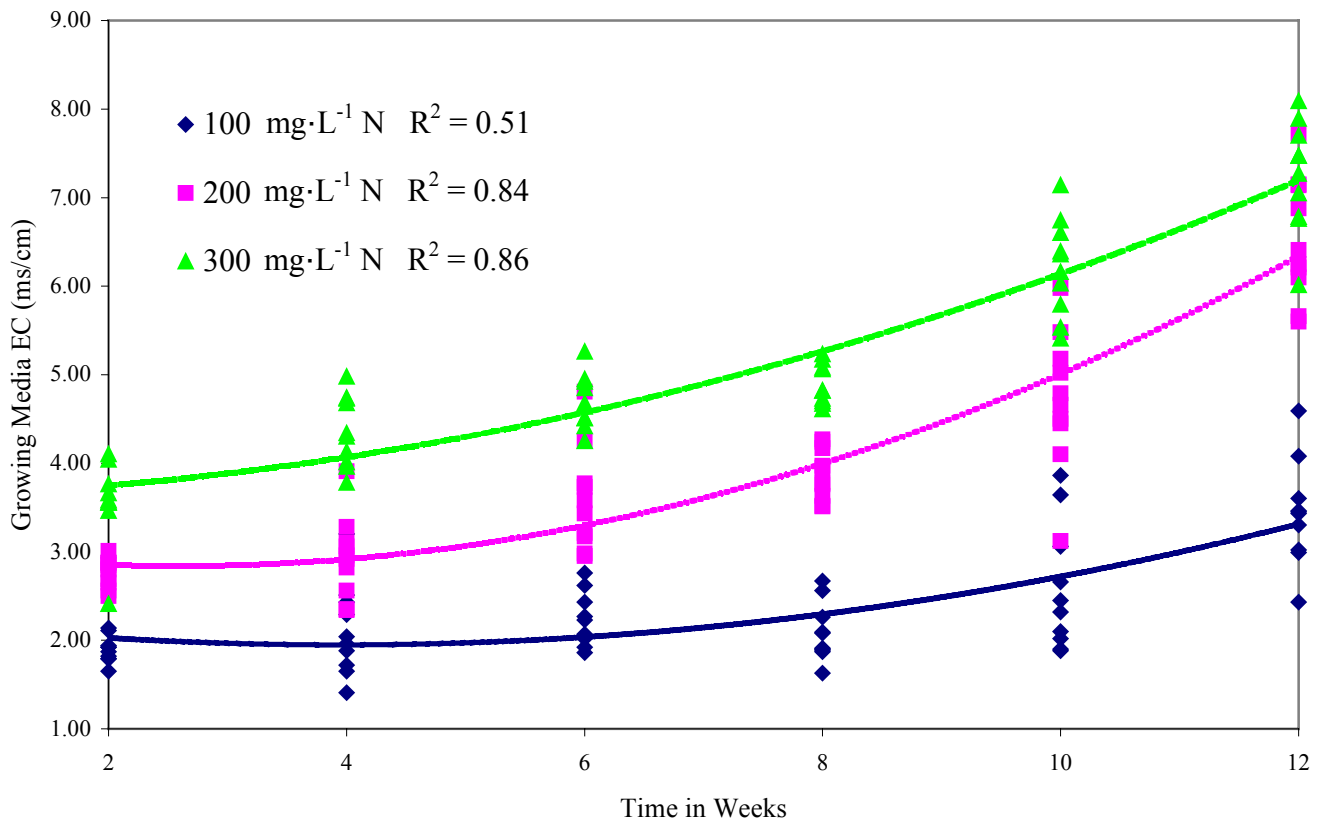


Figure 2.1. Growing media electrical conductivity (EC) over time in weeks at three fertilizer concentrations (100, 200, and 300 mg·L<sup>-1</sup> N) for *Rosmarinus officinalis* L. ‘Athens Blue Spires’ in experiment 1.

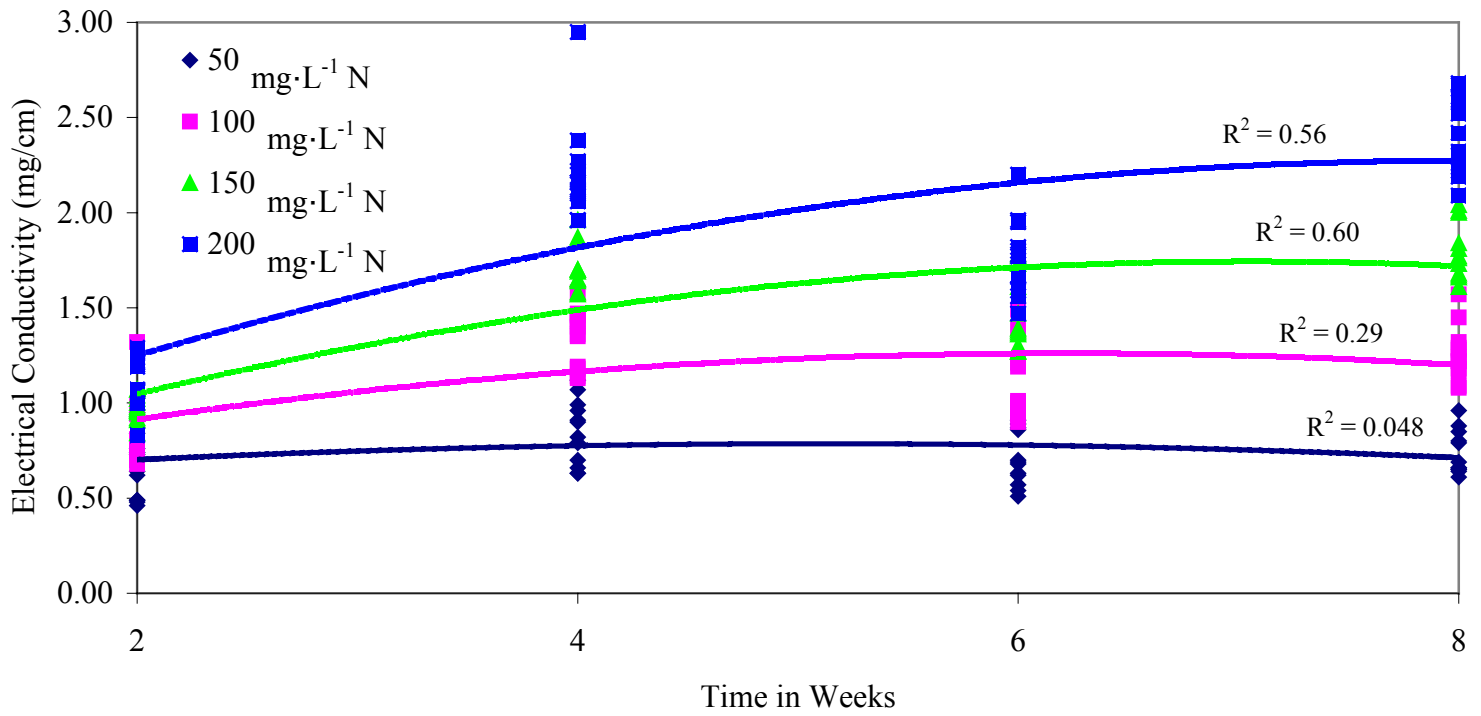


Figure 2.2. Growing media electrical conductivity (EC) over time in weeks at four fertilizer concentrations (50, 100, 150, and 200 mg·L<sup>-1</sup> N) for *Rosmarinus officinalis* in experiment 2.

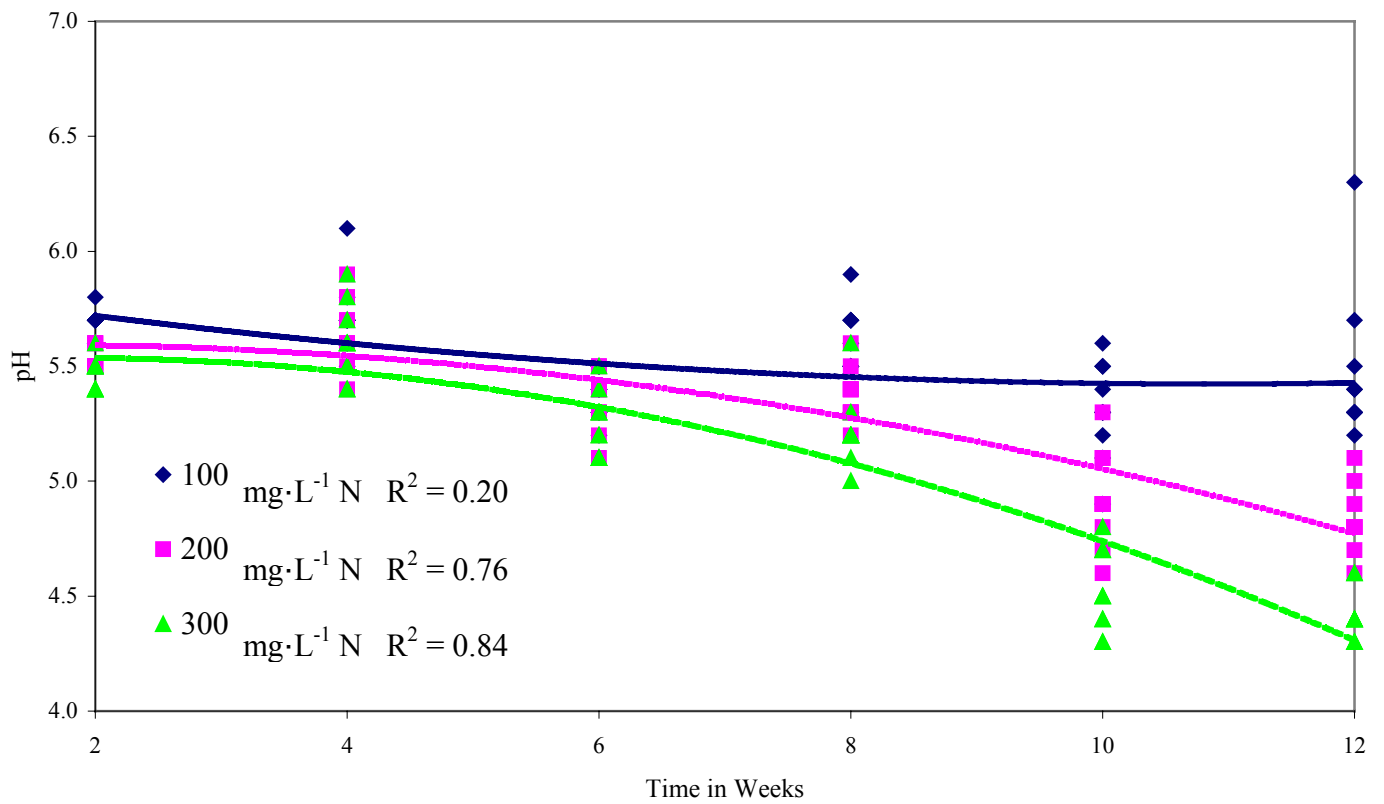


Figure 2.3. Growing media pH over time in weeks at three fertilizer concentrations (100, 200, and 300 mg·L<sup>-1</sup> N) for *Rosmarinus officinalis* in experiment 1.

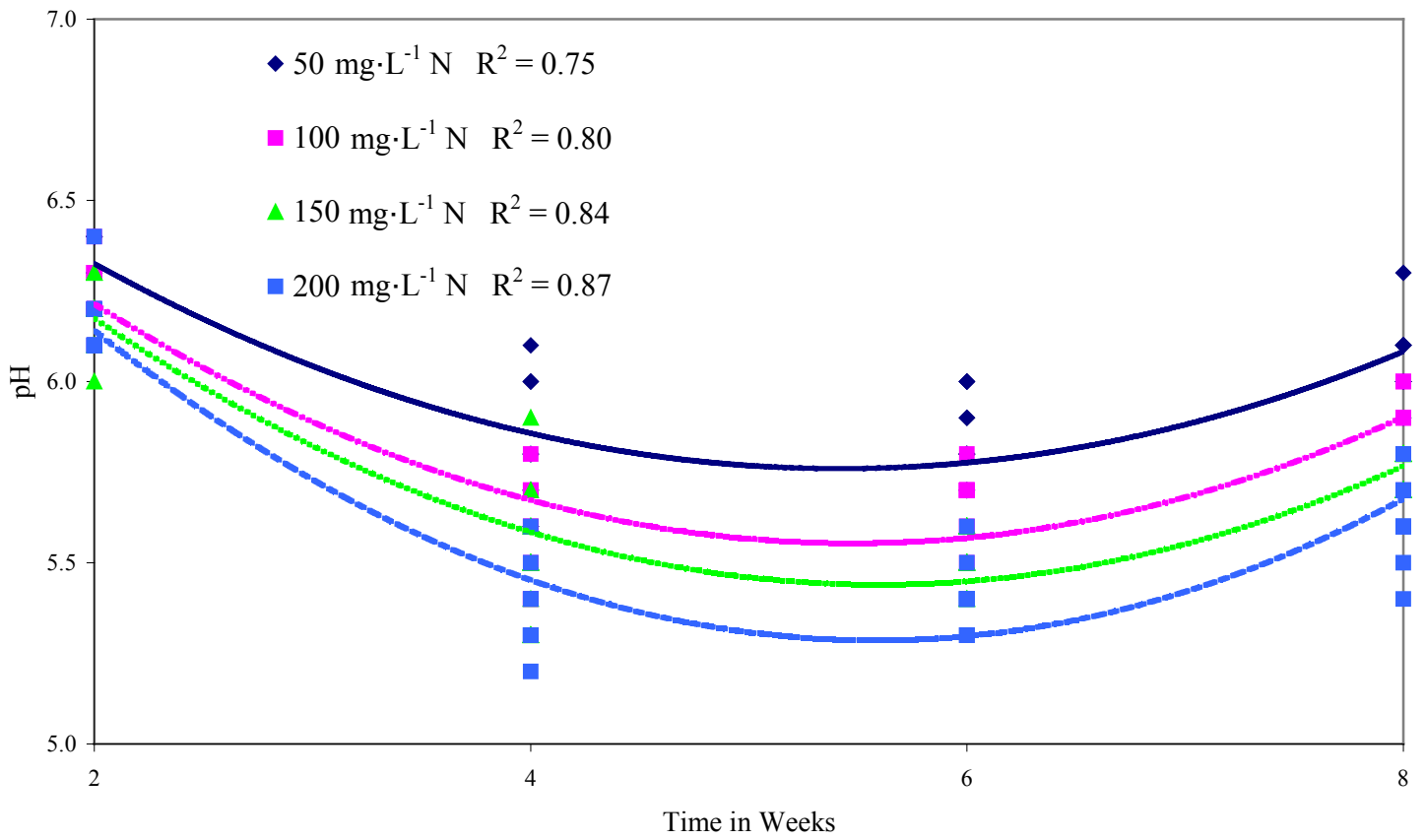


Figure 2.4. Growing media pH over time in weeks at four fertilizer concentrations (50, 100, 150, and 200 mg·L<sup>-1</sup> N) for *Rosmarinus officinalis* in experiment 2.

## EFFECT OF GROWING MEDIUM AND IRRIGATION RATE ON GROWTH OF *ROSMARINUS OFFICINALIS*

**Abstract.** *Rosmarinus officinalis* L. (rosemary) is a popular herb with many uses, but little research has been reported on the greenhouse production of this plant. Effects of growing media and irrigation rate on root and shoot growth were investigated for *R. officinalis*. In the first experiment, *R. officinalis* ‘Athens Blue Spires’ rooted cuttings were potted in five different soilless media [Fafard 52 (24% peat, 60% bark, 8% perlite, 8% vermiculite); Fafard 3B (45% peat, 25% bark, 15% perlite, 15% vermiculite); Scott’s Sierra Perennial Mix (25% peat, 65% bark, 10% perlite); Scott’s Metro Mix 700 with Coir (25% coir, 50% bark, 10% perlite, 15% vermiculite); and a nursery mix (89% pine bark, 11% sand)]. Plants were irrigated for 14 weeks with 150 mg·L<sup>-1</sup>N fertilizer solution when the growing media dried down to less than 30% or 20% volumetric soil moisture content. Growing media affected shoot dry weight with the highest-percentage peat media (Fafard 3B) producing the largest plants. All were of marketable quality. Irrigation rate did not affect root dry weight, but the higher rate produced larger shoots in each of the five media. The second experiment examined the growth of *R. officinalis* ‘Tuscan Blue’ rooted cuttings when planted in five different growing media [Fafard 52, Fafard 3B, Scott’s Perennial, Metro Mix 560 with coir (30% coir, 15% peat, 40% bark, and 15% perlite), and 100% pine bark]. Plants were irrigated with 150 mg·L<sup>-1</sup>N fertilizer solution when the growing media dried down to less than 40%, 30%, or 20% volumetric soil moisture content. Treatments lasted for 2, 4, 6, or 8 weeks and plants were harvested at the end of each treatment. Neither media nor irrigation affected root or shoot dry weight at weeks four or eight. However, at week two, media affected root dry weight with the heaviest roots produced by the two perennial mixes (Scott’s perennial and Fafard 52). Growing media affected shoot dry weight at week six with the highest-percentage peat media (Fafard 3B) producing the largest plants at both the low and high irrigation rate. Irrigation also affected root dry weight at week six with the two lowest irrigation rates producing the heaviest roots in all

**media. Our results indicate rosemary can be grown successfully in any of the six growing medias tested and at any of the three irrigation rates tested.**

## **Introduction**

Native to the Mediterranean region, Portugal, and northwestern Spain (Kowalchik and Hylton, 1987), rosemary (*Rosmarinus officinalis*) is an important herb in the kitchen and the landscape (Armitage, 1997). Essential oil from the leaves of rosemary has even been used in perfumes and medicine (Liberty Hyde Bailey Hortorium, 1976). In recent years it has also gained popularity as a potted crop at Christmas (DeBaggio, 1987).

Soilless media is commonly used for growing greenhouse crops. Research of growing media is crucial for different media may affect a plant species in different ways. As percentages of different components change, so might physical and chemical properties of the growing media (Fonteno, 1996). Composted pine bark, a byproduct of the forest industry, is commonly used in containerized nursery production due to the light weight, low cost, and stability of the component (Dole and Wilkins, 1999). Peat moss, a non-renewable resource, is a commonly used component in soilless mixes intended for annual production due to the high water holding capacity and CEC of the component (Dole and Wilkins, 1999). Coir, a coconut processing byproduct and renewable substitute for peat (Prasad, 1997), has proven a suitable growing media component through numerous production trials (Stamps and Evans, 1997; Evans and Stamps, 1996; Meerow, 1994, 1995). While no literature was found on the suitability of coir dust as a growing media component for the production of rosemary, coir based medias have successfully been used to grow several foliage plants including, but not limited to *Spathiphyllum* (Mak and Yeh, 2001), *Dieffenbachia* (Stamps and Evans, 1996), and *Anthurim* (Meerow, 1995).

Rodale's Encyclopedia of Herbs (Kowalchik and Hylton, 1987) suggests rosemary requires good drainage and recommends a cactus media for container production. Boyle et al. (1991) conducted the only published research on growing media for rosemary finding the growth of rosemary grown in a soilless media was taller with higher fresh and dry shoots weights compared to that grown in a soil-based media. Bell and Courts (1979) found similar results with the herbs lemon balm, peppermint, and sage.

Growth information regarding the irrigation of rosemary is also lacking. While Munne-Bosch et al. (1999) found growth rate of rosemary is reduced if the growing media is too dry and DeBaggio (1990) reported over-watering can potentially kill the plant, neither attempted to determine the ideal irrigation rate. According to Rose et al. (1999) much of the published research involving nutrition of container grown plants based irrigation on the number of days between watering without regard to the moisture status of the growing medium. This can result in under-watering or over-watering depending on environmental conditions. For this reason, we based our irrigation treatment on volumetric soil moisture content.

The objective of the following experiments was to determine the growing medium and irrigation regime that most promoted growth of greenhouse grown rosemary.

## **Materials and Methods**

### *Experiment 1.*

On 16 Oct. 2001, rooted rosemary ‘Athens Blue Spires’ cuttings (82 cells per flat) from Yoder Greenleaf (Lancaster, PA) were transplanted individually into 15.2 cm pots (Dillen Products, Middlefield, OH) using Fafard 52, Fafard 3B (Conrad Fafard, Inc., Agawam, MA), Scott’s Perennial mix, Metro-Mix® 700 with ScottsCoir (The Scotts Company, Marysville, OH) soilless medias and composted pine bark (Table 3.1). The pine bark was amended with 100 g dolomitic lime and 25 g Micromax micronutrients (The Scotts Company). The plants were grown in a glass house located on the Virginia Tech campus Blacksburg, VA with a daytime temperature of 24 to 29°C (75 to 84° F) and a nighttime temperature of 18 to 21°C (64 to 70°F).

Two irrigation treatments consisting of 250 ml constant liquid feed (CLF) when the media averaged less than 30% or 20% volumetric soil moisture content (VSMC) began two weeks after transplanting into the media treatments. Growing media VSMC was determined daily for each plant with a ThetaProbe soil moisture meter (ML2x; Delta-T Devices Ltd, Cambridge, U.K.). All plants of a treatment were irrigated when the average moisture percentage for that treatment fell below the VSMC threshold. Fertigation volume was increased to 350 ml at the end of week six to maintain the leaching fraction (LF) of 20 to 30%. Leaching fraction was determined by dividing the volume of solution leached from the pot by the total solution applied. 15N-2.2P-12.5K (15-5-15) CalMag fertilizer (Miracle Gro Professional

EXCEL; The Scotts Co.) was injected continuously (Dosatron USA, Clearwater, FL) into irrigation water at a concentration of  $150 \text{ mg}\cdot\text{L}^{-1}$  N. Media pH and electrical conductivity (EC) were monitored every 2 weeks using the Virginia Tech Extraction Method (Wright, 1986).

On week fourteen, the plant shoot was cut at the soil line and roots removed and hand-washed. Root and shoot dry weight was determined after drying at  $66^{\circ}\text{C}$  ( $151^{\circ}\text{F}$ ).

The experiment design was a randomized complete block with four blocks. The treatment design was a  $5 \times 2$  factorial with five growing media and two irrigation levels for a total of ten treatments. Data were analyzed by ANOVA and regressions performed on significant effects using SAS Version 8 (SAS Institute, Inc., Cary, N.C.).

### *Experiment 2.*

On 2 Dec. 2002, rooted rosemary ‘Tuscan Blue’ cuttings (100 cells per flat) from Hillcrest Nursery (Millers, MD) were potted individually into 10.2 cm pots (T.O. Plastics, Inc., Bloomington, MN) using Fafard 52, Fafard 3-B, Scott’s Perennial mix, Metro-Mix 560 with ScottsCoir, and 100% composted pine bark (Table 3.1). Pine bark was again amended with 100 g dolomitic lime and 25 g Micromax micronutrients. The plants were grown in a glass house located on the Virginia Tech campus Blacksburg, VA at a daytime temperature of  $24$  to  $29^{\circ}\text{C}$  ( $75$  to  $84^{\circ}\text{F}$ ) and a nighttime temperature of  $18$  to  $21^{\circ}\text{C}$  ( $64$  to  $70^{\circ}\text{F}$ ).

Fifteen treatments – five media each at three irrigation levels – lasted for two, four, six, or eight weeks. Plants were harvested at the end of each treatment. 15N-2.2P-12.5K (15-5-15) fertilizer (Miracle Gro Professional EXCEL; The Scotts Co.) fertilizer was injected continuously into irrigation water at a concentration of  $100 \text{ mg}\cdot\text{L}^{-1}$  N. Media pH and electrical conductivity (EC) were determined using the Virginia Tech Extraction Method (Wright: 1986), from each plant at harvest.

The irrigation treatments consisted of 350 ml CLF when the SVMC averaged less than 40, 30, or 20%. Growing media VSMC was determined daily for each plant with a ThetaProbe soil moisture meter (ML2x; Delta-T Devices Ltd, Cambridge, U.K.). All plants of a treatment were irrigated when the average moisture percentage for that treatment fell below the VSMC threshold. At the end of week six, the fertigation volume increased to 450 ml to maintain the



leaching fraction of 30 to 40%. Leaching fraction was determined by dividing the volume of solution leached from the pot by the total solution applied.

At each harvest date, the plant shoots were cut at the soil line and roots removed and hand-washed. Root and shoot dry weight was determined after drying at 66°C (151° F). The experiment design was a randomized complete block with four blocks. The treatment design was a 5 x 3 factorial with five growing media and three irrigation levels for a total of 15 treatments. Each block contained four of each treatment – one for each harvest. Data were analyzed by ANOVA and regressions performed on significant effects using SAS Version 8 (SAS Institute, Inc., Cary, N.C.).

## **Results and Discussion**

### *Media:*

Growing media had a significant impact on shoot growth in the first experiment (Table 3.2) with the highest-percentage peat media (Fafard 3B) (Table 3.1) producing shoots with the largest dry weight followed by Scott's Perennial, pine bark, Metro Mix 700, and Fafard 52 (Table 3.3).

In the second experiment, media was not significant for shoot growth at the termination or at weeks two or four (Table 3.4). At week six, Fafard 3B produced the largest shoots at the lowest and highest irrigation rates (less than 20 and less than 40% VSMC) while Fafard 52 produced the largest shoots at the medium irrigation rate (less than 30% VSMC). Our results indicate while rosemary can successfully be grown in many soilless media, those with a high percentage of peat may produce larger plants.

Root growth was also significantly affected by media in the first experiment (Table 3.2) with Fafard 3B and Scott's perennial producing the largest root dry weights. Fafard 52 and Metro Mix 700 with coir depressed root dry weights (Table 3.3).

The effect of media on root growth in the second experiment was only significant at week two with the two perennial mixes (Fafard 52 and Scott's Perennial Mix) producing the largest RDWs. According to DeBaggio (1987), rosemary is particularly sensitive to over-watering after transplanting. This may explain the significance of the effect of growing media on root growth in

week two of experiment two. Both Fafard 52 and Scott's Perennial Mix have a high percentage of composted pine bark to allow for extra drainage (Table 3.1).

Boyle et al. (1991) found soilless media produced larger rosemary plants than soil-based media and surmised the decreased water holding capacity (WHC) and increased total porosity (TP) of soilless media (Fonteno, 1996) accounted for the difference. We did not find WHC or TP to be the sole factor impacting growth. In fact, growing media with similar WHCs and TPs (Fafard 52 and Scott's Perennial Mix) were on opposite ends of the spectrum in their ability to impact to shoot and root dry weight. Shoot and root dry weights were not correlated with the container capacity, total porosity, air space, or bulk density of the growing media.

*Irrigation:*

The effect of irrigation on roots in the first experiment was not significant (Table 3.2), but the higher irrigation rate produced the largest SDWs (Table 3.3).

In the second experiment, irrigation was not significant for shoots or for roots at the termination of the study (Table 3.4). However, irrigation significantly affected roots at week six with the highest irrigation rate consistently producing the smallest RDWs. All plants in both experiments were of marketable quality.

While rosemary is reportedly easy to over-water (DeBaggio, 1990), the larger SDWs produced by the higher irrigation rate may be explained by Munne-Bosch et al. (1999) who found whole shoot CO<sub>2</sub> assimilation rates of drought stressed rosemary decreased by 75% and accompanied a substantial reduction in photosynthetic rate. A temporary growth slow down was the only detrimental effect. The suppressed root growth in week six of experiment two resulting from the less than 40% SVMC irrigation treatment may be a result of over-watering though no root rot was evident.

In the first experiment, pH did not correlate to dry weight, but electrical conductivity was positively correlated with shoot ( $r = 0.51$ ) and root ( $r = 0.40$ ) dry weight. This suggests growth of rosemary may increase as fertilizer concentrations increase. In the second experiment, root and shoot dry weight were not correlated with media pH or EC. This may be due to the difference in length of the two experiments.

Our results indicate rosemary can successfully be produced in soilless media with very different component percentages and at several irrigation rates. The peat-based media produced the largest shoot and root dry weight, but the explanation for this data is still unclear. Our results also show that rosemary can successfully be grown over a range of irrigation rates including the relatively wet 40% soil volumetric moisture content.

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Table 3.1. Components and physical properties of growing media in experiment one and two.

| Media                      | WHC  | TP   | BD   | Air  | Peat Moss | Bark | Perlite | Vermiculite | Coir Dust | Sand |
|----------------------------|------|------|------|------|-----------|------|---------|-------------|-----------|------|
| Components %               |      |      |      |      |           |      |         |             |           |      |
| Metro Mix 560              | 79.4 | 94.7 | 0.10 | 15.3 | 15        | 40   | 15      | 0           | 30        | 0    |
| Fafard 3B                  | 70.2 | 84.9 | 0.13 | 14.7 | 45        | 25   | 15      | 15          | 0         | 0    |
| Fafard 52                  | 67.8 | 82.2 | 0.16 | 14.4 | 24        | 60   | 8       | 8           | 0         | 0    |
| Scott's Perennial Mix      | 67.1 | 85.2 | 0.17 | 18.1 | 25        | 65   | 10      | 0           | 0         | 0    |
| Metro Mix 700 <sup>z</sup> | -    | -    | -    | -    | 0         | 50   | 10      | 15          | 25        | 0    |
| Composted pine bark        | 50.2 | 76.0 | 0.21 | 25.7 | 0         | 89   | 0       | 0           | 0         | 11   |

WHC = Water holding capacity (% volume)

TP = Total porosity (% volume)

BD = Bulk density (g/cc)

Air = Air space (% volume)

<sup>z</sup> = Physical properties of growing media not tested

Table 3.2. Analysis of variance summary for growing medium and irrigation rate effect on shoot dry weight (SDW) and root dry weight (RDW) of *Rosmarinus officinalis* L. ‘Athens Blue Spires’ in experiment 1.

| Source         | DF | SDW         |         | RDW         |         |
|----------------|----|-------------|---------|-------------|---------|
|                |    | Mean Square | P-value | Mean Square | P-value |
| Block          | 4  | 1.20        | 0.1513  | 0.16        | 0.0133* |
| Media (M)      | 4  | 17.9        | <.0001* | 0.60        | <.0001* |
| Irrigation (I) | 1  | 21.7        | <.0001* | 0.17        | 0.0539  |
| M x I          | 4  | 0.61        | 0.4680  | 0.11        | 0.0547  |

\*Significant at  $P \leq 0.05$

Table 3.3. Effect of growing medium and irrigation on shoot dry weight (SDW) and root dry weight (RDW) of *Rosmarinus officinalis* L. ‘Athens Blue Spires’ in experiment 1.

|                         | SDW(g)              | RDW(g)  |
|-------------------------|---------------------|---------|
| Irrigation              |                     |         |
| < 30%                   | 5.55 a              | 1.30 a  |
| < 20%                   | 4.23 b              | 1.19 a  |
| Media                   |                     |         |
| Fafard 3B               | 6.89 a <sup>z</sup> | 1.49 a  |
| Scott’s Perennial       | 5.44 b              | 1.48 a  |
| Pine bark               | 4.65 c              | 1.24 b  |
| Metro Mix 560 with Coir | 3.98 cd             | 0.94 c  |
| Fafard 52               | 3.49 d              | 1.07 bc |

<sup>z</sup>Mean separation within a column by the LSD *t* test.

Table 3.4. Analysis of variance summary for growing medium and irrigation rate effect on shoot dry weight (SDW) and root dry weight (RDW) of *Rosmarinus officinalis* L. ‘Tuscan Blue’ in experiment 2.

| Source         | DF | SDW p values   |       |        |       | RDW p values |       |        |       |
|----------------|----|----------------|-------|--------|-------|--------------|-------|--------|-------|
|                |    | 2 <sup>z</sup> | 4     | 6      | 8     | 2            | 4     | 6      | 8     |
| Media (M)      | 4  | 0.153          | 0.192 | 0.010* | 0.454 | 0.033*       | 0.957 | 0.323  | 0.726 |
| Irrigation (I) | 2  | 0.557          | 0.058 | 0.293  | 0.890 | 0.458        | 0.386 | 0.019* | 0.822 |
| M x I          | 8  | 0.968          | 0.440 | 0.020* | 0.085 | 0.510        | 0.723 | 0.316  | 0.614 |

\*Significant at  $P \leq 0.05$

<sup>z</sup>Weeks after planting



# VITA

Paul M. Westervelt

## EDUCATION

**Master of Science, Horticulture**, Expected August 2003

Virginia Tech, Blacksburg, VA

**Thesis:** Challenges in the Greenhouse Production of *Rosmarinus officinalis*

Advisor: Holly L. Scoggins

**Bachelor of Science, Horticulture**, May 2001

Virginia Tech, Blacksburg, VA

**Associate of Science, Horticulture**, May 1998

Lord Fairfax Community College, Middletown, VA

## TEACHING EXPERIENCE

**Graduate Teaching Assistant, Herbaceous Landscape Plants**, Aug. 2002 – May 2003

Taught six herbaceous plant identification labs to 15-30 students per semester.

Advisor: Holly L. Scoggins

Overall rating by students: 3.9/4.0

**Graduate Teaching Assistant, Woody Landscape Plants**, Aug. 2001 – May 2002

Taught thirteen woody plant identification labs to 10-20 students per semester

Advisor: Alex X. Niemiera

Overall rating by students: 3.7/4.0

**Undergraduate Teaching Assistant, Woody Landscape Plants**, Aug. 1999 – May 2000

Taught thirteen woody plant identification labs to 10-20 students per semester

Advisor: Alex X. Niemiera

## PRESENTATIONS

**Southern Region of the American Society of Horticulture Science (ASHS)**, Feb. 2003

“Challenges in the Greenhouse Production of *Rosmarinus officinalis*”

**Virginia Tech: Department seminar**, April 2003

“Challenges in the Greenhouse Production of *Rosmarinus officinalis*”

**Basic Greenhouse Production Seminars:**

“Greenhouse Media, Fertility, and Water” Middletown, VA. January 2002

“Fertilizer Selection and Application” New Market, VA. January 2002, Charlottesville, VA. January 2002

**The Importance of Marketing in Floriculture.** Class lecture. November 2002

## PUBLICATIONS

Selecting media: chapter in Southwest Greenhouse Operators Training Manual.

## RESEARCH EXPERIENCE

Defining best management practices for *Rosmarinus officinalis*. 2001 – 2003

Determining flower trigger and effect of PGRs on *Strobilanthes dyerianus*. 2001 - 2003

Defining best management practices for *Tradescantia virginiana*. 2001 – 2002

Effect of PGRs on marketability of *Tradescantia virginiana*. 2001 – 2002

Interactions of PGRs and slow release fertilizer on growth of *Perovskia atriplicifolia*, *Astilbe sp.*, *Filipendula sp.*, *Artemisia vulgaris* ‘Oriental Limelight’, and *Echinacea purpurea*. 2002

Effect of PGRs on height control of *Perovskia atriplicifolia*, *Echinacea purpurea*, *Sedum x ‘Matrona’*, and *Monarda sp.* 2002

Effect of PGRs on height control *Erysimum sp.*, *Euphorbia x ‘Despina’*, and *Euphorbia x ‘Efanthia’* 2003

## WORK EXPERIENCE

**Research Assistant**, Dr. Holly Scoggins. August 2001 – May 2003.

Assisted in plant care and data collection for all research listed under research experience

**Intern: TruGreen LandCare**, Gainesville, VA. May 2000 – Aug 2000

Landscape maintenance, estimation, and design for a large contractor

**Intern: Greenbrier Nurseries**, Roanoke, VA. May 1999 – Aug 1999

Retail sales for a high-end retail nursery often utilizing quick designs

**Intern: Virginia Tech Horticulture Gardens**, Blacksburg, VA. May 1999 – Aug 1999

Design, maintenance, planning, and public relations for a small public garden

**Locust Landscaping**, Lucketts, VA. May 1998 – Aug 1998  
Landscape installation and maintenance for a small contractor

**Horton's Nursery**, Winchester, VA. Mar 1994 – Aug 1994  
Retail sales and propagation for a large retail nursery

**Winchester City Parks and Recreation**, Winchester, VA. June 1990 – Aug 1993  
Maintained a highly visible, high-maintenance portion of the park

## **LEADERSHIP EXPERIENCE**

**President:** Virginia Tech Horticulture Club, 1999-2000

**President:** Agricultural Club Council, 2000-2001

**President:** Omicron Delta Kappa National Leadership Society, 2001-2003

**Student Director:** Omicron Delta Kappa, Virginia 2002-2003

**Student Coordinator:** Career Fair for the college of Agriculture, 2000 & 2001

**Member:** Order of the Gavel – VT's most prestigious leadership honor society

**Member:** Pi Alpha Xi Horticulture Honor Society, 1998-2003