

Suction Cup Lysimeter Extraction of Pine Bark Substrate Solution

By

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# **Suction Cup Lysimeter Method for Extracting Pine Bark Substrate Solution**

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## **Abstract**

The objective of this study was to determine the effectiveness of suction cup lysimeters (SCL) in extracting substrate solution from pine bark substrates. Lysimeter types tested were 4.8-cm diameter with a ½ or 1-bar air-entry value (AEV) and 2.2-cm diameter also with a ½ or 1-bar AEV. Sufficient volume could be obtained when a vacuum pressure of 30, 40 or 50 cb was applied to lysimeters with a minimum extraction time of five minutes. The 2.2-cm lysimeters were found to be suitable for extracting solution if smaller sample volumes were needed. To determine effect of vacuum pressure and extraction time on volume extracted, the 4.8-cm ½-bar lysimeters were installed in containers with pine bark substrate and *Quercus phellos* L. (willow oak) trees. Volumes extracted were somewhat erratic and not strongly dependent upon centibars of vacuum or extraction time. Lysimeters immersed in water demonstrated that variability was not due to individual lysimeters, but to the coarse nature of the pine bark substrate. Substrate EC levels were not affected when volume of substrate solution extracted by the SCL's varied from 10 to 190 ml.

To determine the effectiveness of SCL's to monitor nutrient status of container-grown shade trees, two-year-old container-grown willow oak trees were grown in a pine bark substrate and fertilized with 0, 50, 100, 150, 200, 250 or 300 grams Osmocote Plus Northern (15N – 3.9P – 9.8K). Plant height and trunk diameter increased with up to 200 grams of Osmocote per container. There was a good relationship between solution EC and plant growth.

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## Chapter One

### Literature Review

#### I. Methods of Obtaining Substrate Solution for Analysis

In recent years, the production of woody nursery crops in containers has become the predominant production method used in the United States. Instead of mineral soil, the container substrate consists primarily of organic substances like peat and pine bark, which supply limited amounts of nutrients to the plant (Murray et al., 1996).

Composition of substrate solution determines the availability of nutrients to plants (Bredemeier et al., 1990). Successful management of fertilizer, substrate and irrigation regimes is needed in order to maintain container fertility for optimal plant growth.

Concerns about potential environmental contamination caused by nutrient and pesticide-laden runoff from woody plant nurseries have also led to the need for careful monitoring of the nutritional status of containerized plants (Hicklenton and Cairns, 1996).

Tissue testing for nutrient analysis is limiting when used as a management tool for container grown woody plants because of the wide range of nutrient levels found in different species and the lack of established species-specific sufficiency levels (Wright and Niemiera, 1987). Sampling methods based on water extraction of nutrients most accurately represent the actual level of nutrients in substrate solution (Lucas et al., 1972). As container size and consequently weight increase, obtaining substrate solution for analysis becomes more difficult. Although several methods exist for obtaining substrate solution from containers, suction cup lysimeters (SCL) may prove to be the most efficient method for sampling substrate solution in large 56.8 L (15-gallon) and above containers.

The saturation extraction method (SEM) was developed in the late 1960's by Lucas and Rieke and was first called the saturated soil extract procedure because of the high rates of mineral soil then used in containers (Warncke, 1986). The procedure involves adding distilled water to 500 cc of the growth medium to be tested until it first becomes saturated. After 1.5 hours, the solution is removed with a vacuum filter and nutritional analysis is conducted on the extracted solution (Warncke, 1986).

An advantage of the SEM is that the media samples can be mixed and extracted as they are received in the lab, allowing for a fast turn-around time because preparatory drying and handling of the sample is not required. A major disadvantage associated with this system is that rupturing of controlled release fertilizer (CRF) granules in the medium may occur during mixing, contributing to an inflation of the nutrient values obtained from analysis of the saturation extract (Warncke, 1986).

Another method commonly used to determine the nutritional content of container solution is the 2:1 (water to substrate) method in which two parts distilled or deionized water is added to one part substrate. The solution is stirred and allowed to stand for fifteen minutes before testing (Sray, 1997).

In 1971, it was validated that the bulk solution displacement (BSD) method could be used to obtain an accurate representation of the immediately available nutrient pool (Pearson, 1971). Bulk solution is that part of the substrate solution that is not influenced by the exchange surface of the root medium components. Bulk solution is therefore the portion of the solution from which plants derive the largest amounts of needed nutrients (Nelson and Faber, 1986). Other testing procedures, like the SEM and the 2:1 method, alter the bulk solution and subsequent nutrient concentrations by raising the moisture content of the root media above the container capacity. While the BSD method does provide an excellent representation of the immediately available nutrient pool, it is a tedious procedure that requires various equipment as well as disruption and removal of substrate from the container.

A common practice for extracting substrate solution for soluble salt, individual nutrients, and pH analyses from container grown plants is the “pour through” nutrient extraction method (PT). This method, (Wright, 1986) involves elevating the medium-filled container above a collection vessel that is wide enough to collect leachate from both the center and side container holes. Enough distilled water is then added to the surface of the media so that approximately 50 ml of solution is leached into the vessel. This usually occurs after about five minutes. The solution is then transferred into another container until analysis takes place. Removal of medium from the container is not required with the PT method, thereby preventing the rupture of slow release fertilizer granules, which may result in incorrect results. Use of the PT method on larger, and

subsequently, heavier containers reduces the efficiency of the method since more time and labor are required in order to elevate the heavy container above the collection vessel.

Although experimental, rhizon soil solution samplers (RSSS) show promise for obtaining substrate solution for nutrient testing of large container grown plants. RSSS's are normally used for extracting soil solution for nutrient analysis of mineral soils, but may prove useful for greenhouse and nursery sites (Argo et. al, 1997).

As described by Argo et al. (1997), the RSSS is a narrow-diameter, cylindrical, microporous tube made of a hydrophilic polymer. One hour after irrigation, the tube is inserted into container substrate via a preaugered hole and a vacuum is created within the tube with an attached syringe. After about 30 minutes, an adequate solution volume can be removed from the syringe for nutrient testing (5–10 ml).

In tests comparing RSSS's with SEM, it was found that pH, potassium (K) concentration, medium EC and  $\text{NO}_3\text{-N}$  values were similar between the two sampling methods (Argo et al., 1997). A major disadvantage of RSSS's is that the small microporous tube can become easily damaged if scraped against the side of the entry hole during insertion. The samplers are also susceptible to damage caused by ultraviolet rays and therefore cannot be left in the sun for extended periods of time.

The use of a suction cup lysimeter was first noted in 1904 by Briggs and McCall where it was termed the "artificial root" (Grossmann and Udluft, 1991). Since 1961, SCL's have been used to test soil water availability and composition at various depths, especially in areas of high groundwater pollution such as landfills and wastewater sites (Jayachandran et al., 1994). Currently, SCL's are not commonly used in nursery settings for substrate solution sampling, however, they may prove to be the most efficient, economic, non-destructive way to monitor the nutritional status of large containers.

A SCL consists of a cylindrical tube of varying materials, length and diameter. Several materials have been used in the construction of the tubes, including acrylic, polyvinyl chloride (PVC) and even stainless steel. However, the use of stainless steel tubes has been found to release copper into the withdrawn solution causing erroneous readings during nutrient testing (Grossmann and Udluft, 1991). The tube is attached to a porous ceramic cup that is available in different materials and pore sizes. After being inserted into a previously augered hole in container medium the SCL is ready for use.

Following irrigation, a vacuum is created within the chamber and substrate solution is drawn into the tube through the porous tip. The solution is then removed with a syringe. The pre-filtered sample can then be analyzed for pH, EC, and nutritional content.

Walden and Niemiera's (1997) study compared SCL and PT extract nitrogen (N) and pH levels in pine bark substrate. They found that results were comparable for each method. However, the time required for extraction of a 30 ml sample using a 1.3-cm diameter SCL ranged from 1 to 3 hours. The objective of this research was to evaluate other existing suction cup lysimeters and to develop the appropriate methodology for use in nursery production using large containers.

## II. Nutrient Application for Containers

The ultimate goal of any fertilizer program is to achieve and maintain an optimum level of nutrients in the growth medium solution (Gouin and Link, 1973). Nutrients can be applied to container plants through the irrigation system, as dry formulations that are preplant incorporated into the medium or surface applied to the medium, or a combination of these methods (Wright and Niemiera, 1987). The two methods generally used in nursery production are liquid feed (LF), in which water-soluble fertilizers are added to irrigation water, and CRF in which dry products are either incorporated into the medium before planting or top dressed following planting. Previous studies have shown that high quality plants can be produced using either LF or CRF as long as adequate nutritional levels are maintained in the medium solution (Catanzaro et al., 1998; Gouin and Link, 1973; and Hicklenton and Cairns, 1992).

CRF's supply nutrients to the plant by releasing them at relatively low levels over an extended period of time (Catanzaro et al., 1998). CRF's are manufactured in several ways: by enclosing soluble fertilizer particles in coatings of low solubility forming "prills", manufacturing fertilizer compounds with low solubility, producing low solubility compounds which require microbial activity for the release of nutrients, and treating natural organic materials so that they require microbial activity for nutrient release (Maynard and Lorenz, 1979).

Because soilless media have relatively low water holding capacities and little ability to fix nutrients, the medium solution is continually depleted of nutrients through

leaching or plant uptake throughout the growing season (Wright and Niemiera, 1987). Nutrient leaching is especially problematic in outdoor conditions where rainfall, in addition to irrigation, contributes to nutrient loss. Excess water facilitates the leaching of nutrients, thereby reducing fertilizer use efficiency and possibly leading to nutrient deficiencies that in turn can limit plant growth (Hicklenton and Cairns, 1992). Use of a CRF alone significantly reduces the amount of N, K and phosphorus (P) that is leached from containers, thus reducing the potential for groundwater pollution (Hicklenton and Cairns, 1992 and Cantanzaro et al., 1998). In the horticultural industry increased nutrient use efficiency (Catanzaro et al., 1998) and lower labor costs (Meadows and Fuller, 1987) can be achieved through the use of CRF's.

CRF products are commonly categorized by the length of time needed for the prill to release ~80% of its contents at a given temperature (Husby, 1999). However, the duration of nutrient release required for optimal growth may fall short of the longevity rating claimed by the manufacturer. When comparing the longevity rating of an 8-9 month and a 12-14 month CRF, it was found that after 4 months N levels in the substrate solution had dropped below 10 ppm, resulting in limited growth (Meadows and Fuller, 1983). One problem with CRF's is that during the early part of the growing season more nutrients are released from CRF's than can be utilized by the young plant, whereas nutrient release may be limiting during the latter part of the season (Wright and Niemiera, 1987; Catanzaro et al., 1998). Growers must then decide if and when to reapply CRF (Shiflett et al., 1994).

### III. Summary

Careful monitoring of the nutrients in container solution allows growers to adjust fertilizer application regimes to supply optimal, not excessive amounts of nutrients to growing plants. Our work was undertaken to test the ability of SCL's to provide an efficient and accurate means of obtaining substrate solution for analysis from pine bark substrate and to determine the EC level associated with optimal growth of *Quercus phellos* L. (willow oak) fertilized with different levels of a CRF.

## Literature Cited

- Argo, W.R., B.J. Weesies, E.M. Bergman, M. Marshal, and J.A. Biernbaum. 1997. Evaluating rhizon soil solution samplers as a method for extracting nutrient solution and analyzing media for container-grown crops. *HortTechnology* 7:404-408.
- Bredemeier, N., N. Lamersdorf, and G.A. Wiedey. 1990. A new mobile and easy to handle suction lysimeter for soil water sampling. *Fresenius' J. of Analy. Chem.* 336:1-4.
- Catanzaro, C.J., K.A. Williams, and R.J. Sauve. 1998. Slow release versus water soluble fertilization affects nutrient leaching and growth of potted *Chrysanthemum*. *J. of Plant Nutr.* 21:1025-1036.
- Gouin, F.R. and C.B. Link. 1973. Growth response of container-grown woody ornamentals to slow-release fertilizers. *HortScience* 8:208-209.
- Grossmann, J. and P. Udluft. 1991. The extraction of soil water by the suction-cup method: a review. *J. of Soil Sci.* 42:83-93.
- Hicklenton, P.R. and K. Cairns. 1996. Plant water relations and mineral nutrition of containerized nursery plants in relation to irrigation method. *Can. J. of Plant Sci.* 76:155-160.
- Hicklenton, P.R. and K. Cairns. 1992. Solubility and application rate of controlled-release fertilizer affect growth and nutrient uptake in containerized woody landscape plants. *J. Amer. Soc. Hort. Sci.* 117:578-583.
- Husby, C.E.. 1999. Influence of temperature, time and product on nutrient release patterns of Osmocote Plus, Nutricote, and Polyon controlled release

fertilizers. Master's Thesis. Virginia Polytechnic and State University. Blacksburg, Virginia.

Jayachandran, K., T.R. Steinheimer, L. Somasundram, T.B. Moorman, R.S. Kanwar, and J.R. Coats. 1994. Occurrence of atrazine and degradates as contaminants of subsurface drainage and shallow groundwater. *J. Environ. Qual.* 23:311-319.

Lucas, R.E., P.E. Rieke, and E.C. Doll. 1972. Soil saturated extract method for determining plant nutrient levels in peats and other soil mixes. 4<sup>th</sup> Intl. Peat Congr. 3:221-230.

Maynard, D.N. and O.A. Lorenz. 1979. Controlled-release fertilizers for horticultural crops. Pp. 79-129. In: J. Janick (ed.). *Hort. Rev.* Van Nostrand Reinhold Company, New York.

Meadows, W.A. and D.L. Fuller. 1983. Nitrogen and Potassium release patterns of five formulations of Osmocote fertilizers and two micronutrient mixes for container grown woody ornaments. *South. Nurseryman Assoc. Res. J.* 9:28-34.

Murray, C.L., G.P. Lumis and C. Chong. 1996. Fertilizer method and container size effects on shade trees grown in in-ground containers. *Can. J. of Plant Sci.* 76: 507-513.

Nelson, P. and W. Faber. 1986. Bulk solution displacement. *HortScience* 21:225-227.

Pearson, R.W. 1971. Introduction to symposium, the soil solution. *Soil Sci. Soc. Amer. Proc.* 35:417-420.

Shiflett, M.C., A.X. Niemiera, and C.E. Leda. 1994. Mid-season reapplication of controlled release fertilizers affect 'Helleri' holly growth and N content of substrate solution and effluent. *J. Environ. Hort.* 12:181-186.

Sray, A. 1997. The ABC's of pH. *Greenhouse Grower*. Mid-September:16-19.

Walden R. and A. Niemiera. 1997. A method of monitoring the nutritional status of pine bark substrate in large containers. *Proc. South. Nurseryman Assoc. Res. Conf.* 42:165-168.

Warncke. D.D. 1986. Analyzing greenhouse growth media by the saturation extraction method. *HortScience* 21:223-225.

Wright, R.D. and A. Niemiera. 1987. Nutrition of container-grown woody nursery crops. p. 75-95 in J. Janick(ed.) *Hort. Rev.* Van Nostrand Reinhold Co., New York.

Wright, R.D. 1986. The pour-through nutrient extraction procedure. *HortScience* 21:227-229.

## **Chapter 2**

### **Evaluation of Suction Cup Lysimeters for Obtaining Substrate Solution from a Pine Bark Substrate**

#### **Abstract**

Because container substrate solution is representative of the nutrients available to plants, methods are needed for extracting this solution that are conducive to production of plants in large containers ( $\geq 18.9$ -L). The objective of this study was therefore to determine the effectiveness of suction cup lysimeters (SCL) in extracting substrate solution from pine bark substrates in large containers. The lysimeter types tested were those with a 4.8-cm diameter and a ½-bar or 1-bar air-entry value (AEV) and those with a 2.2-cm diameter also with a ½-bar or 1-bar AEV. Treatments comparing extraction times of 15, 30, 45 and 60 minutes at 50 centibars (cb) of vacuum demonstrated that either of the 4.8-cm lysimeters were able to extract a volume sufficient for complete nutritional analysis (~ 50 ml) after fifteen minutes of extraction time. The 2.2 cm lysimeters were found to be suitable for extracting solution if smaller sample volumes were needed, extraction time was not a limiting factor or where installation space was limited. It was found that sufficient volume could be obtained after five minutes when a vacuum pressure of 30, 40 or 50 cb was applied to 4.8-cm ½-bar lysimeters. However, volumes extracted were variable and not strongly dependent upon centibars of vacuum pressure or extraction time. Lysimeters immersed in water demonstrated that variability was not due to individual lysimeters, but to the coarse nature of pine bark. EC levels were not affected by volume of substrate solution extracted by the SCL's that varied from 10 to 190 ml.

#### **Introduction**

Production of woody landscape plants in containers has become the predominant production method used in the United States. Container substrates are primarily made up of organic materials, which supply limited amounts of nutrients to plants (Murray et al., 1996). The composition of the substrate solution determines the availability of nutrients

to plants (Bredemeier et al., 1990). Careful monitoring of substrate solution aids the grower in maintaining optimum nutrient availability for plant growth. Environmental concerns regarding nutrient and pesticide laden runoff from woody plant nurseries have also led to the need for careful monitoring of substrate solutions (Hicklenton and Cairns, 1996). Suction cup lysimeters (SCL) show promise as an efficient, economical, non-destructive means for obtaining substrate solution for monitoring the nutritional status of large (18.9 L (5-gallon) or more) container grown plants.

Sampling methods based on water extraction of nutrients most accurately represent the actual level of nutrients in substrate solution (Lucas et al., 1972). The most common method used to obtain solution from containers is the “pour through” nutrient extraction method (PT) (Wright, 1986). This method requires elevation of the media-filled container over a collection vessel. Enough distilled water is then added to the media surface so that approximately 50 ml of solution can be collected in the vessel. This method works well for small containers but as container size and weight increase, elevation of the container becomes more difficult and time consuming.

Another means of obtaining substrate solution are rhizon soil solution samplers (RSSS). RSSS's are normally used to extract solution from mineral soil for nutrient analysis; but may prove useful for greenhouse and nursery sites that utilize soilless as substrate (Argo et al., 1997). A RSSS is a narrow diameter, cylindrical microporous tube made of a hydrophilic polymer. The RSSS utilized in Argo et al.'s experiment (1997) consisted of a 12-cm long x 0.1-cm outside diameter microporous (0.1- $\mu\text{m}$ ) tube attached to a 12-cm x 0.1-cm polyvinyl chloride (PVC) tube. One hour after irrigation the sampler was inserted into the media via a previously augered hole and vacuum was created within the sampler with a 50 ml syringe. After approximately 30 minutes, a volume sufficient for testing (5 to 10 ml) was obtained. An almost 1:1 correlation was found when comparing pH, potassium (K) and  $\text{NO}_3\text{-N}$  concentrations and medium electrical conductivity (EC) values in extracted solutions obtained using the RSSS and the saturated media extract method (Argo et al., 1997). A limitation in using RSSS's is that the small, microporous tubes can become bent or otherwise damaged if carelessly inserted into the media. Samplers are also susceptible to damage caused by ultraviolet rays and therefore cannot be left in the sun for extended periods of time (Argo et al., 1997).

The use of a SCL was first noted in 1904 by Briggs and McCall and was termed the “artificial roof” (Grossman and Udluft, 1991). Since 1961, SCL’s have been used to test soil water availability and composition at various depths especially in areas of high groundwater pollution such as landfills and wastewater sites (Jayachandran et al., 1994). SCL’s consist of cylindrical tubes of varying materials and length and diameter, attached to porous cups of varying materials and pore size (Grossmann and Udluft, 1991). On the opposite end is a stopper assemblage with access tubing to which a vacuum pump can be attached. A plastic ring is used to clamp the tubing after a vacuum is created within the sampler during extraction time. When vacuum (negative pressure or suction) exceeds the surrounding moisture tension of the substrate, solution will flow from pore spaces in the surrounding substrate into the cup until the capillary pressure in the suction cup and substrate are equal (Grossmann and Udluft, 1991, Soil Moisture Equipment Corp., 1997).

SCL’s are manufactured with ceramic cups of varying pore sizes that are referred to as the cup’s air-entry value (AEV). The AEV is the pressure at which air is able to break through the wetted pore channels of the cup. For example, a cup with an AEV of 1-bar means that when a vacuum greater than 1-bar (0.1 mPa) is created within the lysimeter, air enters the sampler column (Soil Moisture Equipment Corp., 1997). The size of the capillary spaces within the substrate determines the amount of vacuum required within the sampler in order to draw substrate solution into the porous cup. For example, a solution can be extracted more easily from a sandy soil with 10% moisture, than from a clay soil containing 30% moisture because the sandy soil holds water with less tension than clay soil (Soil Moisture Equipment Corp., 1997).

Research has shown that SCL’s are able to provide an efficient and reliable means of extracting substrate solution from containers for nutritional analysis. In a study by Walden and Niemiera (1997) it was found that extract nitrogen (N) and pH levels of substrate solution obtained using SCL’s in pine bark media were similar to those of solution obtained using PT. The time required to extract 30 ml of solution from the containers using a 1.3-cm diameter SCL during this study varied from 1 to 3 hours, which may prove to be inconvenient when a large number of samples are required. However, larger lysimeters are available. The intent of this research was to evaluate other

lysimeters and to determine the methodology and lysimeter type that is most effective in extracting substrate solution from large containers (18.9 L (5-gallon) or larger).

### **Materials and Methods**

The capability of four lysimeter types to solution from containers with pine bark substrate was tested. The four lysimeter types were represented by two tube diameters (2.2-cm and 4.8-cm) and two AEV's (½-bar and 1-bar). The 4.8-cm size (Model 1900L24 SoilMoisture Corp. Santa Barbara, CA) consisted of a 61-cm x 4.8-cm PVC tube attached to a 7.6-cm x 4.8-cm porous ceramic cup. On the opposite end of the sampler was a removable stopper assembly with neoprene access tubing to which a vacuum pump could be attached. The 2.2-cm size (Model 1905L24, Soil Moisture Equipment Corp. Santa Barbara, CA) was designed for taking small-volume samples or for use where space is limited. It consisted of a 61-cm x 2.2-cm clear, acrylic tube attached to a 7.6-cm x 2.2-cm porous ceramic cup. On the opposite end was a screw-top acrylic stopper with neoprene tubing for vacuum attachment. On all lysimeter types a plastic ring was used to clamp the tubing in order to hold vacuum within each lysimeter during extraction time.

*Experiment 1:* On February 2, 2001 four lysimeters of each of the four types (16 total) were installed in 56.8 L (15-gallon) black plastic containers filled to within approximately 2.5-cm of the top with unamended pine bark substrate. Lysimeters were randomly assigned to each of the sixteen containers and were inserted to within 2.5-cm of the bottom of the container via a previously augered hole, slightly less than the lysimeter diameter, to promote contact between the ceramic cup and the surrounding substrate. The experiment was conducted in Blacksburg, Virginia in a glass greenhouse with daily temperatures ranging from 15.5°C to 21.1°C.

After installation, the containers were irrigated daily with 3.8 cm of water using an overhead traveling boom system to thoroughly wet the container substrate. On February 8, 2001, one hour after irrigation, containers were randomly assigned an extraction time of 15, 30, 45 or 60 minutes. Using a manual vacuum pump (Model 2005G2 Soil Moisture Equipment Corp. Santa Barbara, CA) 50 centibars (cb) of vacuum was applied to each lysimeter and lysimeters were clamped to retain vacuum. After the designated amount of time the remaining vacuum, if present, was released and solution

was extracted and measured using a 50 ml syringe attached to plastic tubing. The experiment was repeated five times for the purpose of replication and all data were submitted for analysis using the SAS system (version 8.0, SAS Institute, Cary, NC).

*Experiment 2:* The effect of vacuum pressure and time on extracted volume of substrate solution under nursery conditions was conducted outdoors in early June 1999 in Blacksburg, Virginia. Twenty-five, 4.8-cm, ½-bar lysimeters were installed in individual 56.8 L (15-gallon) containers containing a pine bark substrate and two-year-old *Quercus phellos* L. (willow oak) trees. The containers were spray-stake irrigated for 10 to 15 minutes daily to receive approximately 7.6 liters (~2 gallons) of water.

One hour after irrigation, lysimeters were randomly assigned vacuum pressures of 10, 20, 30, 40, or 50 cb and extraction times of 1, 2, 3, 4 or 5 minutes. The experiment was repeated three times and data were analyzed using the ANOVA procedure of SAS (version 8.0, SAS Institute, Cary, NC). Using parameter estimates generated by the ANOVA procedure of SAS (version 8.0), the model:  $\log\text{vol} = 1.17 + 0.075 (\text{centibar}) + 0.267 (\text{time}) - 0.000854 (\text{centibar}^2)$  was developed to fit the data and to predict volumes that could be extracted by the 4.8-cm ½-bar lysimeters at different vacuum pressures and extraction times.

*Experiment 3:* There was concern that the variability of extracted volumes of substrate solution obtained using SCL's in experiment 1 and 2 could be attributed to lysimeter variation. To check for variability under ideal extraction conditions, four 4.8-cm ½-bar lysimeters were placed in each of five 18.9 L (5-gallon) buckets containing 11-cm of water. A vacuum pressure of 10, 20, 30, 40 or 50 cb was assigned to each bucket and time increments of either 4, 8, 12 or 16 minutes were randomly assigned to each lysimeter within a bucket. The experiment was repeated four times and results were analyzed using SigmaPlot (version 5.0, SPSS Inc. Chicago, IL).

*Experiment 4:* To test the effect of extracted volume on EC levels, six 4.8-cm ½-bar lysimeters were installed in six 56.8-L (15-gallon) containers with unamended pine bark substrate in the greenhouse. Containers were fertigated with a 300 ppm N solution of Fafard 20N-8.6P-16.4K (Conrad Fafard, Inc. Agawam, Massachusetts) until EC levels stabilized at  $0.8 \text{ dS}\cdot\text{m}^{-1}$  within each container. A vacuum of 40 cb was applied to each lysimeter and extraction times varied from 3 to 10 minutes in order to obtain different

volumes of substrate solution (10 to 190 ml) within the SCL's. EC on each extracted solution was determined using an Agrimeter (Myron L Company, Carlsbad, California). The experiment was repeated three times and regression analysis was performed on all data using SigmaPlot.

## Results and Discussion

*Experiment 1:* Both the ½-bar and 1-bar 4.8-cm lysimeters at 50 cb of vacuum obtained sufficient amounts (approximately 50 ml) of substrate solution for normal testing by fifteen minutes of extraction time (Figure 1). Although extracted volumes were similar between the 4.8-cm ½-bar and 1-bar lysimeters, the ½-bar size was chosen for further experimentation because the larger pore size (6.1 microns) has less potential for pore space obstruction compared to that of the smaller pores of the 1-bar size (2.1 microns). The 2.2-cm lysimeters extracted around 20 ml of solution after 15 minutes and up to 40 ml after 60 minutes (1-bar size only). The amount of solution (up to 40 ml) and vacuum that the 2.2-cm lysimeters may contain is limited by its relatively small diameter. However, in situations where small volumes are needed, installation space is limited, or when time is not a limiting factor the 2.2-cm lysimeter may be appropriate for use. For example, if only an EC measurement is needed, the 20 ml volume obtained after 15 minutes may be sufficient depending upon instrumentation used for EC readings.

*Experiment 2:* Sufficient substrate solution could be obtained after five minutes when a vacuum of 30, 40 or 50 cb was applied to the 4.8-cm ½-bar lysimeters (Figure 2). There was no centibar x time interaction for extracted volumes ( $p = 0.213$ ) and volumes extracted were somewhat erratic ( $r^2 = 0.55$ ).

The coarse nature of pine bark substrate could account for the erratic volumes obtained from lysimeters ( $r^2 = 0.55$ ). Cohesively held water (one water molecule attached to another) such as that found in the larger pores of pine bark substrate requires less energy (i.e. less vacuum) for bond breaking than does water held adhesively (water molecule to substrate particle) such as that found in smaller pores. In pine bark, as in coarse, sandy soils, increasing vacuum within the SCL results in a more quick depletion of the available moisture in the immediate vicinity of the ceramic cup, thereby reducing hydraulic conductivity and creating a barrier to the flow of water moving to the cup (Soil

Moisture Equipment Corp., 1997). Results from Experiment 1 demonstrate that the volume of solution extracted with the 2.2-cm lysimeters was less variable than that extracted by the 4.8-cm lysimeters (Figure 1). This is probably because the 4.8-cm lysimeters have a greater capacity to contain vacuum due to their larger diameter than do the 2.2-cm lysimeters. Because of this difference, the 2.2-cm lysimeters were able to collect solution more consistently over time whereas the greater vacuum within the 4.8-cm lysimeters quickly depleted the substrate solution supply around the ceramic cup, thus causing interruptions in hydraulic conductivity and increased variability. During these interruptions solution, if available within the substrate, would again have to fill the depleted pore spaces in order for the cup to continue to collect solution, thereby increasing variability in volumes extracted and in extraction time.

*Experiment 3:* When the 4.8-cm ½-bar lysimeters were immersed in water, an increase in applied vacuum resulted in a direct increase in extracted volume (Figure 3). Time had no effect on volume extracted because lysimeters collected solution continuously until equilibrium was reached between the pressure in the lysimeter and in the surrounding solution. This occurred during the first four minutes of extraction time. No inconsistency in individual lysimeters under these conditions was demonstrated. Therefore, the variability in volumes of solution extracted from pine bark substrate using SCL's can be attributed to the coarse nature of the substrate or installation procedures that could affect the contact between the ceramic cup and the surrounding substrate and subsequently the volume of solution extracted.

*Experiment 4:* The EC of solution obtained using SCL's was not affected by volume extracted ranging from 15 ml to 190 ml (Figure 4). Earlier findings by Murray et al. (1996) and Wright (1986) have shown that EC and pH of container leachate obtained using the PT method did not vary significantly with differing volumes of collected leachate.

Results of these experiments demonstrate that SCL's are able to provide growers with a convenient, reliable method for obtaining substrate solution from pine bark substrate in large containers. I recommend that three or four 4.8-cm ½-bar lysimeters (~ \$50/lysimeter) be installed within a block of plants of similar size and fertility regime. A vacuum pressure of 30 to 40 cb should be applied to each lysimeter with an extraction

time of at least five minutes in order to obtain the solution needed for monitoring the nutritional status of large container-grown plants.

## Literature Cited

- Argo, W.R., B.J. Weesies, E.M. Bergman, M. Marshal, and J.A. Biernbaum. 1997. Evaluating rhizon soil solution samplers as a method for extracting nutrient solution and analyzing media for container-grown crops. *HortTechnology* 7:404-408.
- Bredemeier, N., N. Lamersdorf, and G.A. Wiedey. 1990. A new mobile and easy to handle suction lysimeter for soil water sampling. *Fresenius' J. of Analy. Chem.* 336:1-4.
- Grossman, J. and P. Udluft. 1991. The extraction of soil water by the suction-cup method: a review. *J. of Soil Sci.* 42:83-93.
- Hicklenton, P.R. and K. Cairns. 1996. Plant water relations and mineral nutrition of containerized nursery plants in relation to irrigation method. *Can. J. of Plant Sci.* 76:155-160.
- Jayachandran, K., T.R. Steinheimer, L. Somasundram, T.B. Moorman, R.S. Kanwar, and J.R. Coats. 1994. Occurrence of atrazine and degradates as contaminants of subsurface drainage and shallow groundwater. *J. Environ. Qual.* 23:311-319.
- Lucas, R.E., P.E. Rieke, and E.C. Doll. 1972. Soil saturated extract method for determining plant nutrient levels in peats and other soil mixes. 4<sup>th</sup> Intl. Peat Congr. 3:221-230.
- Murray, C.L., G.P. Lumis and C. Chong. 1996. Fertilizer method and container size effects on shade trees grown in in-ground containers. *Can. J. of Plant Sci.* 76:507-513.

SAS 2001. SAS User's Guide: Statistics, Version 8<sup>th</sup> ed. SAS Institute Inc., Cary, N.C.

SoilMoisture Equipment Corporation. 1997. Operating Instructions 1920F1/1920F1K1. October: 1-16.

Walden R. and A. Niemiera. 1997. A method of monitoring the nutritional status of pine bark substrate in large containers. Proc. Southern Nurs. Assoc. Res. Conf. 42:165-168.

Wright, R.D. and A. Niemiera. 1987. Nutrition of container-grown woody nursery crops. p. 75-95 in J. Janick(ed.) Hort. Rev. Van Nostrand Reinhold Co., New York.

Wright, R.D. 1986. The pour-through nutrient extraction procedure. HortScience 21:227-229.

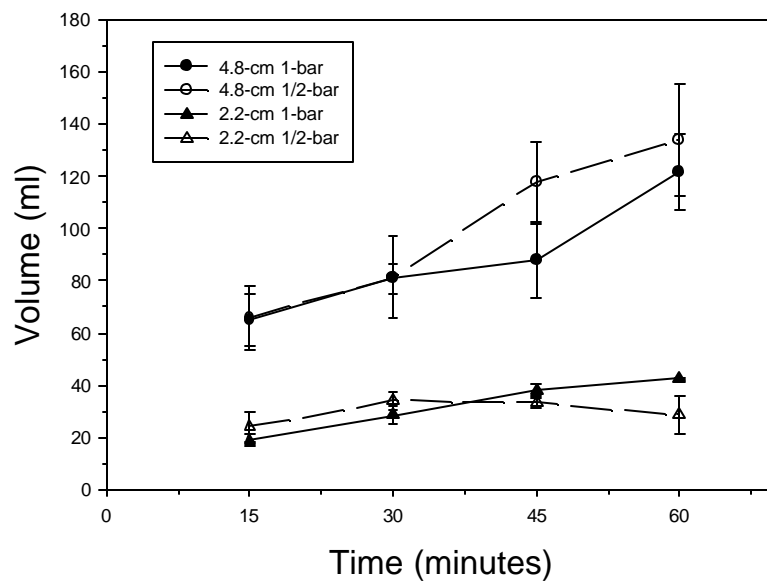


Figure 1. The effect of extraction time and lysimeter type on volume of substrate solution collected at 50 centibars (cb) of vacuum. Bars represent standard error means. n = 5.

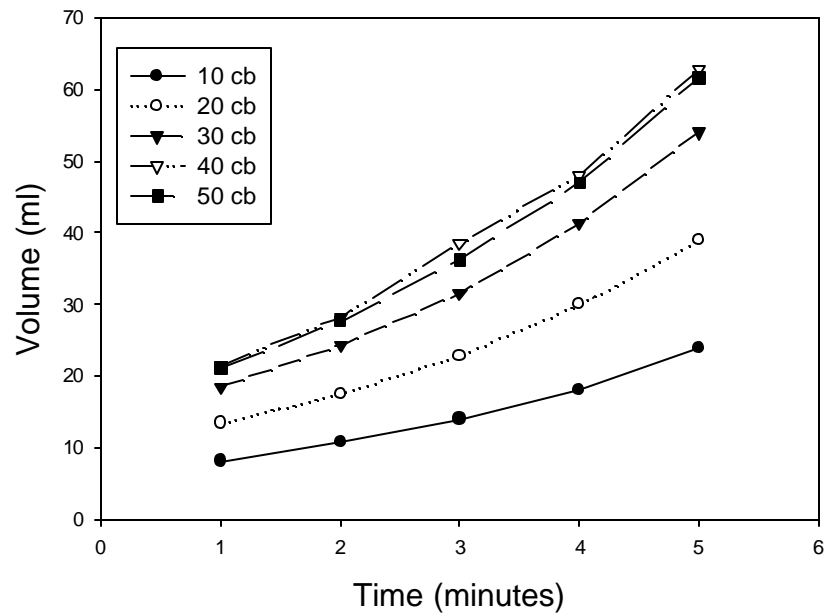


Figure 2. The effect of time and vacuum pressure(cb) on volume of solution extracted with 4.8-cm 1/2-bar lysimeters.  $\log vol = 1.17 + 0.075(\text{centibar}) + 0.267(\text{time}) - 0.000854(\text{centibar}^2)$  ( $r^2 = 0.55$ ).

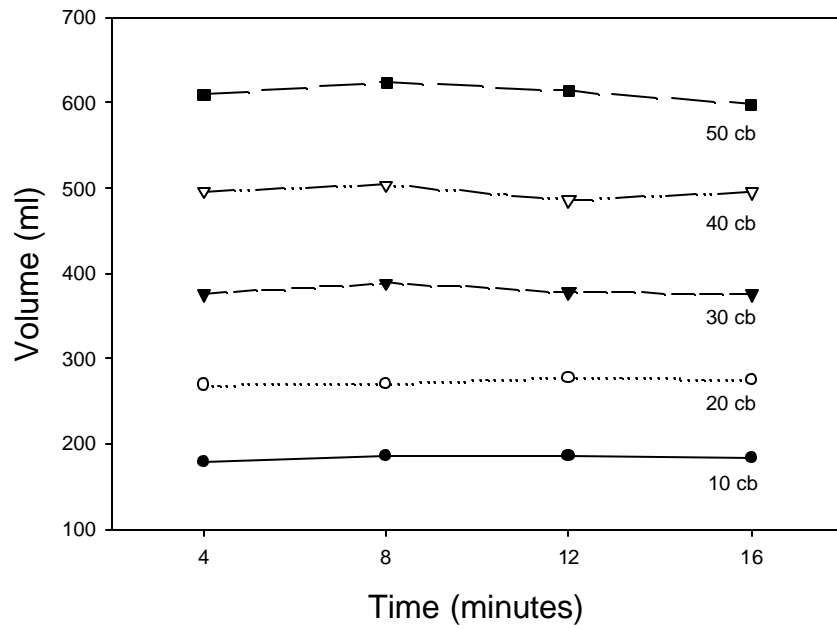


Figure 3. Effect of vacuum pressure (cb) and extraction time on volumes extracted by 4.8-cm 1/2-bar lysimeters immersed in water. n=4.

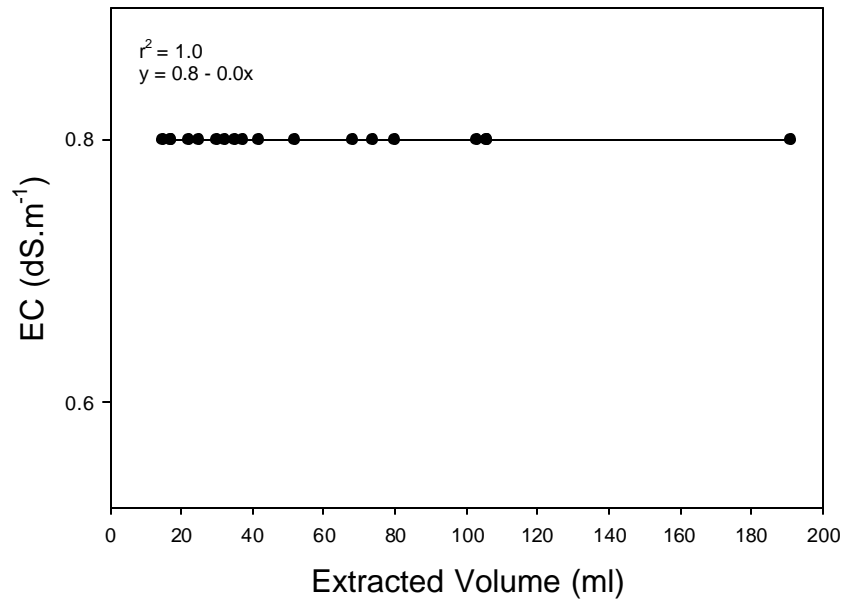


Figure 4. Effect of extracted volume on electrical conductivity (EC) levels of substrate solution obtained from pine bark substrate with 4.8-cm 1/2-bar lysimeters using 40 centibars (cb) of vacuum pressure. n = 18.

## Chapter 3

### Effectiveness of Suction Cup Lysimeters for Monitoring the Nutritional Status of Container Substrate for Optimum Growth of willow oak Trees

#### Abstract

As container size and subsequently weight increase, extracting substrate solution for nutritional analysis becomes difficult. The purpose of this work was therefore to determine with suction cup lysimeters (SCL) to obtain solution, the EC level associated with optimal growth of containerized *Quercus phellos* L. (willow oak) trees. Two-year-old trees were grown in 56.8 L containers and were fertilized with either 0, 50, 100, 150, 200, 250 or 300 grams Osmocote Plus Northern 15N – 3.9P – 9.8K per container. Plant height and trunk diameter were measured at the beginning and end of the growing season. Leaf samples were taken at the conclusion of the experiment to determine nutrient concentration. Growth was optimal at 200g Osmocote per container and corresponded with a seasonal mean EC level of  $0.5 \text{ dS}\cdot\text{m}^{-1}$ . SCL's were shown to be an effective method of extracting solution for EC monitoring from large containers ( $\geq 18.9 \text{ L}$  (5-gallon)).

#### Introduction

In recent years, the production of woody nursery crops in containers has become the predominant method of production in the United States. Because soilless media, regularly used in container production, have relatively low water-holding capacities and ability to fix nutrients, the medium solution is continually being depleted of nutrients through leaching or plant uptake (Wright and Niemiera, 1987). Therefore, intensive management of fertilizer, substrate, and irrigation regimes is needed to maintain container fertility for optimum plant growth. Concerns about potential environmental contamination caused by nutrient and pesticide-laden runoff from woody plant nurseries have also led to the need for careful monitoring of the nutritional status of containerized plants (Hicklenton and Cairns, 1992).

The two methods generally used to supply nutrients to containerized crops are liquid feed (LF) fertilizers, in which water-soluble fertilizers are added to irrigation water, and controlled release fertilizers (CRF) in which dry products are either incorporated into the growth media or top dressed following planting. Previous studies have shown that high quality plants can be produced using either LF or CRF as long as adequate nutritional levels are maintained in the medium solution (Catanzaro et al., 1998; Gouin and Link, 1973; Hicklenton, 1992). However, maintaining adequate levels of nutrients within containers using LF can be difficult, especially in outdoor growing conditions in which rainfall, in addition to irrigation, facilitates leaching of highly soluble nutrients, reducing fertilizer use efficiency and possibly leading to nutrient deficiencies that in turn limit plant growth (Hicklenton and Cairns, 1992). Alternatively, plants grown under high fertility levels show an increase in the shoot:root ratio of the plant and a lowering of concentrations of defensive compounds within the plant that may lead to poor performance after being transplanted to more stressful environments outside the nursery setting (Larimer and Struve, 2002). In addition, applying high rates of nitrogen (N) and other nutrients in order to increase nursery productivity results in detrimental environmental consequences if leachate is not carefully managed.

CRF's supply nutrients to the plant by releasing them at relatively low levels over an extended period of time (Catanzaro et al., 1998). Using CRF's allows for increased nutrient use efficiency (Catanzaro et al., 1998), and lower labor costs because reapplication of the fertilizer is not required as frequently as when using LF fertilizers (Meadows and Fuller, 1987). Use of a CRF can therefore significantly reduce the amount of nutrients that are leached from containers, thus reducing the potential for groundwater pollution (Hicklenton and Cairns, 1992 and Catanzaro et al., 1998).

One problem with CRF's is that during the early part of the growing season larger amounts of nutrients are released from CRF's than can be utilized by the plants, whereas during the latter part of the season, nutrient release may be limiting (Wright and Niemiera, 1987; Catanzaro et al., 1998). The grower must then decide if and when to reapply CRF during the growing season (Catanzaro et al., 1998; Shiflett et al., 1994).

CRF products are categorized by the length of time needed for the prill to release ~80% of its contents at a given temperature with the release rate of most popular CRF

products being directly affected by temperature and not by the moisture content of the substrate (Husby, 1999). However, the adequacy of these longevity ratings has been questioned. When comparing the longevity rating of an 8 to 9 month and a 12 to 14 month CRF, it was found that after 4 months, N levels in the substrate solution had dropped below 10 ppm, contributing to subsequent limited growth (Meadows and Fuller, 1983). In Shiflett et al.'s study (1994) it was determined that *Ilex crenata* 'Helleri' Thunb. plants that received reapplications of CRF's after an initial application at the start of the season were wider than plants receiving just one application of CRF at the beginning of the season. However, mid-season reapplication of CRF increased the amount of N leached from the container by as much as 42%. Therefore, growers should base their decision to reapply CRF upon whether or not the extra growth that results will offset the reapplication costs as well as the impact that reapplication could have on the environment (Shiflett et al., 1994).

Nutritional analysis of container substrate solution is therefore an integral part of maintaining fertility in container systems. It has been shown that substrate solution sampling methods based on water extraction of nutrients, such as the pour through (PT) method (Wright, 1986) most accurately represent the actual level of nutrients in the substrate solution (Lucas et al., 1972). As container size and consequently weight increase, obtaining substrate solution for analysis via methods like the PT becomes more difficult. Several methods currently exist for obtaining substrate solution from containers. However, suction cup lysimeters (SCL) have demonstrated potential for extracting substrate solution for analysis from the large containers (18.9-L (5-gallon) or more) commonly used in nursery production of woody plants (Walden and Niemiera, 1997 and Stanley, 2002).

The objective of this study was to determine the EC levels of substrate solution extracted by suction cup lysimeters that are associated with optimal growth of *Quercus phellos* L. (willow oak), a popular landscape shade tree fertilized with a CRF.

## **Materials and Methods**

This experiment was conducted at the Virginia Polytechnic Institute and State University's Urban Horticulture Center, Blacksburg, Virginia. Fifty-six container-grown

*Quercus phellos* L. (willow oak) trees, seeded in January 1999, were potted individually from 18.9-L (5-gallon) containers into 56.8-L (15-gallon) plastic containers with unamended pine bark medium as substrate in September 2000. The Pot-In-Pot (PIP) method of production was used with sunken containers spaced approximately 1.5 meters on center. Seven different application levels (0, 50, 100, 150, 200, 250, and 300 grams/container) of Osmocote Plus Northern 15N-3.9P-9.8K (15-9-12), a polymeric resin coated CRF with an 8 to 9 month longevity rating at 21.1°C (Scotts-Sierra Horticultural Products Company, Marysville, Ohio) were applied on 26 April 2001. This product also contained micronutrients in the amount of 0.02% boron, 0.05% copper, 0.45% iron, 0.06% manganese, 0.02% molybdenum, and 0.05% zinc. Treatments were replicated eight times and arranged in a completely randomized design (CRD). Four containers from each treatment were randomly chosen to receive a 4.8-cm x 61-cm ½-bar lysimeter (SoilMoisture Corp., Santa Barbara, CA) for removal of substrate solution for EC analysis throughout the experiment. Each SCL was installed approximately 20-cm from the base of the trunk and inserted to near the bottom of the container (~ 2.5-cm) via a previously augered hole with a diameter of approximately 5.0 cm. After lysimeters were installed, the CRF was applied and additional pine bark was then distributed evenly over container surfaces to lightly cover the CRF. When EC levels began to decline, a reapplication rate of 20% of the original amount was applied to each container via top dressing on 26 July 2001 in an attempt to keep EC levels from dropping. The containers were spray-stake irrigated for 10 to 15 minutes daily to receive approximately 7.6 L (~2 gallons) of water each day during the experiment. Substrate temperatures ranged from 16.0 to 27.0°C during the experiment.

Initial plant height and trunk diameter measurements were taken on 30 April 2001. Trunk diameter measurements were taken 15-cm from the base of the tree and marked with a painted line so final measurements could be taken from the same point. Twice weekly, May 7 through September 5, 2001, substrate solution samples were removed from the containers using SCL's one to two hours after irrigation. For extraction of substrate solution, approximately 40 centibars (cb) of vacuum was created within each lysimeter using a vacuum hand pump (Model 2005G2, SoilMoisture Corp. Santa Barbara, CA) and extraction time ranged from five to ten minutes in order to obtain

sufficient solution for EC testing ( $\geq 10$  ml). Solution was then removed from the lysimeter using a 50-ml syringe with plastic tubing. The solution was then tested for EC level (Agrimeter, Myron L Company, Carlsbad, CA) and EC levels were recorded over time throughout the experiment.

Final height and diameter measurements were taken on 18 September 2001. On 21 September approximately 2 grams of the uppermost mature leaf tissue was removed and dried in a 65.6°C drying oven for five days. Leaf tissue was ground in a Cyclone Sample Mill (UD Corporation, Boulder, Colorado) and weighed. Tissue was digested as described by the Kjeldahl Block Digestor Method (Peterson and Chesters, 1964) and analyzed for total N by colorimetric flow injection analysis or ashed in a muffle furnace for four hours for total P, K, Ca, Mg, Fe, Mn and Zn concentrations by inductively coupled plasma (ICP) spectrometry testing. All data obtained during the study were submitted for regression analysis using SigmaPlot (version 5.0, SPSS Inc. Chicago, IL).

## Results and Discussion

Optimal growth was achieved with an initial application rate of 200 g of Osmocote 15N–3.9P–9.8K at the beginning of the growing season and a 40 g reapplication rate on 26 July (Figure 1). Application rates greater than 200 g resulted in only marginal increases in growth of willow oak. Gouin and Link (1973) found that a wide range of Osmocote rates can be used successfully for woody crops such as *Pyracantha* X ‘Loboy’, *Ilex crenata* Thunb., *Prunus laurocerasus* L., *Juniperus horizontalis* Moench. and *Weigela florida* (Bunge.) A. DC.

Substrate solution (via SCL) EC levels increased with fertilizer rate. Levels were relatively high from 30 May to 19 July and then began to decrease over time (Figure 2). The pattern of nutrient release demonstrated in this study is typical for Osmocote, which is temperature dependent but generally releases a higher amount of nutrients initially, with EC levels decreasing over time (Catanzaro et al., 1998 and Shiflett et al., 1994). After EC levels began to drop, a reapplication rate that was 20% of the original amount was applied in order to prevent a further decline and to maintain a more even release of nutrients from the CRF. This resulted in a subsequent increase in EC for all treatments that received fertilizer (Figure 2).

Seasonal average EC levels for all treatments (Figure 3) were calculated after the last reading was taken on 5 September 2001 (n = 28 per treatment) and ranged from 0.1 dS·m<sup>-1</sup> for the control to 0.9 dS·m<sup>-1</sup> for the 300 g treatment. The seasonal average EC level associated with the 200 g treatment was approximately 0.5 dS·m<sup>-1</sup> (Figure 3). There was also a good relationship between EC and trunk diameter increase (Figure 4). While EC levels for the 200 g treatment did drop below 0.5 dS·m<sup>-1</sup>, maintaining this level with reapplications of the CRF during the growing season would help to assure optimum growth. EC levels for treatments below 200 g were rather steady and relatively low, running about the same as the irrigation water (0.1 dS·m<sup>-1</sup>). This indicates that most nutrients were being utilized by the plant or leached from the container during irrigation or rainfall events. Because of variance in irrigation water electrolyte content from different sources and locations, using a threshold EC to signal reapplication should be based upon the specific fertilizer used and on the EC of the native water supply (Shiflett et. al, 1994).

Foliar nutrient levels associated with the 200 g treatment were 2.3% N, 0.15% P, 0.62% K, 0.65% Ca, 0.17% Mg, 42.3 ppm Fe, 134.7 ppm Mn and 61.9 ppm Zn (Table 1). These are comparable to the sufficiency range for willow oak as published in the Plant Analysis Handbook II (Mills and Jones, 1996).

In summary, suction cup lysimeters successfully obtained substrate solution from containers with pine bark substrate for EC analysis throughout this experiment, thus resulting in EC levels which could be associated with optimal growth of *Quercus phellos* L. It was demonstrated that optimal growth of *Quercus phellos* L. trees can be produced with an initial application of 200g of Osmocote at the beginning of the growing season in climates similar to Blacksburg, VA (USDA climate zone 6A). By applying 200 g Osmocote, as compared to larger amounts, the chance for potential environmental contamination from nutrient-rich runoff is decreased. Subsequent CRF applications may be needed in order to maintain EC levels of 0.5 dS·m<sup>-1</sup> depending upon nutrient release fluctuations that may occur throughout the growth period.

## Literature Cited

Catanzaro, C.J, K.A. Williams, and R.J. Sauve. 1998. Slow release versus water soluble fertilization affects nutrient leaching and growth of potted Chrysanthemum. *J. of Plant Nutr.* 21:1025-1036.

Gouin, F.R. and C.B. Link. 1973. Growth response of container-grown woody ornamentals to slow-release fertilizers. *HortScience* 8:208-209.

Hicklenton, P.R. and K. Cairns. 1992. Solubility and application rate of controlled-release fertilizer affect growth and nutrient uptake in containerized woody landscape plants. *J. Amer. Soc. Hort. Sci.* 117:578-583.

Husby, C.E.. 1999. Influence of temperature, time and product on nutrient release patterns of Osmocote Plus, Nutricote, and Polyon controlled release fertilizers. Master's Thesis. Virginia Polytechnic and State University. Blacksburg, Virginia.

Larimer, J. and D. Struve. 2002. Growth, dry weight and nitrogen distribution of red oak and 'autumn flame' red maple under different fertility levels. *J. Environ. Hort.* 20:28-35.

Lucas, R.E., P.E. Rieke, and E.C. Doll. 1972. Soil saturated extract method for determining plant nutrient levels in peats and other soil mixes. 4<sup>th</sup> Intl. Peat Congr. 3:221-230.

Meadows, W.A. and D.L. Fuller. 1983. Nitrogen and Potassium release patterns of five formulations of Osmocote fertilizers and two micronutrient mixes for container grown woody ornamentals. *South. Nurseryman Assoc. Res. J.* 9:28-34.

Mills, H.A. and J.B.J. Jones. Plant Analysis Handbook II. Athens: Micromacro Publishing, 1996.

Shiflett, M.C., A.X. Niemiera, and C.E. Leda. 1994. Mid-season reapplication of controlled release fertilizers affect 'Helleri' holly growth and N content of substrate solution and effluent. *J. Environ. Hort.* 12:181-186.

Stanley, Mary H. 2002. Master's Thesis. Suction Cup Lysimeter Method for Extracting Pine Bark Substrate Solution. Virginia Polytechnic and State University. Blacksburg, Virginia.

Walden R. and A. Niemiera. 1997. A method of monitoring the nutritional status of pine bark substrate in large containers. *Proc. South. Nurseryman Assoc. Res. Conf.* 42:165-168.

Wright, R.D. and A. Niemiera. 1987. Nutrition of container-grown woody nursery crops. p. 75-95 in J. Janick(ed.) *Hort. Rev.* Van Nostrand Reinhold Co., New York.

Wright, R.D. 1986. The pour-through nutrient extraction procedure. *HortScience* 21:227-229.

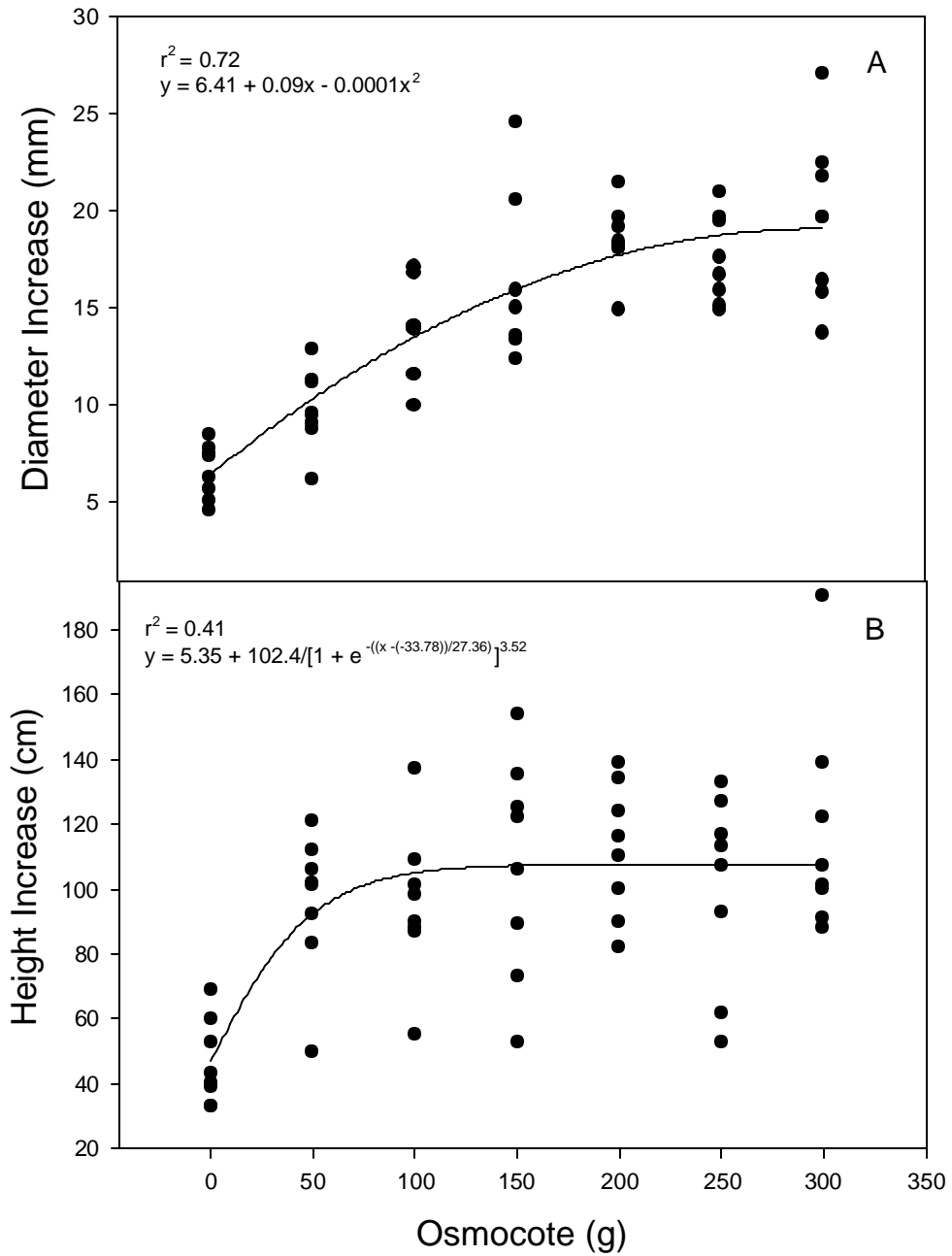


Figure 1. Effect of Osmocote application rate on trunk diameter increase (A) and height increase (B) of two-year-old container-grown willow oak trees.  $n = 8$  per treatment level. ( $p_{reg} = <0.001$  for A and B)

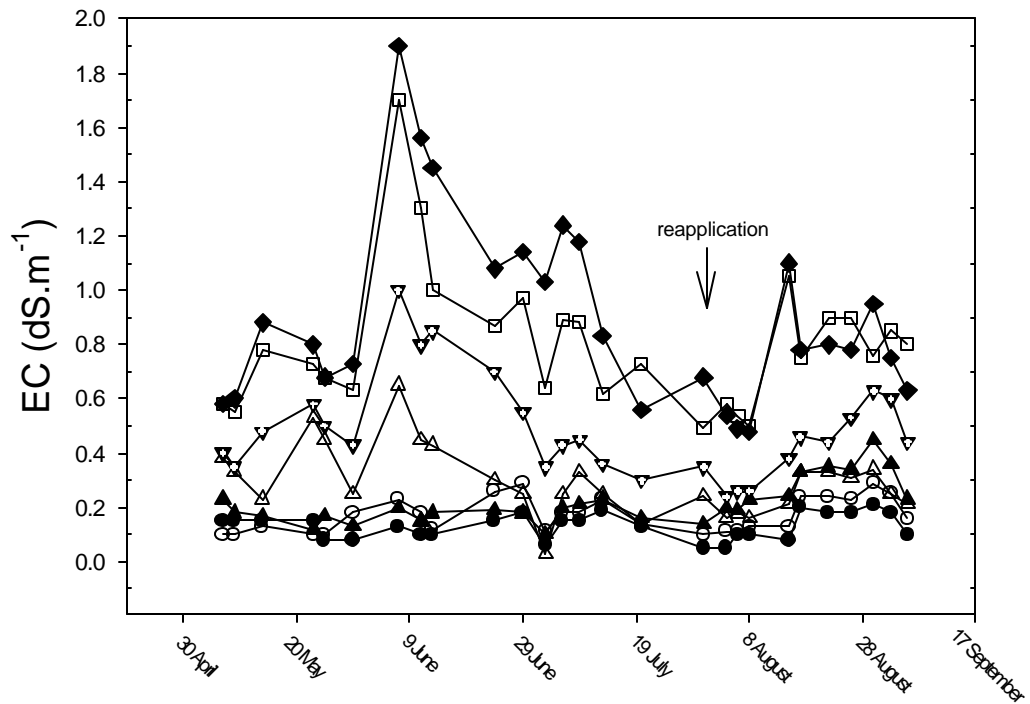


Figure 2. Effect of Osmocote release rate on electrical conductivity (EC) levels of substrate solution 7 May through 5 September 2001. A reapplication rate, 20% of the original treatment level, was applied on 26 July 2001.

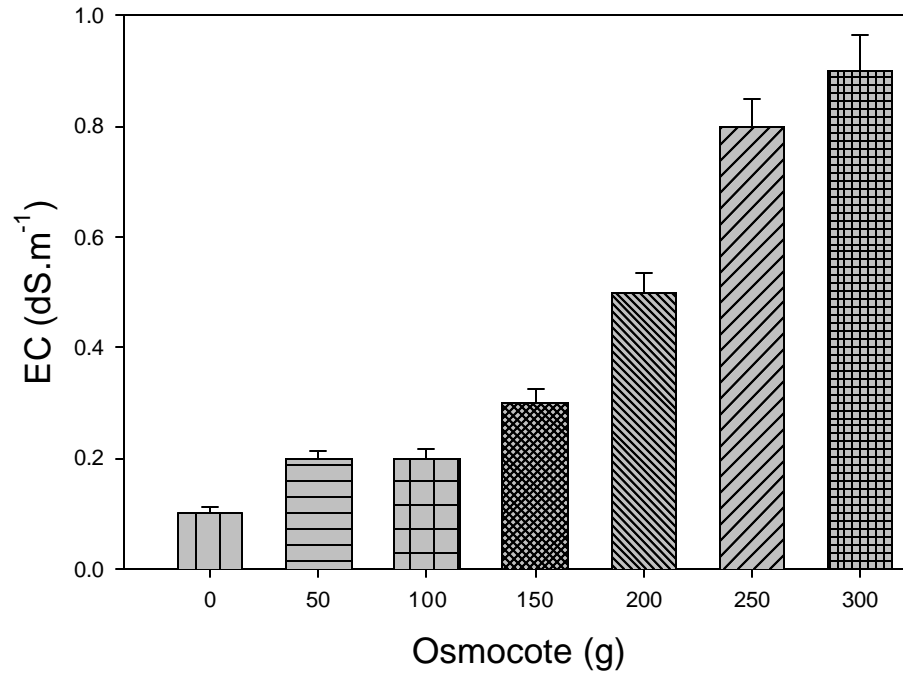


Figure 3. Seasonal average electrical conductivity (EC) levels of substrate solution as affected by different fertilization rates. Standard error bars are given. Means reported are for n = 28 observations.

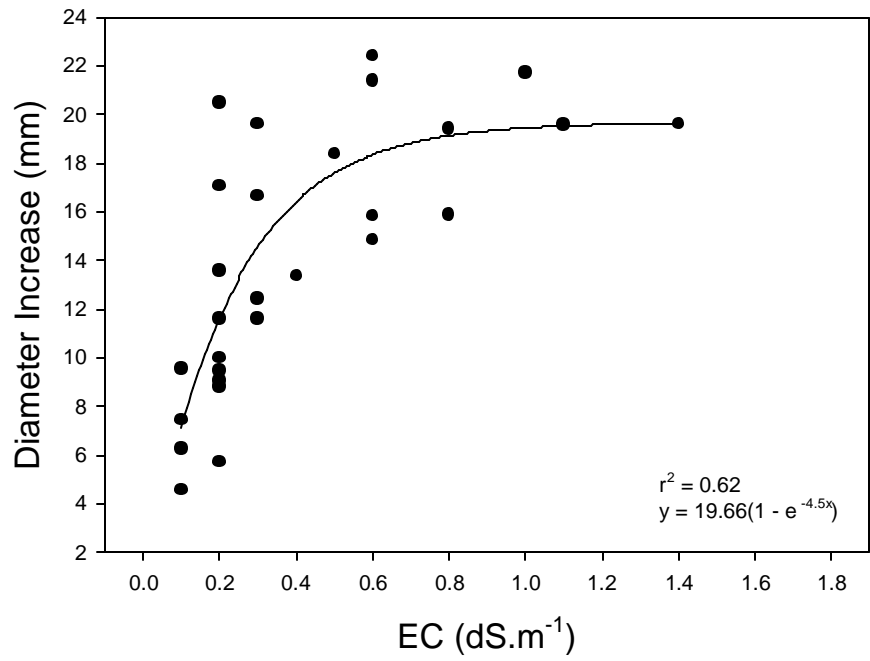


Figure 4. Effect of seasonal average electrical conductivity (EC) level on trunk diameter growth of two-year-old container-grown willow oak trees.  $n = 28$ . ( $p_{\text{reg}} = <0.0001$ ).

Table 1. Foliar concentration of nutrient levels at the end of the season as affected by fertilizer rate. <sup>z</sup> Leaf tissue concentration as of 21 September 2001. n = 56.

Osmocote (g)	<sup>z</sup> N (%)	P (%)	K (%)	Ca (%)	Mg (%)	Fe (ppm)	Mn (ppm)	Zn (ppm)
0	1	0.07	0.57	0.66	0.16	29.2	184	19.9
50	1.4	0.1	0.64	0.73	0.18	27.8	175.3	34.4
100	1.8	0.12	0.65	0.76	0.18	35.3	179.5	42.7
150	2.2	0.14	0.61	0.66	0.16	38.3	164	54.1
200	2.3	0.15	0.62	0.65	0.17	42.3	134.7	61.9
250	2.4	0.17	0.66	0.54	0.17	43.4	132.2	59.5
300	2.4	0.17	0.68	0.49	0.15	40.3	116.1	50.5
				P-value				
Linear	0.0001	0.0001	0.6574	0.1261	0.5646	0.1142	0.4661	0.0001
Quadratic	0.0001	0.0067	0.8734	0.0046	0.3862	0.3922	0.2822	0.0009
r <sup>2</sup>	0.92	0.79	0.08	0.36	0.03	0.14	0.44	0.45

## VITA

Mary Helen Stanley was born on February 7, 1977 in Richmond, Virginia. She grew up in Halifax, Virginia. In 1999 she graduated from the University of North Carolina at Wilmington with a Bachelor of Arts degree in Biology. After graduating, she taught sixth grade math and spelling in Cluster Springs, Virginia for one year. She began graduate work at Virginia Polytechnic and State University in the department of horticulture during the fall of 2000 and graduated in May 2002.