# IRRIGATION MANAGEMENT AND ALTERNATIVE CONTAINERS FOR MORE SUSTAINABLE NURSERY PRODUCTION

By

Xueni Wang

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#### ABSTRACT

# IRRIGATION MANAGEMENT AND ALTERNATIVE CONTAINERS FOR MORE SUSTAINABLE NURSERY PRODUCTION

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Reducing the use of water and plastics in nursery production can have a large impact on the sustainability of a nursery operation. Container-grown woody ornamentals were irrigated at four different levels based on daily water use (DWU) to study the impact on plant growth, leachate electrical conductivity, pH, runoff water volume and nutrient loss. For all taxa, final growth index, leachate electrical conductivity (EC), pH, runoff water volume, runoff NO3<sup>-</sup> and PO4<sup>3-</sup> concentration were similar under all treatments. Water runoff volume and nutrient loss were much lower than the conventional nursery irrigation volume used by Warsaw et al., 2009. Alternative containers were evaluated to compare water use, plant growth, leachate EC, pH, root zone temperature and container physical properties and biodegradability compared to conventional plastic containers. Container type did not affect final plant growth index, leachate EC or pH. The seasonal mean substrate temperature in all alternative containers was lower than that of plastic containers. Paper fiber containers used more water than plastic containers in 2011; however plastic containers had the greater water use than alternative containers in 2012. All alternative containers tested passed the germination tests for biodegradability according to ASTM D6868, 6400 and D5338. Alternative containers tested were not proven to be biodegradable according to the ASTM D 5338 standard.

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LITERATURE REVIEW

### **Alternative Container Evaluation**

### Horticultural Container Overview

The environmental horticulture industry has been recorded as one of the fastest expanding sectors of the nation's agriculture, and it comprises floriculture, greenhouses, nursery and turf grass sod production (Yue et al., 2010). Within this industry, nursery and greenhouse production sectors alone created 436,462 jobs and \$ 27.1 billion in 2007-08 (Hodges et al., 2011). Plastic containers are the most commonly used pots for container production in nursery and greenhouse operations. In nine southern US states, the containers purchased by growers totaled \$ 16.6 million, 99% of those were polyethylene (Hodges and Haydu, 2001). The attributes of light weight and low cost of polyethylene containers are advantages for horticultural use (Amidon, 1994); however, there are many problems associated with plastic containers.

Disposal of plastic containers can cause environmental issues such as toxic gas emission from burning and landfill space occupation (Anand et al., 2007). The most overriding concern is that plastic container production is not sustainable, since approximately 4 percent of annual petroleum resources are used to make plastic and a similar amount of petroleum is used to provide energy for the production process (Thompson et al., 2009). Yet the containers are rarely recycled and usually disposed of after the first use (Evans and Hensley, 2004). In order to address these issues, new materials are being sought for biodegradable and compostable containers such as bioresins, coir, poultry feathers, paper fibers, rice hulls and processed cow manure (Evans and Hensley, 2004; Hall et al., 2010b). Biodegradable and compostable materials mean that the object will be broken down by natural occurring microorganisms (ASTM, 2004). Biodegradable materials might contain toxins while compostable materials must break down into carbon dioxide, water and biomass that is not toxic. In other words, compostable materials by definition are biodegradable while biodegradable materials are not necessarily compostable (Kale et al., 2007).

Limited literature has been published associating the physical properties of alternative containers and their effects on plant growth and water usage. This review will address the following topics related to alternative container background, marketing research and evaluation:

- 1. Agriculture plastic waste disposal and recycling
- 2. Types of alternative containers and their properties
- 3. Consumers' willingness to pay and growers' acceptance
- 4. Plant growth and water use in alternative containers

### Agricultural Plastic Waste Disposal and Recycling

The nursery industry switched from in-ground production to above-ground container production system during the 1950s as container-grown plants are easier and less expensive to harvest and ship (Yue et al., 2010). Plastic containers are usually made from injection-molded or blow molded high density polypropylene. Compared to once conventional clay pots, plastic containers are lighter weight, stronger and have greater moisture preservation (Larson, 1993). Due to the favorable characteristics of plastic containers and widespread use, the industry is generating a huge amount of plastic waste each year. Amidon (1994) indicated that in 1992 the Unites States used 236 million kg of agricultural plastic and the majority of this plastic was in the form of nursery containers. Levitan and Barros (2003) provided an estimation of 1.678 billion pounds of plastic used in the global agriculture sector in 2002, under the assumption that 3% of the plastic sold was for agriculture use.

The current primary disposal methods of plastic containers include landfill burial, incineration, recycling and reuse. Landfill burial is the traditional disposal approach for postconsumer plastic containers; however the landfill space is sparse in some countries and several European countries have imposed landfill bans on combustible waste such as plastic since 1996 (Olofsson et al., 2005). Because plastic has only been produced in large quantities for approximately 60 years, its life cycle in the environment is unknown (Hopewell et al., 2009), therefore, long term risks of soil and groundwater contamination could result from UV stabilizers and additives in the plastic products (Teuten et al., 2009). Moreover, many containers purchased for agricultural use come in contact with pesticides and fertilizers (Hemphill, 1993) and may retain residues which could also add to contamination risks. Incineration reduces the landfill space needed for plastic waste, yet plastic burning could cause environmental problems such as emission of carbon dioxide, which adds to global warming and the release of toxic gases into the atmosphere (Anand et al., 2007; Astrup et al., 2009; Hopewell et al., 2009). As finding new disposal options becomes more difficult, alternatives to disposal have been sought such as recycling the plastic. Although recycling creates a positive public attitude toward generated waste, the impact has been limited (Sakai et al., 1996). Due to several causes, the recycling percent of plastic in 2009 was only 7.9% (Environmental Protection Agency, 2010). First, the plastic product often contains toxic dyes and stabilizers which makes recycling a limited option (Hemphill, 1993). Secondly, many recycling facilities are often unwilling to accept plastics with soil or media residues and shipping and processing fees increase with contamination (Garthe and Kowal, 1993). Additionally, some professional growers have concerns about plant pest outbreaks by reusing pots even after using sanitation practices (Yue et al., 2010). In order to address these issues, significant effort has been made to develop containers from alternative materials (Evans and Hensley, 2004).

Types of Alternative Containers and Their Properties

Numerous alternative containers had been developed to meet the needs of bio-sensitive consumers and growers, including containers made from peat, bioresins, poultry feathers, wood fiber, paper fiber, rice hull, coir and cow manure compost (Evans and Karcher, 2004; Grayed, 1971; Kuehny et al., 2011; Lopez and Camberato, 2011)

Limited research has been published regarding the physical properties of alternative containers. Evans and Karcher (2004) evaluated the dry and wet strength of plastic, peat and feather fiber containers by increasing the amount of pressure on the container using a texture analyzer; they discovered that peat and feather fiber containers had lower dry and wet strength than plastic containers. Moreover, the wet strength was much lower than the dry strength for both containers. Candido et al.(2007) evaluated the tensile strength behavior and chromatic character of traditional polypropylene containers and biodegradable plastic containers during a five month experiment in the greenhouse, finding that the tensile strength of biodegradable plastic containers decreased over time, and all pots except traditional ones exhibited discoloration and concluded they were not suitable for horticultural production. Schettini et al. (2012) tested the physic-chemical characterization of containers made from tomato and hemp fibers with mechanical, water vapor permeability, and morphological analysis. They discovered that the biodegradable pots allowed dense root development and did not cause any transplant shock or root deformation.

Several studies have been done to test the biodegradability or decomposition ratio of containers currently on the market. Candido et al. (2007) evaluated pot degradation by visual assessment, finding containers made from biodegradable plastic with 10% and 20% compostable materials are not suitable for Poinsettia cultivation as their mechanical resistance decreased too

rapidly over time within the production period. Ahn et al. (2011) tested the biodegradability of pots containing polylactic acid and poultry feather fiber by measuring the CO<sub>2</sub> produced during incubation; they also used near infrared spectroscopy to estimate the chemical compounds of the pot material that led to degradation. They found that the poultry feather fiber did not degrade during the compost period but the polyactic acid underwent chemical changes during polymer extruding and molding, which prohibits biodegradation.

# Consumers' Willingness to pay and Growers' Acceptance

Several studies have investigated consumers' attitudes toward environmentally friendly packaging. Coddington (1990) reported that in 1986, 67% of U.S. consumers said that they were willing to pay 5%-10% more for recyclable or biodegradable packaging. Consumers increasingly value environmentally friendly product packaging and this has carried over to the horticulture sector in the forms of biodegradable containers. Yue et al. (2010) conducted research on consumers' willingness to pay for plastic containers and biodegradable containers; they reported that consumers are willing to pay a premium for biodegradable containers but the amount differs by material. The highest premium consumers were willing to pay for rice hull pots, straw pots and wheat starch pots were \$0.58, \$0.37, and \$0.20 per pot compared to traditional plastic pots, respectively. Behe et al. (2013) investigated consumers' preferences for local plant production, finding that 17 % of the consumers were mostly influenced by the container type, plant type and the compostable character of the pot compared to other aspects such as conventional, plantable and recyclable pots. In order to better understand consumers' behavior towards biodegradable containers, several market segments : "Rice Hull Likers", "Straw Likers", "Price Conscious", "Environmentally Conscious", "Carbon Sensitive" and corresponding consumer information

were identified (Hall et al., 2010b). Additionally, Hall et al. (2010b) pointed out that consumers were reluctant to purchase low-quality products with green attributes, so they needed to be convinced these were better or equal to the non-green products.

Growers are willing to adopt biodegradable containers as part of their sustainable production practices. In a survey conducted by the Ohio Florist Association, 95% of U.S. growers had heard about sustainable floriculture and 65.2% value this as "very important" to the environment; 63.1% of the growers had used sustainable practices in daily operations and 24.3% are in the process of becoming sustainable (Hall et al., 2009). Lopez et al. (2008) stated that adopting alternative containers is one important step for a growers' operations to become sustainable.

Converting from plastic containers to biodegradable containers does not only result in becoming more environmentally sustainable, but also could be profitable. Hall et al. (2010a) conducted a financial feasibility analysis of converting from plastic containers to Elle pots, which is a production system that wraps a paper fabric around growing substrate. He found that the net present value for growers who bought a new Elle pot machine and used recommended growing substrate would range from \$26,763 to \$28, 852 based on a 15 year loan based on a 0.8 ha greenhouse.

#### Plant Growth and Water Use in Alternative Containers

Several experiments have been done to compare plant growth and water use in alternative containers. Evans and Hensley (2004) found that when vinca and impatiens were irrigated according to plant needs, plants grown in poultry feather and peat containers required more irrigation than plastic containers. They also reported that the dry shoot weight of impatiens and vinca plants in poultry feather containers were greater than that grown in peat and plastic

containers when irrigated according to plant needs. Keuhny et al. (2011) conducted a similar experiment, evaluating geranium, vinca and impatiens growth in seven alternative containers including 10 cm or 12.7 cm wood pulp pots, cow pots, coir, peat, rice hull, paper, and bioplastic containers and plastic containers at five locations. They reported that the growth of geranium, impatiens and vinca varied by location and container type, however, those plants grown in 5 inch plastic or paper containers basically had better growth than other container types. Minuto et al. (2007) found that sweet basil, rosemary, sages, thymus, cyclamen, daisy and lavender grown in biodegradable containers called Master –Bi had similar growth rate to those in normal plastic containers. Lopez and Camberato (2011) evaluated Poinsettia growth in alternative containers and plastic containers, finding Poinsettias grown in molded paper fiber containers had better growth compared to wheat starch-derived bioresins and plastic containers.

The research above indicates that, in general, plants grown in biodegradable containers have similar or better growth than plants grown in plastic containers when the water supply is sufficient. Yet there are no experiments comparing plant growth between biodegradable and plastic container under nursery conditions or containers larger than 12.7 cm diameter, and the exact water usage amount that plants need to grow relative to alternative container materials has not been determined.

# **Woody Ornamental Irrigation Management**

### Introduction

In 2010, Michigan nursery and floriculture industry receipts totaled \$621 M dollars and accounted for 9.6% of the entire state's agricultural receipts (National Agricultural Stastical Service, 2011). Container nurseries require a large amount of irrigation to produce marketable plants; however, water use is already limited by laws and regulations to varying degrees in several states such as Florida, Delaware, California, North Carolina, Texas, Oregon, Maryland, North Carolina and Michigan (Fernandez et al., 2009). Excessive irrigation not only wastes water but can contaminate water resources with agrichemical runoff. In many agricultural areas, groundwater contamination with nitrates has become a problem, with nitrate levels often exceeding the Federal drinking water standard of 10 mg  $L^{-1}$  (Fare et al., 1994; Rathier and Frink, 1989). Due to increased competition for water resources and stricter environmental regulations, irrigation usage by nursery will is likely to be further restricted and the industries will be need to be more efficient in water use (Majsztrik et al. 2011; Nemali and van Iersel 2006).

This review will address the following topics related to container nursery irrigation and water conservation strategies:

- 1. Container nursery irrigation overview
- 2. Current irrigation systems
  - Overhead irrigation
  - Micro irrigation
  - Subsurface irrigation
- 3. Irrigation efficiency

Cyclic schedule

Leaching fraction

Management allowed deficit irrigation
Precision irrigation based on evapotranspiration and plant water demand
Soil moisture content measurement methods

Time Domain Reflectometer

Capacitance sensors

#### Container Nursery Irrigation Overview

Container nurseries consumes large amounts of water to produce marketable plants. In the southeastern U.S., nurseries generally use 1.8 to 2.9 meters of irrigation water yearly on a relatively small land area, and are considered as high water users (Beeson, 2004). However, water resources are becoming restricted or limited because of drought, competition and legislation (Knox, 1989; Nemali and van Iersel 2006). For example, in some areas of Florida, the amount of water allowed to be used by growers has dropped by 40% in 12 years and the availability of groundwater to container nurseries is expected to drop significantly in the next ten years (Beeson, 2004).

Excessive irrigation in agricultural operations can result in fertilizer and chemical runoff, which can affect surrounding water resources and ecosystems (Cabrera, 2005; Hart et al., 2004; Mitsch et al., 2001). Colangelo and Brand (2001) discovered that for containerized rhododendrons, 51.8 and 60. 5 kg ha<sup>-1</sup> nitrate was released in leachate for overhead and trickle irrigation systems annually. Fare et al. (1994) reported that the nitrate loss through container leachate could reach 63% when 13 mm irrigation was applied in one cycle. Wilson and Albano (2011) found that the nitrate-N concentration in drainage water from container nurseries ranged from 0.5 to 322.0 mg L<sup>-1</sup> when using fertigation with urea and nitrate-based soluble formulations. Additionally, Million et al. (2010) reported that for #1 (~3-Liter) sweet viburnum, the loss of N, P and K increased 34, 38 and 45%, respectively by increasing the irrigation rate from 1 to 2 cm day<sup>-1</sup> under a fertilizer rate of 15 g 18N-2.6P-10K control release fertilizer per container.

Several studies have demonstrated that reducing irrigation volume can reduce runoff volume and nutrient loss. Tyler et al. (1996) reported that runoff volume could be reduced by 63% when the cyclic irrigation volume was reduced by 44%. Additionally, the NO<sub>3</sub>, NH<sub>4</sub> and P content in the runoff decreased by 66%, 62% and 57%, respectively. Similarly, Owen et al. (2008) performed an irrigation study on containerized *Skogholm cotoneaster* by decreasing leaching fractions (LF; effluent/influent) from 0.2 to 0.1, finding that the cumulative container influent and effluent volume was reduced by 25% and 64%, and also the P concentration and load in the runoff was 6% and 64% less. Warsaw et al. (2009a) reported that when irrigation was based on plant daily water use (DWU), the average runoff volume was up to 79% less compared to 19 mm irrigation application per day. The N and P load in the effluent was reduced by 59% and 74% under the most conservative irrigation treatment.

Successful irrigation practices in the container nursery should be able to conserve water and reduce effluent and nutrient loss without compromising plant production quality. Gilman et al. (2009) reported that for holly, pittosporum, and viburnum, there were only minor influences in shrub growth when watered with two irrigation frequencies (2 or 4 days) and three irrigation volumes (3, 6 or 9 liter per plant per event). Warsaw et al. (2009b) reported that woody ornamentals under irrigation scheduling based on plant DWU had greater or equal growth compared to plants under 19 mm irrigation per day. Those studies indicate that excessive

irrigation could negatively impact plant growth however proper irrigation could positively influence plant performance. For container nursery growers to implement best management practices (BMP), irrigation practices should be precise and based on plant actual water use (Yeager et al., 1997). Yet limited research has been published on this.

# Current irrigation systems

When determining irrigation systems, plant water requirements, water availability and irrigation system design need to be considered (Majsztrik, 2011). The most common current irrigation systems used by container nurseries include overhead and microirrigation.

## **Overhead** irrigation

Overhead irrigation systems are the most common irrigation method in container nurseries in the U.S. (Fare et al., 1994). They are widely used for container sizes less than 26.5 liter because installing individual emitters on small containers is not considered economically feasible (Bilderback, 2002; Garber et al., 2002). Beeson and Knox (1991) reported that the irrigation efficiency of the overhead systems was 25% and 37% when the containers were spaced closely and 7.6 cm apart. They also found 57% to 70% of the water was delivered to the substrate surface by overhead irrigation depending on the crop, plant spacing and sprinkler type. In most areas of Florida, overhead irrigation is restricted to nighttime watering with 0.8 to 1.5 cm of water per application because of its low efficiency compared to other irrigation methods (Yeager et al., 2010).

The main advantage of overhead irrigation systems is its flexibility for various container sizes and numbers (Mathers et al., 2005). The overhead system layout configuration could be square,

triangular or rectangular patterns. The most efficient overhead irrigation system layout for most nurseries is a square design with 90 degree emitters at the corners and 180 degree emitters along the sides (Bilderback, 2002).

#### Micro Irrigation

Micro irrigation systems are often used for plants that are grown in containers larger than 15 liters (Beeson and Knox, 1991). These systems use drip emitters or spray stake nozzles to deliver water directly into the containers; therefore, it is more efficient than overhead irrigation systems (Bilderback, 2002). Lamm and Trooien (2003) reported that the efficiency of subsurface micro irrigation can reach to 95% to 99% if the soil evaporation is carefully managed, which is much higher than the efficiency of overhead irrigation mentioned above.

Since the emitters orifices of microirrigation systems are much smaller than overhead sprinklers, the emitters can be clogged and need to be examined often. Microirrigation systems require filters and water treatment may be needed to remove solids and ions that lead to clogging of emitters (Bilderback, 2002).

### Irrigation Efficiency

Irrigation efficiency (IE) is a parameter to evaluate the performance of irrigation water use from a water conservation standpoint (Bos and Wolters, 1990). There are several definitions of water use efficiency related to irrigation systems. Weatherspoon and Harrell (1980) defined irrigation efficiency (IE) as the amount of water retained in the substrate compared to the percentage of the total irrigation amount applied. Burt et al. (1997) expressed IE as a percentage of the water amount plants used to the irrigation volume applied minus the amount changed in

the container storage. Howell (2003) evaluated irrigation efficiency by three factors: the performance of the irrigation system, the irrigation uniformity, and plant response to irrigation. He defined seasonal irrigation efficiency as the percentage of irrigation volume beneficially used by the crop by the water amount delivered to the field. He also defined water use efficiency as the percentage of crop dry matter by amount of water used.

Irrigation efficiency depends on many factors such as environmental conditions, system performance, container spacing, and plant leaf morphology. Beeson and Knox (1991) concluded that water shedding and possible water retention are the major causes for low irrigation efficiency for container nurseries. Beeson and Yeager (2003) evaluated the IE of overhead irrigation systems for viburnum, ligustrum, and azalea grown in 11.4 L containers spaced from 0 to 51 cm apart, finding that for all three species, the percentage of water captured increased as the adjacent canopy interaction decreased. They suggested that maximum IE could be obtained when containers are spaced at the minimum distance where the plant canopy was segregated.

Since water is a valuable resource with increasing demand, and excessive irrigation can result in nutrient loss and water resource contamination, numerous attempts have been made to increase irrigation efficiency and conserve water for container nurseries (Majsztrik et al, 2011). The current solutions to increase irrigation efficiency include: cyclic irrigation, leaching fraction, managed allowable deficit, and precision irrigation.

#### Cyclic Irrigation

Cyclic irrigation is defined as separating the daily irrigation volume into several applications (Beeson and Haydu, 1995). This system includes one phase where the irrigation is active and one phase where irrigation is off (Karmeli and Peri, 1974). Industry adoption of cyclic irrigation is

good, for example, west-central Florida nurseries use cyclic overhead systems 42% of the time and cyclic microirrigation 47% of the time (Schoene et al., 2006). Fare et al. (1994) reported that for *Ilex crenata*, when 13 mm irrigation water was applied in three cycles, the leachate volume was 34% less compared to 13 mm irrigation applied in a single time. They also found that when irrigation was delivered in one, two, or three cycles, the N leachate ratio to N applied was 63%, 56%, or 47% respectively. Karam and Niemiera (1994) reported that water application efficiency was 4% greater when the irrigation was applied in cycles rather than continuously. Additionally, they discovered that the water application efficiency increase as the interval between applications increased from 20 to 60 min.

Research has shown that cyclic microirrigation systems increase water use efficiency, reduce leachate nutrient loss and positively affect plant growth. Lamack and Niemiera (1993) found that cyclic irrigation increases irrigation application efficiency by 24% compared to a single application. Beeson and Haydu (1995) found that red maple, winged elm, live oak and crape myrtle have increased growth under cyclic microirrigation compared to overhead irrigation in single applications. Similarly, Fain et al. (1998) evaluated growth of *Acer rubrum* and leachate nitrate loss under cyclic microirrigation with pot in pot production, finding that *Acer rubrum* growth was greater with irrigation in six cycles than a single cycle. Additionally, they discovered that nitrate loss decreased by 89% with cyclic microirrigation compared to a single application. Warren and Bilderback (2002) investigated the cyclic irrigation timing effect on *Cotoneaster dammeri* 'Skogholm' growth, finding that plants performed better with an afternoon cyclic irrigation than morning applications.

# Leaching Fractions

Leaching fraction (LF) is defined as the leachate volume collected from the container divided by the total irrigation volume applied to the container (Ku and Hershey, 1992). Several studies have been investigated the effects of irrigating to various LF on plant growth, soluble salt accumulation and water usage.

Research has shown that low LF can reduce container nursery influent and effluent, but increases soluble salt accumulation in container substrates. It has been demonstrated that plants respond to low LF irrigation differently depending on their salt tolerance (Ku and Hershey, 1992; Yelanich and Biernbaum, 1993). Tyler et al. (1996) evaluated the effect of two LF levels and two fertilizer rates on IE, nutrient loss and growth of *Cotoneaster dammeri* Schneid, finding that low LF of 0.0 to 0.2 reduced the irrigation and runoff volume by 44% and 63% compared to high LF of 0.4 and 0.6, respectively. Additionally, NO3, NH4 and P load in the effluent was decreased by 66%, 62% and 57% under low LF, respectively. Similarly, Owen et al. (2008) reported that by reducing LF from 0.2 to 0.1, the container influent and effluent volume was reduced 25% and 64%, respectively. Sammons (2008) found that near zero LF was 175% more water efficient than the 0.2 LF regime.

Reduced LF generally increases the soluble salt accumulation in substrates, which might damage plant growth (Sammons, 2008). Ku and Hershey (1992) found that geranium had a 26% dry weight decrease with LFs of 0 and 0.1 comparing to LFs of 0.2 and 0.4; they also reported that EC level increased to 6 dS m<sup>-1</sup> in LF of 0.1 which may result in growth reductions. However, greenhouse crops do not receive rainfall to help moderate soluble salt accumulation as do nursery crops. Tyler et al. (1996) reported a 10% decrease in *Cotoneaster dammeri* Schneid growth when irrigated at LF of 0.0 to 0.2 compared to LF of 0.4 to 0.6. In contrast, Graves et al.

(1995) discovered that the growth of woody legumes was not affected by LF of 0, 0.2 and 0.4 with fertilizer solution rates of 3.6 and 10.7 mol N  $m^{-3}$  for ten weeks.

# Management Allowed Deficit Irrigation

Few nurseries monitor substrate moisture content or evapotranspiration in order to irrigate according to plant need and increase irrigation efficiency. Several studies have been conducted to investigate the effect of substrate moisture level on plant growth. This type of research usually uses a pulsed irrigation system that maintains or initiates irrigation at certain substrate moisture content, which is also refer to management allowed deficit (MAD) irrigation.

Several studies have been published associating the relationship between management allowed deficit (MAD) irrigation level and plant growth. Welsh and Zajicek (1993) evaluated growth and water use of container-grown *Photinia* x *fraseri* (Dress) with the substrate moisture level maintained at 0, 5, 10, 25, 50, 75 and 95% deficit, finding optimal plant growth at 25% MAD. Beeson (2006) reported that high MAD levels of 60% and 80% reduced woody ornamental plant growth and increased production time; he also recommended MAD levels of 20%, 20%, 25% and 40% for optimal growth of *Viburnum odoratissimum* Ker Gawl, *Ligustrum japonicum* Thumb, *Photina* x*fraseri* L., and *Rhaphiolepis indica* Lindl.

# Precision Irrigation Based on Evapotranspiration and Plant Water Demand

Evapotranspiration (ET) of container plants refers to water loss both from substrate evaporation and plant transpiration. It depends on solar radiation, temperature, plant canopy architecture, container substrate, plant physiology and plant size (Bacci et al., 2008). Beeson and Brooks (2006) reported that the same marketable size plants were obtained both under ET-based system and irrigation regime that approximated annual 1800 mm ha<sup>-1</sup> overhead irrigation, however, they found that the production rate of an ET-based irrigation system was three weeks faster with 400 mm ha<sup>-1</sup> less water used. Comparably, Million et al. (2010) compared a ETbased irrigation schedule to a fixed rate irrigation in regards to water use, nutrient loss and plant growth, finding that ET-based irrigation decreased irrigation influent and effluent by 39% and 42% without affecting the growth of viburnum. Moreover, they reported 16%, 25% and 22% reduction in runoff of nitrogen, phosphorus and potassium compared to 10 mm d<sup>-1</sup> rate irrigation, respectively.

Crop Coefficient (Kc) is a ratio of the water use of a specific crop to that of a reference crop, which is defined as the amount of ET from the surface of 8 to 15 cm tall green cover under solar radiation with unlimited water resources (Doorenbos and Pruitt, 1975). There are several factors that influence Kc such as container spacing, plant species, growth stage, and climate condition. Burger et al. (1987) classified twenty-three woody ornamental container grown plants into high water users, moderate water users and light water users by calculating the crop coefficient. They also found that container spacing had an impact on Kc, because the wider the spacing the more surface area of the container will be exposed to the sun, therefore increasing the evapotranspiration and Kc. Schuch and Burger (1997) evaluated the crop coefficient of twelve species of woody ornamentals grown in containers, finding that Kc was dependent on the season and plant growth stages, they also reported that high water use plants have more fluctuations in Kc during the growing season while Kc for low water use plant remains relatively stable. Niu et al. (2006) determined the water use and Kc of five woody species that were grown in both above-ground 10-L containers and 56-liter drainage lysimeters. They reported that the crop

coefficient was not different in two systems within same species; however, Kc fluctuated with sampling days.

## Soil Moisture Content Measurement Methods

Scheduling irrigation according to soil moisture level and plant needs can improve IE and avoid excessive irrigation (Greenwood et al., 2010). Several measurement techniques have been developed in order to precisely measure soil moisture content such as soil water balance calculations, tensiometers, time domain reflectometer and capacitance sensors. The following discussion focuses on time domain reflectometer and capacitance sensors.

## Time Domain Reflectometer

Time Domain Reflectometer (TDR) has been utilized to measure soil moisture content and bulk electrical conductivity since 1980. It measures the propagation time of an electromagnetic signal as it moves through a soil or substrate, which depends on the soil dielectric properties as a function of the water content surrounding the probes (Blonquist et al., 2005). TDR can respond to soil water change quickly; however, it is expensive to install, the initial cost ranged from \$8,000 to 10,000 without dataloggers (Evett, 1999). Calculation curves of TDR and its utilization in irrigation systems have been evaluated. Silva et al. (1998) determined the calibration curve for TDR in several substrates including tuff, vermiculite, perlite and a mix of composted agricultural waste and concluded that the TDR probe needs to be calibrated individually for specific substrates.

Ristvey (2004) reported that irrigating containerized plants according to plant needs using TDR sensors decreased nutrient loss and influent by 60% to 85% for a nursery over 9

months. Miralles-Crespo and van Iersel (2011) studied the performance of begonia under six soil volumetric water content (SVWC) thresholds, measured by TDR, and found that the irrigation system with TDR was able to maintain the SVWC within 0.008 m<sup>3</sup> m<sup>-3</sup> of certain thresholds. Additionally, they reported that TDR could be used for soilless substrates but it needs specific calibration.

## Capacitance Sensors

Capacitance sensors use the technology based capacitive coupling, it detects anything that is conductive or has a dielectric value different from that of air.

Capacitance sensors are able to measure soil water content accurately but factors like soil type and container size need to be considered. Kizito et al. (2008) evaluated capacitance sensors for soil water content measurement under a range of soil types, finding that a single calibration curve could fit all tested mineral soils, and the sensor measurement is accurate regardless of soil salinity. Arguedas et al. (2006) evaluated the performance of capacitance sensors in peat and gravel substrate with various container sizes, finding that the sensors were able to precisely measure the water content in both substrates. Sensor location has a great effect on the moisture content reading; when choosing and placing sensors, factors like substrate property, pot height and size need to be considered. Also there should be adequate contact between the substrate and sensor otherwise the reading will be affected by air gaps between the soil and the sensor (Greenwood et al., 2010; van Iersel et al., 2009). Lea-Cox et al. (2008) integrated capacitance sensors into a network that monitored real time information about environmental parameters and substrate moisture conditions, indicating that growers could install a small 25-sensor network for around \$ 5,000, and this initial investment would be paid back by improved plant growth and reduced nutrient runoff and water cost.

Warsaw et al. (2009b) evaluated irrigation based on plant daily water use and its impact on woody ornamental plant growth and irrigation amount, finding that the growth of all tested woody taxa was not affected by irrigation regime, and the irrigation amount applied was reduced by 6% to 75% with plant daily water use based irrigation compared to fixed 19 mm ha<sup>-1</sup> daily irrigation. Fulcher et al. (2012) tested a demand-based system with substrate moisture set points at 22, 30, 41, 49 m<sup>3</sup> m<sup>-3</sup>, reporting that the plants under 30, 41 and 49 m<sup>3</sup> m<sup>-3</sup> used 1.4, 1.2 and 1.05 times more water than irrigation treatment with set point of 22 m<sup>3</sup> m<sup>-3</sup>. They demonstrated that demand-based irrigation systems could reduce water influent of container nursery without compromising plant production quality.

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## CHAPTER ONE

# GROWTH AND WATER USE OF TEN WOODY ORNAMENTALS UNDER FOUR IRRIGATION REGIMES

#### Abstract

Container-grown woody ornamentals were irrigated at four different levels based on daily water use (DWU) to study the impact on plant growth, leachate electrical conductivity and pH, and runoff water volume and nutrient content. A completely randomized design was used with four overhead irrigation treatments: 1) irrigation scheduled to replace 100% DWU per application (100DWU); 2) irrigation alternating every other application with 100% DWU and 75% DWU the following application (100-75); 3) irrigation scheduled on a three-application cycle replacing 100% DWU followed by two applications replacing 75% DWU (100-75-75); 4) irrigation scheduled on a four-application cycle replacing 100% DWU followed by three applications replacing 75% DWU (100-75-75). The substrate volumetric moisture content ( $\theta$ ) was determined by soil moisture sensors (Model 10 HS, Decagon Devices, Inc., Pullman, WA 99163) placed in a subset of containers. Plant DWU was calculated as the difference between  $\theta$  1 hour after irrigation and  $\theta$  immediately before irrigation the following day. Irrigation was scheduled by a programmed datalogger (CR3000, Campbell Scientific Inc., Logan, Utah 84321) based on the highest DWU calculation from the sensors in each zone. Irrigation applications were separated by at least 24 hrs. Irrigation treatments were applied to *Hibiscus syriacus* 'Bricotts', Euonymus alatus 'Select', Weigela florida 'Alexandra', Spiraea japonica 'Yan' in 10.2-L (#3) containers in 2011. The average daily irrigation amount applied for 100 DWU, 100-75, 100-75-75, and 100-75-75-75 were 513, 424, 473, and 423mL, respectively. In 2012, Viburnum dentatum 'Ralph Senior', Potentilla fruticosa 'Lundy', Thuja occidentalis 'Sunkist', Juniperus horizontalis 'Hegedus', Hydrangea paniculata 'Limelight', Hypericum x 'Cfflpc-1' in 10.2 L containers were exposed to the irrigation treatments. The average daily irrigation amount applied for 100DWU, 100-75, 100-75-75 and 100-75-75-75 were 900, 980, 970, and 910ml,

respectively, with little differences among treatments. There were no differences in final plant growth, final electrical conductivity (EC) and pH, runoff NO<sub>3</sub><sup>-</sup>, or PO<sub>4</sub><sup>3-</sup> concentration among treatments for both years. The seasonal average NO<sub>3</sub><sup>-</sup> and PO<sub>4</sub><sup>3-</sup> runoff loads were not different between treatments in 2011; in 2012, the seasonal average daily PO<sub>4</sub><sup>3-</sup> runoff load of 100-75 was the highest versus 100-75-75-75 which was the lowest compared to other treatments. NO<sub>3</sub><sup>-</sup> load was not different between treatments. The average runoff volume in 2011 and 2012 was 45,457 and 49,954 L·ha<sup>-1</sup>. These results indicate that irrigation could be applied based on plant DWU or at a deficit without negatively affecting plant growth and also reducing water runoff volume.

### Introduction

Container nurseries require intensive irrigation to produce marketable plants; however, excessive irrigation in agricultural operations can result in large quantities of runoff carrying fertilizers and other agrichemicals, which pose threats to surrounding water resources and ecosystems (Cabrera, 2005; Hart et al., 2004; Mitsch et al., 2001). Nursery water use is already limited by law and regulations in several states such as Florida, Delaware, California, North Carolina, Texas, Oregon, Maryland, North Carolina and Michigan (Fernandez et al., 2009). For example, in some areas of Florida, the water amount allowed to use by growers dropped by 40% in 12 years and the availability of ground water to container nurseries is forecasted to drop significantly in the next ten years (Beeson, 2004).

In order to improve water use efficiency and reduce runoff, many studies have investigated irrigation practices that could conserve water and reduce runoff (Fulcher et al., 2012; Gilman et al., 2009; Tyler et al., 1996: Warsaw et al., 2009a, 2009b). Tyler et al. (1996) reported that runoff volume could be reduced by 63% when the cyclic irrigation volume was reduced by 44%. Additionally, the NO<sub>3</sub><sup>-</sup>, NH<sub>4</sub><sup>+</sup> and P content in the runoff decreased by 66%, 62% and 57% respectively. Owen et al. (2008) performed an irrigation study on containerized *Skogholm cotoneaster*, finding that by decreasing leaching fractions (LF; effluent/influent) from 0.2 to 0.1, the cumulative container influent and effluent volume was reduced by 25% and 64%, and the P concentration and content in the runoff was 6% and 64% less.

For container nursery growers to implement best management practices, the irrigation practice should be precise and based on plant actual water use (Yeager et al., 2010). Warsaw et al. (2009a) reported that woody ornamentals with irrigation scheduled based on plant DWU had greater or equal growth compared to plants under 19 mm daily irrigation (control) even under

deficit treatments. Warsaw et al. (2009b) also reported that DWU-based irrigation reduced average runoff volume by up to 79% compared to the control application.

Since the highest deficit irrigation treatment in Warsaw's experiment, 1 day of 100% DWU and 2 days of 75% DWU replacement, did not negatively affect plant growth, the objective of this experiment is to: 1. further restrict the irrigation applications and investigate the impact on plant growth, runoff and nutrient movement. 2. determine the DWU and water use efficiency of several containerized woody ornamental shrubs.

#### **Material and Methods**

#### Site specifications

The experiment was performed on 12 nursery beds at Michigan State University Horticulture Research and Teaching Center (HTRC) located in Holt, Michigan. A detailed description of the nursery beds can be found in Warsaw et al., 2012. Natural precipitation was not excluded in the experiment and was recorded by a Michigan Automated Weather Network station (MAWN) located at the HTRC.

#### Experimental design

This was a one-factor completely randomized experiment with four irrigation treatments. Each of the four irrigation treatment was triplicated and randomly assigned to twelve nursery beds. Irrigation treatments were: 1) irrigation scheduled to replace 100% DWU per application (100DWU); 2) irrigation alternating every other application with 100% replacement of DWU and 75% DWU (100-75); 3) irrigation scheduled on a three-application cycle replacing 100% DWU followed by two applications replacing 75% DWU (100-75-75); 4) irrigation scheduled on

a four-application cycle replacing 100% DWU followed by three applications replacing 75% DWU (100-75-75-75).

In 2011, each nursery bed consisted of 32 plants with two replicates for each experimental species. Plants of all species were randomly arranged in four rows of eight. In 2012, each nursery bed consisted of 36 plants with six replicates for each species. Plants were randomly arranged in six rows of six. Additionally, guard plants rows were placed surrounding the replicates in 2011 and 2012. No data was collected from guard plants since they were designed to minimize edge effects.

## Plant material and culture

Plant species and cultivars used in 2011 and 2012 are shown in Table 1.1. The plants were received from a commercial nursery in August of the years preceding the experimental periods and transplanted into 10.2-L (#3) containers. In 2011, plant material was transplanted from 5.7-cm potted liners on Sep 17, 2010. Container substrate consisted of 85% pine bark: 15% peatmoss (vol: vol). Plants were fertilized on 5 July 2011 using 54 gram 17.0N-3.5P-6.6K control release fertilizer including micronutrients with a release period of 4 months at 27°C (HFI Topdress Special; Harrell's Inc., Lakeland, FL). In 2012, plants were transplanted from 5.7-cm potted liners on Sep 6, 2011 into the same substrate blend. Plants received the same fertilizer application as in 2011 on Aug 16, 2012.

Table 1.1. Container-grown woody ornamentals grown in the 2011 and 2012 irrigation experiments

2011

Hibiscus syriacus ' Bricotts'

Euonymus alatus 'Select'

Weigela florida 'Alexandra'

Spiraea japonica 'Yan'

2012

Viburnum dentatum 'Ralph Senior'

Juniperus horizontalis 'Hegedus'

Potentilla fruticosa 'Lundy'

Hydrangea paniculata 'Limelight'

Thuja occidentalis 'Sunkist'

*Hypericum x* 'Cfflpc-1'

#### Irrigation treatment application

The irrigation system was an overhead system controlled by solenoid valves through a programmed datalogger. Distribution uniformity of each bed (replicate) was determined to be 0.8 or greater during a period without wind according to Fernandez (2010). The irrigation volume applied was based on the highest DWU measurement for each replicate to avoid under-watering any species and assuming that the irrigation water penetrates the canopy at 100%. The irrigation was initiated at 0700 HR each day starting from replicate one. In 2011, irrigation applications were applied from 23 June through 2 Nov. In 2012, irrigation was applied daily from 26 June to 13 Oct.

#### Daily water use

The soil volumetric moisture content ( $\theta$ ) was measured with soil moisture capacitance sensors (Model 10HS, Decagon Devices Inc., Pullman, WA, USA). For each taxon, one plant container from each bed was randomly selected to insert one sensor. The sensors were inserted at the northeast side, centered between the plants and the container edge at a 45° angle. The sensor readings were recorded by a datalogger (Model CR3000, Campbell Scientific Inc., Logan, UT, USA) every 15 min. The container capacity was determined to be 53.4% by measuring  $\theta$  after irrigating to saturation and gravitational drainage. The DWU was determined by the equation: DWU= ( $\theta_{AI}$ - $\theta_{BI}$ ) x container volume, where  $\theta_{AI}$  was measured one hour after irrigation and  $\theta_{BI}$ was measured right before the next irrigation application. The datalogger was programmed to run the irrigation system through relays and solenoid valves to replace the DWU per nursery bed according to specific treatments described above.

#### Plant growth

Plant growth measurements were taken approximately every two weeks. Plant height was taken from the rim of the container to the highest point of the plant; width1 was the width of the plant from north to south direction and width 2 was the width of the plant from west to east direction. Plant growth index (GI) was calculated as GI= (height+width1+width2)/3. The GI increment was defined as the final GI value minus the initial GI value.

## *Leachate electrical conductivity and pH*

Electrical conductivity (EC) and pH measurements of leachate water from individual containers were taken every month during the treatment periods. Two replicate plants per bed for

each taxon were randomly selected at the first measurement and repeatedly measured afterwards. Thirty minutes after irrigation was applied a tray was placed under the container, then 200 ml pH neutral reverse osmosis water was added to the container to force out leachate. A bulb syringe was used to extract leachate from the tray and apply it to the sensors of Cardy Twin EC Meter and Cardy Twin PH Meter (Spectrum Technologies, Inc., Illinois) to determine leachate EC and pH.

#### *Water use efficiency (WUE) and crop coefficient (Kc):*

In order to further investigate the plant response to irrigation volume, WUE and Kc was calculated. WUE was defined by two calculations in this chapter, it was calculated as the increment in growth index divided by plant DWU under 100DWU treatment and it was also calculated as growth index increment divided by water amount applied under four irrigation treatments. Kc was defined as plant DWU under 100DWU treatment divided by reference potential evapotranspiration (RPET).

#### Runoff water collection:

Runoff water was collected every month at the beginning of each irrigation cycle, which was when all the irrigation treatments for the 12 beds were at the 100DWU application cycle. The basins for capturing runoff were cleaned by vacuum on the day prior to the collection days. The runoff was collected on four consecutive days in order to collect runoff for one complete cycle of the 4 treatments. The runoff from the basin was pumped into a calibrated collection container in order to determine the volume. Runoff volume was converted to liter per hectare by multiplying the ratio between production area and hectare area. Two 20 ml bottles were used to take water samples for each bed. The water samples were filtered through Watson 504 filter paper and then transfer into 15 ml corning tubes. The filtered samples were shipped to USDA Horticulture Research Laboratory (Fort Pierce, FL) to analyze for phosphorus, nitrogen and micronutrients concentrations. The nutrient concentration result was obtained as mg per liter and then converted to nutrient load by multiplying by the runoff volume.

## Statistical analysis:

GI, leachate EC and pH were analyzed as repeated measurements using the PROC MIX procedure of Statistical Analysis Software (SAS Version 9.2; SAS institute, Cary, NC). When treatment effects were significant at  $p \le 0.05$  level, treatment means were separated using t-test in the PDIFF option of the LSMEANS statement and the SLICING option of PROC MIXED ( $\alpha$ =0.05). WUE, DWU, total volume of water applied, runoff volume and nutrient loss were analyzed using PROC GLM with Tukey's adjustment.

#### **Results and Discussion**

#### Water applied 2011 and 2012

In 2011, there was 133 irrigation applications. When precipitation occurred,  $\theta_{BI}$  value occasionally was greater than  $\theta_{AI}$  resulting in a negative DWU; the program was set to not irrigate when DWU was negative. Irrigation applied of four treatments gradually increased during the first half of the experiment before gradually declining during the second half (Figure 1.1 A-D). Daily irrigation applied under 100DWU treatment was generally greater than 100-75, 100-75-75 and 100-75-75 treatment. Irrigation amount of most treatments peaked on day 80, 81 and 82 (Sep 11-Sep 13, 2011). The daily irrigation amount fluctuation might be caused by

fluctuation of the RPET (Figure 1.3). The coefficient variation of 100DWU, 100-75, 100-75-75 and 100-75-75 was 0.47, 0.49, 0.58 and 0.62, respectively. The coefficient variation increased from 0.49 to 0.58 when the irrigation treatment changed from 100-75 to 100-75-75, meaning daily irrigation amount fluctuated more under 100-75-75 and 100-75-75 treatment, which is also shown on Figure 1.1. The seasonal average daily water applied per container for 100DWU, 100-75, 100-75-75 and 100-75-75-75 treatments was 0.51, 0.42, 0.47, 0.42 L, respectively (Table1.2). The water applied for 100DWU was the greatest among all treatments; the water applied for 100-75 and 100-75-75-75 treatment was similar, 100-75 treatment provide a more stable daily irrigation amount compare to 100-75-75-75.

In 2012, there was 109 irrigation applications. Water applied of four treatment generally peaked during the first quarter of the experiment before gradually declining during the rest period (Figure 1.2 A-D). The peak daily irrigation amount under most irrigation treatment appeared from day 6 to day 20 (July 2-July 16, 2012). The daily irrigation amount fluctuation might be caused by fluctuation of RPET in 2012 (Figure 1.3). The coefficient variation within treatment 100DWU, 100-75, 100-75-75 and 100-75-75-75 was 0.33, 0.32, 0.32 and 0.33, respectively. The coefficient variation within each treatment was similar, which means the daily irrigation amount fluctuate similarly under four treatments. However, comparing to 2011, the irrigation amount applied per container for 100DWU, 100-75, 100-75-75 was 76.5%, 133.3%, 106.4% and 116.7% greater than in 2011, respectively. This may be due to larger plants and higher RPET rate in 2012 (Figure 1.3). The seasonal average daily water applied per container for the four treatments was 0.94 L with no differences between treatments. Fare et al. (1994) found that nursery growers generally irrigate for 1 hour during growing season

assuming that 254,000 L ha<sup>-1</sup> water is applied daily, which is generally much more than our averaged 122,000 L ha<sup>-1</sup> experimental application rates. Warsaw et al. (2009b) evaluated similar irrigation treatments based plant DWU and its impact to on woody ornamental plant growth and irrigation amounts, finding that the growth of all tested woody taxa was not affected by irrigation regime, and the irrigation amount applied was reduced by 6% to 75% depending on taxa compared to a fixed 190,000 L ha<sup>-1</sup> irrigation rate.

Table 1.2. Daily water applied averaged over the season and seasonal total water applied from 23 June through 2 Nov. 2011 (133 d) for all plants. Plants were grown in 10.2-L containers under four irrigation treatments.

Treatment <sup>z</sup>	Avg water applied per	Total seasonal water applied	
	container per application $(L)^{y}$	per container (L)	
100DWU	$0.51a^{\mathrm{x}}$	68.2a	
100-75	0.42b	56.3b	
100-75-75	0.47ab	62.9ab	
100-75-75-75	0.42b	56.2b	

<sup>2</sup>100DWU = irrigation scheduled to replace 100% DWU per application; 100-75 = irrigation alternating every other application with 100% replacement of DWU and 75% DWU the following application; 100-75-75 = irrigation scheduled on a three-application cycle replacing 100% DWU followed by two applications replacing 75% DWU; 100-75-75-75 = irrigation scheduled on a four-application cycle replacing 100% DWU followed by three application replacing 75% DWU. Irrigation volume applied = highest DWU of the four species on each measurement day. Irrigation applications separated by at least 24h.

<sup>y</sup>Means separation using Tukey's test ( $\alpha = 0.05$ ), n=133.

<sup>x</sup>Means with same letters are not significantly different ( $\propto = 0.05$ )



Figure 1.1 A-D. Daily irrigation volume applied to containerized woody ornamental plants under four irrigation treatments showing seasonal patterns from 23 June (Day 0) to 2 Nov, 2011. 100DWU = irrigation scheduled to replace 100% DWU per application; 100-75 = irrigation alternating every other application with 100% replacement of DWU and 75% DWU the following application; 100-75-75 = irrigation scheduled on a three-application cycle replacing 100% DWU followed by two applications replacing 75% DWU; 100-75-75-75 = irrigation scheduled on a four-application cycle replacing 100% DWU followed by three application replacing 75% DWU. Irrigation volume applied = highest DWU of the four species on each measurement day. Irrigation applications separated by at least 24h.



Figure 1.2 A-D. Daily irrigation volume applied to containerized woody ornamental plants under four irrigation treatments showing seasonal patterns from 26 June (Day 0) to 13 Oct, 2012. 100DWU = irrigation scheduled to replace 100% DWU per application; 100-75 = irrigation alternating every other application with 100% replacement of DWU and 75% DWU the following application; 100-75-75 = irrigation scheduled on a three-application cycle replacing 100% DWU followed by two applications replacing 75% DWU; 100-75-75-75 = irrigation scheduled on a four-application cycle replacing 100% DWU followed by three application replacing 75% DWU. Irrigation volume applied = highest DWU of the four species on each measurement day. Irrigation applications separated by at least 24h



Figure 1.3. Referential potential evapotranspiration rate (RPET) of 2011 and 2012 from 23 June to 2 Nov, 2011 and 2012. Data recorded at an Enviro-weather weather station located at the Michigan State University Horticulture Teaching and Research Center

#### Growth index (GI)

In 2011, the final GI for *H. syriacus* 'Bricotts', *E. alatus* 'Select', *W. florida* 'Alexandra' and *S. japonica* 'Yan' was 41.03, 20.05, 55.28 and 31.31 cm, respectively, with no difference between treatments. In 2012, the final GI of *V. dentatum* 'Ralph senior', *J. horizontalis* 'Hegedus' *P. fruiticosa* 'Lundy', *H. paniculata* 'Limelight' *T. occidentalis* 'Sunkist' and *H. x* 'Cfflpc-1' was 33.88, 24.44, 38.27, 51.92, 24.06 and 35.74 cm, respectively, also with no differences between treatments.

Other studies have also reported that substantial reductions in irrigation did not negatively affect plant growth. Welsh et al. (1991) irrigated *Photina x fraseri* plants at 100%, 75% and 50% replacement of water use during the summer season (49 days), finding that the shoot extension, shoot dry weight, leaf number and leaf area of the plant was not affected by the treatments. In Warsaw et al. (2009a,b), three of the irrigation treatments were the same as in the current study, 100DWU, 100-75, and 100-75-75, and the GI of the woody ornamental shrubs was similar for the three treatments.

#### WUE

In 2011, the WUE expressed as GI increment divided by DWU under 100DWU of *H. syriacus* 'Bricotts', *W. florida* 'Alexandra' and *S. japonica* 'Yan' was 0.57 with no difference between taxa. The WUE of *E. alatus* 'Select' was excluded from the table because of its negative growth increment which might have been caused by overwatering since the DWU of *E. alatus* 'Select' was the least among four species. For *H. syriacus* 'Bricotts' and *S. japonica* 'Yan', there were no differences in WUE between treatments. For *W. florida* 'Alexandra', the WUE under 100-75

was greater than that of 100DWU. Seasonal mean WUE of *W. florida* 'Alexandra' was greater than that of *H. syriacus* 'Bricotts' which was greater than *S. japonica* 'Yan' under all treatments.

	treatment <sup>y</sup>			
taxa	100DWU	100-75	100-75-75	100-75-75-75
total water applied <sup>x</sup> <i>Hibiscus syriacus</i> Bricotts	68.2	56.3	62.9	56.2
increased in GI (cm)	25.39	21.30	19.75	24.72
WUE <i>Weigela florida</i> Alexandra	0.37a <sup>v</sup> B <sup>w</sup>	0.39aB	0.31aB	0.45aB
increased in GI (cm)	35.57	38.91	35.89	37.00
WUE	0.52bA	0.69aA	0.57abA	0.66abA
<i>Spiraea japonica</i> Yan				
increased in GI (cm)	17.07	15.61	15.86	17.51
WUE	0.25aC	0.28aC	0.25aC	0.31aC

Table 1.3. Estimated water use efficiency (WUE) and GI increment of three container-grown woody ornamentals under four irrigation regimes from June 21 to Sep 27, 2011<sup>Z</sup>

<sup>Z</sup>WUE estimated as increase in growth index (cm) per liter of water per container

 $^{y}$ 100DWU = irrigation scheduled to replace 100% DWU per application; 100-75 = irrigation alternating every other application with 100% replacement of DWU and 75% DWU; 100-75-75 = irrigation scheduled on a three-application cycle replacing 100% DWU followed by two applications replacing 75% DWU; 100-75-75-75 = irrigation scheduled on a four-application cycle replacing 100% DWU followed by three application replacing 75% DWU. DWU volume applied based on the highest DWU of the four species on each measurement day. Irrigation applications separated by at least 24h.

<sup>x</sup>Liters per container from 21 June to 27 Sep. 2011

<sup>v</sup>Means with same lowercase letters within the same row are not significantly different.

<sup>w</sup>Means with same uppercase letters within the same column are not significantly different. Means separation with Tukey's test( $\alpha = 0.05$ )

GI= growth index

In 2012, the WUE expressed as GI increment divided by DWU under 100DWU of *V*. *dentatum* 'Ralph Senior', *Juniperus horizontali* 'Hegedus', *P. fruticosa* 'Lundy', *T. occidentalis* 'Sunkist', *H. x* 'Cfflpc-1' and *H. paniculata* 'Limelight' was 0.045, 0.027, 0.046, 0.083 and 0.270 respectively. *H. paniculata* 'Limelight' had the greatest WUE among the taxa studied. The WUE of *J. horizontalis* 'Hegedus' was excluded from table because of negative growth increment, which may have been caused by overwatering. The WUE of *H. paniculata* 'Limelight' was greater than of other taxa under all treatments. The WUE under 100-75, 100-75-75 and 100-75-75-75 treatments was greater than that of 100DWU, and the lack of difference in GI between DWU treatments could be due to drought adaptation with improved WUE. DeLucia and Heckathorn (1989) also documented increased WUE of *Pinus ponderosa* Laws caused by repeated drought cycles; they also reported that the primary factor contributing to higher WUE was stomata closure which reduced transpiration.

			treatment <sup>y</sup>	
taxa	100DWU	100-75	100-75-75	100-75-75-75
total water applied <sup>x</sup>	99.1	107.5	106.2	99.8
V. dentatum Ralph Senior				
increased in GI (cm)	3.167	3.833	4.574	2.870
WUE	$0.032b^{V}$	0.036b	0.043b	0.029b
P. fruticosa Lundy,				
increased in GI (cm)	1.315	1.500	2.922	4.188
WUE	0.013b	0.014b	0.028b	0.042b
H. paniculata Limelight				
increased in GI (cm)	15.185	15.185	17.481	19.833
WUE	0.153a	0.141a	0.165a	0.199a
T. occidentalis sunkist				
increased in GI(cm)	1.537	1.778	4.000	0.630
WUE	0.016b	0.017b	0.038b	0.006b
<i>Hypericum x</i> Cfflpc-1				
increased in GI(cm)	6.259	3.593	3.407	3.037
WUE	0.063b	0.033b	0.032b	0.030b

Table 1.4. WUE and GI increment of five container-grown woody ornamentals under four irrigation regimes from June 26 to Oct 11, 2012<sup>z</sup>

<sup>Z</sup>WUE estimated as increase in growth index (cm) per liter of water per container

 $^{y}100$ DWU = irrigation scheduled to replace 100% DWU per application; 100-75 = irrigation alternating every other application with 100% replacement of DWU and 75% DWU the following application; 100-75-75 = irrigation scheduled on a three-application cycle replacing 100% DWU followed by two applications replacing 75% DWU; 100-75-75-75 = irrigation scheduled on a four-application cycle replacing 100% DWU followed by three application replacing 75% DWU. Irrigation volume applied = highest DWU of the four species on each measurement day. Irrigation applications separated by at least 24h.

<sup>x</sup>Liters per container from 26June to 11 Oct. 2012

<sup>v</sup>Means with the same letters within the same column are not significantly different. Means separation with Tukey's test ( $\alpha = 0.05$ ).

GI= growth index

#### DWU

In 2011, plants responded differently to irrigation treatments within each taxon (Figure 1.4).

The seasonal average DWU of H. syriacus' Bricotts' under 100DWU and 100-75-75-75 was

higher than that of 100-75-75. For *E. alatus* 'Select', the DWU under 100DWU was lower than other treatments. For *W. florida* 'Alexandra', DWU under 100-75-75 was higher than 100-75. For *S. japonica* 'Yan', DWU under 100DWU and 100-75-75-75 was higher than 100-75.

In 2012, the seasonal mean DWU of *H. paniculata* 'Limelight' was greater than that of *V. dentatum* 'Ralph Senior'. The seasonal average DWU of *V. dentatum* 'Ralph Senior' was highest under treatment 100-75, followed by 100-75-75, 100DWU and 100-75-75-75 had the lowest DWU (Figure 1.5). For *J. horizontalis* 'Hegedus', DWU under 100-75-75 and 100-75-75-75 was greater than that of 100-75. For *P. fruticosa* 'Lundy', DWU under 100-75 was the highest compared to other treatments. For *T. occidentalis* 'Sunkist', DWU under 100-75 and 100-75-75-75 was larger than that of 100DWU and 100-75-75. For *H. paniculata* 'Limelight', DWU under 100-75-75-75 was the highest while 100DWU had the least. For *H. x*'Cfflpc-1', DWU under 100-75-75-75 was greater than 100DWU and 100-75.

Plant DWU ranged from 4,120 to 200,000 L ha<sup>-1</sup> and was higher during the summer and lower in fall (Figure. 1.6, Figure 1.7), reflecting variation in RPET. Kc was calculated as plant DWU under 100DWU treatment divided by RPET and can be found in Table 1.5. Schuch and Burger (1997) estimated Kc values of 12 woody ornamentals according to a 20 month study at two California locations. They recommended using Kc to schedule irrigation only for low water use plants since the Kc of high water users varied by location, microclimate and plant growth stage. Burger et al. (1987) reported that Kc of container nursery plants varied by species and container spacing, since as the container spacing increase more sunlight caused increased temperature of the black nursery containers and thus increase the evapotranspiration. Due to these complications, using Kc to scheduling irrigation in container nurseries is uncommon.



Figure 1.4. Daily water use (DWU) from 23 June through 2 Nov. 2011 (133 d) for *Hibiscus syriacus* 'Bricotts', *Euonymus alatus* 'Select', *Weigela florida* 'Alexandra', *Spiraea japonica* 'Yan' grown in 10.2-L containers under four irrigation treatments.

100DWU = irrigation scheduled to replace 100% DWU per application; 100-75 = irrigation alternating every other application with 100% replacement of DWU and 75% DWU the following application; 100-75-75 = irrigation scheduled on a three-application cycle replacing 100% DWU followed by two applications replacing 75% DWU; 100-75-75-75 = irrigation scheduled on a four-application cycle replacing 100% DWU followed by three application replacing 75% DWU. Irrigation volume applied = highest DWU of the four species on each measurement day. Irrigation applications separated by at least 24h.

<sup>x</sup>Means for each taxa with the same letters are not significantly different from each other. Mean separated by t-test (p=0.05). n = 18.

Error bars represent standard error of means from 18 plants of each species.



Figure 1.5. Daily water use (DWU) of *Viburnum dentatum* 'Ralph Senior', *Juniperus horizontalis* 'Hegedus', *Potentilla fruticosa* 'Lundy', *Hydrangea paniculata* 'Limelight', *Thuja occidentalis* 'Sunkist', *Hypericum x* 'Cfflpc-1' grown in 10.2-L containers under four irrigation treatments from June 26, 2012 to October 13, 2012.

100DWU = irrigation scheduled to replace 100% DWU per application; 100-75 = irrigation alternating every other application with 100% replacement of DWU and 75% DWU the following application; 100-75-75 = irrigation scheduled on a three-application cycle replacing 100% DWU followed by two applications replacing 75% DWU; 100-75-75-75 = irrigation scheduled on a four-application cycle replacing 100% DWU followed by three application replacing 75% DWU. Irrigation volume applied = highest DWU of the four species on each measurement day. Irrigation applications separated by at least 24h.

<sup>x</sup>Means for each taxa with the same letters are not significantly different from each other. Mean separated by t-test (p=0.05). n =18. Error bars represent standard error of means from 18 plants of each species



Figure 1.6 A-D. Daily water use (DWU) from June 23, 2011 to Nov 2, 2011 for *Hibiscus* syriacus 'Bricotts', *Euonymus alatus* 'Select', *Weigela florida* 'Alexandra', *Spiraea japonica* 'Yan' grown in 10.2-L containers under 100DWU irrigation treatment.



Figure 1.7 A-F. Daily water use (DWU) of *Viburnum dentatum* 'Ralph Senior', *Juniperus horizontalis* 'Hegedus', *Potentilla fruticosa* 'Lundy', *Hydrangea paniculata* 'Limelight', *Thuja occidentalis* 'Sunkist', *Hypericum x* 'Cfflpc-1' grown in 10.2-L containers under 100DWU irrigation treatment and PET from 26 June to 13 Oct, 2012



Taxa	Кс
2011	
Hibiscus syriacus 'Bricotts'	1.91
Euonymus alatus 'Select'	1.04
Weigela florida ' Alexandra'	2.50
Spiraea japonica 'Yan'	1.61
2012	
Viburnum dentatum 'Ralph Senior'	1.62
Juniperus horizontalis 'Hegedus'	2.31
Potentilla fruticosa 'Lundy'	2.52
Hydrangea paniculata 'Limelight'	1.69
Thuja occidentalis 'Sunkist'	2.88
<i>Hypericum x</i> 'Cfflpc-1'	3.47

Table 1.5. Crop Coefficient (Kc) of ten woody ornamental taxa from June to October in 2011 and 2012

## Leachate EC

In 2011, leachate EC was similar among all taxa except for *H.syriacus* 'Bricotts' on day 19 where the leachate EC under 100DWU, 100-75, 100-75-75 and 100-75-75-75 was 1.19, 1.08, 1.26, and 1.48 dS m<sup>-1</sup>, respectively; with EC under 100-75-75-75 greater than that of 100-75. The seasonal mean leachate EC of *E. atalus* 'Select', *W. florida* 'Alexandra' and *S. japonica* 'Yan' was 0.86, 0.88 and 1.01 dS m<sup>-1</sup>, respectively.

In 2012, differences in leachate EC between treatments was observed only on day 6 and 100 and only for *T. occidentalis* 'Sunkist'. On day 6, the leachate EC of *T. occidentalis* 'Sunkist' under 100DWU, 100-75, 100-75-75 and 100-75-75-75 was 0.82, 0.47, 0.58 and 0.77 dS m<sup>-1</sup>, respectively; EC under 100DWU was greater than that of 100-75 and 100-75-75. On day 100, the mean leachate EC of *T. occidentalis* 'Sunkist' under 100DWU, 100-75, 100-75-75 and 100-75-75 was 1.15, 0.91, 0.88 and 1.43, respectively; EC under 100-75-75-75 was greater than that of 100-75-75 and 100-75-75. The seasonal mean leachate EC of *V. dentatum* 'Ralph Senior', *J. horizontalis*' Hegedus', *P. fruticosa* 'Lundy', *H.paniculata* 'Limelight', *H. x* 'Cfflpc-1' was 0.96, 1.02, 0.99, 1.06 and 1.08 dS m<sup>-1</sup>, respectively.

## *Leachate pH*

In 2011, leachate pH difference between treatments was only observed on day 19 for *W*. *florida* 'Alexandra' and day 132 for *H. syriacus* 'Bricotts'. On day 19, the mean leachate pH of *W. florida* 'Alexandra' under 100DWU, 100-75, 100-75-75 and 100-75-75-75 was 7.13, 7.21, 6.82 and 7.06, respectively; pH under 100-75 was greater than that of 100-75-75. On day 132, the mean leachate pH of *H. syriacus* 'Bricotts' under 100DWU, 100-75, 100-75, 100-75-75 and 100-75-75 and 100-75-75.

75-75 was 7.65, 7.07, 7.88 and 7.64, respectively; the mean pH under 100-75-75 was greater than that of 100-75. The seasonal mean leachate pH of *E. atalus* 'select' and *S. japonica* 'Yan' was 7.42 and 7.40.

In 2012, on day 41, 72 and 100, leachate pH of several of the deficit irrigation treatments was greater than 100DWU for some taxa (Figure 1.8). On day 41, the leachate pH of *H. x* 'Cfflp-1' under 100-75-75-75 was greater than that of 100DWU. On day 72, the leachate pH of *P. fruiticosa* 'Lundy' under 100-75 was greater than that of 100DWU. On day 100, the leachate pH of *V. dentatum* 'Ralph senior' under 100-75, 100-75-75 and 100-75-75-75 was greater than that of 100DWU. The seasonal mean leachate of *J. horizontalis* 'Hegedus', *T. occidentalis* 'Sunkist' and *H. paniculata* 'Limelight' was 7.68, 7.65 and 7.79.



Figure 1.8 A-F. Leachate pH for *Viburnum dentatum* 'Ralph Senior', *Juniperus horizontalis* 'Hegedus', *Potentilla fruticosa* 'Lundy', *Hydrangea paniculata* 'Limelight', *Thuja occidentalis* 'Sunkist', *Hypericum x* 'Cfflpc-1' grown in 10.2-L containers under four irrigation treatments on experimental day 6, 41, 72 and 100.

100DWU = irrigation scheduled to replace 100% DWU per application; 100-75 = irrigation alternating every other application with 100% replacement of DWU and 75% DWU the following application; 100-75-75 = irrigation scheduled on a three-application cycle replacing 100% DWU followed by two applications replacing 75% DWU; 100-75-75-75 = irrigation scheduled on a four-application cycle replacing 100% DWU followed by three application replacing 75% DWU. Irrigation volume applied = highest DWU of the four species on each measurement day. Irrigation applications separated by at least 24h. Means within taxa with the same letters are not significantly different between treatments. Mean separated by tukey's t-test ( $\alpha$ =0.05). n =18. ns = no significance

#### Nutrient loss and runoff

In 2011 and 2012, there was no difference in water runoff volume, runoff  $NO_3^- - N$ ,  $PO_4^{3-} - P$ load and concentration between treatments. In 2011, the seasonal mean runoff volume was  $45,457 \text{ L} \text{ ha}^{-1}\text{d}^{-1}$ , the seasonal mean runoff  $PO_4^{3-} - P$  and  $NO_3^- - N$  load was 37 and 655 g  $\cdot \text{ha}^{-1}$ , and the seasonal mean runoff  $PO_4^{3-} - P$  and  $NO_3^- - N$  concentration was 0.83 and 14.13 mg L<sup>-1</sup>. In 2012, the seasonal mean runoff volume was 49,954 L ha<sup>-1</sup>d<sup>-1</sup>, the seasonal mean runoff  $PO_4^{3-} - P$  and  $NO_3^- - N$  concentration was 1.17 and 29.12 mg L<sup>-1</sup>, and the seasonal mean runoff  $PO_4^{3-} - P$  and  $NO_3^- - N$  load is shown in Table 1.6; runoff  $PO_4^{3-} - P$  load under 100-75 was greater than that of 100-75-75-75.

Warsaw et al. (2009b) used the same research site and experimental design as the current experiment to evaluate irrigation treatment effects on runoff volume. In Warsaw's research, a daily 19 mm control irrigation rate was use and had a seasonal mean runoff volume of 114,000 L ha<sup>-1</sup>d<sup>-1</sup>, which is over twice the seasonal runoff volume in current study. Since the seasonal average runoff volume of DWU irrigation treatments was much less than that of this common nursery rate both in the current study and Warsaw et al. (2009b) study, this demonstrates that the runoff volume leaving the nursery can be reduced by scheduling irrigation based on plant DWU. The seasonal mean  $NO_3^-$  -N concentration in the current study exceeded 10 mg L<sup>-1</sup> maximum drinking water contamination level established by U.S. Environmental Protection Agency (U.S. Environmental protection Agency, 2003). However, Warsaw et al. (2009a) reported that when irrigation was based on plant DWU, the N and P loss in the effluent was reduced by 59% and
74% under the most conservative irrigation treatment and it was also below 10 mg  $L^{-1}$ . This

difference may be caused by the different fertilizing ratio used in the different studies.

0		0
Treatment <sup>z</sup>	$PO_4^{3-}$ -P Load (g ha <sup>-1</sup> )	$NO_3^ N Load (g ha^{-1})$
100DWU	68ab <sup>x</sup>	1485a
100-75	88a	1308a
100-75-75	60ab	1110a
100-75-75-75	56b	1090a

Table 1.6. Average seasonal runoff  $PO_4^{3-}$  -P and  $NO_3^-$  –N load under four irrigation treatments.

<sup>z</sup>100DWU = irrigation scheduled to replace 100% DWU per application; 100-75 = irrigation alternating every other application with 100% replacement of DWU and 75% DWU the following application; 100-75-75 = irrigation scheduled on a three applications cycle replacing 100% DWU followed by two applications replacing 75% DWU; 100-75-75-75 = irrigation scheduled on a four-application cycle replacing 100% DWU followed by three application replacing 75% DWU. Irrigation volume applied = highest DWU of the four species on each measurement day. Irrigation applications separated by at least 24h.

<sup>x</sup>Means with same letters are not significantly different ( $\alpha$ =0.05)

#### Conclusions

Scheduling irrigation based on DWU did not negatively impact plant growth from June to October during 2011 and 2012 even when using deficit irrigation applications. When compared to the 19 mm ha<sup>-1</sup>d<sup>-1</sup> treatment in Warsaw et al. (2009a,b), the water applied and runoff volume was much lower in current experiment. These results indicate that nursery growers could substantially reduce irrigation effluent without affecting plant growth while reducing runoff volume and nutrient loss.

The pour through EC value of the substrate was generally above the recommended range of  $0.2 \text{ to } 0.5 \text{ dS m}^{-1}$  for container grown woody ornamentals in pine bark substrate fertilized with only a CRF (Southern Nursery Association, 2007). However, we did not notice any apparent damage from soluble salts at these levels nor did previous studies (Warsaw et al., 2009a, b).

DWU, WUE and Kc of ten woody ornamental plants were identified. This information will allow growers to group species with similar water use together in irrigation zones to conserve water. Additionally, the method used in this experiment can be applied to identify the DWU and Kc of more woody ornamentals in the future. In order to improve water conservation and minimize environmental impact, growers could water crops based on DWU and group plants by similar water use.

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#### LITERATURE CITED

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## CHAPTER TWO

## PHYSICAL PROPERTIES AND COMPOSTABILITY OF ALTERNATIVE CONTAINERS FOR NURSERY PRODUCTION

#### Abstract

The purpose of this work was to evaluate the use of alternative containers made from materials other than virgin plastic under nursery conditions. Containers made from recycled paper and a conventional high density polyethylene (plastic) were used to grow *Euonymus fortunei* 'Roemertwo' from July 2011 to June 2012. Containers made from recycled paper, processed poultry feathers, a mixed of natural fiber with recycled plastic fiber and plastic were used to grow *Buxus x* 'Green Velvet' from June 2012 to June 2013. Changes in the mechanical strength and physical properties of the containers were recorded. Compostability of the alternative containers was tested using ASTM D6868 and 6400 (ASTM, 2004, 2011).

Alternative containers, except the one made from recycled plastic fiber mix, had greater compression strength than plastic containers. Fiber container sidewalls had a higher water vapor transmission rate than that of plastic containers. According to ASTM D 6400, a compostable product produced with a heterogeneous structure must degrade 90% during simulated composting when compared with a cellulose positive control, pass the disintegration test and ecotoxicity test. All containers passed the ecotoxicity test, however, failed the composting test. Therefore alternative containers in this experiment were not proven to be compostable according to ASTM standards.

#### Introduction

Plastic containers are traditionally used by greenhouse and nursery operations. Despite the advantages of low cost and light weight, there are several major concerns about using them, such as disposal issues and environmental pollution. Therefore, there is a need for alternative containers to improve sustainable nursery practices. Materials such as peat, bioresins, poultry feathers, wood fiber, paper fiber, rice hull, coir and cow manure compost have been used to manufacture horticulture alternative containers (Evans and Karcher, 2004; Grayed, 1971; Kuehny et al., 2011; Lopez and Camberato, 2011).

There are relatively few studies in the literature that evaluate physical properties of alternative containers. Evans and Karcher (2004) evaluated dry and wet strength of plastic, peat and feather fiber containers by increasing the amount of pressure on the container using a texture analyzer; they discovered that peat and feather fiber containers had lower dry and wet strength than plastic containers. Moreover, the wet strength was much less than dry strength for both the plastic and fiber containers. Candido et al.(2007) evaluated the tensile strength behavior and chromatic characteristics of traditional polypropylene containers and biodegradable plastic containers during a five month experiment in the greenhouse, finding that the tensile strength of biodegradable plastic containers decreased over time, and all containers except traditional containers exhibited discoloration. Schettini et al. (2012) tested the physical-chemical characterization of containers made from tomato and hemp fibers with mechanical, water vapor permeability tests, and morphological analysis. They discovered that there was a correlation between polymer cross-linking, water diffusion and mechanical performance.

A few studies tested the biodegradability or decomposition ratio of the containers available on the market. Evans and Karcher (2004) planted plants with intact plastic, peat and feather

containers for 16 weeks and evaluated the decomposition ratio, defined as the ratio of the weight of the containers before and after planting; they found that the decomposition ratio was greater for feather containers than that of peat containers when vinca and marigold were grown in the containers. Candido et al. (2007) evaluated container degradation by visual assessment, finding containers made from biodegradable plastic with 10% and 20% compostable materials were not suitable for Poinsettia cultivation as they showed lesions on the basal surface and at the edge of the containers constructed of polylactic acid and poultry feather fiber by measuring the CO<sub>2</sub> produced during composting incubation; they also used near infrared spectroscopy to estimate the chemical composition of container material that resulted during degradation. They found that the poultry feather fiber did not degrade during the compost period and the polyactic acid underwent chemical changes during polymer extruding and molding which inhibited biodegradation. None of the experiments stated above used ASTM standards to determine the compostability of alternative containers.

The goal of this study was to study the performance of alternative containers in nursery production using ASTM standards. In order to achieve this goal, this experiment focused on the following specific objectives: 1) evaluating the physical property changes of alternative containers under nursery practices; 2) assessing the compostability of alternative containers with ASTM D6868 and 6400.

#### **Material and Methods**

#### Site specifications and plant material

The experiment was conducted at the Michigan State University Horticulture Teaching and Research Center (HTRC) located in Holt, MI. The HTRC is located at latitude 42.7  $^{\circ}$ N, longitude 84.5  $^{\circ}$ E, and elevation 264 m. Air temperature, relative humidity, and solar radiation recorded during the experiments are shown in Fig 2.1 a-c, the total radiation was 4704 MJ m<sup>-2</sup> from 2011 to 2012 and 4687 MJ m<sup>-2</sup> from 2012 to 2013. During winter, the experimental site was covered with white plastic film providing 70% shade for winter protection, therefore, the plants and containers experienced less solar radiation as indicated in Figure. 2.1 –c during this period.

Plants were selected based on capability of tolerating USDA cold hardiness zone 5-8 conditions since this was part of a multi-state project. *Euonymus fortunei* 'Roemertwo' was used in the alternative container study in 2011. Plants were transplanted from 5-cm plugs into treatment containers on 1 June 2011. Container substrate consisted of 85% pine bark: 15% peat-moss (vol: vol). Plants were fertilized on 5 June with 26 g per container of a 17.0N-3.5P-6.6K fertilizer, which contained micronutrients and had a nutrient release period at  $27^{\circ}$ C of 4 months (HFI Topdress special; Harrell's Inc., Lakeland, FL). *Buxus x* 'Green Velvet' was used in the 2012 study. Plants were potted up on 14 May and received the same fertilizer as 2011 on 5 June, 2012.



Figure 2.1. Air temperature (A), relative humidity (B) and solar radiation (C) at the Michigan State University Horticulture Teaching and Research Center weather station from June 2011 to June 2013

#### Experimental design

This was a one factor completely randomized design experiment. Each of the twelve irrigation zones served as one treatment replicate; each container type was replicated three times and randomly assigned to the irrigation zones. Containers were spaced 32 cm apart on center and located at the middle of irrigation zone. In each irrigation zone, there were fifteen containers in three rows of five with twenty guard plants surrounding the border to minimize edge effects. Container treatment types and information can be found in Table 2.1. Western pulp (WP) and Kord fiber (Kord) containers were both made from up to 72% recycled paper. Keratin (KR) containers contained processed poultry feathers and recycled plastic. The components of Root pouch (RP) containers were recycled plastic fiber and natural fibers.

Treatment	Abbreviation	Top diameter	Height (cm)	Volume (liter)	Manufacture
		(cm)			
2011					
Polyethylene PS400-SM	Plastic	19.05	18.10	3.78	Nursery Supplies Inc., Chambersburg, PA
Western Pulp 7X7RD	WP	18.70	17.10	3.89	Western Pulp Products Co., Jacksonville, TX
Kord 07.50 Fiber Grow Nursery Po	t Kord	19.05	17.78	3.94	Texon Polymer Group Inc., Waco, TX
2012					
Polyethylene PS400-SM	Plastic	19.05	18.10	3.78	Nursery Supplies Inc., Chambersburg, PA
Western Pulp 7X7RD	WP	18.70	17.1	3.89	Western Pulp Products Co., Jacksonville, TX
Root pouch 15-20 month	) RP	15.24	17.78	3.36	Central bag& Burlap, Denver, CO
Keratin container	KR	16.51	17.78	2.95	Horticultural Research Institution, Washington, DC

Table 2.1. Container treatments used in 2011 and 2012 alternative container studies.

#### Irrigation application

The irrigation was delivered by a solenoid-controlled overhead system. Nine Toro 570 Shrub Spray Sprinklers (The Toro Company, Riverside, CA) were mounted on 0.66m high, 1.3 cm diameter risers in each irrigation zone spaced 2.50 m apart. Each irrigation zone had four 90 degree emitters located at four corners of the beds with four 180 degree emitters placed in the middle of the four sides; two 360 degree emitters were placed at the center of irrigation zone. The irrigation zone area was 4.5 m long and 7.5 m wide. All irrigation was directed into the zone with a 2.44-m radius distance of throw. Distribution uniformity of each bed was measured at 0.8 or greater during a period without wind. In 2011, two soil moisture sensors (model EC5, Decagon Devices, Inc., Pullman, WA) were inserted into two containers for each zone to determined plant daily water use (DWU); in 2012, two different soil moisture sensors (model GS3, Decagon Devices, Inc., Pullman, WA) per zone were used to determined DWU in addition to the EC5 sensors. The irrigation was applied to replace total DWU back to the containers and was based on the average DWU of the two containers in each zone with moisture sensors. For a detailed description of how DWU was determined see Chapter 3. Irrigation was split into two applications per day initiated at 0700HR and 1900HR.

#### Container physical properties

In 2011, two containers from each replicate were harvested at month 1, 2, 4, 6, 8 and 12 (June 2011=month 0) and taken to Michigan State University School of Packaging laboratory for physical property tests. In 2012, two containers from each replicate were harvested at month 2, 6, and 12 (June 2012=month 0).

The containers were pre-conditioned according to ATSM D685 (ATSM, 2012). A squeezer (Lansmont Corporation, Monterey, CA) was used to test compression strength of the container using a fixed platen moving at 0.05 in/div. The platen stopped moving when the container showed 0 preload and 20% deformation yield. A Squeezer Reader version 2.0.0 (Lansmont Corporation, Monterey CA) was used to interpret and record data.

A universal tester machine from Instron, Inc. (Norwood, MA) was used to test tensile strength for each RP container sample according to ASTM D3822 (2007). The samples were pre-conditioned in a humidity bucket at 23  $^{\circ}$ C and 62 ±2% relative humidity (RH) for 72 hours according to ASTM D1776 (2009). After conditioning, 2.54 cm x 12.7 cm strips of fabric were

cut out on the vertical direction of the RP. Ten sample strips of each container were tested. The strips were fixed by the upper and lower clamps to create stiff tension. The tester began to elongate the fabric and stopped at the point of fabric breakage.

Measurement of water vapor transmission rate (WVTR) was conducted according to ASTM E 96-95 (1995). For each treatment, two round pieces were cut from each container (3 containers in total) and then fitted into a methacrylate cell (permeation cell) with an inner diameter of 4.50 cm and inner depth of 2 cm. Three permeation cells of each container type were filled with desiccant and another 3 cells left empty. The cells were then placed in an environmental chamber set at 85% RH and 37.8°C. The weight of cells was measured by a Discovery DV314C microbalance (Chaus Corportation, Pine Brook, NJ) approximately every hour for WP and RP, and twice a day for Plastic and KR until the weight reached equilibrium. The WVTR was determined as the difference between initial cell weight and final cell weight then divided by cell surface area and elapse time.

#### Fourier transform infrared spectroscopy (FTIR)

For each container, the samples were dried in a vacuum oven (Model 1410, Sheldon Manufacturing Inc., Cornelius, Oregon) at 60°C for 48 hours. Three samples cut from the container wall and the bottom and were scanned on both sides using a Shimadzu IR-Prestige 21 (Columbia, MD) at the range of 650 to 4000 cm<sup>-1</sup> with the following settings: no. of scan 40, resolution of 4 cm<sup>-1</sup>, absorbance to detect any changes in the spectra shifts which associated with the formation and destruction of functional groups of the container material.

#### *Compostability*

The compostability tests were conducted according to ASTM Standard D 6400 (ASTM, 2004). The tests included a biodegradation test and an ecotoxicity test.

A direct measurement respirometric (DMR) system (Kijchavengkul et al., 2006) was used for the biodegradability test. Triplicate bioreactors were used for each treatment (compost mixed with alternative container material) and the control (compost only). Each bioreactor was filled with approximately 500 g compost consisting of 80% manure blend and 20% vermiculite. In 2011, 8 g container material for each treatment was ground into powder and added to the compost. In 2012, the container material for each treatment was cut into 1 x 1 cm pieces and added into the compost. The bioreactors were set to  $58 \pm 2$  °C,  $55 \pm 5\%$  RH with an air flow rate at  $40\pm5$  cc min<sup>-1</sup> for 90 days. The carbon component of the material was determined by Serious II CHNS/O Analyzer 2400 (PerkinElmer, Waltham, Massachusetts). The degree of degradation was defined as the percentage of mineralization by the following equation (Kijchavengkul et al, 2006), namely the proportion of carbon molecules of the material converted to  $CO_2$  due to microbial respiration, where  $gCO_2 - gCO_2$  means the difference between the mass of total evolved CO<sub>2</sub> and blank CO<sub>2</sub> (g), gmat is the mass of the test material (g) and %Cmat is the percentage of carbon content in the test material:

% Mineralization = 
$$\frac{gCO_2 - gCO_2b}{gmat\frac{\%C_{mat}44}{100-22}} \times 100$$

The ecotoxicity tests include heavy metal analysis, plant germination test and growth test. The WP and Kord containers were sent to Soil Control Lab (Watsonville, California, USA) for heavy mental analysis. The germination test was carried out as part of the biodegradable test according to ASTM D6868, 6400, and OECD Guideline 208 Terrestrial Plants, Growth Test. In 2011, cucumber and onion seeds (Seedway, Hall, NY) were selected to conduct the germination tests; in 2012, cucumber and oat seeds (Botanical Interests Inc., Broomfield, CO) were used. Ten 15.24 cm diameter plastic dishes were used for each treatment compost and control compost (compost only) after the incubation from the biodegradability test. Each dish was filled 75 g potting substrate and 75 g treatment compost or 75 g of control compost. For each treatment, five dishes were evenly seeded with 30 cucumber seeds per dish and the other five dishes were seeded with 30 onion (2011) or 30 oat grass seeds (2012) per dish. The dishes were transferred into a greenhouse at 25 °C, 95% RH. The dishes were irrigated until saturation every other day, and the germination rate was recorded daily. After three weeks, the plants were harvested and cleaned. Height and fresh weight of the plants were measured. The plants were oven dried at 70  $^{\circ}$  until the weight reached constant and dry weight was then recorded.

#### Statistical analysis

Physical property test results and germination data were analyzed using PROC GLM procedure of statistical analysis software (SAS Version 9.2; SAS institute, Cary, NC) with Tukey adjustment at 0.05 significance level. The compression strength was analyzed using PROC REG procedure of SAS.

#### **Results and Discussion**

#### Compression strength

In 2011, the compression strength of Kord and WP containers were reduced during the 12month experimental period (Figure 2.2). The WP had greater or similar compression strength compared to that of Kord containers during the experimental period. The compression strength decreased rapidly for both Kord, from 367 lbs. at month 0 to 262.5 lbs. at month 4, and WP containers, from 633 lbs. at month 0 to 379 lbs. at month 4. This reduction in compression strength can be explained by photo-degradation, thermal and hydrolysis reactions, and biodegradation resulting from irrigation and solar radiation.

In 2012, the RP container was not included in the compression test due to its deformable structure. The compression strength of the WP containers at month 0 was 600 lbs. in 2011 and 400 lbs. in 2012 (Figure 2.3). This data suggests that manufactured components of WP containers had changed between 2011 and 2012. The compression strength of WP decreased throughout the experiment from 409 lbs. at month 0 to 234 lbs. at month 12. The KR containers had the highest compression strength compared to other containers; conversely, plastic containers had the lowest compression strength. There was no change in compression strength of either KR or plastic during the experiment. The compression strength difference between plastic containers and WP and Kord containers may be attributed to strength differences in plastic polymers and wood fiber.

Evans et al. (2010) tested the dry vertical strength of plastic container and paper container walls by crushing the containers vertically for 30 mm, finding that the amount of pressure needed between the two container types was similar. The difference between Evans' result and this

experiment is that the paper container used in Evan's test was produced from paper pulp with binder while WP containers were made from post-consumer paper and molding technique.



Figure 2.2. The compression strength for Kord fiber (Kord) and Western pulp (WP) containers from May 2011 to May 2012



Figure 2.3. The compression strength for Western pulp (WP), Plastic and Keratin (KR) containers from June 2012 to June 2013. \*NS = No significance

#### Tensile strength of RP containers

The tensile strength of RP containers generally decreased during the experiment (Table 2.2). The extension at break length decreased from 32.32 mm at month 0 to 16.08 mm at month 12. Modulus is the ratio of stress to strain. The modulus of RP containers increased from 22.94 at month 0 to 32.69 at month 12. These results indicate that the fiber of RP containers underwent weathering after being in the field for two months, and cross-linking of the polymers might have occurred during this process due to photo-degradation and oxidation. Candido et al. (2007) also found that the tensile strength of biodegradable containers decreased during 6 months of experiment period placed inside of greenhouse.

Table 2.2. Tensile strength test result of root pouch container under field condition for 0, 2, 6 and 12 months

month	Extension at yield (mm)	Load at yield (N)	Extension at break (mm)	Load at break (N)	Strain at yield (%)	Modulus (Mpa)
0	26.51a <sup>x</sup>	44.65a	32.32a	13.39b	20.98a	22.94b
2	13.56b	29.94ab	17.50b	8.96b	10.70b	35.19a
6	12.69b	23.30b	15.82b	25.10a	10.00b	34.80a
12	12.29b	37.54ab	16.08b	10.84b	9.68b	32.69ab

<sup>x</sup>Means with the same letter in the same column is not significantly different ( $\alpha$ =0.05)

#### Water vapor transmission rate (WVTR)

In 2011, the WVTR of Kord containers was greater than that of WP containers. The WVTR of Kord containers remained constant throughout the experiment (Table 2.3). The WVTR of WP containers increased from 1.42 kg m<sup>-2</sup> ·s<sup>-1</sup> ·10 <sup>-5</sup> at month 0 to 1.76 kg m<sup>-2</sup> ·s<sup>-1</sup> ·10 <sup>-5</sup> at month 12, which could be caused by scissoring of the polymer chain resulting from thermal and hydrolysis degradation.

In 2012, the WVTR of RP containers was greater than that of WP containers, which was greater than KR containers (Table 2.4). The WVTR of RP containers dropped from 6.21 kg m<sup>-2</sup>  $\cdot$ s<sup>-1</sup> 10<sup>-5</sup> at month 0 to 2.36 kg m<sup>-2</sup>  $\cdot$ s<sup>-1</sup> 10<sup>-5</sup> at month 12, which could be explained by cross-linking of the polymer chains. The WVTR of WP and KR containers remained nearly unchanged during 6 months under field condition. The KR container had the lowest WVTR probably due to the high thickness of the container wall.

Table 2.3. Water Vapor Transmission Rate (WVTR) of Kord and Western pulp (WP) container under field conditions from June 2010 to June 2011 for month 0, 2, 6 and 12

Container	WVTR (kg m <sup>-2</sup> $\cdot$ s <sup>-1</sup> 10 <sup>-5</sup> )								
	month 0	month 2	month 6	month 12					
date	(new container)	(9/1/11)	(1/8/12)	(6/13/12)					
Kord	1.73a <sup>x</sup> A <sup>y</sup>	1.81aA	1.81aA	1.78aA					
WP	1.42bB	1.65aB	1.68aB	1.76aB					

<sup>x</sup>Means with the same lowercase letter in the same row are not significantly different ( $\alpha$ =0.05) <sup>y</sup>Means with the same uppercase letter in the same column are not significantly different ( $\alpha$ =0.05)

Table 2.4. Water Vapor Transmission Rates (WVTR) of Western pulp (WP), Root pouch (RP), and Keratin (KR) containers from June 2011 to June 2012 for month 0, 2, 6 and 12

Container	WVTR (kg m <sup>-2</sup> ·s <sup>-1</sup> ·10 <sup>-5</sup> )						
date	month 0 (new container)	month 2 (8/20/12)	month 6 (1/6/13)	month 12 (6/25/13)			
WP	$1.43a^{x}B^{y}$	1.33abB	1.23bcB	1.11cB			
RP	6.21aA	5.81aA	3.03bA	2.36cA			
KR	0.00105aC	0.0111aC	0.000554aC	0.00424aC			

<sup>x</sup>Means with the same lowercase letter in the same row are not significantly different ( $\alpha$ =0.05) <sup>y</sup>Means with the same uppercase letter in the same column are not significantly different ( $\alpha$ =0.05)

FTIR

For the WP containers, there are formations of new peaks at wavenumber 1410 (scissoring vibration of CH<sub>2</sub>) and 873 cm<sup>-1</sup> (skeletal vibration of CH<sub>2</sub> or out-of-plane ring stretching in cellulose) indicating changes in the cellulose main chain due to weathering (Figure 2.4). For the Kord fiber pot (Figure 2.5), there are formations of new peaks at wavenumber 1648 (C=O with intramolecular hydrogen bonds) and 1320 cm<sup>-1</sup> (wagging vibration of CH<sub>2</sub>) as well as a reduction in absorbance at wavenumber 1110 cm<sup>-1</sup> (C-O-C stretching of glycosidic bond) indicating main chain scission or depolymerization of the cellulose fiber.



Figure 2.4. Fourier transform infrared spectroscopy of Western pulp containers outside wall of experimental month 0, 4, 8 and 12 in 2011



Figure 2.5. Fourier transform infrared spectroscopy of Kord containers outside wall of experimental month 0, 4, 8 and 12 in 2011

#### *Compostability*

In 2011, after 49 days of the biodegradation test, the percent mineralization rate of Kord, WP and cellulose powder were 89.7, 93.0 and 98.6%, respectively (Figure 2.6). In 2012, after 90 days of the biodegradation test, the percent mineralization rate of KP, RP, WP, and cellulose powder were 20.5, 13.2, 26.1, and 92.4%, respectively (Figure 2.7). The mineralization value of the control groups in both years were greater than 90% as specified in ASTM D6868 standard (ASTM, 2011). In 2011, Kord and WP were ground to a powder, while in 2012 KP, RP and WP were cut into 1 cm x 1 cm pieces. Although both methods are according to ASTM D 6400, the larger size in 2012 may have resulted in the containers not being considered biodegradable. Barker (1997) reported that the decomposition will be accelerated when the surface area is increased by grinding or shredding when nitrogen is available. Ahn et al. (2011) also found that poultry feather fibers did not degrade during incubation in dairy manure compost inoculum. These limitations should be considered in the case that these containers will be disposed of with farm composting processes.



Figure 2.6. Mineralization ratio of Western pulp (WP), Kord container comparing to cellulose powder in manure compost at 58°C and 55% relative humidity during 50 day of direct measurement respirometric experiment



Day of Experiment

Figure 2.7. Percent Mineralization of cellulose powder, Keratin (KR), Root pouch (RP) and Western pulp (WP) container in manure compost at 58°C and 55% relative humidity during 90 days of direct measurement respirometric experiment

In 2011, both WP and Kord containers passed heavy metal testing according to ASTM standards 6868 (2011b) (Table 2.5, 2.6). In 2012, heavy mental tests were not conducted since no alternative containers passed the biodegradation test.

In the 2011 germination test, the average germination rate of onion in Kord, WP and control compost was 90%, 92% and 91.3% (Table 2.7). The average germination rate of cucumber in Kord, WP and control compost was 96%, 94% and 95.3%. Both Kord and WP meet the requirement of germination according to ASTM D6868 since the germination rates of onion and cucumber were greater than 90% of the rate in control compost. Similar to 2011, in 2012 seed germination test, the germination rate of cucumber in WP, KR, RP and control compost was 96%, 96.7%, 96.7% and 90% (Table 2.8). The germination rate of oat in WP, KR, RP and control compost was 100%, 100%, 98.7% and 98%. These results indicate that WP, KR and RP containers meet the requirement of germination according to ASTM D6868 since the germination is higher than 90% of that of control compost. The average shoot height of oat seedlings and cucumber was 16.00 cm and 10.39 cm with no difference between treatments. The average dry weight of oat and cucumber was 0.533 gram and 1.131 gram with no difference between treatments (data not shown).

	Results	Reporting		Region		
	mg/Kg dry					
Analyte	weight	Limit	US	Canada	Europe	Janpan
Arsenic (As)	less than 0.5	0.5	Pass	Pass	Pass	Pass
Cadminum (Cd)	less than 0.5	0.5	Pass	Pass	Pass	Pass
Copper (Cu)	29	0.5	Pass	NA*	Pass	Pass
Lead (Pb)	0.56	0.5	Pass	Pass	Pass	Pass
Mercury (Hg)	less than 0.2	0.2	Pass	Pass	Pass	Pass
Nickel (Ni)	12	0.5	Pass	Pass	Pass	Pass
Selenium (Se)	less than 0.5	0.5	Pass	Pass	Pass	NA
Zinc (Zn)	14	0.5	Pass	Pass	Pass	Pass
Cobalt (Co)	less than 0.5	0.5	NA	Pass	NA	NA
Chrominum (Cr)	7.2	0.5	NA	NA	Pass	Pass
Molybdenum (Mo)	1.6	0.5	NA	Pass	Fail	NA

Table 2.5. Heavy mental concentration result of Kord containers.

\*NA means 'not applicable'

Table 2.6. Heavy mental concentration result of Western pulp containers.

	Results	Reporting		Region		
Analyte	mg/Kg dry weight	Limit	US	Canada	Europe	Janpan
Arsenic (As)	less than 0.5	0.5	Pass	Pass	Pass	Pass
Cadminum (Cd)	less than 0.5	0.5	Pass	Pass	Pass	Pass
Copper (Cu)	18	0.5	Pass	NA*	Pass	Pass
Lead (Pb)	1.1	0.5	Pass	Pass	Pass	Pass
Mercury (Hg)	less than 0.2	0.2	Pass	Pass	Pass	Pass
Nickel (Ni)	14	0.5	Pass	Pass	Pass	Pass
Selenium (Se)	less than 0.5	0.5	Pass	Pass	Pass	NA
Zinc (Zn)	13	0.5	Pass	Pass	Pass	Pass
Cobalt (Co)	less than 0.5	0.5	NA	Pass	NA	NA
Chrominum (Cr)	2	0.5	NA	NA	Pass	Pass
Molybdenum (Mo)	1.6	0.5	NA	Pass	Fail	NA

\*NA means 'not applicable'

							% Germination	%
Treatment	Rep1	Rep 2	Rep 3	Rep 4	Rep 5	Average	$\pm$ S.D.	Control
Onion								
Control	26	27	26	28	30	27.4	$91.3 \pm 5.6$	100
Kord	24	28	27	29	27	27	$90.0 \pm 6.2$	98.5
WP	26	26	29	30	27	27.6	$92.0 \pm 6.1$	100.7
Cucumber								
Control	28	29	30	28	28	28.6	$95.3 \pm 3.0$	100
Kord	29	30	28	27	30	28.8	$96.0 \pm 4.3$	100.7
WP	27	29	30	28	27	28.2	$94.0 \pm 4.3$	98.6

Table 2.7. Onion and cucumber seed germination rate in control compost (compost only) and final compost containing Kord fiber pot or Western pulp (WP) containers including 5 replicates, average germination rate and percentage comparing to that of control compost in 2011.

Table 2.8. Oat and cucumber seed germination rate in control compost (compost only) and final compost containing Western pulp (WP), Keratin (KR) and Root pouch (RP) containers including 5 replicates, average germination rate and the percentage comparing to that of control compost in 2012.

							%	
	Rep	Rep	Rep	Rep	Rep		Germination	%
Treatment	1	2	3	4	5	Average	+S.D	control
Oat								
Control	30	30	28	29	30	29.4	98.0+3	100%
WP	30	30	30	30	30	30	100 + 0	106.70%
KR	30	30	30	30	30	30	100 + 0	107.40%
RP	30	28	30	30	30	29.6	98.7+3	107.40%
Cucumber								
Control	28	27	26	27	27	27	90.0 + 2.4	100%
WP	29	28	28	29	30	28.8	96 + 2.8	106.70%
KR	29	29	29	30	28	29	96.7+2.4	107.40%
RP	29	29	29	30	28	29	96.7+2.4	107.40%

#### Conclusions

The physical properties of the alternative container varied. WP and Kord containers are both made from molded recycled paper. They have greater compression strength than that of Plastic containers; however, they have a higher WVTR, which might consume more water than Plastic containers (Chapter 3). The FTIR test indicated that WP and Kord containers suffer photo-oxidation from depolymerization and polymer changes under field conditions after 12 months. These results indicate that when adopting WP and Kord containers, growers could benefit from their greater compression strength during transportation, however, the containers bottom and rim may disintegrate after approximately 12 months depending on the nursery local climate and irrigation practices. RP containers are made from recycled plastic fibers and natural fibers. RP containers had the greatest WVTR than other containers, which might lead to more water use (Chapter 3). The tensile strength of RP containers decreased after use in the field for two months which could cause container damage during transportation. The KR containers are made from recycled plastic and processed poultry feathers. It had the greatest compression strength than other containers.

In terms of compostability, WP and Kord containers passed biodegradation test when ground to a powder form but not in 1x 1 cm pieces. Since we do not have the formula of the containers from the manufacturer, we could not conclude that WP and Kord containers are compostable. Additionally, alternative containers are often cut into similar sized pieces when being disposed, and they were not proven to be compostable under this common practice. All containers tested passed the germination test, showing that the containers had no negative impact on seedling growth.

LITERATURE CITED

#### LITERATURE CITED

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# CHAPTER THREE

# PLANT GROWTH AND WATER USE IN ALTERNATIVE CONTAINERS FOR NURSERY PRODUCTION

#### Abstract

This one-factor completely randomized experiment was conducted at the Michigan State University Horticulture Teaching and Research Center to test plant growth and water use in containers made from material other than virgin plastic. From July 2011 to June 2012, Euonymus fortunei 'Roemertwo' were planted in three types of #1 (~3.8 L) containers and evaluated. Container types were: 1) polyethylene PF400-SM (Plastic); 2) Western Pulp 7X7RD (WP); 3) Kord 07.50 Fiber Pot (Kord). From June 2012 to May 2013, Buxus x 'Green Velvet' were evaluated in four types of #1 containers: 1) Plastic; 2) WP; 3) Root pouch 15-20 month (RP) 4) Keratin pot (KR). Substrate volumetric moisture content ( $\Theta$ ) was determined by EC-5 moisture sensors in 2011; GS3 and EC-5 sensors were used in 2012 (Decagon Devices, Inc., Pullman, WA). Volumetric substrate moisture was measured 5 min after irrigation application ( $\theta_{AI}$ ), and immediately before the next irrigation ( $\theta_{BI}$ ). The DWU was determined by the difference between  $\theta_{AI}$  and  $\theta_{BI}$  multiplying container volume. Plants were irrigated to replace 100% DWU. For E. fortunei, the plant final growth index was not different between treatments. Plants grown in the Plastic containers had a greater root and leaf biomass than that of WP and Kord containers. The seasonal average DWU of plants grown in WP and Kord containers was greater than that of Plastic containers. The mortality rate of plants grown in WP and Kord containers was 2% in October 2011 and 52% in May 2012. The mortality rate of plants grown in Plastic containers was 13% in October 2011 and 15% in May 2012. For Buxus x Green Velvet, the final growth index of plants was similar between treatments. The dry leaf weight of plants grown in KR containers was greater than that of plants grown in WP containers. Plants grown in KR containers had the
least water use while plants in Plastic had the highest water use. The mortality of *Buxus* was 0% for all treatments.

### Introduction

Plastic containers are the most commonly used pots for container production in nursery and greenhouse operations. In nine southern states, the value of containers purchased by growers totaled \$16.6 million, 99% of which were polyethylene (Hodges and Haydu 2001). The light weight and low cost of plastic material are the primary reasons for use in container production, however, there are environmental and sustainability concerns when using plastic containers.

Disposal issues with used plastic containers is a growing concern. Today, the primary method of plastic container disposal is in the landfill. Since plastic has only been produced in large quantities for around 60 years, its longevity in the natural environment remains uncertain, therefore long term risks of soil and ground contamination from UV stabilizers and additives used in plastic products are unknown (Hopewell et al., 2009; Teuten et al. 2009). Incineration is a disposal alternative that reduces the landfill space needed for plastic waste; however, burning results in toxic gas and carbon dioxide emissions, which contributes to climate change (Anand et al., 2007; Hopewell et al., 2009).

Secondly, the overriding manufacturing concern is that the current plastic container production is not sustainable; approximately 4 percent of annual petroleum production is used to make plastic plus a similar amount of petroleum is used to provide the needed energy in the production process (Thompson et al., 2009). Yet no widespread recycling is evident and the containers will be ultimately discarded by commercial or end users (Evans and Hensley, 2004). In order to solve these economic and environmental issues, new materials such as bioresins, coir, poultry feathers, paper fibers, rice hulls and processed cow manure are being investigated for biodegradable and compostable containers are being developed and evaluated (Evans et al. 2004; Hall et al. 2005).

Limited research to date has compared plant growth and water use in alternative containers to plastic containers. Evans and Hensley (2004) found that when vinca and impatiens were irrigated according to plant needs, plants grown in poultry feather and peat containers required more irrigation than plastic containers. They also reported that the shoot dry weight of impatiens and vinca plants in poultry feather containers were greater than that of peat and plastic containers. When the plants were irrigated uniformly, vinca had a greater shoot dry weight grown in plastic containers than peat or feather containers, and there was no difference for impatiens. Lopez and Camerato (2011) evaluated Poinsettia growth in alternative containers and plastic containers, finding Poinsettias grown in molded fiber had better growth compared to wheat starch-derived bioresins and plastic containers when irrigated as necessary with water-soluble fertilizer.

The research above indicates that the plants in biodegradable containers have similar or better performance than plants grown in the plastic containers in the greenhouse when the water supply is sufficient. Yet there are no experiments comparing plant growth between biodegradable and plastic containers under outdoor nursery practices. This experiment assesses plant growth and water use in alternative and plastic containers. The objectives were to: 1) assess plant growth and biomass in alternative and plastic containers; 2) determine the water usage of woody ornamental plants in alternative and plastic containers; 3) determine the suitability of alternative containers for a one-year production cycle of woody ornamental plants under outdoor nursery conditions.

### **Material and Methods**

# Site specifications and experimental design

The experiment was conducted at the Michigan State University Horticulture Teaching and Research Center (HTRC) located in Holt, MI. The HTRC is located at latitude 42.7 °N, longitude 84.5 °E, and elevation 264 m.. A 250 m<sup>2</sup> hoophouse was separated into 12 irrigation zones with each zone serving as a treatment replicate. The hoophouse was covered with 70% white plastic film during the winter (mid-November through mid-May) for crop protection. A one factor completely randomized design was utilized. Each container type (treatment) was replicated three times with 15 sub replicates and randomly assigned to an irrigation zone (replicate). Containers were spaced 32 cm apart on center and located in the middle of the irrigation zone in three rows of five with twenty guard plants surrounding the border to minimize edge effects.

## Plant material and treatments

In 2011, *Euonymus fortunei* 'Roemertwo' were transplanted from 5-cm plugs into #1 containers on 1 June and evaluated through May 2012. Container substrate consisted of 85% pine bark: 15% peat-moss (vol: vol). Plants were fertilized on 5 June with 26 g per container of a 17.0N-3.5P-6.6K fertilizer, which contained micronutrients and had a nutrient release period at  $27^{\circ}$ C of 4 months (HFI Topdress special; Harrell's Inc., Lakeland, FL). Container treatments in 2011 were: 1) polyethylene PF400-SM (Plastic); 2) Western Pulp 7X7RD (WP); 3) Kord 07.50 Fiber Pot (Kord). In 2012, *Buxus x* 'Green Velvet' were potted from 5-cm plugs into #1 containers on 14 May with the same substrate mixture and evaluated through May 2013. Plants received the same fertilizer as used in 2011 on 5 June, 2012. Container treatments in 2012 were:

1) Plastic; 2) WP; 3) Root pouch 15-20 month (RP) 4) Keratin pot (KR). A detailed description of the containers is provided in Table 2.1 (Chapter 2).

## Irrigation application and daily water use (DWU)

The irrigation was delivered by a solenoid-controlled overhead system. Nine Toro 570 Shrub Spray Sprinklers (The Toro Company, Riverside, CA) were mounted on 0.66m high, 1.3 cm diameter risers in each irrigation zone spaced 2.50 m apart. Each irrigation zone had four 90 degree emitters located at four corners of the beds with four 180 degree emitters placed in the middle of the sides; two 360 degree emitters were placed at the center of irrigation zone. Each irrigation zone is 4.5m long and 7.5m wide. All irrigation was directed into the block with a 2.44-m radius distance of throw. Distribution uniformity of each bed was measured at 0.8 or greater during a period without wind. In 2011, two EC5 (Decagon Devices Inc., Pullman, WA, USA) sensors were inserted into two containers for each zone to determined plant daily water use (DWU); in 2012, two GS3 (Decagon Devices Inc., Pullman, WA, USA) sensors per zone were used to determined DWU. The probes were inserted in the northeast side of the containers, centered between plants and the container edge, to maximize the probe reading uniformity and accuracy. The sensors were calibrated by correlating the datalogger reading with container weight change during a substrate dry down cycle. The probe readings were recorded by a datalogger (model CR1000, Campbell Scientific Inc., Logan, UT, USA) every 15 minutes. Volumetric substrate moisture was measured 5 min after irrigation application ( $\theta_{AI}$ ), and immediately before the next irrigation ( $\theta_{BI}$ ). The DWU was determined by the equation: DWU=  $(\theta_{AI}-\theta_{BI})$  x container volume. The container was saturated on the first day of experiment. The irrigation was applied to replace total DWU back to the containers and was based on the average

DWU of two containers in each zone. Irrigation was split into two applications per day initiated at 0700HR and 1900HR.

### Plant growth index and biomass

Plant growth index (GI) was measured approximately every two weeks. GI was calculated as GI= (height+width1+width2)/3, where the plant height was taken from the rim of the container to the highest point of the plant, width1 was the width of the plant in the north to south direction and width 2 was the width of the plant in the west to east direction using fixed pot labels to maintain orientation. In 2011, the plants were harvested and separated into roots, stem, and leaves on May 23. The plant materials were dried in a Partlow 1400 oven (The GRIEVE Corporation, Round Lake, Illinois) at 73 °C for two weeks and then the weights were recorded. In 2012, the plants were harvest on May 31 with the same methods used to determine dry weight.

#### *Leachate EC, pH and root zone temperature*

Electrical conductivity (EC) and pH was measured approximately every month using the pour through method described by Yeager (2003). A plastic tray was placed under the container 30 minutes after irrigation was applied, then 200 ml reverse osmosis water was added to the container, a bulb syringe was used to extract leachate from the tray and release it onto the sensor of a Cardy Twin EC Meter and Cardy Twin PH Meter (Spectrum Technologies, Inc., Illinois 60585). Four of the fifteen replicate containers in each block were randomly selected at the first measurement and repeatedly measured afterwards. The root zone temperature was measured by thermistors (model 107-LC Campbell Scientific Inc., Logan, UT, USA) connected to the datalogger. The probe was inserted between plants (in the center of the containers) and the

container edge into one randomly selected subreplicate container in each replicate. The datalogger was programmed to record the temperature from each probe every 15 min.

#### Statistical analysis

Growth index, EC and pH were analyzed as repeated measurements using PROC MIXED procedure of Statistical Analysis Software (SAS Version 9.2; SAS Institute, Cary, NC). When significant at the 0.05 level, treatment means on each measurement day were separated using a t test in the PDIFF option of the LSMEANS statement and the SLICING option of PROC MIXED ( $\alpha$ =0.05). Temperature and DWU were analyzed using PROC GLM procedure of SAS and, when significant, means were separated using Tukey's test at 0.05 significance level.

# 3. Results and Discussion

#### DWU

In 2011, the DWU of plants in WP and Kord containers was similar to that of Plastic containers in the beginning of the season but generally higher than that of Plastic containers after day 50 (Figure 3.1). This can be partially explained by side wall chemical component changes resulting from UV degradation and more evaporative surface of the WP and Kord containers (Chapter 2). The seasonal daily average DWU of *E. fortunei* grown in WP, Kord and Plastic containers was 193, 119 and 30 ml, respectively. The plant DWU in WP containers was the greatest while DWU in Plastic was the smallest. Similarly, Evans et al. (2010) reported that when irrigated as necessary, plants grown in paper container use more water and have a lower irrigation interval than that of Plastic containers. Additionally, they found that the rate of water loss through the container wall was a major factor affecting water use. In 2012, the seasonal trend of DWU of plant grown in WP, KP, RP and Plastic containers was similar, high water use in the summer season and then decreased in the fall (Figure 3.2). Generally, DWU of plants grown in Plastic containers was the highest compared to other treatments in the summer season but similar to that of WP containers in the fall season. In terms of seasonal means, among the treatments, plants grown in KR containers had the least water use while plants in Plastic container had the highest water use. Plants grown in WP containers used less water than that of Plastic containers, but were higher than that of RP containers. DWU of *Buxus* in WP, Plastic, KP, and RP containers were 214.71, 294.68, 159.95, and 191.64 mL, respectively. The difference in water usage of WP containers in 2011 and 2012 may be due to changes in manufacturing of the pots (see Chapter 2).



Figure 3.1. Daily water use (DWU) of *Euonymus fortunei* grown in western pulp (WP), Kord fiber (Kord) and Plastic containers from June 16, 2011 (Day 0) to Oct 26, 2011. All plants were irrigated to replace total DWU back to the container.



Figure 3.2. Daily water use (DWU) of *Buxus* x 'Green Velvet' grown in western pulp (WP), keratin (KR), Plastic and root pouch (RP) containers from June 23, 2012 (Day 0) to Oct 28, 2012. All plants were irrigated to replace DWU back to the container.

### Plant growth and biomass

The final GI of *E. fortunei* in WP, Kord and Plastic containers was 18.83 cm with no difference between treatments. The leaf and root dry weights of plants grown in Plastic were greater than that of WP and Kord containers while the dry stem weight between treatments was similar (Table 3.1). The mortality rate of plants grown in WP, Kord and Plastic was 2, 2, and 13% on Oct 11, 2011 and increased to 52, 52, and 15% on Jun 6, 2012, respectively. Since there was no irrigation supply for the hoophouses during winter, the higher mortality rate of plants grown in WP and Kord containers after the winter could be attributed to faster desiccation of

substrate in fiber containers than Plastic containers, which may have also resulted in reduced root and leaf dry weights of plants in WP and Kord containers.

The final GI of *Buxus* was 16.65 cm with no difference between container treatments. The leaf dry weight of *Buxus* grown in KR containers was greater than that of those grown in WP containers (Table 3.2); the stem and root dry weights were not different for any treatment.

In this experiment, the plants grown in KR containers performed similarly to Plastic containers. Evans and Hensley (2004) reported that when irrigation was applied as needed, plants grown in poultry feather containers had a greater growth than those in Plastic containers. The poultry feather containers used in their experiment consisted of 15% kraft paper and 85% processed feather fiber, which provided an available nitrogen resource to the plants. However, there was no indication that the poultry feather component in KR contributed to plant growth in the current experiment, which may be due to different keratin container constituents.

Container type	Leaves weight (g)	Stem weight (g)	Root weight (g)	Total Weight (g)
Plastic	8.863a <sup>x</sup>	4.814a	27.822a	41.499a
WP	6.061b	5.190a	21.478b	32.729a
Kord	3.806b	3.791a	17.358b	24.955a

Table 3.1. Leaves, stem, and root dry weight of *Euonymus fortunei* grown in Plastic, Western pulp (WP), and Kord containers on June 6, 2011.

<sup>x</sup> Means with the same letter in the same column are not different ( $\alpha$ =0.05)

Table 3.2. Leaves, stem, and root dry weight of *Buxus x* 'Green Velvet' grown in Plastic, Western pulp (WP), Root pouch (RP) and Keratin (KR) containers on June 14, 2012.

Container type	Leaves weight (g)	Stem weight (g)	Root weight (g)	Total Weight (g)
Plastic	11.197ab <sup>x</sup>	4.043a	9.935a	25.175a
WP	10.402b	3.627a	9.195a	23.224a
KR	12.864a	4.344a	8.297a	25.505a
RP	10.559ab	3.279a	8.896a	22.734a

<sup>x</sup> Means with the same letter in the same column are not different ( $\alpha$ =0.05)

#### *Root zone temperature*

In 2011, the seasonal root zone temperature in Plastic, Kord and WP containers was highest in the summer and then decreased toward fall season (Figure 3.3). The average daily root zone temperature was greater in Plastic containers than the Kord containers and the Kord containers had higher temperature than the WP containers. Temperature differences of Plastic, Kord, WP containers was also similar for maximum temperature and minimum temperature, but the difference in average temperature between Plastic, Kord and WP containers was primarily due to differences in maximum temperature. The average seasonal root zone temperature in Plastic, Kord, WP containers were 22.43, 17.92, and 15.85 °C, respectively. The seasonal maximum root zone temperature in Plastic, Kord, WP containers were 13.67, 11.05, and 9.23 °C. The higher temperature in Plastic containers was likely due to carbon black additive in the plastic, which absorbs more heat from solar radiation than other colors.

In 2012, the seasonal trend of root zone temperature in Plastic, KP, WP, and RP containers was similar to that of 2011. All containers had higher temperatures in the summer that gradually decreased into the fall (Figure 3.4). Among treatments, Plastic containers had a higher daily temperature than WP and RP, but it was similar to KR containers, and the results for maximum temperature and minimum temperature was similar to that of average temperature. The average seasonal substrate temperature in Plastic, KR, WP and RP containers were 22.13, 21.12, 20.12, and 18.84 °C, respectively. The seasonal maximum root zone temperature in Plastic, KR, WP and RP containers were 29.96, 31.40, 27.79 and 25.09 °C. The seasonal minimum root zone temperature in Plastic, KR, WP and RP containers were 14.94, 13.07, 13.62 and 13.01 °C. KR containers were made from bio Plastic resins and were a tan color, so the substrate temperature



in KR was similar to Plastic containers. RP containers were also black, however, its porous texture probably allowed better heat dissipation due to evaporative cooling.

Figure 3.3. Substrate temperature in Western Pulp (WP), Kord fiber (Kord) and Plastic containers located at Horticulture Teaching and Research Center (Holt, MI) from July 20 (Day 0), 2011 to Oct 27, 2011. Daily average temperature (A) daily maximum temperature (B), daily minimum temperature(C)



Figure 3.4. Substrate temperature in Western Pulp (WP), Plastic, keratin (KR) and Root Pouch (RP) containers from June 10 (Day 0) to Oct 29 (Day 143), 2012. Daily average temperature (A), daily maximum temperature (B), daily minimum temperature (C).

# *Leachate EC and pH*

In 2011, the seasonal average leachate EC and pH were 0.421 mS cm<sup>-1</sup> and 7.4 with no differences between treatments for any dates measured. In 2012, on day 57 and 85, the substrate EC in KR containers was greater than in RP container (Figure 3.5). The substrate EC in WP and Plastic containers were generally in the middle. This is an indication that there was likely more rapid leachating from RP containers since the RP containers are made from more porous material. Leachate pH from RP containers was generally higher than that of other containers; however, the final leachate pH was similar between treatments.



Figure 3.5. Leachate EC (ms cm<sup>-1</sup>) and pH from *Buxus* x 'Green Velvet' grown in Western pulp, Keratin, Plastic and Root pouch containers on Experiment day 23, 42, 57, 85, 116 and 114 (day 0=May 14, 2012). Means with the same letter within the same date are not different ( $\alpha=0.05$ )

# Conclusions

During 2011 and 2012, plant growth in all alternative containers was similar to those grown in Plastic containers. This result indicates that the alternative containers do not negatively impact plant growth.

In 2011, WP and Kord containers used 543.3% and 296.7% more water than that of Plastic containers, which could be explained by the higher water vapor transmission rate (WVTR) of WP and Kord containers than that of Plastic containers (Chapter 2). Similarly, Evans et al. (2010) found more water was required to grow a geranium to marketable size in paper containers than in plastic containers. They also reported that the rate of water loss through the wall plays a major role in container water use. The mortality rate of *E. fortunei* grown in WP and Kord containers was 2% in October 2011, however, the mortality rate of *E. fortunei* grown in WP and Kord containers increased to 52%, higher than that of Plastic containers after being stored in a hoophouse during winter of November 2011 through May 2012 with no irrigation. Conversely, there were no *Buxus* lost to mortality in the 2012-2013 experiment. This suggests that growers need to consider substrate moisture availability and plant water stress tolerance when WP and Kord containers are used in climates where winter irrigation is not typical.

RP containers used less water than that of Plastic containers. However, its lower EC indicates the possibility of leaching of nutrients from the container walls. Therefore using fabric containers such as RP containers could potentially lead to more nutrient loss. The plants grown in KR containers required the least amount of irrigation among all containers. This could be provide another management technique for nursery growers where irrigation usage is limited.

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# CHATPER FOUR

CONCLUSIONS AND FUTURE DIRECTION OF CONTAINER NURSERY IRRIGATION MANAGEMENT AND ALTERNATIVE CONTAINERS

#### **Woody Ornamental Irrigation Management**

The aim of this project was to discover the impact of plant daily water use (DWU) based irrigation scheduling on plant growth, runoff volume, runoff nutrient content, substrate electrical conductivity (EC) and pH.

During the 2011 and 2012 experiment, the plant growth was similar between all irrigation treatments for all taxa. The water volume applied daily averaged over the season was 79,825 L ha<sup>-1</sup> in 2011 and 164,912 L ha<sup>-1</sup> in 2012. The larger irrigation amount in 2012 may have resulted from larger plant size and higher reference potential evapotranspiration rate (Figure 1.3, Chapter 1). The daily water runoff volume averaged over the season was 45,457 L ha<sup>-1</sup> in 2011 and 49,954 L ha<sup>-1</sup> in 2012. Warsaw et al. (2009a) used the same research site and experimental design as the current study to evaluate irrigation effects on runoff volume. In Warsaw's research, a daily 190,000 L ha<sup>-1</sup> irrigation rate was applied as the common nursery irrigation rate. The average runoff volume under this treatment was 114,000 L ha<sup>-1</sup> per day. Both irrigation and runoff volume in the current study was much lower than that of common nursery irrigation rate in Warsaw's research and would likely have been so if had a similar rate included in this study. Similarly, Million at el. (2010) also reported that when comparing a plant demand based irrigation scheduling with a daily 100,000 L  $\cdot$ ha<sup>-1</sup> irrigation rate, the plant demand-based irrigation decrease irrigation amount and water runoff volume by 39% and 42% without affecting the plant growth. Many growers water plants more than needed since they prefer the risk of more leaching than the consequences of under watering (Yeager et al., 2010). These

results demonstrate that growers could irrigate their plants according to the need to reduce irrigation amount and runoff without concerns about plant growth or quality.

Irrigation scheduling based on plant DWU not only reduced water runoff volume but could also possibly reduce nutrient loss. In 2012, the daily seasonal average  $PO4^{3-}$ -P load under 100-75-75-75 treatment was 56 g  $\cdot$ ha<sup>-1</sup> which was less than 88 g  $\cdot$ ha<sup>-1</sup> under 100-75 treatment. Similar to this result, Owen et al. (2008) performed an irrigation study containerized woody ornamental crop Skogholm cotoneaster by decreasing leaching fractions (effluent/influent) from 0.2 to 0.1, finding that the P load was 64% less under 0.1 leaching fractions than that of 0.2. Warsaw et al. (2009a) reported that when irrigation was based on plant daily water use (DWU), The N and P loss in the effluent was reduced by 59% and 74% under the most conservative irrigation treatment. Therefore, growers and the surrounding ecosystem could also benefit from less nutrient leaving production areas by scheduling irrigation based on plant demand.

While scheduling irrigation based on plant DWU could be beneficial, there are certain aspects that growers need to take into consideration when adopting such practice. The pour through EC value of the substrate in current study was generally above recommended range 0.2 to 0.5 dS m<sup>-1</sup> for container grown woody ornamentals in pine bark substrate fertilized with only a CRF (Southern Nursery Association, 2007). This was a result of salt accumulation from the fertilizer, however, there was no plant salt damage observed in the current study nor in previous similar studies (Warsaw et al., 2009a, b). Since woody ornamentals have different salt tolerance levels (Monk and Wiebe, 1961), container nursery growers that irrigate at zero leaching fraction should monitor the substrate EC levels to avoid possible salt damage to the plant.

The DWU, WUE and Kc of ten woody ornamental plants evaluated in this study will allow nursery growers to group plants with similar water use into appropriate irrigation zone, therefore conserve water and avoid over-watering or under-watering plants. Additionally, the method used in this experiment can be applied to identify the DWU and Kc of more woody ornamentals in the future.

# **Alternative Containers**

The objective of this project was to look for alternative to plastic containers that are suitable for nursery production. In order to achieve this aim, plant growth, water use and substrate temperature in alternative containers and plastic containers were evaluated, and the physical properties and biodegradability of the containers were tested using ASTM standards.

During 2011 and 2012, results of plant growth, water use, substrate temperature and physical properties of alternative containers and plastic containers was obtained. During 2011 and 2012, plant final growth in all alternative containers was not different to those grown in plastic containers. Evans and Hensley (2004) found that when irrigated according to plant needs, the dry shoot weight of impatiens and vinca plants in poultry feather containers were greater than that grown in peat and plastic containers. The results above indicate that when water supply is sufficient, plants grown in biodegradable containers have similar or better growth than plants grown in plastic containers. The mortality rate of Euonymus fortunei grown in Western pulp (WP) and Kord fiber (Kord) containers was 2% at the end of October, 2011, however, the mortality rate of E. fortunei grown in WP and Kord containers increased to 52% after being stored in the hoophouse during winter of November 2011 through May 2012 with no irrigation.

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On the contrary, there were no *Buxus x* 'Green Velvet' lost throughout the experiment. This indicates that growers could adopt alternative containers without affecting plant growth, however, growers need to consider substrate moisture availability and plant water stress tolerance when paper fiber containers are used in climates where winter irrigation is not possible.

In 2011, plants grown in WP and Kord containers used 543.3% and 296.7% more water than those grown in Plastic containers, which could be explained by higher water vapor transmission rate (WVTR) from alternative containers than that of Plastic containers (Chapter 2). Similarly, Evans et al. (2010) found more water was required for geraniums to achieve marketable size in paper containers than those grown in Plastic containers. They also reported that the rate of water loss through the wall plays a major role in container water use. These results suggest growers should consider irrigation budgets and water availability when adopting paper fiber containers. Plants grown in low WVTR alternative containers, such as the keratin containers, generally require similar or less water than those grown in plastic containers. The substrate temperature of all alternative containers was lower than that of Plastic containers. The higher temperature of substrate in Plastic containers was attributed to more heat absorption by the carbon black additive used as UV stabilizer. Growers may use alternative containers to replace plastic containers in the summer to achieve a more stable root zone temperature for the plants.

The physical properties of alternative containers differ from plastic containers according to their components. All alternative containers had greater compression strength than that of Plastic containers except Root pouch (RP) containers. Growers may experience transportation difficulty with RP containers as the containers will easily deform, moreover, the decreased tensile strength of RP containers after 2 months in the nursery could also result product damage during transportation. In terms of compostability, WP and Kord containers passed biodegradation tests when ground to a powder form but not in 1x 1 cm pieces. Since we do not have the formula of the containers from the manufacturer, we could not conclude that WP and Kord containers are compostable. Alternative containers are often cut into similar sized pieces when being disposed, and they were not proven to be compostable under this common practice. All containers tested passed the germination test, showing that the containers had no negative impact on seedling growth.

The results stated above demonstrate that alternative containers do not have a negative impact on plant growth when irrigated according to plant needs. However, the growers located in areas with restricted water use or high water costs should consider alternative containers with low WVTR such as Keratin containers. Growers should also choose the containers according to their product commercial shelf life since containers, for example, WP, Kord and RP containers will show signs of wear after being in the field for 12 month or shorter and, therefore, they are not suitable for multi-season production.

# **Future Research**

We conducted woody ornamental irrigation management and alternative container studies to look for more sustainable practices for container nurseries. A container nursery that pursues sustainable practices could combine the plant DWU based irrigation scheduling with the adoption of alternative containers to reduce water use and minimize plastic waste environmental impact.

Since both water and petroleum are valuable resource with increasing global demand, growers that choose paper pulp based containers or fabric containers, such as Kord and WP

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containers, should balance the benefit of reducing plastic waste against more water use. Greater irrigation use could result in more runoff effluent and nutrient loss (Warsaw et al, 2009). Growers may select alternative containers with a smaller or similar water use to that of plastic containers, such as KR containers, to further reduce irrigation amount and water cost.

Increasing environmental regulations and restrictions faced by nursery operations create the challenge to growers to adopt sustainable practices while maintaining economic viability. Since adopting alternative containers in container nursery production could potentially increase water consumption, future research on nursery production could focus on greater efficiency of irrigation and fertilization for production using alternative containers. Meanwhile, future alternative container research should focus on material physical properties such as low WVTR, high compression and tensile strength, and good water retention ability.

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