CRITICAL EVALUATION OF SUSTAINABLE PRACTICES FOR THE LANDSCAPE INDUSTRY

by

BETHANY A. HARRIS

(Under the Direction of Bodie V. Pennisi)

ABSTRACT

Positive environmental impacts and sustainability by the green industry have translated into increased interest of soil microbial inoculants and plantable biodegradable containers. Biodegradable containers have the potential to serve as alternatives to petroleum-based plastic containers and eliminate plastic waste and disposal and improve labor efficiency while promoting healthy plant growth. However, adoption of biodegradable containers by the landscape industry has been slow and could be due to incomplete decomposition, particularly for seasonal color rotations. A field and laboratory study evaluate the effect of nitrogen fertilizer, soil moisture, and bark soil amendment on decomposition of several types of biodegradable containers. It appeared that soil amendment and fertilizer significantly impacted decomposition of recycled paper and coconut coir containers. There was higher carbon dioxide released for each container type in the presence of soil amendment and under low fertilizer. However, carbon : nitrogen analysis revealed higher decomposition of wood pulp and coconut coir containers under absence of amendment and for all containers under 60% WHC. The field study results confirmed that decomposition was significantly impacted by container type, with those high in cellulose (i.e. cow manure) degrading more rapidly over the six-month study. On average, low fertilizer treatment application did lead to higher degradation of coconut coir, wood pulp fiber, and recycled paper pots. To further assess adoption of biodegradable containers, an online survey instrument was implemented to assess producer and landscaper knowledge and familiarity regarding biodegradable containers in the state of Georgia. Results indicated 83% of horticultural producers do not purchase biodegradable containers. However, horticultural producers and installers agreed that use of plantable containers can limit use of plastic containers. The survey results suggest a need for augmented outreach to producers and landscapers. In our field evaluation assessing microbial inoculant performance, we found that microbial inoculants significantly influenced GI and inflorescence number in lantana. Effective Microorganims-1 (EM) and Companion Biological Fungicide (CM) appeared to positively boost GI when compared to untreated plants in 2016. In 2017, GI and inflorescence count was higher in untreated plants and in those treated with CM.

INDEX WORDS: biodegradable containers, microbial inoculants, microorganisms, ornamental plants, biocontainer public perception, demographics

EFFECT OF ENVIRONMENTAL AND CULTURAL FACTORS ON BIODEGRADATION OF PLANTABLE CONTAINERS AND MICROBIAL INOCULANTS ON PLANT GROWTH

by

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DEDICATION

I dedicate this work to the good Lord above who has continuously provided all opportunities, valuable learning experiences, and exemplar mentors needed to help me learn, grow, and reach my educational goals. “Every good thing given and every perfect gift is from above, coming down from the Father of the heavenly lights, who does not change like shifting shadows.” (James 1:17, New International Version of the Bible). This dissertation is also dedicated to my loving and supportive parents, Clay and Debra Harris. You have always been great Christian examples, provided encouragement, are my biggest cheerleaders, and reminded me to pursue my passions. To my brother, Jordan, this work is for you. Thank you for always making me laugh and being a shoulder to lean on during my time in graduate school. This dissertation is also dedicated to my grandparents, Nanny and Papa Harris and Mimi and Papa Jackson, who have taught me life’s greatest lessons and cultivated my passion for agriculture. The uplifting and kind words of my family, friends, and church family have inspired and motivated me during this journey. All of you have been valuable encouragers as I pursued my degree.

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CHAPTER 1

INTRODUCTION AND LITERATURE REVIEW

Ornamental plant production and installation are labor and product intensive processes with the goal of producing superior and uniform plants. Ornamental plants are grown with high inputs of water, fertilizer, growth regulators, and pesticides (Hall et al., 2009). Additionally, use of plastic pots, flats, and cell packs in production and installation as well as plastic container disposal by growers, consumers, and landscapers have increased interest in adopting sustainable practices by the green industry (Evans and Hensley, 2004). The Floriculture Sustainability Research Coalition defines sustainable production as aiming to reduce environmental degradation, maintaining agricultural productivity while promoting economic viability, conserving resources and energy, and maintaining stable communities and quality of life (Krug et al., 2008). Examples of sustainable practices include recycling irrigation water, implementing biological controls, and using alternative energy sources (Lopez et al., 2008). Other sustainable practices such as biodegradable containers during production and installation as well as means of enhancing plant growth by utilizing biofertilizers, phytostimulators, and various biological agents are gaining interest by horticultural firms.

Petroleum-based plastic containers have been utilized by the green industry as the primary container option for ornamental plant production in the United States since the 1980s (Hurley, 2008; Mooney, 2009; Hall et al., 2010). The ornamental industry has used plastic containers to produce flowering crops, perennials, annual bedding plants, vegetable transplants and more recently nursery crops due to their durability, shipping ease, superior function, low cost, and diversity of sizes available. Plastic container manufacturing has also progressed over the years, with container products that are injection molded, blow molded, pressure formed, vacuum formed, and thermoformed, ultimately providing various advantages such as reducing root disruption/transplant shock and allowing effortless shipping (Chappell and Knox, 2012).

In the United States today, four billion container/plant units are produced annually with petroleum-based plastic containers accounting for 1.6 billion pounds of plastic (Schrader, 2013). The U.S. Environmental Protection Agency reported 32 million tons of plastic waste generated in 2012, with only 9% total plastic recovered for recycling (Thompson et al., 2009). The volume of plastics and the disposal process in the landfill poses a threat of soil and groundwater contamination due to the ultraviolet light additives used in plastic products (Thompson et al., 2009). To aid in reduction of such concerns, alternative containers have been employed which can reduce environmental impact of crop production.

Biodegradable containers are made from a variety of materials usually derived from renewable sources such as bioplastic, coir, poultry feathers, processed cow manure, paper fibers, and rice hulls (Evans et al., 2015). Additionally, these containers are typically categorized as compostable or plantable (Sun et al., 2015). Plantable biocontainers can be directly planted in the landscape, raised bed, or planters and allow plant roots to penetrate through their walls. These containers can limit installation waste/disposal of plastic and improve labor efficiency during planting (Nambuthiri et al., 2015). In contrast, compostable containers must be removed before planting as they do not degrade rapidly enough for plant roots to protrude through the container walls, however, when placed in a compost pile they degrade relatively quickly (Mooney, 2009).

Numerous studies have observed exceptional plant growth and performance of annual, perennial, ornamental, and vegetable plants grown in these containers (Center for Applied

Research, 2009; Kuehny et al., 2011; Lopez and Camberato, 2011; Beeks and Evans, 2013). One study observed increases in the growth index of petunia (*Petunia x hybrid* Juss) when grown in bioplastic wrap and slotted rice hull containers was greater than growth in plastic containers (Center for Applied Horticulture Research, 2010). Kuehny et al. (2011) reported variable root and shoot growth of sedum (*Sedum hybridum* L. 'Immergrunchen' and *Sedum spuricum* L. 'Red Carpet Stonecrop') and liriope (*Liriope muscari* (Decne.) L. H. Bailey) when planted in bioplastic, paper, and slotted rice hull containers. When Rainier Purple' cyclamen (*Cyclamen persicum* Mill.) was grown in bioplastic, solid rice hull, slotted rice hull, recycled paper, peat, cow manure, rice straw, and coconut fiber pots, the plants produced greater plant shoot dry weight as compared to those produced in plastic containers (Beeks and Evans, 2013).

Lopez and Camberato (2011) reported increased root and shoot dry weight, plant height, and bract area index of 'Eckespoint Classic Red' poinsettia (*Euphorbia pulcherrima* Willd. ex Klotzsch) grown in recycled paper in the greenhouse. Additional studies have shown certain biodegradable container types (i.e. fiber) have been utilized effectively to grow temperature sensitive plants such as cherry laurel (*Prunus laurocerasus* L.), wintercreeper (*Euonymus fortunei* (Turcz.) Hand.-Maz.), rhododendron (*Rhododendron* spp. L.), and daylily (*Hemerocallis* spp. L.) (Ruter, 1999; Ruter, 2000; Fulcher et al., 2015).

Few studies have examined rate of plantable biocontainer degradation in landscape. Through field evaluations, Evans and Karcher (2004) observed decomposition of peat and feather containers and determined rate of degradation is dependent on container type and plant species grown in the container. Feather containers previously planted with vinca (*Catharanthus roseus* L.) and marigolds (*Tagetes* spp. L.), had faster decomposition post-production compared to peat containers with same planting. Additionally, field trials in Louisiana and Pennsylvania found cow manure containers tend to break down faster in the soil when compared to peat, straw, and wood fiber, and coir pots (Evans et al., 2010). Landscape trials in 2011 and 2012 in Illinois, Kentucky, Mississippi, Texas, and West Virginia that revealed after three-months post-production, manure containers (high cellulose content) had the fastest decomposition (88%) when planted with New Guinea impatiens (*Impatiens x hybrid* Hook. f.), lantana (*Lantana camara* L.), and cleome (*Cleome x hybrida* L.*)* (Sun et al., 2015). This decomposition rate was followed by straw (47%), wood fiber (46%), soil wrap (42%), peat (38%). Coir (25%), and Rice hull (18%) containers had the lowest decomposition and because of their high lignin content (Sun et al., 2015). As observed in these works, biodegradable container decomposition is highly dependent on the container type/material and plant species grown in the container (Evans and Karcher, 2004; Evans et al., 2010; Li et al., 2015; Sun et al., 2015).

Although numerous favorable reports exist regarding successful use of plantable biodegradable containers in production and installation, wider adoption of such containers has been limited. Incomplete container decomposition (Harris and Kraft, pers. comm.; Harris and Mobley, pers. comm.) has been one of the barriers impeding the adoption of biodegradable containers as a primary container choice by the landscape industry. Due to incomplete decomposition, container remnants may have to be removed manually and can negatively impact installation efficiency and labor costs. Practical concerns such as this do influence the willingness of the green industry to successfully adopt biodegradable containers.

The rate of container decomposition is essential to plant growth and should occur fast enough to prevent disruption of root growth after planting but slow enough to remain functional during withstand nursery production (Nambuthiri et al., 2015). If the biodegradable container does not degrade quickly enough, root circling can occur and remaining container fragments may disrupt rototilling in subsequent seasons and hinder planting (Evans and Hensley, 2004; Evans and Karcher, 2004). Biodegradation in the landscape is influenced by many factors such as including container material (thickness, density), container carbon : nitrogen content, soil nitrogen availability, organic matter content, soil moisture, soil temperature, and soil pH as well as abundance and diversity of soil microorganisms present in the rhizosphere (Evans et al., 2010; Nambuthiri et al., 2015). Cultural practices such as irrigation, fertilizer, and soil amendment application can also influence rate of degradation (Sun et al., 2015).

However, to the best of our knowledge, no studies have examined the effect of cultural practices (i.e. fertilizer, soil amendment, irrigation) on plantable biocontainer decomposition in the landscape and in a controlled environment. Additional research is needed to further assess biodegradable container decomposition under such practices and to identify potential barriers preventing adoption of biodegradable containers by the green industry.

Microbial inoculants are readily available on the market and are becoming of increasing interest for use on agricultural and horticultural crops (Velivelli et al., 2014). They are a "final product of one formulation containing a carrier and a bacterial agent or a consortium of microbes" and have the potential to improve plant growth while reducing use of chemical inputs (i.e. synthetic fertilizers and pesticides) (Ambrosini et al., 2016). These microbial products contain of a wide variety of bacteria, fungi, and protozoa but can be classified into several groups including plant-growth-promoting bacteria (PGPB) and arbuscular mycorrhizal fungi (AMF) (Gupta et al., 2013).

These two groups (PGPB and AMF) contribute as biofertilizers, biological control agents, phytostimulators, or as stress controllers to enhance plant growth (Jakobsen et al., 1992; Jha et al., 2013). As biofertilizers, microorganisms improve plant nutrient availability by fixing nitrogen, sequestering iron, oxidizing sulphur or participating in phosphorus and potassium solubilization

(Velivelli et al., 2014). As phytostimulators, microorganisms within these products regulate growth through the production of plant growth hormones including cytokinins, gibberellins, abscisic acid, ethylene, and brassinosteroids (Chauhan et al., 2015). Several studies have reported increased plant growth through the production of plant growth hormones by soil bacteria (Vessey, 2003; Arkihpova et al., 2005; Dimpka et al., 2009; Budiharjo, 2011; Kang et al., 2014). Additionally, PGPB can aid in the control or prevention of diseases and acting as biological control agents (Velivelli et al., 2014). Several studies have observed successful suppression of pathogen and insect pests when utilizing PGPB or AMF products (Pozo et al., 2002; Garmendia et al., 2006; Zhan et al., 2010, Gonzalez et al., 2016, and Arthurs and Bruck, 2017).

Microbial inoculant products are typically formulated and sold in powder, granule, and liquid form (Gaskin et al., 2010). Several methods can be used when applying inoculants, including direct soil drench, seed treatment, root dip or foliar application, but, different formulations demand different application methods (Metting, 1993; Bashan, 1998). To see effective results after microbial product has been applied, microorganism survival and colonization in the rhizosphere is essential (Chauhan et al., 2015). Several studies have evaluated the use of locally effective microorganisms, in which microorganisms utilized are from the local region of application, and have found observed improvement in soil quality and nutrient status (Hattabaugh, 2017; Ney et al., 2018).

Several challenges to be addressed when utilizing microbial inoculants which contain AMF and PGPB. These include compatibility of species or the ability of the introduced AMF or PGPB to adapt to local agricultural and soil conditions (Trabelsi and Mhamdi, 2013). The formulation carrying capacity of microorganisms can also influence their effectiveness in the soil as biofertilizers, biocontrol agents, abiotic and biotic stress controllers, and rhizomediators

(Verbruggen et al., 2013). More practical challenges in the adoption and use of microbial inoculants by the agricultural industry consist of developing carriers that have higher microbial abundance in the field, extending product shelf life, and improving convenience of use and cost effectiveness (Bashan, 1998).

Microbial product use during horticultural production and installation is increasing in interest (Harris and Hardgrave, pers. comm.), (Harris and Russell, pers. comm.). However, little research has been conducted to evaluate the potential of microbial products to enhance plant growth in landscape annuals under local Georgia conditions. It is also necessary to provide information on plant growth as influenced by microbial inoculants and cultural factors.

There is increased interest in microbial product use during horticultural production and installation (Harris and Hardgrave, pers. comm.), (Harris and Russell, pers. comm.). However, little research has been conducted to evaluate potential of microbial products to enhance plant growth in landscape annuals under local Georgia conditions. It is also necessary to provide information on plant growth as influenced by microbial inoculants and cultural factors.

The overarching goal of this research was to explore the potential of sustainable practices for the landscape industry, namely biodegradable container decomposition and microbial inoculant efficacy. The specific objectives were as follows:

1. Examine various types of biodegradable containers and their decomposition under different cultural and environmental factors in the landscape

2. Evaluate various types of biodegradable containers and their decomposition and the effect of simulated cultural factors in a controlled environment

3. Identify barriers preventing adoption of biodegradable containers by horticultural firms

4. Assess plant performance as impacted by microbial inoculants and cultural factors

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CHAPTER 2

EFFECT OF FERTILIZER, PINE BARK AMENDMENT, AND IRRIGATION ON DECOMPOSITION OF BURIED BIODEGRADABLE CONTAINERS IN LANDSCAPE

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ABSTRACT

Interest of plantable biodegradable containers by the Green Industry has increased because of the positive environmental impacts and increased interest. Plantable biodegradable containers are alternatives to petroleum-based plastic containers that eliminate plastic waste and facilitate efficient planting while promoting healthy plant growth. However, adoption of biodegradable containers by the landscape industry has been slow for ornamental annuals which could be due to incomplete container decomposition, particularly for seasonal color rotations. A field study using the litterbag method was conducted at two locations on the UGA Griffin Campus (Spalding Co., GA) in 2015 and at one location in 2017 to evaluate the effect of cultural practices (nitrogen fertilizer, irrigation amount, and bark soil amendment application) on decomposition of four types of biodegradable containers: coconut coir fiber, processed cow manure, recycled paper, and wood pulp fiber Processed manure containers had the greatest decomposition amount at both locations followed by coir and wood pulp fiber containers. Low fertilizer treatment application led to higher degradation of coconut coir, wood pulp fiber, and recycled paper pots. Post-study carbon analysis revealed that recycled paper containers degraded more rapidly over a six-month season than to the other three types of containers. This suggests that cow manure and recycled paper sleeve containers exhibit an acceptable level of degradation within a six-month period. Processed cow manure and recycled paper containers appeared to degrade at consistent rate over the length of the study while wood pulp fiber and coconut coir containers exhibited a peak in degradation toward the end of the study.

KEY WORDS Biodegradable Containers, Nitrogen Fertilizer, Irrigation, Soil Organic Amendment, Cow Manure Container, Wood Pulp Fiber Containers, Coconut Coir Container, Recycled Paper Container

Petroleum-based plastic containers have been used for decades in ornamental plant production (Hurley, 2008). Biodegradable containers are an attractive choice because they have the potential to become a viable alternative container option to petroleum-based containers due to societal pressures and increased interest in sustainable practices. Use of alternative containers can reduce the amount of plastic municipal solid waste that is produced in the United States (Environmental Protection Agency, 2005; Environmental Protection Agency, 2007). Agricultural plastic can be difficult to recycle due to the adhered soil and media residue on the plastic, limited plastic collection and storage space, heavier weight, and waste transportation expenses (Hall et al., 2010). Continual utilization of plastic is further exacerbated by soil contamination and photo-degradation, which occurs when plastics are exposed to extreme heat and sunlight and prevents plastic from being recycled (Hurley, 2008).

Biodegradable containers have the potential to minimize and/or eliminate environmental concerns with plastic waste and disposal (Schrader et al., 2015). Biocontainers are typically categorized as plantable or compostable. Those that can be directly planted in the field, raised beds, or pots and allow plant roots to protrude through their walls are plantable containers. This plantable biodegradable container' can be used to eliminate plastic waste/recycling and improve landscape installation efficiency (Nambuthiri et al., 2015). Most plantable biodegradable containers are highly porous and allow water to easily penetrate through the container to the surrounding soil. When utilizing such containers, decomposition must be slow enough to survive production and planting, yet rapid enough not to impede normal plant growth. On the other hand, compostable containers must be removed prior to planting, as they do not degrade quickly and will not allow plant roots to grow through the container walls (Mooney, 2009). Compostable containers should be placed in a compost pile where they can decompose relatively rapidly (Mooney, 2009).

Numerous studies have documented similar or greater plant growth and post-production performance of annual and perennial ornamentals, and vegetable plants grown in biodegradable as compared to plastic containers (Kuehny et al., 2011; Lopez and Camberato, 2011; Beeks and Evans, 2013a, Nambuthiri and Ingram, 2014). Likewise, research suggests that plant growth has not been negatively impacted at post-planting (Evans and Karcher, 2004; Evans et al., 2010; Sun et al., 2015). Despite favorable reports of successful plant performance when plants are produced and installed in the landscape in biodegradable containers, adoption of such containers by the landscape industry has been limited. This slow adoption of biodegradable containers could be attributed to concerns with incomplete container decomposition (Harris and Kraft, pers. comm.; Harris and Mobley, pers. comm.). During planting, container remnants from the previous season's planting may have to be removed manually, decreasing installation efficiency and increasing labor costs.

Decomposition of the biodegradable container is necessary for proper plant growth and establishment; if the container does not degrade quickly, root circling may occur. Furthermore, container fragments may disrupt rototilling and impede planting (Evans and Hensley, 2004; Evans and Karcher, 2004). A plethora of factors can impact rate of decomposition in the landscape: container material (thickness, density, and porosity), container carbon:nitrogen ratio (C:N); soil conditions such as nitrogen availability, organic matter content, moisture, temperature, and pH, availability and density of soil microorganisms, and other soil-related factors that may be attributed to the geographical region (Nambuthiri et al., 2015). Cultural practices such as irrigation frequency, fertilizer application, and soil amendment may also influence rate of degradation (Sun et al., 2015).

Only a few studies have examined the rate of biodegradable container degradation of plantable biocontainers in landscape. Evans and Karcher (2004) observed that feather containers containing vinca (*Catharanthus roseus* L.) and marigolds (*Tagetes* sp. L.) decomposed more rapidly compared to peat containers. They concluded that the rate of decomposition was dependent on container type and plant species. Field trials in Louisiana and Pennsylvania both indicated cow manure containers broke down faster in the soil than peat, straw, or wood fiber containers with coir pots having the slowest decomposition (Evans et al., 2010). In 2011 and 2012, landscape trials conducted in Illinois, Kentucky, Mississippi, Texas, and West Virginia, found that manure containers planted with SunPatiens® 'Compact Magenta' New Guinea impatiens (*Impatiens x hybrid*), Luscious Citrus Blend™ lantana (*Lantana camara* L.), and Senorita Rosalita® cleome (*Cleome x hybrid*) had the highest decomposition compared to other biodegradable containers (Sun et al., 2015). Both studies concluded that container material is a major factor contributing to pot decomposition, plant establishment, and post-transplant plant growth. However, there is limited information regarding the effect of cultural factors on biodegradable container decomposition.

To further increase green industry sustainability and adoption of biodegradable containers, a better understanding of the impact of cultural practices on biodegradable container degradation in the landscape is indicated. Previous studies have assessed biodegradable container decomposition post-planting (Karcher and Evans, 2004; Evans et al., 2010; Sun et al., 2015). However, our study seeks to eliminate the complicating factor of the plant itself which produces root acids and exudates that may influence container decomposition (Haas, 1916.; Six et al., 2004). The goal of this research is to examine various types of biodegradable containers and their decomposition under different cultural and environmental factors. We will examine degradation of three biodegradable container types over a 10-month period in fertilized or non-fertilized soil.

We will also assess degradation of three biodegradable container types over a 6-month period under various fertilizer levels, irrigation amounts, and presence or absence of organic soil amendment. The ultimate goal of these analyses was to determine the importance of the interactions between the main effects because significant interactions indicate that maximum container loss (%) is best achieved by specific combinations of the effects.

Materials and Methods

Two separate studies were conducted: October 2015 to July 2016 (10 month duration) and May 2017 to October 2017 (6 month duration).

2015-2016 Study: October to July

A field study to assess biodegradable container decomposition was conducted at two locations at the University of Georgia Griffin Campus: Dempsey Farm, 33°15’39”N 84°17’20”W, USDA Hardiness zone 7b, Spalding Co., GA; soil series: Lloyd; sandy clay, and Bledsoe Farm, 33°10’14”N 84°24’30”W, USDA Hardiness zone 7b, Pike Co., GA; soil series: Cecil-Davidson-Appling; sandy clay. Over the period of October 2015 to July 2016, the total rainfall amounts were 144.3 cm and 135.0 cm for Dempsey and Bledsoe locations, respectively. Soil preparation for both locations is discussed below.

Experimental Design, Plot Layout, and Treatment Application

Field plots (2 plots, 83.6 m^2 each at distance of 7.62 meters apart) were established in native soil in a Randomized Complete Block Design with five blocks (5.57 m^2 each) per container type treatment (Fig. 2.1.; container types designated in red = coconut coir, blue = wood pulp, and yellow = cow manure). One field plot received nitrogen fertilizer (designated as “Fertilized” or “F”, 10N-$10P_2O_5$-$10K_2O$, Pennington Seed, Inc., Madison, GA): 1 lb per 9.29 square meters applied to entire plot at first month of study (October 2015). Nitrogen fertilizer treatment was applied utilizing a drop spreader (Scotts® Turf Builder Classic Spreader, Scotts Miracle Gro Company, Marysville, OH) and rototilled to a depth of 15.2 cm. The second field plot was not amended with nitrogen fertilizer and served as the control (designated as "Non- Fertilized" or "NF").

Design and Placement of Mesh Litter Bags and Measurements

Litter bags were designed from mesh fiberglass screen (Phifer Incorporated, Tuscaloosa, AL, 15.25 cm x 25.4 cm, 0.02 cm mesh diameter; Fig. 2.2). The litter bags were filled with one of types of biodegradable containers: cow manure (Cowpot Square #4, Freund's Farm, East Canaan, CT), wood pulp fiber (Fertilpot FP 513, Fertil International, Boulogne-Billancourt, France), and coconut coir (Greenhouse Megastore Inc., Los Angeles, CA). In the field, the litter bags were spaced at 35 cm apart and buried at 10 cm depth. Within each block, every container type was represented and there were 10 replicates (one for each month of the study; Fig. 2.1.). There were a total of 300 litter bags per farm location [2 fertilizer treatments x 3 container types x 5 blocks x 10 months].

Biodegradable Container Data

To assess amount of container decomposition two parameters were examined: container weight difference (initial container weight and container weight after ten months) and container C:N amount and ratio (assessed at ten months). Container weight was measured in grams after drying for 48 hours at 65°C in a convection oven (ThermoFisher, Inc., Precision Compact Gravity Convection Oven, Model 3510, Waltham, MA). Container weight was assessed using the formula: container weight loss = $Weight_{Initial} - Weight_{Dry}$; %container weight loss =container weight loss/ $Weight_{Initial}$ to determine decomposition. Carbon : nitrogen content and ratio was assessed for each container type pre- post-experiment; analysis was performed by the University of Georgia

Agricultural and Environmental Services Laboratory (Clarke Co., GA) (not subjected to statistical analysis).

Statistical Analysis

Container loss (%) data were analyzed using the General Linear Model (GLM) Procedure (SAS Institute, 2016). Each farm location was analyzed separately. Means were separated using Tukey's Honestly Significant Difference Test. The main effects of container type and fertilizer were analyzed as well as the interaction effects between these variables.

2017 Study: May to October

A field study was conducted in 2017 to assess the effect of fertilizer level, irrigation amount, and soil amendment on decomposition of plantable biodegradable containers. This study was conducted at the University of Georgia Research and Education Garden (33°24'67"N 84°26'40"W, USDA Hardiness zone 7b, Spalding Co., GA, soil series: Lloyd; clay loam). Over the period of May to October 2017, the total rainfall amount at this location was 62.4 cm. Soil preparation is discussed below.

Experimental Design, Plot Layout, and Treatment Applications

Field plots (2 plots, 232.3 m^2 each, at distance of 22.8 meters apart) were established in native soil in a Split-Strip Plot Design (Fig. 2.3.). The fertilization treatments were applied as follows. Field plots received fertilizer ($10N$-$10P_2O_5$-$10K_2O$, Pennington Seed, Inc., Madison, GA): 1 lb per 9.29 square meters was applied to entire plot at transplant. Fertilizer was applied utilizing drop spreader (Scotts® Turf Builder Classic Spreader, Scotts Miracle Gro Company, Marysville, OH) and rototilled at depth of 15.2 cm. Vertical strip plots (116.1 m^2 each) within each larger plot (232.3 m^2) received 1 lb. fertilizer per 9.29 square meters at transplant only (designated as "LOW" or "LF") or 1 lb fertilizer per 9.29 square meters at transplant and additional 0.02 lb slow release fertilizer (12N-4P_2O_5-8K_2O, Miracle Gro Shake n' Feed Slow Release Fertilizer, Scotts Miracle-Gro Company, Marysville, OH) applied to buried litter bags at four and eight week post-transplant (designated as "HIGH" or "HF"; Fig. 2.3.).

The vertical strips (2 strips per 232.3m^2 research plot, 116.1 m^2 each) were split into four subplots (58.0 m^2 each) in which two subplots were amended with pine bark (Pine Bark Humus, Nature's Choice Inc., Glennville, GA) at a rate of 7.62 cm per 9.29 square meters at depth of 15.2 cm utilizing tine tiller (designated as "Amended" or "AM"; Fig. 2.3.). Two subplots (58.0 m^2) did not receive pine bark amendment treatment (designated as "Unamended" or "UN"). Low and high fertilizer treatments and pine bark application were selected according to standard recommendations for summer annuals (Chappell and Pennisi, 2006).

Irrigation Application and Amount

Water was supplied with overhead sprinklers was in place (Fig. 2.3.). Irrigation treatments were 2.54 cm water/per week (66.0 cm for 26 weeks, designated as "Low Irrigation" or "LI") or 3.81 cm water/per week (99.1 cm for 26 weeks, designated as "High Irrigation" or "HI"). Irrigation treatments were selected based on general recommendations of 2.54 cm water /per week for summer annuals (Henson et al., 2006; Zlesak et al., 2014).

Design and Placement of Mesh Litter Bags

Organza bags (12.7 cm x 17.8 cm, 0.01 cm mesh diameter, Uline, Inc., Pleasant Prairie, WI) served as mesh litter bags (Fig. 2.4.). The litter bags were filled with one of the following biodegradable containers types: recycled paper sleeve (Ellepot A/S, Storstrømsvej, Denmark), wood pulp fiber (Fertilpot FP 513, Fertil International, Boulogne-Billancourt, France), and coconut coir (Greenhouse Megastore Inc., Los Angeles, CA). Each amendment treatment subplot within each fertilizer vertical strip plot contained twelve litter bags per container type treatment (3 container types x 2 samples x 6 months =36 litter bags (Fig. 2.3.). There were a total of 144 litter bags per field plot.

Biodegradable Container Data

To assess amount of container decomposition two parameters were examined: container weight difference (initial container weight and container weight after six months) and container C:N amount and ratio (assessed at six months) as follows. Container weight was measured in grams after drying for 48 hours at 65°C in a convection oven (ThermoFisher, Inc., Precision Compact Gravity Convection Oven, Model 3510, Waltham, MA). container weight loss = $Weight_{Initial} - Weight_{Dry}$; %container weight loss =container weight loss/ $Weight_{Initial}$ to determine decomposition. Carbon:nitrogen content and ratio was assessed pre- and post-experiment (University of Georgia Agricultural and Environmental Services Laboratory, Clarke Co., GA) (not subjected to statistical analysis).

Average monthly rainfall data was also collected using the University of Georgia Weather Network (http://www.georgiaweather.net). Soil temperature (°C) and soil moisture (% volumetric water content) using the Hanna Instrument 99121 temperature probe (Hanna Instruments, Woonsocket, RI) and time domain reflectometer probe (FieldScout® TDR 300 Soil Moisture Meter, Spectrum Technologies, Bridgend, United Kingdom, 10.2 cm prongs) was also assessed monthly from July to October 2017 (8 sample measurements per month).

Statistical Analysis

The experimental design was a Split-Strip-Plot. Irrigation was the main plot, fertilizer and soil amendment were strip plot factors and inoculation was the sub-sub-plot factor. Container loss (%) was analyzed using PROC MIXED (SAS Institute, 2016). The model included all main effects and two way interactions. Replication was a random effect. Differences in Least Square Means were determined by pair-wise t-tests.

Results

2015-2016 Study, October to July: Assessment of Container Decomposition of Containers Made From Processed Cow Manure, Wood Pulp Fiber, and Coconut Coir

At each location, processed cow manure (Cowpot™) and wood pulp fiber containers had greater container loss as compared to coconut coir containers at the end of the ten-month cycle. The presence or absence of fertilizer in the soil did not consistently affect container loss at Bledsoe or Dempsey farm locations (Table 2.1., refer to App., Table 2.5.). The interaction effects between container type x fertilizer treatment at Bledsoe and Dempsey locations did not indicate that fertilizer significantly impacted container decomposition (container loss %) (Table 2.1.).

2015-2016 Study, October to July: Percentage of Carbon Remaining in Processed Cow Manure, Wood Pulp Fiber, and Coconut Coir Containers at Ten Months in two farm locations

When the study started, processed cow manure containers had 46.5% carbon content. For, processed cow manure containers, lowest carbon (%) was observed under fertilized treatment at the Bledsoe (38.0%) and Dempsey (33.7%) farm locations (Table 2.2.). Wood pulp fiber (Fertilpot) containers had 50.4% carbon at pre-experiment. At the Bledsoe farm location, wood pulp fiber pots that were buried in presence of fertilizer had lower carbon remaining (46.1%) in the container as compared to unfertilized treatment (47.2%). However, at the Dempsey farm location, wood pulp fiber containers under the fertilizer treatment had higher carbon remaining (47.0%) in the container than when there was absence of fertilizer (46.3%). The initial carbon content of the coconut coir container was 49.9%. After ten months at the Bledsoe farm location, containers receiving the fertilized treatment had higher carbon remaining (49.7%) as compared with non-fertilized treatments (47.7%). Coconut coir containers under the presence of fertilizer had lowest carbon remaining in the container (43.7%) at the Dempsey farm location (Table 2.2.).

<u>2017 Study, May to October: Assessment of Container Weight Loss (%) of Containers Made From Recycled Paper, Wood Pulp Fiber, and Coconut Coir</u>

The interaction effect of container type and irrigation level significantly influenced decomposition with recycled paper sleeve containers receiving low and high irrigation levels having greater degradation compared to other two container types under the two irrigation levels (Table 2.3.). Container decomposition (% container loss) was significantly influenced by biodegradable container type over the six-month period from May to October 2017. Recycled paper sleeve (Ellepot®) containers had the highest container loss when compared to wood pulp fiber and coconut coir containers (Table 2.3.). Likewise, fertilizer treatment also influenced container loss with biodegradable containers receiving low fertilizer (LF) treatment having higher container loss %. Irrigation and organic soil amendment treatments did not significantly influence biodegradable container loss (Table 2.3., refer to App., Table 2.6.). Container type x fertilizer treatment, container type x soil amendment treatment, fertilizer treatment x soil amendment treatment, fertilizer treatment x irrigation level, and soil amendment treatment x irrigation level interactions did not significantly impact biodegradable container loss (Table 2.3., refer to App., Table 2.6.).

<u>2017 Study, May to October: Percentage of Carbon Remaining in Recycled Paper, Wood Pulp Fiber, and Coconut Coir Containers at Six Months</u>

Although not statistically-analyzed, recycled paper sleeve containers pre-experiment contained 49.8% carbon content. At six months, recycled paper (Ellepot®) containers under low irrigation level x high fertilizer treatment x soil amendment treatment (19.0%), high irrigation level x low fertilizer treatment x soil amendment treatment (21.5%), and high irrigation level x low fertilizer treatment x unamended treatment (24.0%) had lowest amount of carbon remaining in the container (Table 2.4.). For wood pulp fiber containers, the pre-experiment container carbon content was 51.2%. Wood pulp fiber pots placed under low irrigation level x low fertilizer treatment x unamended (35.7%) treatment, high irrigation level x low fertilizer treatment x soil amendment treatment (40.2%), and high irrigation level x high fertilizer treatment x soil amendment treatment (43.0%) had the lowest carbon remaining (Table 2.4.). At pre-experiment, coconut coir containers had 53.3% carbon content. However, at six- month sampling, coconut coir containers had the lowest carbon when placed under low irrigation level x low fertilizer treatment x and unamended treatment (49.0)%; Table 2.4.).

Recycled Paper Sleeve, Wood Pulp Fiber, and Coconut Coir Container Loss (%) over Six-Month Period

Irrigation received for each month from month 1-6 was 25.4 cm (Fig. 2.5.). For recycled paper containers, the largest container decomposition (container loss %) was observed in July (43.7) when average rainfall was also greatest (Fig. 2.5.).

Discussion

The current study is one of the first to explore the effects of cultural practices such as fertilizer, organic soil amendment, and irrigation on loss of plantable biodegradable containers in the landscape. We observed a significant interaction effect between irrigation and container type with recycled paper sleeves under low and high irrigation exhibiting greater container loss as compared to other containers under the two irrigation levels. These findings are consistent with previously published research that decomposition and container loss is dependent on the type of material that the container is composed of. Processed cow manure containers exhibited the highest loss compared to wood pulp and coconut coir containers in two farm locations (2015-2016, 10-month study). Paper sleeve containers showed highest container loss compared to wood pulp and coconut coir pots (2017, 6-month study). Findings were substantiated by percentage container decomposition and carbon content remaining in container material post ten-months and six-months, respectively.

Previous studies have reported the influence of container type on the biodegradation of plantable pots suggesting containers high in cellulose (e.g. processed manure) had higher decomposition/loss than those composed of cellulose and lignin (e.g. coconut fiber and wood pulp) (Evans and Karcher, 2004; McCabe et al., 2014; Nambuthiri et al., 2015; Sun et al., 2015). Although composed primarily of cellulose, the paper sleeve container used in our study had substantially less bulk weight as compared to all other container types, so it is not surprising that it decomposed the most.

Our study is unique in that container loss was evaluated without the confounding effect of a plant and it was also performed over longer periods of time (6 months and 10 months). In previous studies the research protocol differed from ours in that plants were transplanted into the biodegradable container at the time of planting in the field and the study lasted only three to four months during summer (Evans and Karcher, 2004; Sun et al., 2015). It is logical to assume that the plant itself affected container decomposition, accelerating the degradation process.

Contrary to expected, we found that higher fertilizer rate did not result in higher decomposition, in fact, container loss (%) was higher under the lower fertilizer rate (2017 study) but only by 4.8% and in practical terms, this may not be of importance. Previous studies (Hobbie, 2000; Knorr et al., 2005; Talbot and Treseder, 2012) have suggested that nitrogen fertilization could increase decomposition of low-lignin plant litter and decrease decomposition of high-lignin plant litter. The 4.8% container loss represents statistically significant main effect averaged for all biodegradable container types used in the current study. Since the interaction effects were not significant, we could not determine whether low-lignin (cow manure) vs. high-lignin (wood pulp and coconut coir) material behaved differently under the two fertilizer treatments.

Incorporation of organic amendment is a standard practice in annual landscape beds (Jackson et al., 2009; Taylor et al., 2012) and consequently we sought to explore its effect on container decomposition. Bark amendment application did not significantly affect container loss (2017 study) for any container types. In addition, although not subjected to statistical analysis, carbon : nitrogen analysis revealed that containers high in cellulose and lignin (e.g. wood pulp and coconut coir) had least carbon remaining in container material in absence of bark (Table 4). Similar results were observed under controlled laboratory conditions in which wood pulp fiber and coconut coir containers in absence of bark had the lowest carbon content remaining in the container material post six months (Harris et al., unpublished). In absence of bark amendment, the soil microorganisms may be utilizing the biodegradable container material as major carbon energy source. It is logical, therefore, to assume that in the presence of additional organic matter, soil microorganisms would have higher total soil carbon to humify and mineralize (Brussaard, 1994; Janzen et al., 1998).

Another important factor in degradation of organic matter is soil moisture, which is comprised of natural rainfall and any supplemental irrigation. In our 2017 study, the supplemental irrigation did not have a significant impact on container loss (%). However, for recycled paper pots, there was lower amount of carbon remaining in container material post six-months under low irrigation (Table 2.4.). Under controlled laboratory conditions, recycled paper containers had less carbon remaining under 60% water content (Harris et al., unpublished, refer to Chapter 3). Differences in carbon loss of recycled paper containers under field and controlled conditions, may be directly linked to other soil and environmental factors such as soil temperature and microbial activity (Davidson and Janssens, 2006; Nambuthiri et al., 2015).

To examine the results in more depth and attempt to explain degradation in relation to soil moisture and temperature, we plotted container decomposition, amount of natural rainfall, and supplemental irrigation (Fig. 2.4.). During the 2017 study, recycled paper containers had highest decomposition in July which correlated with highest total volumetric water content (27.9 %) and soil temperature (28.6°C) (Refer to App., Table 2.7.). Previous research has established soil moisture as a major environmental player in organic matter decomposition and respiration responses in the soil (Skopp et al., 1990; Gabriel and Kellman, 2006). Moreover, water content in the soil can influence microbial activity and solute and oxygen diffusion which in turn can affect the rate and amount of decomposition as well as the survival and diversity of microorganisms present (Davidson and Janssens, 2006 Research has shown that by maintaining favorable soil moisture and temperature levels, maximum solubilization of organic matter can occur (Moyano et al., 2013; Sierra et al., 2017); therefore, it could be argued that the same processes would apply to any organic matter including biodegradable containers.

Results of this study underscore that landscape professionals should consider the different types of plantable containers and the differences in their degradation rates. Clearly, cellulose (i.e. processed cow manure) types of containers as well as those of low bulk weight (i.e. recycled paper sleeve) had largest loss at the end of an annual color rotation. We established that even without the compounding effect of plant roots (i.e. plant in biodegradable pot in the soil), there were differences among container loss of various plantable containers. Our study taken with the previous research which utilized the plant component suggests that container biodegradation is primarily dependent on the container material and container bulk weight. Sun et al. (2015) established that after four months under landscape conditions, decomposition was highest in cow manure (88%) pots followed by straw (47%), wood fiber (46%), soil wrap (42%), peat (38%), coir (25%), and rice (18%) containers. While container loss was lower in our study [recycled paper sleeve (33%), cow manure (21%), wood pulp fiber (17%), and coconut coir (12%)], plant-filled and installed containers that are high in cellulose (cow manure) or have low bulk weight (recycled paper sleeve) should undergo sufficient degradation during a six-month growing season. Our results suggest that the commonly expressed concern by landscape professionals, namely incomplete container degradation for certain biodegradable container types was not substantiated by our research. Moreover, standard cultural practices such as organic matter incorporation, fertilizer, and irrigation do not significantly affect container decomposition.

In summary, our study as well as post-production studies have affirmed that certain biodegradable container types could be successfully used during plant production and installation without impeding post-production plant performance. This underscores the need for augmented outreach to communicate the body of research regarding not only biodegradable container decomposition, but also how it is affected by cultural practices. Research assessing growth of annual and perennial ornamentals and vegetables produced in biodegradable containers have attested to superior plant performance and limited concerns during production (Kuehny et al., 2011; Lopez and Camberato, 2011; Beeks and Evans, 2013a, Nambuthiri and Ingram, 2014). The horticulture industry should explore the wider adoption of plantable biodegradable containers to eliminate plastic waste and disposal, to increase landscape installation efficiency, and to improve sustainable efforts.

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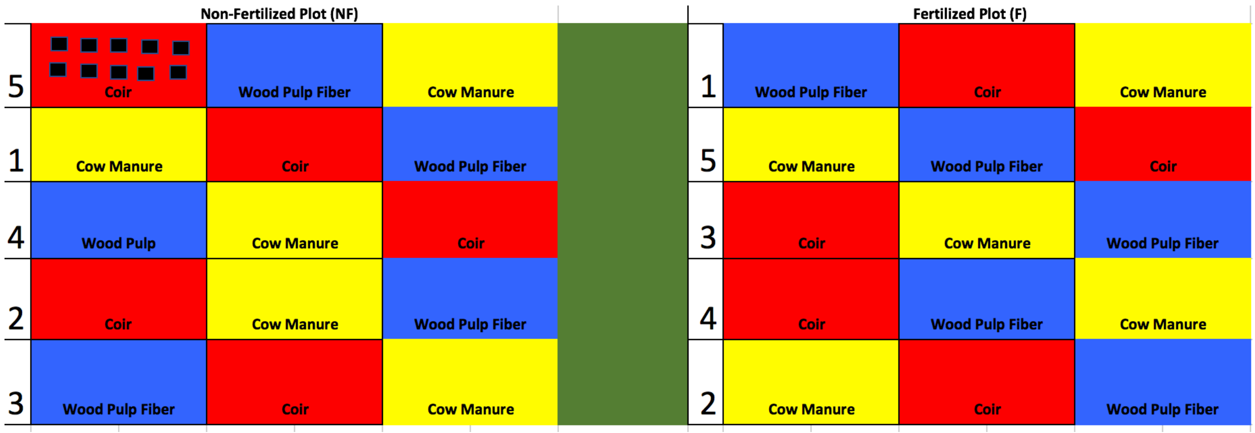


Figure 2.1. Experimental design field plot layout and treatment (container types designated as red=coconut coir, blue= wood pulp, and yellow=cow manure). Numbers designate blocks and black boxes indicate 10 replicate litter bags (1 litter bag removed monthly for each block).

Figure 2.2. Mesh litter bag with aluminum label containing biodegradable container (15.25 cm x 25.4 cm, 0.02 cm mesh diameter)

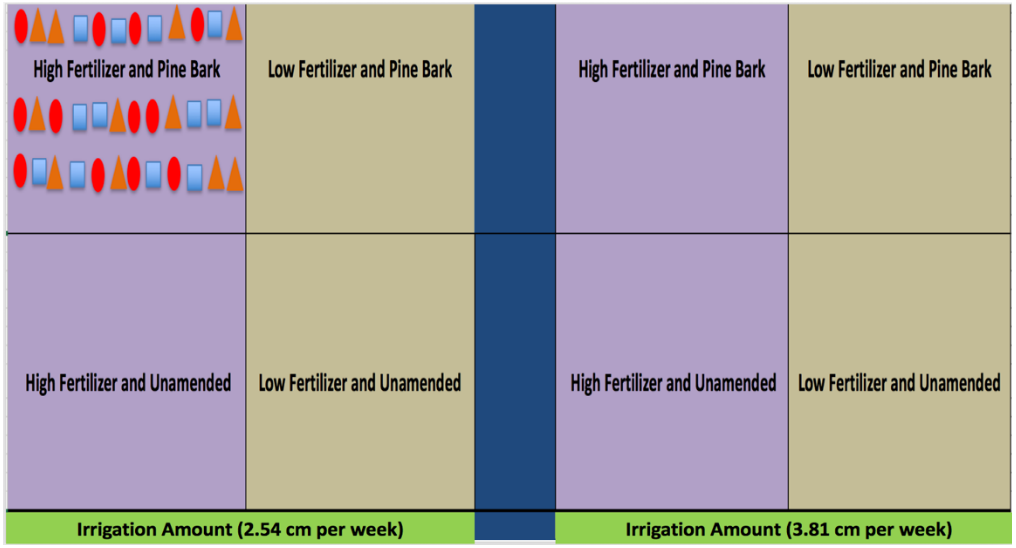


Figure 2.3. Field plots (232.3 m^2) with each irrigation treatment (Hunter Industries Controller with MP Rotator heads on risers, San Marcos, CA, USA) in Split-Strip Plot Design with vertical fertilizer strip (116.1 m^2 each) treatments and soil amendment subplots (58.0 m^2 each).

Figure 2.4. Organza mesh litter bag containing biodegradable container (12.7 cm x 17.8 cm, 0.01 cm mesh diameter).

Table 2.1. Container loss (%) as affected by container type and fertilizer treatment at two farm locations over ten months from 2015 to 2016. Abbreviations: Processed Cow Manure =PCM; Wood Pulp Fiber =WPF; Coconut Coir =CC.

Treatment	**p-value**	**Container Loss (%) (Bledsoe Farm)**		
Container Type		**PCM**	**WPF**	**CC**
	<.0001***	20.9a (0.03)[X]	17.4a[Y] (0.04)	11.8b (0.05)
Fertilizer	0.84	N.S.		
Fertilizer*Container Type	0.20	N.S.		
Treatment	**p-value**	**Container Loss (%) (Dempsey Farm)**		
Container Type		**PCM**	**WPF**	**CC**
	0.04*	17.0a (0.03)	14.8ab (0.05)	12.0b (0.04)
Fertilizer	0.33	N.S.		
Fertilizer*Container Type	0.10	N.S.		

N.S., *, **, *** indicates No statistical significance, significance at the P<0.05 level, P<0.01 level, or P<0.001 level, respectively.

[X]Values are averages of ten replicates with standard error in parentheses.

[Y]Values followed by the same lowercase letter are not significantly different at P<0.05.

Table 2.2. Percentage of Carbon (C) in processed cow manure (Cowpot^{TM}), wood pulp fiber (Fertilpot), and coconut coir container remaining post-experiment at ten months under fertilizer treatments at Bledsoe and Dempsey Farms from 2015 to 2016. Abbreviations: Processed Cow Manure=PCM; Wood Pulp Fiber=WPF; Coconut Coir =CC; Fertilized=F; Non-Fertilized=NF.

Container Types	**Fertilizer Treatments**	**Bledsoe Location**	**Dempsey Location**
PCM	F	38.0[a]	33.7
PCM	NF	42.5	39.1
WPF	F	46.1	47.0
WPF	NF	47.2	46.3
CC	F	49.7	43.7
CC	NF	47.7	48.9

Initial carbon content for PCM (46.5%), WPF (50.4%), and CC (49.9%).

[a]Values represent means pooled from five replicates.

Table 2.3. Container loss (%) as affected by container type, irrigation level, soil amendment treatment, and fertilizer treatment over six months in 2017. Abbreviations: Recycled Paper Sleeve=RPS; Processed Cow Manure=PCM; Wood Pulp Fiber =WPF; Coconut Coir =CC; LF=Low Fertilizer; HF=High Fertilizer; LI=Low Irrigation; HI=High Irrigation.

Treatment	p-value	Container Loss (%)					
Container Type	<.0001***	**RPS**			**WPF**		**CC**
		33.1a[Y] (0.07)			12.3b (0.06)[X]		7.80c (0.07)
Irrigation	0.64	N.S.					
Amendment	0.65	N.S.					
Fertilizer	0.01**	**LF**			**HF**		
		17.4a (0.06)			12.6b (0.06)		
Irrigation*Fertilizer	0.29	N.S.					
Irrigation* Amendment	0.28	N.S.					
Irrigation* Container Type	0.01**	**LI*RPS**	**LI*WPF**	**LI*CC**	**HI*RPS**	**HI*WPF**	**HI*CC**
		37.2a (0.10)	10.2b (0.09)	10bc (0.10)	28.8a (0.10)	15.1b (0.10)	5.90c (0.09)
Fertilizer*Amendment	0.79	N.S.					
Fertilizer* Container Type	0.78	N.S.					
Amendment* Container Type	0.18	N.S.					

N.S., *, **, *** indicates No statistical significance, significance at the P<0.05 level, P<0.01 level, or P<0.001 level, respectively.

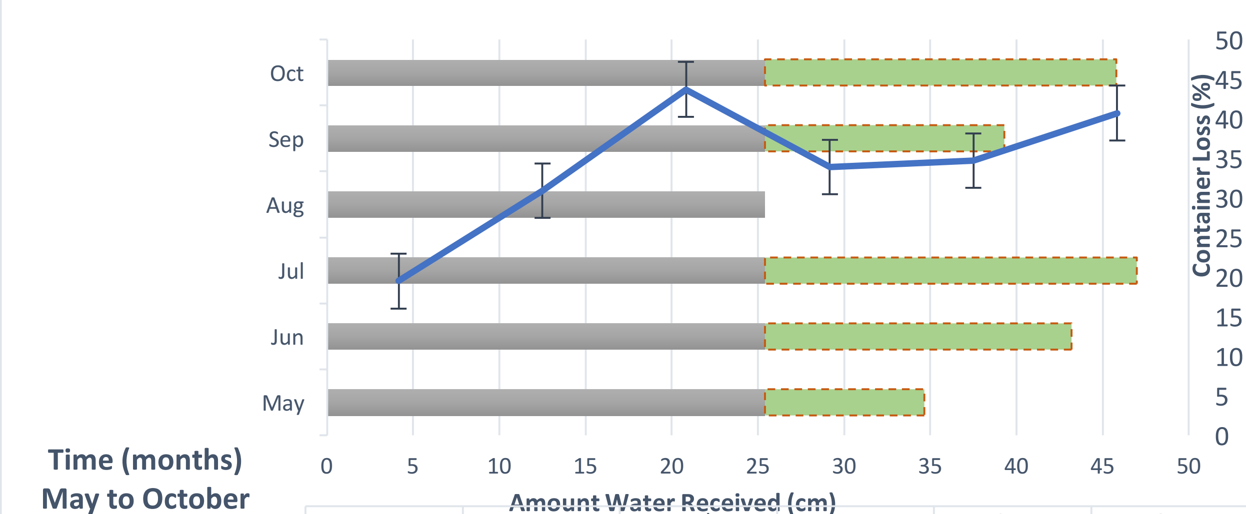
[X]Values are averages of six samples with standard error in parentheses.

[Y]Values followed by the same lowercase letter are not significantly different at P<0.05.

Table 2.4. Percentage of Carbon (C) in recycled paper sleeve (Ellepot®), wood pulp fiber (Fertilpot), and coconut coir container pre-experiment and remaining post-experiment under fertilizer, amendment, and irrigation treatments. Abbreviation: Table Key: Low Irrigation=LI; High Irrigation=HI; Low Fertilizer=LF; High Fertilizer=HF; No Soil Amendment=UN; Soil Amendment=AM; Recycled Paper Sleeve =RPS; Wood Pulp Fiber =WPF; Coconut Coir =CC.

Treatment	
Recycled Paper Sleeve Container	**% Carbon**
Pre-Experiment	49.8[a]
RPS-LI-LF-AM	27.5
RPS-LI-LF-UN	45.5
RPS-HI-LF-AM	21.5
RPS-HI-LF-UN	24.0
RPS-LI-HF-AM	19.0
RPS-LI-HF-UN	34.7
RPS-HI-HF-AM	27.7
RPS-HI-HF-UN	38.2
Wood Pulp Fiber Container	
Pre-Experiment	51.2
WPF-LI-LF-AM	48.2
WPF-LI-LF-UN	35.7
WPF-HI-LF-AM	40.2
WPF-HI-LF-UN	44.7
WPF-LI-HF-AM	50.9
WPF-LI-HF-UN	49.2
WPF-HI-HF-AM	43.0
WPF-HI-HF-UN	47.8
Coconut Coir Container	
Pre-Experiment	53.3
CC-LI-LF-AM	51.4
CC-LI-LF-UN	49.0
CC-HI-LF-AM	51.0
CC-HI-LF-UN	50.3
CC-LI-HF-AM	52.2
CC-LI-HF-UN	51.5
CC-HI-HF-AM	51.1
CC-HI-HF-UN	51.1

[a]Values represent means pooled from five samples.



	May	Jun	Jul	Aug	Sep	Oct
Supplemental Irrigation	25.4	25.4	25.4	25.4	25.4	25.4
Rainfall	9.27	17.8	21.6	0	13.9	20.4
RPS	19.5	30.9	43.7	33.9	34.7	40.7

Figure 2.5. Average monthly rainfall and supplemental irrigation and mean (± S.E.) container loss (%) of recycled paper (Ellepot®, RPS) from months 1 through 6 in 2017. Means presented are pooled from all irrigation, fertilizer, and soil amendment treatments.

CHAPTER 3

CONTROLLED ENVIRONMENT EVALUATION OF EFFECT OF NITROGEN, PINE BARK AMENDMENT, AND WATER CONTENT ON BIOCONTAINER DECOMPOSITION

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ABSTRACT

Biodegradable containers have become of increasing interest in plant production and installation due to the potential of eliminating plastic waste, accelerate plant installation, and limit transplant shock. However, biodegradable container adoption by the landscape industry has been slow and could be attributed to incomplete decomposition, particularly in seasonal color rotations. Laboratory studies were conducted at the UGA Griffin Campus (Spalding Co., GA) to evaluate effect of container, nitrogen fertilizer, soil water content, and bark soil amendment on decomposition of three types of biodegradable containers: recycled paper, wood pulp fiber, and coconut coir over 182 days. Soil carbon dioxide respiration through standard titration (mg CO_2-C) was assessed to determine decomposition of biodegradable containers. To further investigate results and assess decomposition, percentage of carbon content remaining in the container material after 182 days was also quantified. For recycled paper and coconut coir pots, amending the soil with pine bark significantly increased soil respiration. However, amending the soil did not significantly influence soil respiration in wood pulp fiber container study. Post-experiment carbon : nitrogen analysis revealed less carbon remained in the recycled paper container under high fertilizer and unamended treatment. Similarly, less carbon remained in container material for wood pulp and coconut coir containers in the absence of pine bark amendment. Additionally, the low fertilizer rate significantly increased soil respiration for coconut coir container, with higher carbon dioxide released under low fertilizer. Wood pulp and recycled paper container decomposition, assessed through soil respiration was not significant, and carbon content remaining in all container types under low and high fertilizer treatments was variable. Relative to soil water content, recycled paper containers under 40% Water Holding Capacity (WHC) had higher carbon dioxide released. Carbon : nitrogen analysis showed less carbon remained for all container types under 60% WHC.

KEY WORDS Biodegradable Containers, Nitrogen Fertilizer, Soil Water Content, Soil Organic Amendment, Recycled Paper Container, Wood Pulp Fiber Container, Coconut Coir Container

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In ornamental plant production, petroleum-based plastic containers have been used for decades by the green industry. However, the large plastic waste volume produced, waste transport expenses, and potential for soil contamination and photo-degradation when plastics are exposed to extreme light have fostered increased interest in sustainable landscape practices (Hurley, 2008). Sustainable efforts in plant production and installation can be achieved through the use of plantable biodegradable containers in the landscape. Use of plantable containers by the green industry may be an effective way to reduce plastic waste as well as to minimize plastic removal and disposable costs and reduce installation clean-up time.

Biodegradable containers are produced from a variety of animal- and plant-based by-products including bioplastic, coir, poultry feathers, processed cow manure, paper fibers, and rice hull. These containers have the potential to serve as a replacement option to the standard plastic nursery container during production and installation (Evans et al., 2015). Biodegradable containers are either considered compostable or plantable. Plantable containers are highly porous and can be directly installed in landscape and decompose readily in the soil whereas compostable containers must be removed before planting and placed in a compost pile for degradation to occur (Mooney, 2009; Evans et al., 2010). When utilizing such containers, decomposition must remain slow to remain functional during withstand production, yet fast enough to prevent root circling and facilitate plant growth and establishment after the plant is transplanted with the container.

Several studies have indicated superior plant growth and performance of annual, perennial, ornamental, and vegetable plants when produced in these containers as well as at post-production after transplanting (Kuehny et al., 2011; Lopez and Camberato, 2011; Beeks and Evans, 2013; Sun et al., 2015). Although these reports regarding plant performance during production and installation are favorable, adoption of plantable biodegradable containers by the landscape industry has been slow (Chapter 5). This reluctance in the adoption of biodegradable containers by landscape professionals may be due to concerns regarding container decomposition (Harris and Kraft, pers. comm.; Harris and Mobley, pers. comm.). At planting, biocontainer remnants may remain in the soil and require manual removal, impacting labor and installation efficiency and costs in subsequent plantings. Practical matters such as this can impede use of biodegradable containers by landscape firms.

There have been limited studies that evaluated rate and amount of biodegradable container decomposition in the landscape. Evans and Karcher (2004) observed that feather containers decomposed more rapidly compared to peat containers when planted with annual vinca and marigolds. Additionally, they found that container decomposition was primarily impacted by container type and plant species. In a 2010 study, cow manure container decomposed more rapidly than peat, straw, or wood fiber containers with coir pots having the slowest decomposition when placed in the landscape (Evans et al., 2010). Sun et al. (2015) observed through his field trials in Illinois, Kentucky, Mississippi, Texas, and West Virginia, that manure containers planted with SunPatiens® Compact Magenta New Guinea impatiens (*Impatiens x hybrid*), Luscious Citrus Blend™ lantana (*Lantana camara* L.), and Senorita Rosalita® cleome (*Cleome x hybrid*) had greatest decomposition compared to other biodegradable containers types. According to these studies, container material and plant species influenced container decomposition, plant establishment, and post-production plant growth. However, more information is needed regarding biodegradable container decomposition under controlled settings.

Container decomposition rate is essential to this process and must occur rapid enough to prevent root obstruction, particularly in annual color beds which are changed two times per year (Evans and Hensley, 2004). Many factors can influence container decomposition including container material (thickness, density, and porosity), container carbon : nitrogen ratio (C:N); soil conditions such as nitrogen availability, organic matter content, moisture, temperature, pH, abundance and diversity of soil microorganisms, and other soil-related factors which may be attributed to the geographical region (Nambuthiri et al., 2015). Cultural practices such as irrigation amount, fertilization, and soil amendment application may also impact decomposition (Sun et al., 2015).

Decomposition of organic matter in the soil is biologically-driven; soil microorganisms such as bacteria, fungi, and actinomycetes are responsible for greater than 90% of total heterotrophic respiration (Berger and Foissner, 1987). Soil respiration occurs due to aerobic microbial decomposition of soil organic matter (SOM) to obtain energy, with concomitant release of carbon dioxide (Parkin et al., 1996; Moinet et al., 2018). Measurement of this carbon dioxide is a standard assessment of soil respiration (Hanson et al., 2000; Bond-Lamberty et al., 2018). The total decomposition of soil organic matter or organic material and degradation rate can be assessed by determining the ratio of carbon and nitrogen remaining in the organic source (Kuhry and Vitt, 1996). Previous studies have assessed decomposition of soil organic matter through residual carbon and nitrogen analysis (Liu et al., 2007; Hu et al., 2017).

Under field conditions, we studied degradation of different types of containers and effect of cultural practices with respect to irrigation, fertilizer, and soil amendment (refer to Chapter 2). No published information regarding biodegradable container decomposition under controlled environment exists. The objectives of the current study are three-fold: 1) assess decomposition (expressed in mg CO_2-C released and through carbon : nitrogen container material analysis) of three biodegradable container types; 2) evaluate container decomposition as influenced by soil amendment, fertilizer, and water content and their interactions. The ultimate goal of these analyses was to determine the importance of the interactions between the main effects because significant interactions indicate that maximum decomposition is best achieved by specific combinations of the effects.

Materials and Methods

Source of Soil

Native soil from University of Georgia Research and Education Garden (33°24’67”N 84°26’40”W, USDA Hardiness zone 7b, Spalding Co., GA, soil series: Lloyd; clay loam; Organic Matter=3.25%; %C=0.16%; %N=0.04) was extracted at a depth of 15.2 to 20.3 cm. At the time of soil extraction, the field had been left fallow for two years; vegetative cover consisted of predominately annual weeds and volunteer species.

Experimental Setup and Treatment Application

Three separate laboratory studies (each utilizing a different container type) were conducted. Field soil was sieved using a 2 mm sieve, weighed (100 grams), and placed in a glass container (1 liter) (Ball Corporation, Broomfield, CO) (Fig. 3.1.). In order to ensure uniform distribution of fertilizer, organic amendment, and container material throughout the 100 g soil sample, treatments were applied in the following order: fertilizer, amendment, container material, and water content.

To simulate cultural practices used in the field, the following fertilizer treatments were used: low fertilizer (“LF”) applied at experiment set-up and high fertilizer (“HF”) applied at six weeks and twelve weeks. Fertilizer source was 10N-10P_2O_5-10K_2O (Pennington Seed, Inc., Madison, GA). Below are details regarding calculation and application of fertilizer treatments.

The appropriate fertilizer concentration was determined:

Area of 1 liter Glass Jar= 7.07 in^2

Radius of 1 liter Glass Jar=1.5 in^2

Application rate of $10N\text{-}10P_2O_5\text{-}10K_2O$ Fertilizer in the Field: 1 lb/100 sq. feet

100 sq. feet=14,400 in^2

Application rate of $10N\text{-}10P_2O_5\text{-}10K_2O$ fertilizer in the Field: 1 lb/14,400 in^2

1 lb of fertilizer= 453.592 grams fertilizer

453.592 g fertilizer/ 14,400 in^2=0.0315 X 7.07 in^2 = 0.22 g $10N\text{-}10P_2O_5\text{-}10K_2O$ fertilizer per 1L glass jar

Therefore, fertilizer treatments consisted of a rate of 0.22 grams $10N\text{-}10P_2O_5\text{-}10K_2O$ fertilizer at experiment set-up ("LF") or 0.22 grams $10N\text{-}10P_2O_5\text{-}10K_2O$ fertilizer at experiment set-up and at six weeks and twelve weeks (total 0.66 grams; "HF").The fertilizer was manually mixed and thoroughly incorporated with the 100 g of soil. Fertilizer treatments were individually mixed in each soil sample prior to placement in the 1 liter glass jar.

To simulate cultural practice (i. e. organic amendment application), soil samples placed in the glass jars were amended with pine bark humus (Nature's Choice Inc., Glennville, GA) or unamended. The organic amendment was weighed using the compact bench scale and manually incorporated at a rate of 25% sample mass (25 grams) following protocol by Cely et al. (2014). Therefore, samples receiving pine bark ("AM") weighed 125 grams while unamended samples ("UN") weighed 100 grams at experiment setup. Similar to preparation of fertilizer treatments, the organic soil amendment was manually mixed and thoroughly incorporated with the 100 g of soil. Bark amendment treatment was individually mixed in each soil sample prior to placement in the 1 liter glass jar.

As previously mentioned, three separate studies were conducted and each evaluated a certain container type: recyclable paper sleeve (Ellepot®, Ellegard Components A/S, Viborg, Denmark), wood pulp fiber (Fertilpot, Fertil S.A.S, Boulogne-Billancourt, France), or coconut coir (Greenhouse Megastore, Danville, IL). The following describes the general procedure for container material preparation. A piece (7.62 cm x 2.54 cm) of the biodegradable container was laid on a cutting mat and manually shredded using a rotary blade cutter (Fiskars Titanium Rotary Cutter, 45 mm, Middleton, WI) into 1mm^2 pieces. A sample of shredded container pieces (120 mg) was weighed and placed into a plastic bag (1 liter, Ziploc® storage bags, SC Johnson, Racine, WI) with 100 g soil (with appropriate fertilizer, organic amendment, and water content treatments). Container material pieces were manually incorporated into the soil sample ("C"). Uniform dispersion of the shredded container material was achieved through continuous manual incorporation. Controls without any container material consisted of soil only ("NC") with appropriate fertilizer, pine bark amendment, and water content treatments.

For the chosen native soil, we determined that there was 71% Gravimetric Water Content (GWC) of the soil at field capacity (calculations described in detail below). Based on this, soil moisture treatments of 40% and 60% WHC were selected. Due to the moisture already present in the native field soil, additional water (mL) was added to achieve the designated soil water treatments in the following manner. Soil was air-dried for 72 hours at 25°C and 10 g was weighed (calculations described in detail below) in order to remove moisture and to achieve the 40% WHC treatment for the first study. Field-extracted soil (100 g) was placed in a wetting column and suspended under a drainage 1 L beaker (Fig. 3.2.) to bring the soil to field capacity. Deionized water was added to the soil wetting column (soil saturation) and freely drained over a 24-hour period until there was no water dripping into the drainage beaker (field capacity). A saturated soil sample (roughly 10 g) was weighed (calculations described in detail below). Wet and field capacity soil samples were placed in a convection oven (ThermoFisher, Inc., Precision Compact Gravity Convection Oven, Model 3510, Waltham, MA) and dried for 48 hours at 105°C (calculations described in detail below).

Below is an example of the soil water content assessment and calculations to achieve appropriate water content treatment performed according to Sower (1965). Identical calculations were performed before each of the three laboratory studies and moisture was added accordingly to achieve desired 40% or 60% WHC treatments.

Weight of Soil at Field Capacity: 10.07 g

Weight of Wet Soil: 10.05 g

Dry Weight of Soil at Field Capacity: 5.88 g

Dry Weight of Wet Soil: 7.82 g

Water Weight of Soil at Field Capacity: 10.07 g - 5.88 g = 4.19 g

Water Weight of Wet Soil: 10.05 g - 7.82 g = 2.23 g

% Gravimetric Water Content (GWC) at Field Capacity: 4.19 g / 5.88 g = 0.71 x 100=71% GWC at Field Capacity

% Gravimetric Water Content of Wet Soil: 2.23 g / 7.82 g = 0.28 x 100=28%

100 grams = Wet Soil

100 g of Wet Soil / 1.28 = 78 grams of soil in sample

100 g - 78 g = 22 ml water already present in Wet Soil

At Field Capacity, water content = 0.71 (% GWC at Field Capacity) X 78 (gram soil) = 55 ml water

At 60% WHC = 78 (gram soil) X 0.71 (% GWC at Field Capacity) = 55 ml water X .60 (60% WHC) = 33 ml

33ml water – 22 ml (already present in soil) = 11 ml that was added to achieve 60% WHC

At 40% WHC = 78 (gram soil) X 0.71 (% GWC at Field Capacity) = 55 ml water X .40 (40% WHC) = 22 ml

22 ml water – 22 ml (already present in soil) = 0 ml, no water added to achieve 40% WHC

Determination of Soil Respiration, Container Carbon : Nitrogen Analysis, and Experimental Layout

Soil respiration was assessed using standard protocols (Anderson, 1982). A carbon dioxide trap [30 mL open glass container (also referred to as alkali trap or simply trap)] containing 15 ml of 0.3 *N* $BaH_{18}O_{10}$ (Sigma-Aldrich, St. Louis, MO) is used to capture CO_2 emission from soil (CO_2 reaction = $C_6H_{12}O_6 + O_2 \rightarrow CO_2 + H_2O$ +ATP). Samples were titrated and details follow. The trap (inside a 10 mL plastic beaker used for support) was placed in the 1 L glass jars on soil surface and containers were sealed using Parafilm M Laboratory Film (10.2 cm x 76.2 m, Beamis Company, Inc., Neenah, WI). Five containers had CO_2 traps only (no soil) and served as controls to distinguish between CO_2 emission from soil versus CO_2 emission from air. Sealed jars were placed at 5 cm spacing on shelves (64.2 cm x 37.2 cm) in an incubation chamber (78.7 cm x 86.4 cm x 195.6 cm, Illuminated Incubator 818, Thermo Fischer Scientific, Inc., Waltham, MA) in a completely randomized design (CRD) with five replications per treatment combination (i.e. container, low fertilizer, soil amendment, 40% WC; total number of jars placed in the chamber in one study=85) (Fig. 3.3.). Temperature was set at 26°C and humidity was set at 50% in the environmental chambers.

The carbon dioxide traps were removed periodically following the timeline: date 4, 9, 16, 30, 45, 58, 88, 118, 148, and 182 days. Upon removal from the glass jar, traps were capped and transferred to laboratory for further analysis. Titration of samples was performed using an automatic titrator (Titroline® 6000/7000, SI Analytics, College Station, Texas). Unreacted alkali in the $BaH_{18}O_{10}$ traps was back-titrated with 0.3 *N* HCl to determine CO_2-C (Anderson, 1982). Mg CO_2-C was calculated using the following equation (Stotzky, 1965):

mg C as CO_2 = (B-V) x N x E

where;

B = ml standard acid for the blank

V = ml standard acid for the amended treatments

N = normality of the standard acid

E = equivalent weight of C (= 6)

Prior to processing samples and at each sampling date, pH buffer standards (pH 4, 7, and 10) were used to standardize the titrator following manufacturer recommendations (SI-Analytics TitroLine 6000/7000 Operating Manual).

New traps were placed inside, the glass jars were re-sealed, and placed back into the incubation chamber. Care was taken to ensure that jars were randomly distributed within the incubation chamber at each sampling date.

<u>Container C : N Analysis</u>

To further assess amount of container decomposition, carbon : nitrogen content and ratio was determined for each container type pre- and post-experiment as follows. At experiment termination, samples were processed through a 5 mm sieve to extract container material remnants and sent for analysis to the University of Georgia Agricultural and Environmental Services Laboratory (Clarke Co., GA) (not subjected to statistical analysis).

Statistical Analysis

Carbon dioxide respiration data was analyzed using PROC MIXED (SAS Institute, 2016). The model included all main effects and two way interactions. Replication was a random effect. Differences in Least Square Means were determined by pair-wise t-tests.

Results

Recycled Paper Container (RPS, Ellepot®): Assessment of Carbon Released

Significant interaction effect was found for container x amendment; samples with container x amendment had greater CO_2-C released (Table 3.1.). The interaction between amendment x water holding capacity was significant with higher CO_2-C levels in samples receiving amendment x 40% WHC (Table 3.1.). Container x fertilizer, fertilizer x amendment, and fertilizer x water holding capacity interactions were not significant. Over 182 days, the main effect of soil amendment significantly influenced amount of carbon released (i.e. soil respiration) with samples amended with pine bark having higher mg CO_2-C released as compared to the unamended treatments. The main effect of water holding capacity significantly affected amount of carbon released. With lower water holding capacity (40%WHC), samples had higher CO_2-C released when compared to those with 60% WHC (Table 3.1.). However, container and fertilizer main effects were not significant.

Recycled Paper Container (RPS, Ellepot®): Percentage of Carbon Remaining in Container Material and Controls (Soil Only)

Carbon content remaining in the recycled paper sleeve container was lowest after 182 days in the following sample treatments: 60% WHC x high fertilizer x unamended (5.22%), 60% WHC x low fertilizer x amended (6.01%), 60% WHC x low fertilizer x unamended (19.0%), and 40% WHC x high fertilizer x unamended (20.7%) (Table 3.2.). For the controls (soil only and no container), carbon content was lowest in samples receiving soil amendment 40% WHC x low fertilizer x amended (3.77%), 60% WHC x low fertilizer x amended (3.67%), 40% WHC x high fertilizer x amended (3.89%), and 60% WHC x high fertilizer x amended (3.60%) as compared to unamended treatments (Table 3.2.). Weight determination of container material remnants after 182 days was not attempted as the original 1 mm^2 pieces were too minute for practical extraction.

Soil Respiration over 182 days (6 Months) under Fertilizer, Amendment, and Water Content Treatments

For amended and unamended treatments, it appeared that amount of carbon released was comparable on day 5 through day 25. However, on day 50, 100, 142, 182, the amount of carbon released was higher in the pine bark amendment treatments (Fig. 3.4.). For the water holding capacity treatments, amount of carbon was similar on day 5, 25, and 50. However, on day 100, the 60% WHC treatment had higher carbon released whereas at day 142 and 182, the 40% WHC treatment had greatest amount of carbon released (Fig. 3.5.). Amount of carbon released was comparable for fertilizer treatments on day 5 through day 142. However, on day 182, the low fertilizer treatment had higher amount of CO_2-C released as compared to high fertilizer treatment (Refer to App., Fig. 3.6.).

Wood Pulp Fiber Container (WPF, Fertilpot): Assessment of Carbon Released

Over the 182 days, the main effect of container was significant (Table 3.3.). Soil samples containing wood pulp fiber container had higher mg CO_2-C released as compared to the control (soil only) with no container. However, the main effects of amendment, fertilizer, and water holding capacity (WHC) did not significantly impact amount of CO_2-C released over the 182-day period. Likewise, container x amendment, container x fertilizer, container x water holding capacity, fertilizer x amendment, fertilizer x water holding capacity, and amendment x water holding capacity interactions were not significant (Table 3.3.).

<u>Wood Pulp Fiber Container (WPF, Fertilpot): Percentage of Carbon Remaining in Container Material and Controls (Soil Only)</u>

The percentage of carbon remaining in the wood pulp fiber container after 182 days was lowest in 60% WHC x high fertilizer x unamended (16.3%) and 60% WHC x low fertilizer x amended (21.1%) (Table 3.4.). The majority treatments receiving bark amendment had higher percentage of carbon remaining in the container as compared to unamended treatments. Likewise, samples with 40% WHC had higher levels of carbon remaining in the container material when compared to those with 60% WHC (Table 3.4.). After 182 days, the controls (soil only and no container) had higher carbon from those receiving bark amendment (an organic carbon source): 40% WHC x low fertilizer x amended (5.28%), 60% WHC x low fertilizer x amended (5.82%), 40% WHC x high fertilizer x amended (5.88%), and 60% WHC x high fertilizer x amended (6.47%) as compared to unamended treatments (Table 3.4.). Weight determination of container material remnants after 182 days was not attempted as the original 1 mm^2 pieces were too minute for practical extraction.

Coconut Coir Container (CC): Assessment of Carbon Released

Significant interaction effects were found between container x fertilizer and container x amendment. Soil samples with coconut coir container x low fertilizer, coconut coir container x high fertilizer had greater CO_2-C released as compared to control treatments with low and high fertilizer (Table 3.5.). Coconut coir container x amendment and coconut coir x unamended had higher CO_2-C released as compared to controls which were unamended or amended with pine bark (Table 3.5.). Over 182 days, the main effect of container was significant (Table 3.5.) with samples with coconut coir container having higher mg CO_2-C released as compared to the control (soil only). However, the main effects of amendment, fertilizer, and water holding capacity (WHC) were not significant. Weight determination of container material remnants after 182 days was not attempted as the original 1 mm^2 pieces were too minute for practical extraction.

Coconut Coir Container (CC): Percentage of Carbon Remaining in Container Material and Controls (Soil Only)

After 182 days, coconut coir container with 60% WHC x low fertilizer x unamended (4.65%) and 40% WHC x low fertilizer x unamended (6.06%) had the lowest carbon remaining in the container (Table 3.6.). Similarly to the recycled paper (RPS, Ellepot®) and wood pulp container (WPF, Fertilpot), the percentage of carbon remaining in the coconut coir container after 182 days was also low in 60% WHC x high fertilizer x unamended treatments (5.83%) (Table 3.6.). All samples receiving amendment had greater percentage of carbon remaining in the container material as compared to unamended treatments. Additionally, samples with 40% WHC had higher levels of carbon remaining in the container material when compared to those with 60% WHC (Table 3.6.). After 182 days, the control (soil only) samples had greater carbon remaining in container material in those with bark amendment (an organic carbon source): 40% WHC x low fertilizer x amended (5.08%), NC x 60% WHC x low fertilizer x amended (5.82%), 40% WHC x high fertilizer x amended (5.35%), and 60% x high fertilizer x amended (4.85%) as compared to unamended treatments (Table 3.6.).

Discussion

The novel aspect of the current study is the assessment of various cultural and environmental factors on decomposition of plantable biodegradable containers under controlled conditions. In previously published research under field conditions, container type was shown to impact decomposition with containers high in cellulose (e.g. recycled paper) degrading more rapidly than those of cellulose and lignin (e.g. coconut fiber and wood pulp) (McCabe et al., 2014; Nambuthiri et al., 2015; Sun et al., 2015). Plant species produced in biodegradable containers has also been reported to impact container degradation (Evans and Karcher, 2004). To more accurately evaluate container decomposition, the current study was conducted under a controlled setting to minimize variable environmental factors (i.e. temperature, rainfall) that may impact container degradation.

Container x Organic Soil Amendment Interaction

Organic amendment application in annual landscape beds is a standard practice in preparation of planting annual color beds (Jackson et al., 2009; Taylor et al., 2012). Our research aimed to assess its impact on container decomposition. We found that for recycled paper and coconut coir containers, soil organic amendment significantly influenced soil respiration as evidenced by the greater amount of carbon dioxide released (Tables 3.1. and 3.5.). However, soil amendment did not significantly impact carbon released for wood pulp fiber containers. We further investigated decomposition by assessing percentage carbon content remaining in container material post 182 days (Table 3.2., 3.4., and 3.6.). Although not subjected to statistical analysis, lower carbon remained in recycled paper containers under high fertilizer and unamended treatments. For wood pulp fiber and coconut coir containers, unamended treatment had lower carbon remaining in container material as compared to those with soil amendment. Similar results were observed under field conditions in which wood pulp fiber and coconut coir containers in absence of bark had the lowest carbon content remaining in the container material post six months (Harris et al., unpublished, refer to Chapter 2). The soil microorganisms appear to be utilizing the container material as a carbon energy source when no soil amendment is present. Therefore, in the presence of additional organic matter (pine bark), soil microorganisms have a larger total soil carbon to humify and mineralize (Brussaard, 1994; Janzen et al., 1998) and are not utilizing the container material as their primary carbon source.

Container x Fertilizer Interaction

With respect to nutrition, we found that application of higher fertilizer rate did not result in concomitant higher soil respiration for lignin-rich coconut coir container. In fact, there was significantly higher amount of carbon released for coconut coir container under low fertilizer. Although not significant, similar result was observed for wood pulp fiber pots but not for high-cellulose recycled paper sleeve containers (refer to App., Tables 3.7. and 3.8.). Previous studies (Fog, 1988; Hobbie, 2000; Knorr et al., 2005) have suggested that nitrogen fertilization may increase decomposition of low-lignin plant litter and decrease decomposition of high-lignin plant litter. Consistent with our findings for high fertilizer rate, one research study found that nitrogen fertilization increased the N-acetyl glucosaminidase (NAG) enzymatic activity required for lignin degradation in the early stages of decay, however, additional nitrogen fertilization in the later stages of decomposition led to reduction in lignin loss (Talbot and Treseder, 2012). In our study, inconsistent results were found for all three container types with respect to percentage carbon remaining in container material (Tables 3.2., 3.4., and 3.6.).

Container x Water Content Interaction

Contrary to expected, for the recycled paper containers, we found that water holding capacity significantly affected soil respiration with samples under 40% WHC having higher carbon released. Although not statistically significant, we observed a similar result for coconut coir containers (refer to App., Table 3.9.). On the other hand, wood pulp fiber containers had higher carbon released under 60% WHC treatment (refer to App., Table 3.8.).

Through carbon : nitrogen analysis, we determined that less carbon remained in container material when all three container types were subjected to soil with 60% WHC. This is consistent with several studies that observed plant residues (containing lignin and cellulose) had increased degradation under higher soil moisture contents (Donnelly et al., 1990; Kumar and Goh, 1999; Tuomela et al., 2000; Thongjoo et al., 2005). Under field conditions, there was lower amount of carbon remaining in recycled paper container material post six-months under low irrigation (Harris et al., unpublished, refer to Chapter 2). However, under controlled laboratory conditions, recycled paper containers had less carbon remaining under 60% water content (Table 3.2.). Differences in carbon loss of recycled paper containers under field and controlled conditions, may be directly linked to other soil and environmental factors such as soil temperature and microbial activity (Devevre and Horwath, 2000; Nambuthiri et al., 2015).

Conclusions

Results in this research highlight the complexity of biocontainer decomposition. Even in a relatively simple system as the one presented here, general conclusions remain elusive. Container material (thickness, density, and porosity), container carbon : nitrogen ratio (C:N), soil nitrogen availability, organic matter content, soil moisture, soil temperature, and soil pH, availability and density of soil microorganisms, and other soil-related factors have the potential to impact degradation (Nambuthiri et al., 2015). In the landscape, irrigation amount, fertilization, and soil amendment application can also affect decomposition (Sun et al., 2015).

Under controlled conditions and for some biodegradable container types, we found that simulated cultural practices such as soil amendment and fertilizer application influenced container decomposition as determined by amount of carbon released and post-experiment container carbon content. We also observed that under soil moisture content of 60% WHC there was less carbon remaining in container material for all container types. Therefore, it appears that certain cultural practices (i.e. fertilizer application) can be used to enhance degradation for certain biodegradable container types. However, in order to provide specific recommendations for landscape professionals, additional field evaluations are needed (Harris et al., unpublished, refer to Chapter 2).

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Figure 3.1. One liter glass jar filled with 100 g field soil and labelled with appropriate treatment.

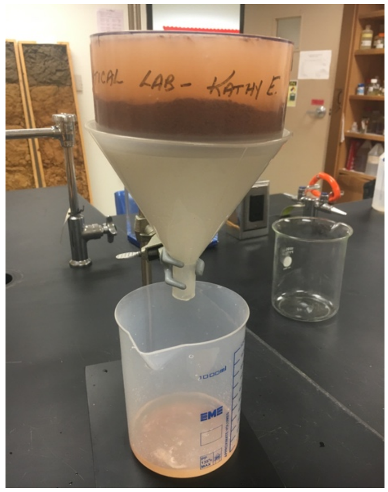


Figure 3.2. Field soil undergoing soil saturation and drainage using a wetting column to assess gravimetric water content of the soil at field capacity.

Figure 3.3. Soil incubation chamber filled with glass jars.

Table 3.1. Amount of carbon released (mg CO_2-C/100 g soil) over 182 days. Statistics for the main effects [recycled paper container (RPS, Ellepot®), fertilizer, organic amendment, and water holding capacity (WHC)] and their two-way interactions are shown. Abbreviations: C = With Container Material; NC = Soil Only (Without Container Material); 40% Water Holding Capacity= 40WHC; 60% Water Holding Capacity= 60WHC; Low Fertilizer = LF; High Fertilizer = HF; Unamended = UN; Soil Amendment = AM.

Main and Interaction Effects	**Statistics**	**Carbon Released (mg CO_2-C/100 g soil)**			
	P-value				
Container	0.51	N.S.			
Fertilizer	0.20	N.S.			
Amendment	<.0001***	**AM**		**UN**	
		7.65a[Y] (0.66)[X]		3.35b (0.65)	
Water Holding Capacity (WHC)	0.01*	**40WHC**		**60WHC**	
		6.67a (0.66)		4.33b (0.64)	
Container *Fertilizer	0.18	N.S.			
Container *Amendment	0.03*	**C*AM**	**NC*AM**	**C*UN**	**NC*UN**
		9.00a (0.93)	6.30ab (0.94)	2.62c (0.94)	4.08bc (0.93)
Container *WHC	0.08	N.S.			
Fertilizer*Amendment	0.77	N.S.			
Fertilizer*WHC	0.34	N.S.			
Amendment*WHC	0.05*	**AM*40WHC**	**AM*60WHC**	**UN*40WHC**	**UN*60WHC**
		9.73a (0.94)	5.56b (0.93)	3.60b (0.94)	3.10b (0.93)

N.S., *, **, *** indicates No statistical significance, significance at the P<0.05 level, P<0.01 level, or P<0.001 level, respectively.

[X]Values are averages of five replicates with standard error in parentheses.

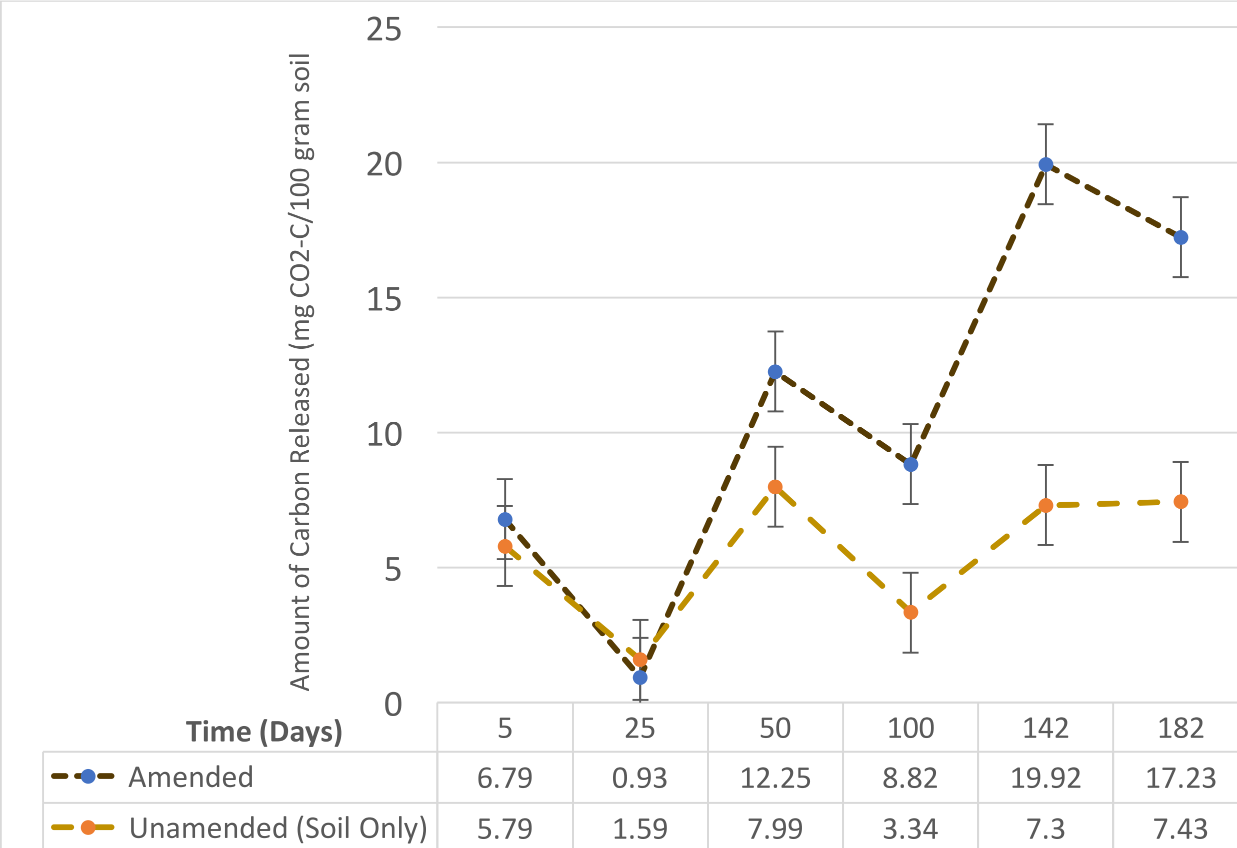
[Y]Values followed by the same lowercase letter are not significantly different at P<0.05.

Table 3.2. Percentage of carbon (C) remaining in recycled paper sleeve (RPS, Ellepot®) and in control samples (soil only) with fertilizer, amendment, and water holding capacity (WHC) treatments post-experiment (at 182 days). Abbreviations: 40% Water Holding Capacity= 40WHC; 60% Water Holding Capacity = 60WHC; Low Fertilizer = LF; High Fertilizer = HF; Unamended = UN; Soil Amendment = AM.

Treatment Combination	% Carbon Remaining in Container Material	% Carbon in Control (Soil Only)
40WHC-LF-AM	30.5[a]	3.8
40WHC-LF-UN	51.1	1.3
60WHC-LF-AM	6.0	3.7
60WHC-LF-UN	19.0	1.2
40WHC-HF-AM	42.2	3.9
40WHC-HF-UN	20.7	1.3
60WHC-HF-AM	31.6	3.6
60WHC-HF-UN	5.2	1.2

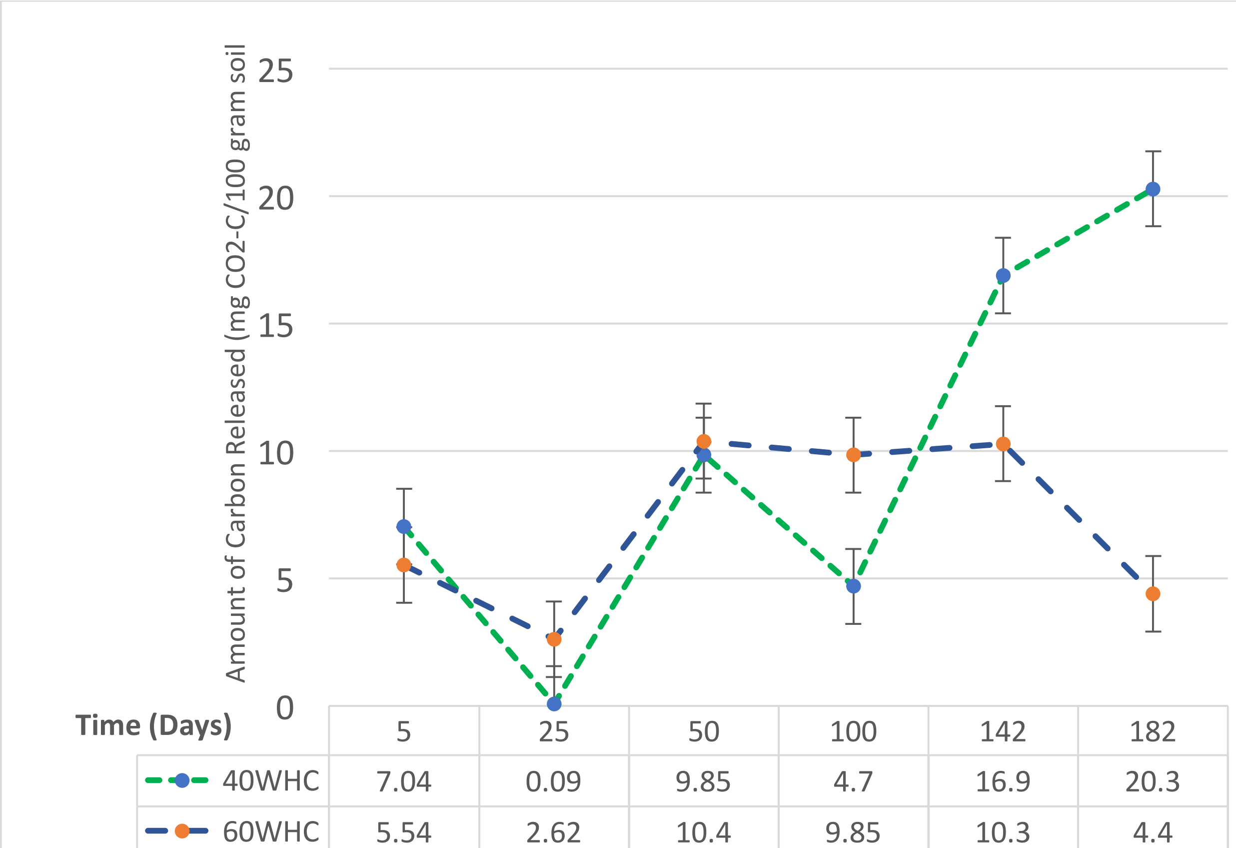
Initial carbon content for RPS is 54.1%.

[a]Values represent means pooled from five replicates.



Time (Days)	5	25	50	100	142	182
Amended	6.79	0.93	12.25	8.82	19.92	17.23
Unamended (Soil Only)	5.79	1.59	7.99	3.34	7.3	7.43

Figure 3.4. Mean (± S.E.) amount of carbon released (mg CO_2-C/100 g. soil) over 182 days with amended and unamended treatments for recycled paper sleeve container (RPS, Ellepot®).



Time (Days)	5	25	50	100	142	182
40WHC	7.04	0.09	9.85	4.7	16.9	20.3
60WHC	5.54	2.62	10.4	9.85	10.3	4.4

Figure 3.5. Mean (± S.E.) amount of carbon released (mg CO_2-C/100 g. soil) over 182 days with 40% and 60% water holding capacity (WHC) treatments for recycled paper sleeve container (RPS, Ellepot®).

Table 3.3. Amount of carbon released (mg CO_2-C/100 g soil) over 182 days. Statistics for the main effects [wood pulp fiber container (WPF, Fertilpot), fertilizer, organic amendment, and water holding capacity (WHC)] and their two-way interactions are shown. Abbreviations: C = With Container Material; NC = Soil Only (Without Container Material); 40% Water Holding Capacity = 40WHC; 60% Water Holding Capacity = 60WHC; Low Fertilizer = LF; High Fertilizer = HF; Unamended = UN; Soil Amendment = AM.

Main and Interaction Effects	**Statistics**	**Carbon Released (mg CO_2-C/100 g soil)**	
	P-value		
Container	0.02*	**C**	**NC**
		3.20b[Y](0.34)[X]	4.37a (0.35)
Fertilizer	0.27	N.S.	
Amendment	0.97	N.S.	
Water Holding Capacity (WHC)	0.84	N.S.	
Container *Fertilizer	0.99	N.S.	
Container *Amendment	0.23	N.S.	
Container*WHC	0.56	N.S.	
Fertilizer*Amendment	0.68	N.S.	
Fertilizer*WHC	0.91	N.S.	
Amendment*WHC	0.54	N.S.	

N.S., *, **, *** indicates No statistical significance, significance at the P<0.05 level, P<0.01 level, or P<0.001 level, respectively.

[X]Values are averages of five replicates with standard error in parentheses.

[Y]Values followed by the same lowercase letter are not significantly different at P<0.05.

Table 3.4. Percentage of carbon (C) remaining in recycled paper sleeve (WPF, Fertilpot) and in control samples (soil only) with fertilizer, amendment, and water holding capacity (WHC) treatments post-experiment (at 182 days). Abbreviations: 40% Water Holding Capacity= 40WHC; 60% Water Holding Capacity = 60WHC; Low Fertilizer = LF; High Fertilizer = HF; Unamended = UN; Soil Amendment = AM.

Treatment Combination	**% Carbon Remaining in Container Material**	**% Carbon in Control (Soil Only)**
40WHC-LF-AM	30.1[a]	5.3
40WHC-LF-UN	29.5	1.1
60WHC-LF-AM	21.1	5.8
60WHC-LF-UN	16.3	1.4
40WHC-HF-AM	45.9	5.9
40WHC-HF-UN	27.6	1.1
60WHC-HF-AM	22.4	6.5
60WHC-HF-UN	23.9	1.3

Initial carbon content for WPF is 50.7%.

[a]Values represent means pooled from five replicates.

Table 3.5. Amount of carbon released (mg CO_2-C/100 g soil) over 182 days. Statistics for the main effects [coconut coir container (CC), fertilizer, organic amendment, and water holding capacity (WHC)] and their two-way interactions are shown. Abbreviations: C = With Container Material; NC = Soil Only (Without Container Material); 40% Water Holding Capacity= 40WHC; 60% Water Holding Capacity= 60WC; Low Fertilizer = LF; High Fertilizer = HF; Unamended = UN; Soil Amendment = AM.

Main and Interaction Effects	**Statistics**	**Carbon Released (mg CO_2-C/100 g soil)**			
	P-value				
Container	0.0004***	**C**		**NC**	
		4.68a[Y] (0.44)[X]		2.49b (0.43)	
Fertilizer	0.24	N.S.			
Amendment	0.23	N.S.			
Water Holding Capacity (WHC)	0.93	N.S.			
Container * Fertilizer	0.03*	**C*LF**	**NC*LF**	**C*HF**	**NC*HF**
		4.97a (0.62)	1.47b (0.61)	3.51ab(0.61)	4.39a (0.63)
Container*Amendment	0.07	**C*AM**	**NC*AM**	**C*UN**	**NC*UN**
		4.88a (0.64)	1.56b (0.61)	4.49a (0.62)	3.42ab (0.61)
Container *WHC	0.95	N.S.			
Fertilizer*Amendment	0.68	N.S.			
Fertilizer*WHC	0.27	N.S.			
Amendment*WHC	0.75	N.S.			

N.S., *, **, *** indicates No statistical significance, significance at the P<0.05 level, P<0.01 level, or P<0.001 level, respectively.

[X]Values are averages of five replicates with standard error in parentheses.

Table 3.6. Percentage of carbon (C) remaining in coconut coir container (CC) and in control samples (soil only) with fertilizer, amendment, and water holding capacity (WHC) treatments post-experiment (at 182 days). Abbreviations: 40% Water Holding Capacity= 40WHC; 60% Water Holding Capacity= 60WHC; Low Fertilizer = LF; High Fertilizer = HF; Unamended = UN; Soil Amendment = AM.

Treatment Combination	**% Carbon Remaining in Container Material**	**% Carbon in Control (Soil Only)**
40WHC-LF-AM	28.3[a]	5.1
40WHC-LF-UN	6.1	1.2
60WHC-LF-AM	18.9	5.4
60WHC-LF-UN	4.7	1.0
40WHC-HF-AM	28.2	4.9
40WHC-HF-UN	25.6	1.2
60WHC-HF-AM	13.5	5.6
60WHC-HF-UN	5.8	1.2

Initial carbon content for WPF is 49.2%.

[a]Values represent means pooled from five replicates.

CHAPTER 4

FAMILIARITY AND ATTRIBUTES OF BIODEGRADABLE CONTAINERS BY HORTICULTURAL PRODUCTION AND LANDSCAPE PROFESSIONALS

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ABSTRACT

Plastic containers are the primary container option utilized by the Green Industry for ornamental crop production. Although biodegradable containers of various types also have been available, their adoption has been slow. Previous research has shown that these containers aid in plant growth and limit root disruption during installation. In addition, they reduce plastic waste and can increase labor efficiency. It is crucial to assess the level of knowledge and use of biodegradable containers by horticultural producers and installers to help understand their slow rate of adoption by the industry. An online survey instrument was implemented to assess producer and landscaper knowledge and familiarity regarding biodegradable containers in the state of Georgia. Results indicated 83% of horticultural producers do not purchase biodegradable containers. Peat biodegradable containers were primarily purchased when these containers were used. Horticultural producers and installers agreed that use of plantable containers can limit use of plastic containers. Plant installers also suggested that use of these containers has the potential to acceleration plant installation, reduce worker time during the installation process, and eliminate cleanup that occurs when using plastic containers during planting. The survey results suggest a need for coordinated outreach to producers and landscapers. Future work also should focus on education of the public to increase consumer demand that could translate to wider adoption of biodegradable containers.

KEY WORDS Georgia Green Industry Association, Survey, Biodegradable Containers, Compostable Containers, Plantable Containers, Plastic Containers

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Petroleum-based plastic containers have been utilized by the green industry as the primary container option for ornamental plant production in the United States since the 1980s (Hall et al., 2010). Virgin petroleum-based resins which consist of 8% of consumed petroleum have been used to produce plastic containers (Thompson et al., 2009). Today, four billion container/plant units are produced by the container-crop industry annually in the United States with petroleum-based plastic containers accounting for 1.6 billion pounds of plastic (Schrader, 2013). However, due to increasing concerns by environmentally conscious consumers, alternative containers have been employed as they can reduce environmental impact of crop production. Recent market research reports that ornamental plant consumers are willing to pay more for non-plastic and recyclable containers (Fulcher et al., 2015). This expansion in consumer preference, along with a desire for sustainability by green industry stakeholders, can potentially increase the adoption of alternative containers in landscape (Diver et al., 2001).

Traditionally, the ornamental industry has relied on plastic containers when producing flowering crops, perennials, annual bedding plants, vegetable transplants and more recently nursery crops. Plastic containers are used because of their durability, shipping ease, superior function, low cost, and the diversity of available sizes and shapes (Evans and Hensley, 2004; Kratsch et al., 2015). However, plastic container manufacturing has progressed over the years, producing container products that are injection-molded, blow-molded, pressure-formed, vacuum-formed, and thermo-formed. These plastic container products have various advantages on plant growth and establishment by eliminating root disruption/transplant shock and increasing shipping and marketing ease (Chappell and Knox, 2012).

The volume of plastics, disposed at landfills, poses potential for soil and groundwater contamination due to the ultraviolet light additives used in plastic products (Thompson et al., 2009). Koeser et al. (2014) report 16% of the carbon dioxide (CO_2) emissions of petunia (*Petunia x hybrida)* production are linked to the traditional plastic containers used to grow the plants. Interest has increased in the adoption and use of alternative and biodegradable containers in landscape.

Alternative containers are made from a variety of animal- and plant-based materials that are derived from renewable sources including bioplastic, coir, poultry feathers, processed cow manure, paper fibers, and rice hulls (Evans et al., 2015) and may serve as a replacement for the standard plastic nursery container. Biodegradable containers are typically categorized as compostable or plantable. Plantable biocontainers may be directly planted in the field, raised bed, or pots and allow plant roots to protrude through their walls. They have the potential to eliminate plastic waste and improve labor and installation efficiency (Nambuthiri et al., 2015a). Compostable containers must be removed before planting because they degrade too slowly for plant roots to grow through the container walls. However, they decompose relatively rapidly in a compost pile (Mooney, 2009). Due to the low compression strength, alternative containers can decrease landfill space and decompose more rapidly than traditional plastic containers (Fulcher et al., 2015).

When using biodegradable containers in a greenhouse or landscape, plant growth and development, water use, and container integrity/lifespan have been evaluated to determine if these containers have the ability to contend with petroleum-based plastic containers (Sun et al., 2015). Several studies have reported increased or similar plant growth in bedding plants such as impatiens, petunia, sedum, liriope and cyclamen grown in biodegradable containers (Center for Applied Horticulture Research, 2010; Kuehny et al., 2011; Beeks and Evans, 2013a). Likewise, Lopez and Camberato (2011) reported increased root and shoot dry weight, plant height, and bract area index of ‘Eckespoint Classic Red’ poinsettia (*Euphorbia pulcherrima*) grown in recycled paper (Western Pulp Inc., Corvallis, OR) in the greenhouse for 12-16 weeks when compared to plastic containers. Additional research indicates fiber containers have improved plant production, survival, quality, and growth because of their ability to control substrate temperature of ‘Otto Luyken’ cherry laurel (*Prunus laurocerasus*), Gold Splash® wintercreeper (*Euonymus fortunei*), ‘Cunningham’s White’ rhododendron (*Rhododendron* spp.), and ‘Aztec Gold’ daylily (*Hemerocallis* spp.) and may be effectively used to grow temperature-sensitive plants (Ruter, 1999; Ruter, 2000; Fulcher et al., 2012).

Water use is also an important component that may influence adoption of biodegradable containers by horticultural firms. Alternative containers can be hydrophilic or hydrophobic depending on their sidewall properties (Evans and Karcher, 2004). Both stage of production and evaporation through alternative container sidewalls can foster water loss (Evans et al., 2010). High sidewall water loss has been found in wood fiber (Fertil Pot), peat (Jiffy-Pot), and manure (Cowpot) containers whereas low sidewall water loss has been detected in coir, rice straw, and slotted rice hull containers, and bioplastic containers. Taylor et al. (2011) also indicated that irrigation frequency typically increases for plants potted in biocontainers.

A four-month study determined average water use of Gold Splash wintercreeper (*Euonymus fortunei*) grown in 1-gallon paper and recycled paper containers was 30-50% higher than plastic containers (Nambuthiri et al., 2015a). Nambuthiri et al. (2012) noted total water loss under a 2.6 $kg \cdot m^{-1} \cdot s^{-2}$ kPa vapor pressure deficit after eight hours in a growth chamber was 15% for plastic and rice-hulled containers, and 50% for recycled paper pots. Additional studies have also indicated water loss from peat wood fiber, straw, manure, rice straw, and recycled paper containers in bedding plants including marigolds, petunias, and geraniums (Evan and Hensley, 2004; Koeser et al., 2013a; Nambuthiri et al., 2012). Likewise, rice hull and bioplastic containers have been found to be comparable in water loss to standard plastic containers (Nambuthiri et al., 2012). To improve irrigation requirements and prevent water loss, plastic shuttle trays may also be used (Beeks and Evans, 2013a; Evans et al., 2015).

Container integrity and lifespan must be considered before adoption of alternative containers. Greenhouse operators may experience losses as a results of plant injury if biodegradable containers are broken or torn during production, packaging, shipping, and retailing. Koeser et al. (2013b) reported manure and peat pots have been prone to break or tear more easily, especially when wet and therefore require more care when handling. Rice hull, coir, and recycled paper containers have greatest wet and dry vertical and lateral strength when compared to standard plastic containers whereas porous rice and bioplastic containers have the lowest dry punch strength. Additionally, wood fiber (Fertil Pot), peat (Jiffy-Pot), and manure (CowPot) had low wet strength (Wang et al., 2015).

Greenhouse studies reported plants grown in peat, cow manure, wood fiber, and rice straw pots could not be sold after production due to insufficient container integrity while plants produced in plastic, rice hull, wheat starch, and recycled paper containers were sold and had unchanged container integrity after fourteen weeks (Lopez and Camberato, 2011; Beeks and Evans 2013b). These studies indicate alternative container types may be more effective in long-term crop production, while other types can be used in short-term greenhouse production. Alternative container lifespan can range from a few months to several years depending on the container materials, biodegradable adhesives and binding agents, resins, and waxes that are used. On average, alternative containers are used in short-term crop production and persist in the soil for 1 to 3 years (Nambuthiri et al., 2015a).

As noted, the use of specific biodegradable container types is influenced by many factors, including such attributes as the ability to protect the plant and assure proper growth. The choice of container is also determined by familiarity within the industry, especially in the case of novel products. There are several biodegradable containers competing on the market and, although many in the industry may be aware of the broad category of "biodegradable containers", the degree of knowledge about specific types of biodegradable containers has not been explored. Such information is of interest to the manufacturers and distributors seeking ways to improve sales as well as to organizations interested in reducing the use of plastic containers due to their environmental impact, limiting the amount of solid waste disposed at landfills, and reducing the cost of solid waste collection.

The overall objectives of this study are to: 1) identify barriers preventing adoption of biodegradable containers by horticultural firms; 2) determine use and familiarity of biodegradable containers vs. plastic containers by horticultural producers and landscapers/installers; 3) determine attribute perceptions of biodegradable containers vs. plastic containers by horticultural producers and landscapers/installers. Results of this study may aid in marketing and promotion of these products as an environmentally-friendly option to standard plastic containers.

Materials and Methods

Survey Participants

Survey respondents were holders of the Georgia Department of Agriculture's live plant license in 2017 and included participants involved in landscape installation and horticultural production. Only one respondent from each firm participated in the survey. The survey was evaluated by the University of Georgia Office of Human Subjects (STUDY 00005434) and ruled that the study did not require IRB approval as the survey targeted plant production and installation firms rather than individual survey respondents.

Survey Instrument

A survey instrument was created to: 1) determine use and familiarity of biodegradable containers by the people engaged in the green industry; 2) assess their perceptions of the attributes of biodegradable containers; 3) evaluate potential of containers to enhance sustainability by horticultural professionals. The online survey instrument was placed on the designated webpage and an invitation to participate was sent via email to horticultural firms. Respondents provided socio-demographic information, and indicated knowledge of biodegradable containers, and responded to questions probing for knowledge about biodegradable containers. Figure 4.1 shows the first screen with two survey questions as an illustration.

Survey Demographics and Questions

The questionnaire consisted of thirty-seven questions and was administered online through Survey Monkey Inc. (San Mateo, CA). The program recorded survey results and data were collected weekly from April to August 2017. Personal information shared by respondents included respondent's age, gender, company position, years of schooling, and years of experience in their business area. In addition, questions were also asked for details about their horticultural firm and included county location of the firm, company activity, annual company revenue, and number of hires and types of employees hired (i.e. seasonal, full-time, or part-time).

With the green industry striving to adopt more sustainable practices such as limiting plastic use and disposal, plant producers were evaluated for their use and familiarity of biodegradable containers and to determine potential barriers preventing biodegradable container adoption. To better understand their purchasing history in regards to biodegradable containers, several questions asked about the previous purchase, length of use, and storage of biodegradable containers.

Additionally, questions asked what types of containers were used in production, types of produced and sold plants, and the respondent's familiarity of growing plants in biodegradable containers. Information was collected about the cost per unit of marketed coconut coir, wood pulp fiber, manure, peat, recycled paper, and rice hull containers as well as the share of plants produced in biodegradable or plastic containers. Our questionnaire also addressed the disposal process of plastic containers as well as the pounds of plastic containers, liners, and trays discarded monthly. An additional question was evaluated each firm's algaecide use.

The survey also included statements regarding the respondent's opinions of biodegradable containers. Each producer was asked how biodegradable containers compare to plastic containers in regards to plant growth, microbial growth in or on containers, labor savings, convenience, container and firm expense, storage and transport, durability and standardization, customer demand, and environmental impact. In addition, to determine previous use, plant producers were asked how use of biodegradable containers influenced firm's revenue, customer feedback, labor efficiency, plant growth, landscape installation, water efficiency, root circling during production and planting, root zone heat dissipation, and plastic container use. Respondents provided answers on a scale of 1 ("strongly disagree") to 6 ("don't know").

Plant installers were asked the types of plants they purchase for installing in landscape to better understand their firm's installation activity. We asked plant installers to gauge previous use and opinion of biodegradable containers. A series of statements was provided about biodegradable containers regarding plant growth, firm's revenue, customer feedback, reduced worker time during installation, plant growth, container durability, plastic waste reduction, root circling during production and planting of trees and shrubs, and limited decomposition when used for annuals/seasonal color. In addition, installers rated familiarity, decomposition, and plant growth in commercially-available biodegradable containers on a scale from 1 (low) to 10 (high) (Figure 4.2).

A total of 214 online questionnaires were collected. Data was collected from all respondents and descriptive data is being reported for each of the questions addressed for plant producers and installers as well as for demographics collected. There were 1,076 survey invitations sent to plant producers and installers throughout the state. There were 163 (15%) of the total respondents that opted to not participate in the survey, 105 respondents (10%) which did not open the online survey instrument, and 24 respondents (2%) did not participate due to emails bounced, and 570 respondents (53%) that opened the online survey document but did not complete. A total of 214 survey participants (20%) responded and completed online survey questionnaire.

Results

Demographics Regarding Horticultural Firms and Survey Respondents

Survey respondents were also asked demographics regarding their horticultural firm to better assess the activity, economic, and hiring aspects of each company. Upon asking the 214 survey respondents what percent of the company activity was, we determined that 37% of horticultural firms had <50% landscape design, build, installation activity and 38% of firms had <50% landscape maintenance. Moreover, there were 65% of firms involved in <50% wholesale container and in-ground nurseries, 47% of companies had <50% in wholesale greenhouse operations, and 56% of firms had <50% retail greenhouse company activity (Table 4.1).

We also evaluated the 2016 economic revenue of each firm. Most respondents indicated their firm had revenues of less than $50,000 in 2016 (refer to App., Table 4.10). In regards to types and number of employees hired, most horticultural firms had <10 full-time, part-time, seasonal full-time, and seasonal part-time employees. There were 74% of firms which employed less than 10 individuals (refer to App., Table 4.10).

To gauge the socio-demographic characteristics of survey respondents connected to each horticultural firm, respondents were asked their gender, age, years of schooling, position in the company, and years of experience in the business area of their firm. It appeared that 90% of all survey respondents were in the owner/manager position in the company. The majority of these participants also had 30.5-39 years of experience in the business area of their company (refer to App., Table 4.11). Survey respondents were predominately male and in the age range of 51-60 years old. The primary years of schooling by the respondents consisted of 13-16 years (refer to App., Table 4.11).

Familiarity of Biodegradable Containers by Plant Producers

Plant producers were asked a series of questions to seek understanding regarding their familiarity and previous use of biodegradable containers. To assess biodegradable container use, producers were asked whether they purchased these containers with 15% of respondents stating "yes" and 83% replying "no" (Figure 4.3). If biodegradable containers were purchased and used, respondents were also asked the length of use of containers for plant production. Most respondents had been using biodegradable less than a year or for a year (Figure 4.4).

To further assess use of biodegradable container types, respondents were asked whether they use plantable or compostable biodegradable containers or plastic containers. There were 80% of respondents that indicated plastic containers were used "very often". However, plantable or compostable containers were "almost never" used (Table 4.2). In fact, in the production of annuals, herbaceous perennials, shrubs, ornamental trees, fruit trees, ornamental shrub or tree liners, vegetables or edible vines, firms "almost never" used biodegradable containers (Table 4.2).

According to survey results, plastic containers are primarily used to grow these crops (Table 4.3). Plastic containers are also the primary container option purchased by horticultural firms (Table 4.3).

In order to assess knowledge regarding manufactured biodegradable containers and container costs, survey respondents were asked what types of alternative containers they are most familiar with and cost of these containers. Of manufactured biodegradable containers on the market, horticultural producers were most familiar with peat (36), coconut coir (16), and recycled paper (11) containers followed by processed cow manure (8), other (5), and rice hull (1) containers (Table 4.4). On average, respondents concluded that the approximate cost per unit of manure, peat, rice hull, and recycled paper containers ranged from $0.01-$0.25. For wood pulp and other biodegradable containers, some respondents indicated that the cost per unit/container ranged from $0.01-$0.25. Other participants suggested it ranged from $0.51-$0.75 per unit (Table 4.4).

<u>Attributes of Biodegradable Containers by Plant Producers</u>

A series of questions regarding disposal, use of algaecides, and storage of biodegradable containers were asked to horticultural firms to better gauge knowledge and adoption of these containers. It was apparent that for most horticultural firms, disposal of plastic containers, trays, and liners was not regulated in their county (refer to App., Table 4.12). Typically, 1-5 pounds of plastic was disposed by horticultural firms monthly (refer to App., Table 4.12). It was also indicated that plastic containers are almost never discarded with regular waste to landfill or separated for recycling, reused, or discarded in other ways (refer to App., Table 4.13). Producers also almost never place plastic containers in bins with other waste or in bins for recyclable waste (refer to App., Table 4.13).

In regards to biodegradable container storage on-site, 58% of individuals said they “did not know” if these containers are difficult to store, 26% responded “yes”, and 16% of participants indicated “no” (refer to App., Table 4.13). In addition, most horticultural firms “almost never” use algaecides to clean the greenhouse or plastic containers, trays, and flats (refer to App., Table 4.14). The majority of plant producers “did not know” if use of biodegradable containers led to higher algaecide and fungicide applications when compared to standard plastic containers (refer to App., Table 4.14).

Plant producers were also asked questions regarding attributes of biodegradable containers to further assess knowledge and adoption of biodegradable containers. Respondents agreed that these containers are convenient as well as environmentally-friendly (Table 4.5). According to most producers, they “strongly disagreed” that their customers demand biodegradable containers. The vast majority of respondents also “strongly disagreed” that biodegradable containers have replaced conventional plastic containers (Table 4.5). Respondents “did not know” if these containers were less expensive than plastic containers. When asked whether they felt use of these containers could increase costs in the firm, they “neither agreed nor disagreed”.

In regards to container sturdiness, most horticultural firms “agreed” that biodegradable containers are less sturdy than plastic containers. However, it was apparent that most producers “did not know” if these containers are less standardized in regards to volume than plastic containers. Moreover, respondents “neither agreed nor disagreed” that biodegradable containers are easier to store, transport, and handle compared to conventional plastic containers. When asked if biodegradable containers improve plant growth, plant producers “neither agreed nor disagreed”. Most respondents indicated that they “neither agreed nor disagreed” that use of biodegradable containers could encourage mold/fungal growth which can contribute to poor plant performance.

They also “neither agreed nor disagreed” that using biodegradable containers saves worker time (Table 4.5).

Additional questions were asked to respondents regarding plant performance in these containers. Most producers “did not know” if biodegradable container use would enhance plant growth (Figure 4.5). Producers were also unsure if these containers would allow roots to easily penetrate through container walls. Horticultural production firms also “did not know” if biodegradable containers allowed heat dissipation from the root zone better than plastic containers (Figure 4.5). To assess use of these containers in regards to water efficiency, it was apparent most producers “did not know” how biodegradable containers would impact water efficiency. According to most producers, they did feel that use of these alternative container would limit use of standard plastic containers (Figure 4.5). However, a large number of producers were unsure that biodegradable container use could increase the firm’s revenue, generate positive customer feedback, aid in labor efficiency or improve installation process (Figure 4.5).

Familiarity of Biodegradable Containers by Landscapers/Plant Installers

The online survey instrument also included questions to assess familiarity and previous use of biodegradable containers by plant installers as well as the types of plants purchased for planting. Landscapers were asked what types of plants they purchase in regards to landscape installation and indicated they “almost never” purchase annuals, fruit trees, vegetables, ornamental shrubs and tree liners, or edible vines. However, they “often” purchase herbaceous perennials and “very often” purchase shrubs and ornamental trees when installing in landscape (Table 4.6).

In regards to familiarity, horticultural installers were also asked to rank their familiarity of various manufactured containers (1 = low familiarity, 10 = high familiarity). Processed manure, coconut coir (four-inch pot size and 1 gallon or larger), wood pulp fiber (four-inch pot size and 1 gallon or larger), and recycled paper were ranked with low familiarity by installers (Table 4.7). Likewise, 29% of installers ranked peat containers with low familiarity while 20% of installers ranked peat containers with high familiarity. In addition, plastic containers (four-inch pot size and 1 gallon or larger) were ranked with high familiarity (Table 4.7).

Attributes of Biodegradable Containers by Landscapers/Plant Installers

Several questions were also addressed to better understand knowledge of marketed biodegradable container attributes by plant installers. Landscapers/installers were asked to rate plant growth of plants grown in manufactured containers with 1 = low growth and 10 = high growth. Processed manure, peat, coconut coir (four-inch pot size and 1 gallon or larger), wood pulp fiber (four-inch pot size and 1 gallon or larger), and recycled paper containers were all primarily rated “5” or medium growth. However, plastic containers (four-inch pot size and 1 gallon or larger) were primarily ranked “10” or high plant growth (Table 4.8). To address biodegradable container decomposition, respondents were also asked to rate decomposition of these manufactured containers with “1” being low decomposition and “10” being high decomposition. Most landscapers rated decomposition of processed manure, peat, coir (four-inch pot size or 1 gallon or larger), wood pulp fiber (four-inch pot size or 1 gallon or larger), and recycled paper as “5” or having marginal decomposition. Both plastic container sizes were rated as “1” or having low decomposition (Table 4.9).

Plant installers were also provided statements in order to evaluate their opinions of plantable biodegradable containers (Figure 4.6). Most plant installers “neither agreed or disagreed” that use of biodegradable containers increased their firm’s revenue. According to most installers, they “neither agreed nor disagreed” that use of biodegradable containers generate positive customer feedback. Installers also “did not know” if planting in biodegradable containers led to better plant growth after installation. It was apparent that landscapers were unsure if biodegradable containers break when handled at installation or require more careful handling than conventional plastic containers (Figure 4.6).

To assess use of biodegradable containers when planting annuals, landscapers were asked whether alternative containers do not break by season's end impeding the rototiller. Most installers "did not know" if biodegradable containers break down at the end of the annual growing season. To evaluate biodegradable container use for trees and shrubs, plant installers were asked if containers do not break down in several growing seasons causing root circling. Most installers were unsure if these containers break down after several growing seasons when utilized for woody trees and shrubs (Figure 4.6). However, on average, most installers "did agree" that use of alternative containers would require less worker time during landscape installation, eliminate the clean-up process when using plastic containers at planting, accelerate installation process, and limit plastic container use (Figure 4.6).

Discussion

In Georgia, we found that 83% of plant producers do not use biodegradable containers and if they do they have used them for less than a year or for a year. Producers were also asked whether they used plastic, plantable, or compostable containers and 80% of respondents indicated that they use plastic containers. When asked which manufactured biodegradable containers respondents were most familiar with, it appeared that peat containers were the primary choice for both horticultural producers. This suggests that certain manufactured containers may not be as readily available for purchase, both producers and installers are unaware of these containers because they use plastic containers, or the container unit cost and shipping costs are limiting use and purchase of these containers. Brumfield et al. (2015) indicated differences in cost per container unit in which black plastic container (3.8 L) cost $0.40 while wood pulp (3.9 L) were $0.62, fabric (3.4 L) were $0.44.

After asking horticultural producers' opinions of biodegradable containers, most agreed that these are convenient and environmentally-friendly, however, they do not believe that their customers demand these containers or that these containers have replaced use of standard plastic containers. It was also apparent that these producers are not familiar with these containers as they were unsure of the cost, how standardized biodegradable container products are, and the ability of these products to improve plant growth and save worker time. They did indicate that use of these containers would aid in limited use of plastic containers.

Horticultural installers were also asked their opinions regarding biodegradable containers and indicated that they did not know if biodegradable container use would lead to plants growing bettering after installation, necessitate more careful handling than plastic containers, and break when handled during installation. They also did not agree nor disagree that these containers have the potential to increase firm revenue and lead to positive customer feedback. However, they did agree that use of these containers would accelerate plant installation, eliminate the clean-up process during installation, limit plastic container use, and require less worker time during landscape installation.

The results of this survey indicate that additional education regarding the benefits of using biodegradable containers should be provided to horticultural producers and consumers in order to effectively eliminate the barrier of adoption of manufactured biodegradable containers. Horticultural firms should be educated on plant growth, water use, costs, and the benefits of labor efficiency and reduced installation time for landscapers when utilizing biodegradable containers. Additional work is also needed to provide education to the consumers regarding the benefits of biodegradable containers. Increases in alternative container demand by the consumer could lead to widespread adoption of biodegradable containers.

Yue et al. (2011) suggests that it is necessary for horticultural professionals to better understand the feasibility and performance of alternative containers in landscape and the crops planted within them as well as the renewable features of biodegradable containers for adoption to take place. Individual growers must determine if the benefits of using biodegradable containers outweigh the upfront container costs and potential changes in production (i.e. water use). These containers have the potential to alleviate the environmental impact by reducing plastic waste and disposal, aid in long-term sustainability by the horticultural industry, and impact efficiency of landscape installation.

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Table 4.1. Frequency of firms that have percentage of company activity in six environmental horticulture sectors in Georgia.

Business Scope	**<10%**	**11-25%**	**26-50%**	**>50%**
Landscape-design, build, installation	11/13%	16/18%	27/32%	32/37%
Landscape maintenance	9/11%	10/12%	25/31%	38/46%
Wholesale container and in-ground nurseries	7/9%	7/9%	13/17%	51/65%
Wholesale greenhouse operations	5/12%	6/14%	12/27%	20/47%
Retail Greenhouse	6/12%	5/9%	12/23%	29/56%
Other	0	0	0	0

Table 4.2. Frequency of use of biodegradable container types used by horticultural producers and types of plants grown in biodegradable containers.

Use of Container Types	BPC	BCC	Plastic	Types of Plants Grown in Biodegradable Containers	Almost never	Seldom	Neither often nor seldom	Often	Very Often
Almost never	55/71%	60/78%	5/5%	**Annuals**	46/69%	6/9%	4/6%	8/12%	3/4%
Seldom	7/9%	4/5%	1/1%	**Herbaceous Perennials**	52/75%	3/4%	4/6%	9/13%	1/1%
Neither often, nor seldom	5/6%	4/5%	2/2%	**Shrubs (1 gallon or larger)**	55/86%	1/2%	4/6%	2/3%	2/3%
Often	3/4%	4/5%	10/11%	**Ornamental trees (1 gallon or larger)**	57/88%	1/2%	3/5%	2/3%	2/3%
Very Often	4/5%	-	73/80%	**Fruit Trees**	54/86%	1/2%	5/8%	3/5%	-
Don't Know	4/5%	5/6%	1/1%	**Vegetable Transplants/Herbs**	42/66%	4/6%	4/6%	10/16%	4/6%
				Ornamental shrub or tree liner	53/82%	3/5%	3/5%	4/6%	2/3%
				Edible Vines	54/86%	1/2%	5/8%	2/3%	1/2%

Table 4.3. Frequency of purchase of biodegradable container types used by horticultural producers and types of plants grown in biodegradable container type.

Purchase of Biodegradable Containers	Yes	No	Don't Know	Annuals	Herbaceous Perennials	Shrubs	Ornamental Trees	Fruit Trees	Vegetables	Ornamental shrubs and tree liners	Edible Vines
Compostable Containers	6/7%	77/92%	1/1%	4/100%	2/100%	2/100%	2/100%	2/100%	2/100%	1/100%	1/100%
Plantable Containers	14/17%	69/83%	-	8/100%	7/100%	2/100%	1/100%	2/100%	13/100%	2/100%	2/100%
Plastic Containers	80/91%	8/9%	-	36/100%	46/100%	49/100%	42/100%	23/100%	31/100%	42/100%	17/100%

Table 4.4. Familiarity of type and price of manufactured biodegradable containers used by horticultural producers.

Coconut Coir		**Processed Cow Manure**	**Peat**	**Wood Pulp**	**Recyclable Paper Sleeve**	**Rice Hull**	**Other**
16/100%		8/100%	36/100%	3/100%	11/100%	1/100%	5/100%
Approximate Price per unit	**Coconut Coir**	**Processed Cow Manure**	**Peat**	**Wood Pulp Fiber**	**Recyclable Paper Sleeve**	**Rice Hull**	**Other**
$0.01-$0.25	2/29%	2/50%	8/57%	1/50%	2/100%	2/100%	1/50%
$0.26-$0.50	3/14%	3/25%	11/22%	-	-	-	-
$0.51-$0.75	4/14%	4/25%	-	1/50%	-	-	-
>$0.75	7/43%	-	14/21%	-	-	-	1/50%

Table 4.5. Respondents' opinion regarding biodegradable containers.

Business Scope **Biodegradable containers are…**	**Strongly Disagree**	**Disagree**	**Neither agree, nor disagree**	**Agree**	**Strongly Agree**	**Don't Know**
Convenient	7/3%	20/10%	51/25%	56/28%	29/14%	35/17%
Save worker time	10/5%	30/15%	48/24%	46/23%	22/11%	39/19%
Replace plastic containers	72/36%	47/24%	33/17%	6/3%	6/3%	6/3%
Environmentally friendly	0	5/2%	25/12%	88/44%	64/32%	15/7%
Improve plant growth	4/2%	16/8%	77/38%	24/12%	13/6%	60/30%
My customers demand these	64/32%	55/28%	36/18%	3/2%	3/2%	13/7%
Less expensive than plastic containers	27/13%	24/12%	49/24%	6/3%	2/1%	84/42%
Less standardized than plastic containers because volume is more variable	1/1%	12/6%	58/29%	28/14%	5/2%	85/42%
Less sturdy than plastic containers	6/8%	1/1%	31/39%	41/52%	-	-
Easier to store on premises than plastic container	12/15%	26/33%	38/49%	2/3%	-	-
Easier to handle and transport than plastic containers	10/13%	31/40%	36/46%	1/1%	-	-
Increase costs in our firm as compared to plastic containers	7/9%	1/1%	44/57%	25/32%	-	-
Encourage mold/fungal growth resulting in poor plant growth compared to plastic containers	4/5%	5/6%	65/83%	4/5%	-	-

Table 4.6. Types of plants purchased for landscape installation by landscapers/plant installers.

Plant Type	Almost Never	Seldom	Neither often, nor seldom	Often	Very often
Annuals	27/30%	10/12%	9/10%	24/27%	19/21%
Herbaceous perennials	28/31%	8/9%	5/6%	32/35%	17/19%
Shrubs	26/29%	5/5%	8/8%	22/25%	30/33%
Ornamental trees	26/29%	10/11%	7/7%	20/22%	28/31%
Fruit trees	45/54%	18/21%	11/13%	6/7%	4/5%
Vegetables	47/57%	14/17%	6/7%	10/12%	6/7%
Ornamental shrubs or tree liners	42/47%	14/16%	12/14%	10/11%	11/12%
Edible Vines	48/59%	16/20%	12/14%	5/6%	1/1%

Table 4.7. Degree of familiarity of commercially-available manufactured containers by landscapers/plant installers (1 = low familiarity, 10 = high familiarity).

Container Type	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
Processed Manure (CowPot™)	45/46%	6/6%	4/4%	3/3%	12/12%	3/3%	9/9%	5/5%	1/1%	9/9%
Peat (Jiffy-Pot®)	29/29%	1/1%	6/6%	3/3%	17/17%	2/2%	4/4%	11/11%	6/6%	20/20%
Coconut Coir	47/49%	12/13%	6/6%	2/2%	10/10%	6/6%	3/3%	3/3%	2/2%	5/5%
Wood Pulp Fiber (Fertilpot)	43/44%	4/4%	9/9%	4/4%	12/12%	6/6%	3/3%	6/6%	3/3%	7/7%
Recycled Paper (Ellepot®)	46/47%	7/7%	5/5%	5/5%	8/8%	4/4%	4/4%	5/5%	2/2%	12/12%
Plastic	5/5%	1/1%	4/4%	-	3/3%	1/1%	3/3%	3/3%	4/4%	72/75%
Coconut coir (1 gallon or larger)	57/60%	9/9%	5/5%	6/6%	5/5%	6/6%	1/1%	-	1/1%	5/5%
Wood Pulp Fiber (Fertilpot 1 gallon or larger)	59/61%	9/9%	4/4%	6/6%	5/8%	3/3%	2/2%	1/1%	1/1%	3/3%
Plastic Container (1 gallon or larger)	4/4%	-	4/4%	1/1%	1/1%	-	-	2/2%	2/2%	84/86%

Table 4.8. Rating of plant growth (1 = low, 10 = high) by landscapers/plant installers of plants grown in commercially-available manufactured containers.

Container Type	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
Processed Manure (CowPot™)	5/9%	2/4%	5/9%	2/4%	23/41%	3/5%	7/13%	5/9%	2/4%	2/4%
Peat (Jiffy-Pot®)	6/10%	1/2%	5/9%	1/2%	24/41%	4/7%	10/17%	3/5%	1/2%	3/5%
Coconut Coir	5/9%	1/2%	8/15%	3/6%	24/45%	4/8%	2/4%	4/8%	-	2/4%
Wood Pulp Fiber (Fertilpot)	7/13%	1/2%	4/7%	4/7%	24/44%	2/4%	5/9%	4/7%	2/4%	1/2%
Recycled Paper (Ellepot®)	6/10%	1/7%	6/10%	2/3%	21/36%	5/8%	5/8%	4/7%	3/5%	6/10%
Plastic	9/13%	1/4%	1/4%	3/4%	14/20%	-	7/10%	11/16%	2/3%	21/30%
Coconut coir (1 gallon or larger)	9/16%	2/4%	3/6%	1/2%	24/44%	5/9%	5/9%	3/6%	-	2/4%
Wood Pulp Fiber (Fertilpot 1 gallon or larger)	6/11%	1/2%	5/9%	4/7%	20/37%	5/9%	5/9%	5/9%	1/2%	2/4%
Plastic Container (1 gallon or larger)	9/13%	-	1/4%	1/4%	13/18%	3/4%	5/7%	11/15%	2/3%	26/37%

Table 4.9. Rating of container decomposition (1 = low, 10 = high) by landscapers/plant installers of plants grown in commercially-available manufactured containers.

Container Type	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
Processed Manure (CowPot™)	8/13%	1/2%	3/5%	2/3%	22/37%	2/3%	12/20%	6/10%	1/2%	3/5%
Peat (Jiffy-Pot®)	8/13%	2/3%	5/8%	3/5%	19/30%	7/11%	11/17%	7/11%	1/2%	1/2%
Coconut Coir	12/21%	2/4%	5/9%	3/5%	17/30%	4/7%	6/11%	5/9%	1/2%	2/4%
Wood Pulp Fiber (Fertilpot)	8/14%	2/4%	2/4%	3/5%	23/40%	5/9%	5/9%	5/9%	2/4%	2/4%
Recycled Paper (Ellepot®)	6/10%	2/3%	5/8%	2/3%	19/32%	6/10%	4/7%	6/10%	2/3%	7/12%
Plastic	53/73%	3/4%	1/1%	-	3/4%	2/3%	1/1%	-	1/3%	9/12%
Coconut coir (1 gallon or larger)	10/18%	1/2%	4/7%	7/12%	18/32%	5/9%	6/11%	4/7%	1/2%	1/2%
Wood Pulp Fiber (Fertilpot 1 gallon or larger)	9/16%	2/4%	5/9%	7/13%	16/29%	4/7%	8/14%	3/5%	1/2%	1/2%
Plastic Container (1 gallon or larger)	51/68%	4/5%	1/1%	-	3/4%	1/1%	1/1%	-	-	14/19%

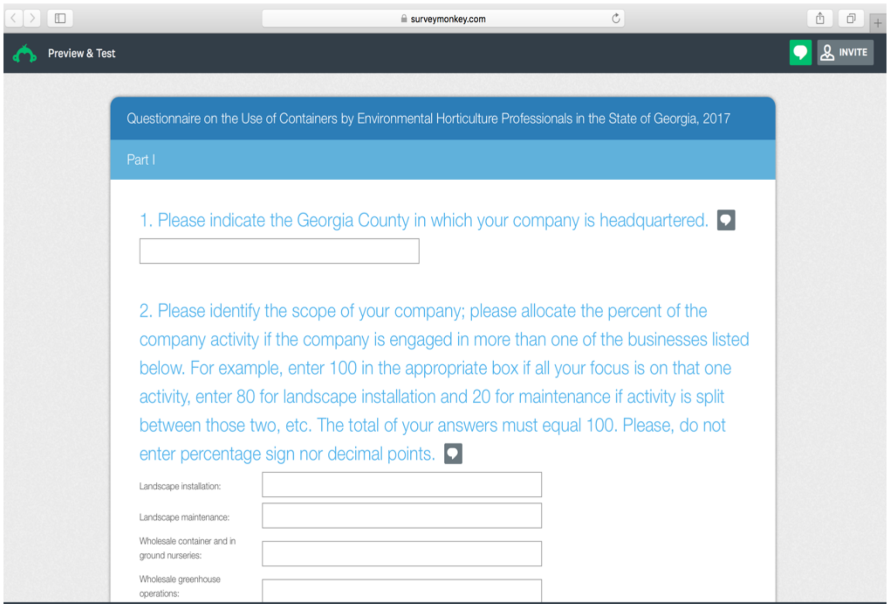

Figure 4.1. Computer display of survey on Survey Monkey Website.

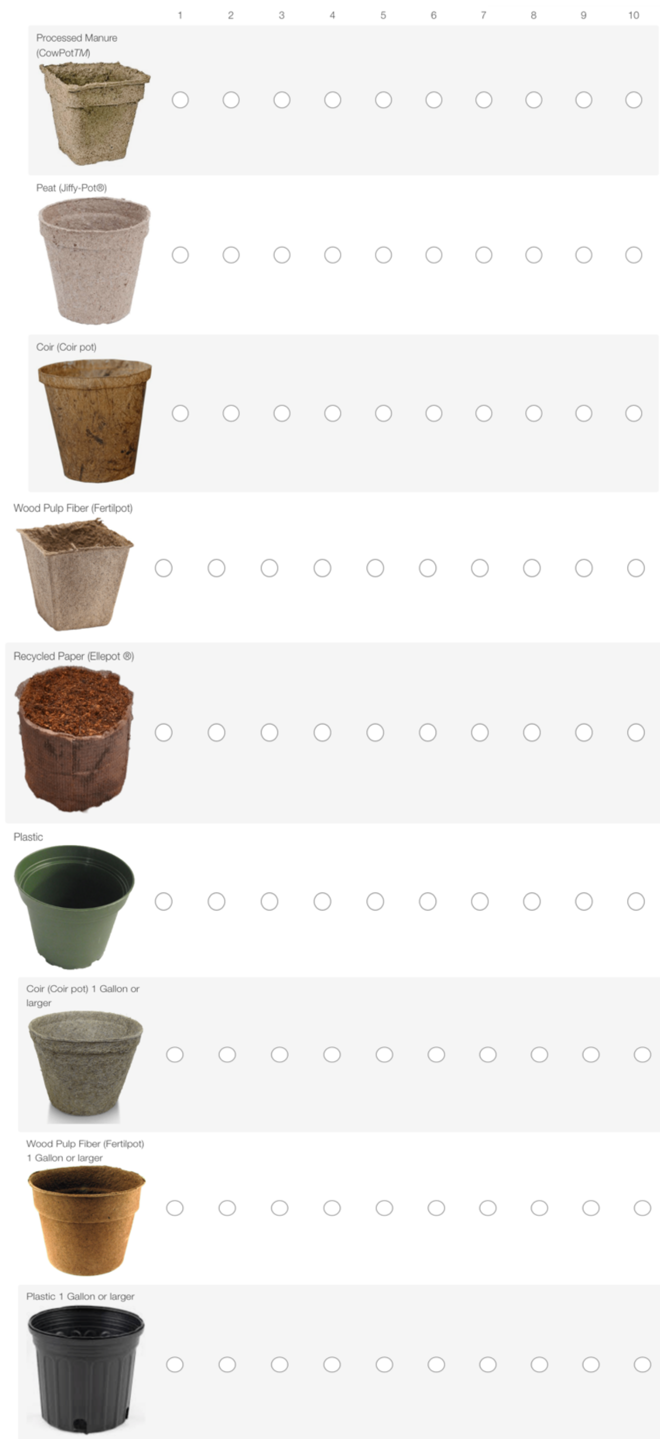

Figure 4.2. Display of manufactured biodegradable containers addressed in plant installers' survey questions regarding familiarity, plant growth, and container decomposition.

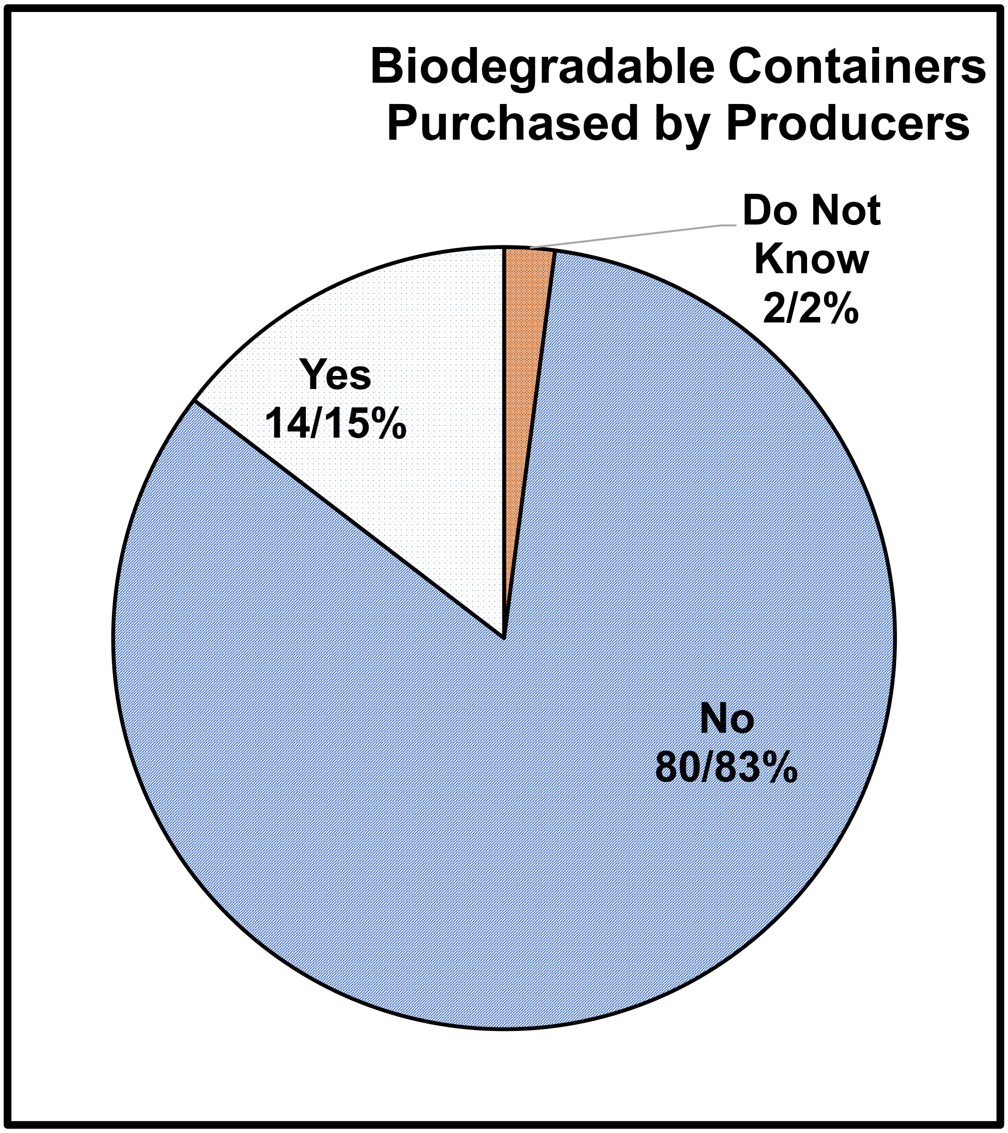

Figure 4.3. Frequency of horticultural producers that purchase biodegradable containers.

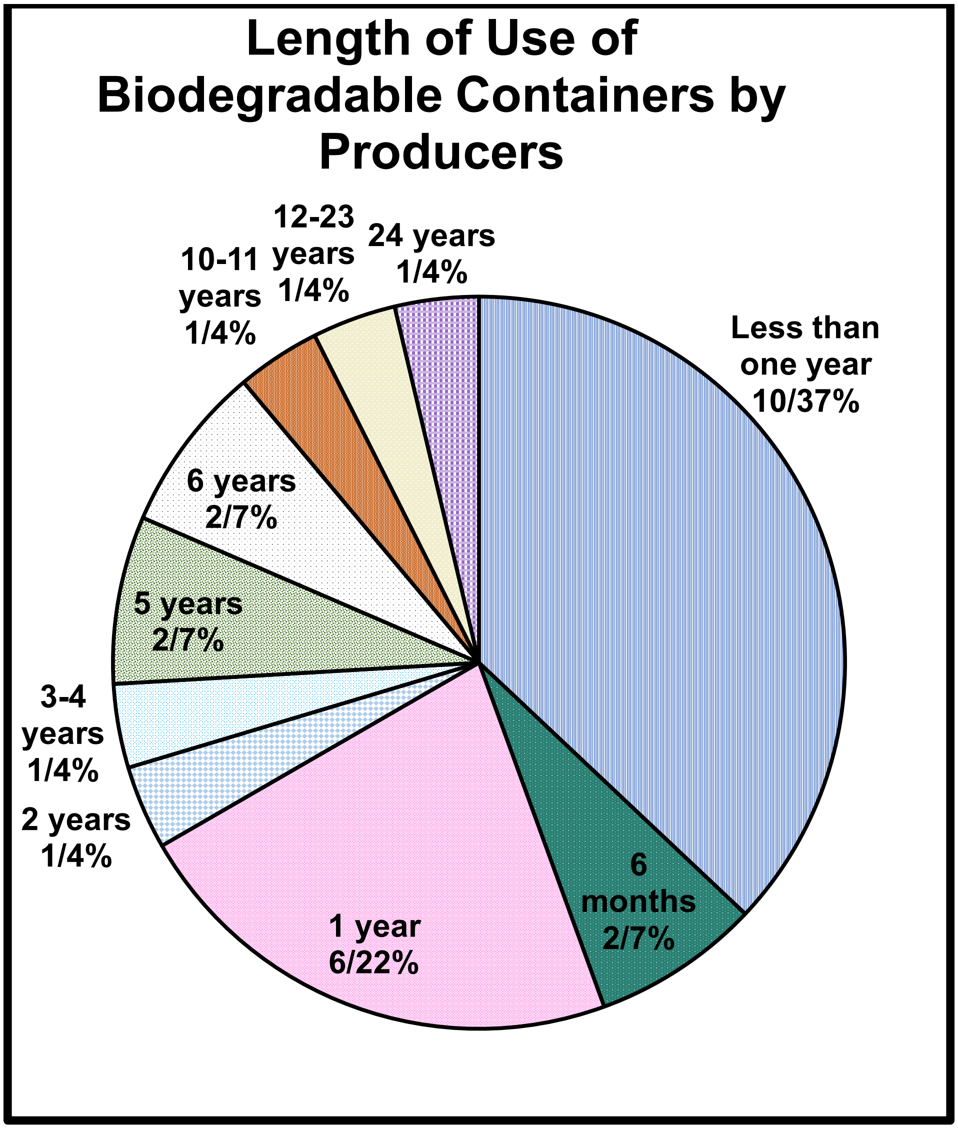

Figure 4.4. Frequency and length of use of biodegradable containers by horticultural producers.

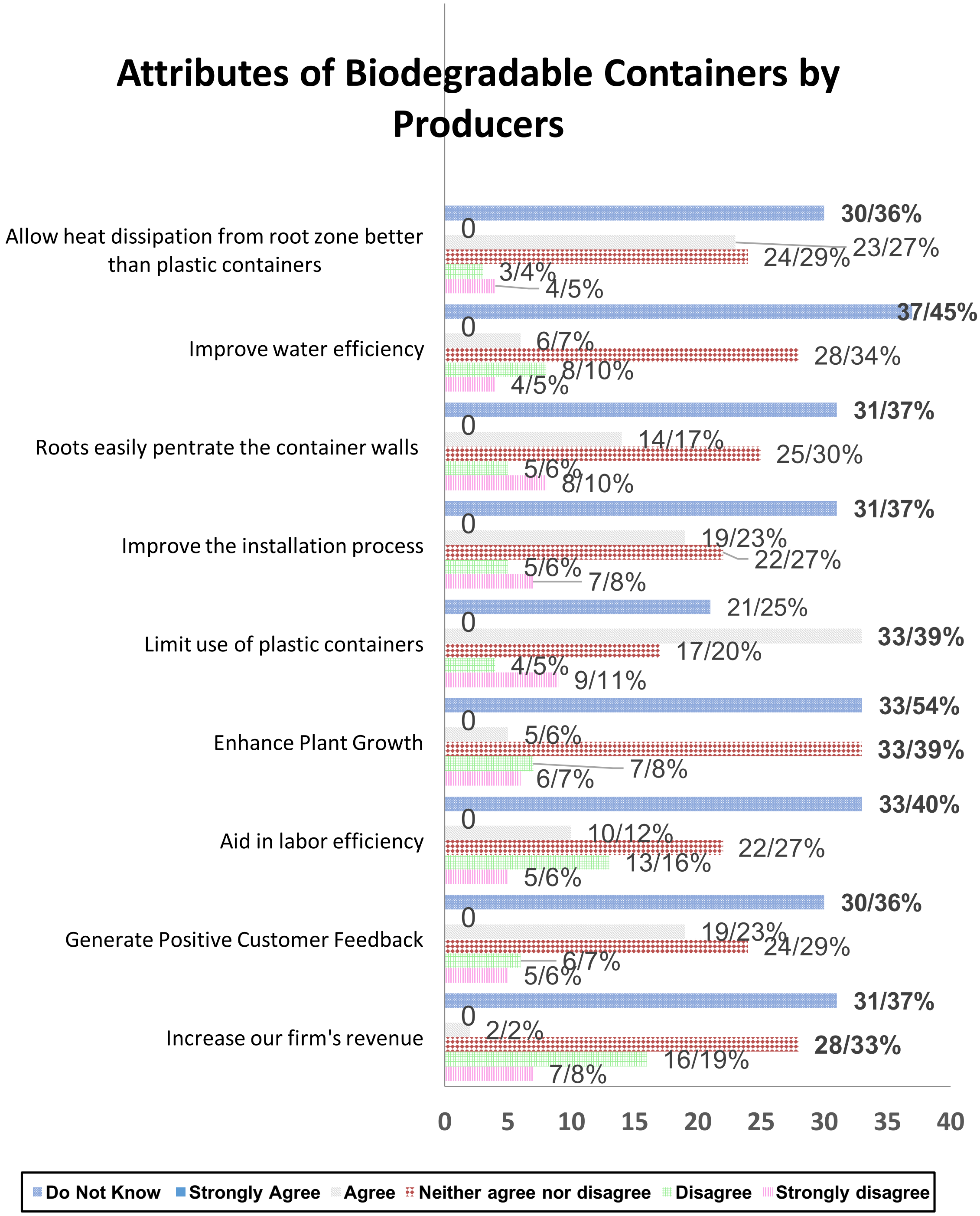

Figure 4.5. Respondents' opinion regarding their use of biodegradable containers.

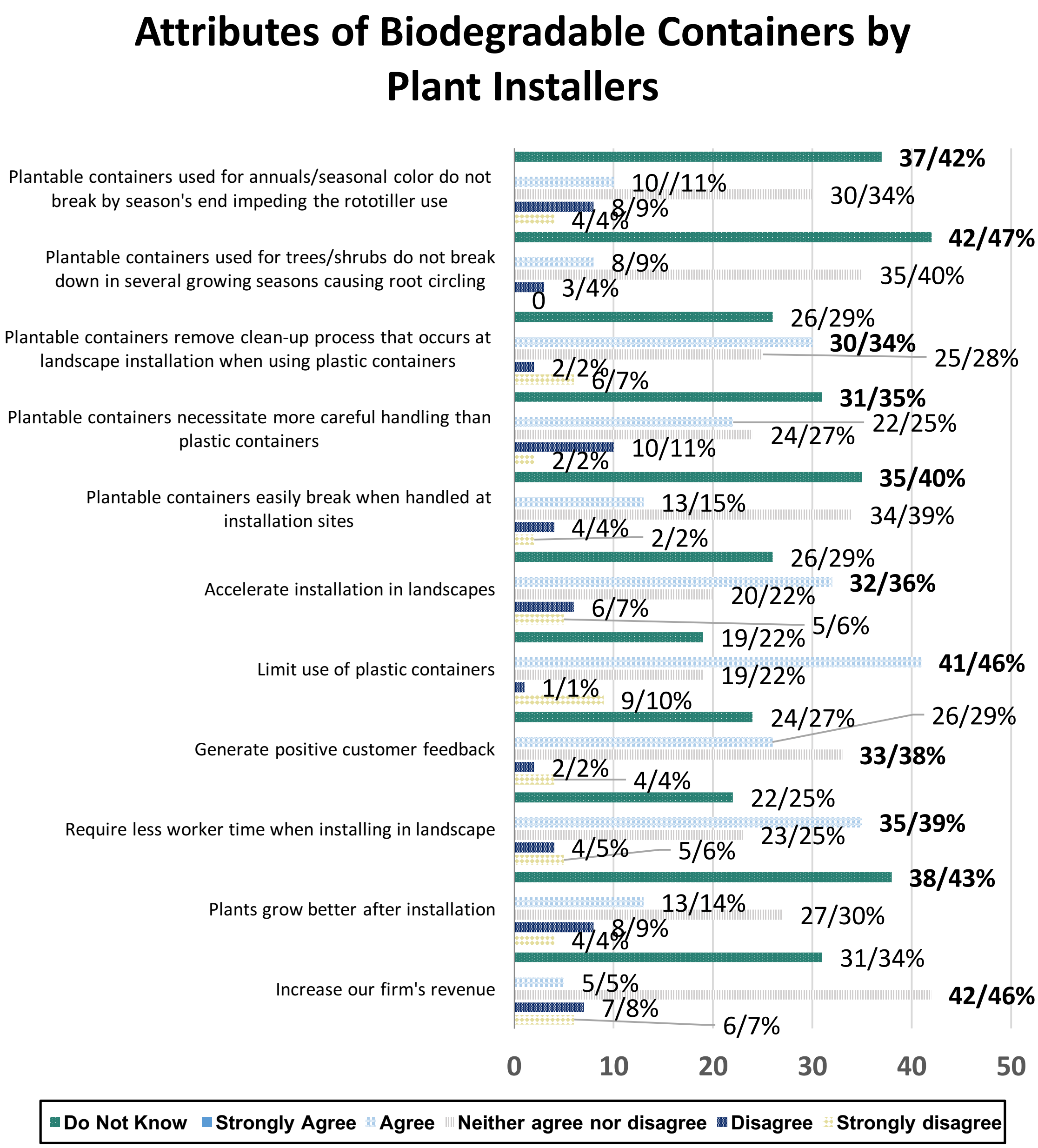

Figure 4.6. Plant installers' opinion regarding attributes of biodegradable containers.

CHAPTER 5

DO MICROBIAL INOCULANTS ENHANCE PLANT GROWTH: ASSESSMENT OF THEIR PERFORMANCE AND INTERACTION WITH CULTURAL PRACTICES

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ABSTRACT

Microbial inoculants, Effective Microorganisms-1 (EM) and Companion Biological Fungicide (CM) are commercially-available microbial products being used in nursery production and landscape installation to enhance plant growth. However, limited information is known regarding the effectiveness of these products on *Lantana camara*. It is also important to determine the influence of cultural practices such as fertilizer, irrigation, and soil amendment on soil microbial inoculation performance to better provide best management recommendations when utilizing these products during landscape installation and maintenance. EM and CM treatments both appeared to positively boost growth index (GI) when compared to untreated plants in 2016. However, in 2017, GI and inflorescence count was higher in untreated plants and in those treated with CM. Although microbial inoculants appeared to improve certain growth parameters, this response was significant only under favorable environmental conditions. From the data, it appeared that the microbial products, Effective Microorganims-1 (EM) and Companion Biological Fungicide (CM), may improve *L. camara* growth if plants are receiving higher irrigation than 2.54 cm irrigation/per week. Our study suggests that implementing use of microbial inoculants into a routine landscape maintenance program should only be considered after the costs (i.e. product and application) and site-specific environmental conditions and cultural practices are assessed.

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KEY WORDS Microbial Inoculants, Effective Microorganisms-1 (EM-1), Companion Biological Fungicide, Nitrogen Fertilizer, Irrigation, Soil Organic Amendment

Microbial inoculant products have become increasingly popular in horticulture crop production due to their potential to reduce the use of chemical fertilizers and pesticides while enhancing plant growth. Microbial products' ability to satisfy production efficiency, economic viability, and environmental compatibility have increased the number of microbial products being produced for agricultural and ornamental crops (Velivelli et al., 2014). Most products are biodegradable and organic, are a cost-effective option when compared to synthetic fertilizers, and may aid in limiting chemical inputs which can be toxic to bees and other wildlife (Sahoo et al., 2013).

Microbial inoculants are a "final product of one formulation containing a carrier and a bacterial agent or a consortium of microbes" (Ambrosini et al., 2016). There are two major categories of microorganisms are: plant-growth-promoting bacteria (PGPB) and arbuscular mycorrhizal fungi (AMF). The former consists of a large group of bacteria that contribute to plant growth in one of four ways as biofertilizers, rhizoremediators, phytostimulators, or as stress controllers (Toyota and Watanabe, 2012; Jha et al., 2013). These microbes can improve nutrient availability by fixing nitrogen, sequestering iron, oxidizing sulphur, or participating in phosphorus and potassium solubilization (Velivelli et al., 2014). Plant-growth-promoting bacteria are also involved in nutrient cycling (Lugtenberg and Kamilova, 2009). In ornamental plant production, plant-growth-promoting bacteria have served as biofertilizers to enhance growth of marigolds (Pushkar et al., 2008), petunias (Kumari and Prasad, 2017), and other horticultural plants (Ruzzi and Aroca, 2015).

Arbuscular mycorrhizal fungi contribute to plant defenses, supply water and nutrients through their hyphal network, and protect plants from biotic and abiotic stresses (Jakobsen et al., 1992). Research suggest AMF can improve drought, toxic metal, and salt resistance in plants (Wu and Xia, 2006). Several studies have affirmed use of arbuscular mycorrhizal fungi as plant disease defense agents in *Coleus* L. (Singh et al., 2018), *Chrysanthemum* L. (Hanudin et al, 2017), and in *Gerbera* L. (Panda et al., 2017). Gonzalez et al. (2016) and Arthurs and Bruck (2017) noted microbial products with arbuscular mycorrhizal fungi and other bacteria as plant biological control agents against phytophageous mites, wood-boring beetles/caterpillars, root-feeding weevils, defoliating beetles/caterpillars, and sap-feeding insects including aphids, whiteflies, and thrips.

Depending on the mode of action of the microbial inoculant and the type of pest, disease, or growth response, liquid or powder-based microbial products are typically applied as seed treatment, root dip, soil drench, or foliar spray (Metting, 1993). Benefits of utilizing a foliar spray include application of microbial inoculant on the plant at certain stage to encourage plant growth or at certain environmental conditions (i.e. moisture) when there an increased pest and/or disease pressure. Microbial sprays can also be applied more frequently throughout the growing season to effectively combat pest and diseases and improve crop growth and yield (Preininger et al., 2018). Direct soil application can be used in which the microbial product is distributed at the base of the plant near the root system; benefits include improved longevity and fewer applications (Bashan, 1998). Aside from commercially-available microbial products which consist of microorganisms which may not be native to the geographical region of application, use of locally-derived soil microorganisms are being utilized to improve decomposition, soil quality, and soil nutrient status (Hattabaugh, 2017; Ney et al., 2018).

However, several challenges have been associated with the wider adoption of microbial inoculants (Bashan et al. 2014). These include ability of the introduced microorganisms to adapt and compatibility with local environmental and soil conditions (Trabelsi and Mhamdi, 2013); the carrying capacity of the microorganisms which, influence effectiveness (Verbruggen et al., 2013);

limited shelf life, convenience of use, and cost effectiveness (Bashan, 1998). Additionally, there is an abundance of microbial products and formulations on the market, yet unbiased research for their effectiveness is limited. Such research is essential to provide practical recommendations that would facilitate adoption of commercially-available microbial products. In addition, each microbial formulation must be evaluated for a specific crop under certain environmental and soil conditions.

Several studies have indicated that microbial product, Effective Microorganisms (EM-1) have enhanced plant growth, yield, and biomass on crops such as wheat, spinach, barley, chard, rice, and corn (Hussain et al., 1999; Hu and Qi, 2013; Shaheen et al., 2017; Mouhamad et al., 2017). In field evaluations, EM-1 have been reported to increase growth in periwinkle (*Catharanthus roseus* L.) and marigold (*Calendula officinalis* L.) (Wolna-Maruwka et al., 2015; Pierce et al., 2016). Górski and Kleiber (2010) found EM-1 to increase flower number and diameter in roses (*Rosa x hybrid* L.) and Barberton daisies (*Gerbera jamesonii* Bolus ex. Hooker f.). Likewise, Companion Biological Fungicide has been reported to aid in growth stimulation and plant protection in chili (*Capsicum annuum* L.), tomato (*Solanum lycopersicum* L.), corn (*Zea mays* L.), and rice (*Oryza* sp. L.) (Udayashankar et al., 2011; Calvo et al., 2017; Dwi et al., 2017; Qiao et al., 2017).

Interest in 'green' products to improve plant performance has been increasing both in the production (Harris and Russell, pers. comm.) and the landscape industry, particularly for turf (Harris and Hoban, pers. comm.) and annuals (Harris and Hardgrave, pers. comm.). Previous research at the University of Georgia has targeted the use of commercially-available microbial products in turf (Diera et al., 2017). Limited information exists regarding potential of microbial products to enhance plant growth in landscape annuals under Georgia conditions. To date, the focus of published works has solely addressed plant growth; however, to the best of our knowledge no research has explored potential interactions between microbial inoculants and specific cultural practices (i.e. irrigation, fertilizer, and soil amendment). The goal of this research is to furnish information on plant performance as impacted by microbial inoculants and cultural factors. The specific objectives were to compare effectiveness of foliar- and soil drench-applied microbial inoculants to enhance plant growth and explore potential interactions between microbial inoculants and specific fertilizer, irrigation, and soil amendment effects. The ultimate goal of these analyses was to determine the importance of the interactions between the main effects because significant interactions indicate that maximum lantana growth is best achieved by specific combinations of the effects.

Lantana camara L. is a herbaceous annual/perennial plant was chosen for this study due to popularity as an annual selection for full sun color beds, adaptability to southeastern landscapes, drought tolerance, and high attractiveness to Lepidoptera (Bruner et al., 2008; Harris et al., 2016).

Materials and Methods

Field studies were conducted in 2016 and repeated in 2017 at the University of Georgia Research and Education Garden (33°24’67”N 84°26’40”W, USDA Hardiness zone 8a, Spalding Co., GA, soil series: Lloyd; clay loam). Over the period of May to October, the total rainfall amount at this location was 31.6 cm (2016) and 62.4 cm (2017).

Experimental Design, Plot Layout, and Treatment Applications

Field plots (2 plots, 232.3 m^2 each, at distance of 22.8 meters apart) were established in native soil in a Split-Strip Plot Design (Fig. 5.1.). The fertilization treatments were applied as follows. Field plots received fertilizer (10N-10P_2O_5-10K_2O, Pennington Seed, Inc., Madison, GA): 1 lb per 9.3 square meters was applied to entire plot at transplant. Fertilizer was and rototilled at depth of 15.2 cm. Vertical strip plots (116.1 m^2 each) within each larger plot (232.3 m^2) received 1 lb fertilizer per 9.3 square meters at transplant only ("LF") or 1 lb fertilizer per 9.3 square meters at transplant and additional 0.02 lb slow release fertilizer ($12N-4P_2O_5-8K_2O$, Miracle Gro Shake n' Feed Slow Release Fertilizer, Scotts Miracle-Gro Company, Marysville, OH) applied to immediate root area of plants at four and eight week post-transplant ("HF"; Fig. 5.1.).

The vertical strips (2 strips per 232.3m^2 research plot, 116.1 m^2 each) were split into four subplots (58.0 m^2 each) in which two subplots were amended with pine bark (Pine Bark Humus, Nature's Choice Inc., Glennville, GA) at a rate of 7.6 cm per 9.3 square meters at depth of 15.2 cm utilizing tine tiller ("AM"; Fig. 5.1.). Two subplots (58.0 m^2) did not receive pine bark amendment treatment ("UN"). Low and high fertilizer treatments and pine bark application were selected according to standard recommendations for summer annuals (Chappell and Pennisi, 2006).

Irrigation Application and Amount

The field plots were irrigated with overhead sprinklers (Hunter Industries Controller with MP Rotator heads on risers, San Marcos, CA, USA; Fig. 5.1.). Irrigation treatments were 2.54 cm water/per week (66.0 cm for 26 weeks, "LI") or 3.81 cm water/per week (99.1 cm for 26 weeks, "HI"). Irrigation treatments were selected based on general recommendations of 2.54 cm water /per week for summer annuals (Henson et al., 2006; Zlesak et al., 2014). Although utilizing the same irrigation system and in the same location, the 2017 study was conducted in area immediately adjacent to the 2016 study and in soil that had been left fallow in 2016.

Plant Material

Lantana (*Lantana camara* L. 'Lucky Red Flame' 'Balandimfla', standard size: 50 mm) plants produced in Ellepot® paper sleeves were obtained from a local commercial source. Planting took place the first week of May 2016 and 2017. In the field, *L. camara* plants were spaced 35 cm apart (Fig. 5.2.). Each amendment treatment subplot within each fertilizer vertical strip plot contained ten *L. camara* plants per microbial inoculant treatment (3 microbial inoculant treatments x 10 *L. camara* plants = yielded 30 plants (Fig. 5.1.). There were a total of 120 plants per field plot. No pesticides were used for pest control throughout the study and weed control was manual.

<u>Microbial Inoculants: Treatment Application and Viability Assessment</u>

Microbial inoculant products were chosen based on mode of delivery (foliar and drench), commercial availability, and reported enhancement to plant growth (Udayashankar et al., 2011; Wolna-Maruwka et al., 2015; Pierce et al., 2016; Dwi et al., 2017). Two microbial products were used in this study; Companion Biological Fungicide (Growth Products, Ltd., White Plains, NY, *Bacillus subtilis* Ehrenberg) and Effective Microorganisms-1 (TeraGanix, Inc., Alto, TX, *Lactobacillus plantarum* Orla-Jensen, *Lactobacillus casei* Orla-Jensen, *Lactobacillus fermentum* Beijerinck, *Lactobacillus delbrueckii* Orla-Jensen, *Bacillus subtilis* Ehrenberg, *Saccharomyces cerevisiae* Meyen, and *Rhodopseudomonas palustris* Molisch). Companion Biological Fungicide (abbr. CM) was mixed at label rate of 10 mL of product per 4 L of water. Each plant received 378 ml mixed product per 0.09 m^2 of plant soil area per label specification. Drench application of microbial product occurred monthly from June to October 2016 and 2017.

The second microbial inoculant, Effective Microorganisms-1 (abbr. EM) was applied utilizing a calibrated backpack sprayer [Smith Max Professional Series Backpack Sprayer, 15.1 L, 25 psi regulator, spray nozzle: low volume flat fan (0.15 Gallon Per Minute, 30 ° fan), New York Mills, NY] to plant foliage biweekly from June to October 2016 and 2017 (Fig. 5.3.). The microbial product was mixed at label rate of 29 mL of product per 3.78 L of water. Plants were sprayed with EM-1 solution until leaves were completely wet and solution ran off the leaves. To ensure uniformity, spray application was timed for each plant. Application amounts were increased as plants grew as per manufacturer's directions and consisted of: 50 ml on June 23, 100 ml on July 8 and 22, 150 ml on August 12 and 26, 200 ml on September 9 and 23, and 250 ml on October 7 and 21 in 2016 and 2017. No foliar adjuvants were used during application to eliminate any possible negative effect on the microbial product. The control plant received no microbial inoculant.

Microbial Product Plating and Colony Forming Unit (CFU) Count

Prior to application in the field, both microbial products were assessed for viability using standard-spread plating protocols as outlined below (Sanders, 2012). For bacterial isolation, the Effective-Microorganisms and Companion Biological Fungicide products were plated on nutrient agar at 10^{-2} - 10^{-7} dilutions (two plates per dilution). Likewise, to assess and isolate fungi, the Effective-Microorganisms-1 product was plated on Rose-Bengal glucose (RBG) plates at 10^{-2} - 10^{-7} dilutions (two plates per dilution). Bacterial plates were incubated in the dark in an inverted position at 30°C for 7 days. Fungal plates were incubated for 14 days. The average bacterial colony forming units (CFU) on a standard agar plate at dilution 10^{-3} for Companion Biological Fungicide was 31 CFUs or 31 X 10^3 CFU per ml of product and for Effective Microorganisms-1 at a dilution of 10^{-2} was 46 bacterial CFUs or 46 x 10^2 per ml of product and 31 fungal CFUS or 31 x 10^2 per ml of product. The accepted range of bacterial colony forming units on a standard agar plate is between 25-250 CFUs and fungal counts on a standard agar plate is between 8-80 CFUs (Sutton, 2011).

Plant and Soil Measurements

Plant growth was assessed through the following morphological parameters: growth index, number of inflorescences, and shoot dry weight. Plant measurements were collected at the end of every month over a five-date period from June to October 2016 and 2017. Plant height (H, cm, measured from soil surface to top growing point) and two widths (W1, widest and W2, perpendicular to W1, cm) were measured and used to calculate growth index (GI) according Olberg and Lopez (2017) using the following formula: [(H + W1+ W2)/3]. Total number of inflorescences (corymb count open and exhibiting color) were counted.

Chlorophyll content was measured using SPAD-502 chlorophyll meter (unitless, Minolta Co., Osaka, Japan) according to Fanizza et al. (1991) in the field between 10:00 a.m. and 11:00 a.m. to assess the degree of abiotic and biotic stress on plant performance. The adaxial side of the last fully mature leaf was placed toward the emitting window of the instrument and major veins were avoided. Chlorophyll fluorescence (Fv'/Fm', Fluorpen FP-100 Max, Photon System Instruments, Brno, Czech Republic) also was measured in a light adapted state according to Baker (2008) to assess plant photosynthetic mechanisms and environmental stress impact. Similarly to chlorophyll content, the adaxial side of the last fully mature leaf was placed toward the emitting window of the chlorophyll fluorescence instrument. Measurements took place between 10:00 a.m. and 11:00 a.m.

Shoot dry weight (g) was determined after six months at experiment termination. Plant shoots were dried in a drying oven (ThermoFisher, Inc., Precision Compact Gravity Convection Oven, Model 3510, Waltham, MA) at 65 °C for a one week and weighed. After drying, plant tissue analysis was performed by the University of Georgia Agricultural and Environmental Services Laboratory (Clarke Co., GA).

Soil measurements were collected at the end of every month over a five-date period from June to October 2016 and 2017 (8 sample measurements per month). Soil temperature (°C) was assessed at a depth of 10.2 cm using the Hanna Instrument 99121 Soil temperature probe (Hanna Instruments, Woonsocket, RI). Soil moisture (% volumetric water content) also was measured at

10.2 cm depth using the time domain reflectometer probe (FieldScout® TDR 300 Soil Moisture Meter, Spectrum Technologies, Bridgend, United Kingdom, 10.2 cm length prongs). Average monthly rainfall data was also collected using the University of Georgia Weather Network (http://www.georgiaweather.net, Griffin weather station).

Statistical Analysis

Growth index (GI), chlorophyll content, chlorophyll fluorescence, and shoot dry weight (SDW) data was analyzed using Mixed Procedure (PROC MIXED) of SAS (SAS Institute, 2010) with means separated with Least Squares Means. Count data (inflorescence number) was analyzed using General Linear Mixed Model (PROC GLIMMIX) with means separated using Least Squares Means. Microbial inoculant, fertilizer, irrigation and soil amendment were treated as main effects and analyzed as well as their interaction effects. Means were separated using Least Square Means procedure.

Results

Morphological Parameters: Growth Index (GI) 2016

Irrigation x fertilizer interaction was significant with higher GI in plants under low irrigation x low fertilizer, low irrigation x high fertilizer, high irrigation x low fertilizer when compared to high irrigation x high fertilizer treatment (Table 5.1.). Irrigation x soil amendment also significantly influenced plant growth with higher GI under low irrigation x amended treatment as compared to low irrigation x unamended, high irrigation x unamended, and high irrigation x amended treatments. Irrigation x microbial inoculant interaction effect was significant. Plants under low irrigation x no inoculant (NM), low irrigation x EM, low irrigation x CM, high irrigation x EM, high irrigation x CM as compared to high irrigation x NM treatment. Amendment x inoculant interaction effects were also significant with increased plant growth index observed in plants under amended x EM, unamended x CM, and amended x NM as compared to unamended x EM, amended x CM, and unamended x NM treatments. Under the amended treatment (91.1), the control (NM) had higher GI as compared to under the unamended treatment (85.3; Fig. 5.4.). Likewise, lantana plants applied with the EM product and grown in the amended soil (97.8) had increased GI as compared to those grown in unamended soil (90.3). Plants treated with the CM product had greater GI when under the unamended soil (94.2) as compared to the amended soil (87.9; Fig. 5.4.). The interaction effects of fertilizer x soil amendment and fertilizer x microbial inoculant were not significant.

Lantana growth index was significantly influenced by the main effects of irrigation and fertilizer; GI was higher in plants receiving 2.54 cm water/per week as compared to 3.81 cm/per week (Table 5.1.). Likewise, plants receiving low fertilizer had higher GI as compared to those grown under high fertilizer (Table 5.1.). Furthermore, the main effect of microbial inoculant significantly influenced GI with greater numbers in plants treated with Effective Microorganisms-1 (EM) as compared to Companion Biological Fungicide (CM) and the control (no microbial inoculant, NM). Soil amendment main effect was not significant (Table 5.1.).

Both types of microbial inoculants appeared similar in their effect for months 1-4 with average GI slightly lower for the control (no microbial inoculant, NM; Fig. 5.5.). However, at month 5, EM had higher GI (94.1) as compared to CM (91.1) and control (NM, 88.2; Fig. 5.5.).

<u>Morphological Parameters: Shoot Dry Weight (g) 2016</u>

The main effect of irrigation significantly impacted shoot dry weight (SDW). Higher values were observed in plants receiving 2.54 cm irrigation/per week as compared to 3.81 cm irrigation/per week (Table 5.1.). However, fertilizer, soil amendment, and microbial inoculant main effects were not significant. The interaction effects: irrigation x fertilizer, irrigation x soil amendment, irrigation x microbial inoculant, fertilizer x soil amendment, fertilizer x microbial inoculant, and amendment x microbial inoculant were not significant (Table 5.1.).

Morphological Parameters: 2017 Growth Index (GI)

The main effects of fertilizer and microbial inoculant (Table 5.2.) significantly influenced growth in lantana. Plant GI was greater under high fertilizer as compared to low fertilizer treatment. Likewise, plants receiving no inoculant (NM) and CM microbial inoculant had greater growth as compared to EM. The main effects of irrigation and soil amendment were not significant. Likewise, irrigation x fertilizer, irrigation x soil amendment, irrigation x microbial inoculant, fertilizer x soil amendment, fertilizer x microbial inoculant, and soil amendment x microbial inoculant interactions were not significant (Table 5.2.). Both EM and CM appeared similar in their effect on GI for months 1-5 with the control (NM) having highest values (Fig. 5.6.). At month 5, the control (NM) had highest GI (60.3) followed by CM (55.7) and EM (53.8; Fig. 5.6.).

Morphological Parameters: 2017 Shoot Dry Weight (g)

The interaction of irrigation x soil amendment was significant with plants under low irrigation x amended treatment and high irrigation x amended treatment having greater SDW compared to other treatments. All other interaction effects were not significant. The main effects of fertilizer and soil amendment significantly impacted SDW. Lantana plants under high fertilizer had greater SDW (Table 5.2.) as compared to low fertilizer treatment. Greater SDW values were observed in lantana growing in amended soil as compared unamended treatments. The main effects of irrigation and microbial inoculant were not significant.

Morphological Parameters: 2016 Inflorescence Counts

Higher number of inflorescences were observed in lantana under low irrigation x unamended and low irrigation x amended treatments as compared to other treatments. Greater number of inflorescences were observed in plants under high fertilizer x unamended, low fertilizer x unamended, and low fertilizer x amended treatments. Inflorescence counts were highest in plants under unamended soil with either microbial inoculant treatment. The other interactions were not significant. Irrigation x soil amendment, fertilizer x soil amendment, and soil amendment x microbial inoculant interactions were significant._The main effects of irrigation and soil amendment significantly impacted total inflorescences. Lantana receiving 2.54 cm irrigation/per week had higher inflorescences as compared to those receiving 3.81 cm irrigation/per week (Table 5.3.). Likewise, inflorescence counts were greater in plants growing in unamended soil as compared to those grown in amended one. The main effects of fertilizer and microbial inoculant were not significant.

Morphological Parameters: 2017 Inflorescence Counts

Fertilizer x soil amendment was significant with lantana under high fertilizer x and unamended treatment having higher inflorescence numbers as compared to other treatments. The other interaction effects were not significant. Main effects of fertilizer and microbial inoculant significantly influenced total number of inflorescences. (Table 5.4.). Higher inflorescence counts were observed in plants under low fertilizer as compared to high fertilizer. Additionally, lantana which did not receive microbial inoculant (NM) and those receiving CM had largest number of inflorescences as compared to those receiving EM. The main effects of irrigation and soil amendment were not significant.

Physiological Parameters: 2016 Chlorophyll Content and Fluorescence

For chlorophyll content, the interaction effect of irrigation x fertilizer was significant. Higher chlorophyll content was observed in lantana under low irrigation x high fertilizer and low irrigation x low fertilizer as compared to other treatments. For chlorophyll fluorescence, the interaction effect of soil amendment x microbial inoculant was significant. Plants under unamended x NM, amended x CM, amended x EM, unamended x CM, and unamended x EM had higher chlorophyll fluorescence as compared to amended x NM treatment (Table 5.5.). The other interaction effects were not significant. Irrigation significantly impacted chlorophyll content, with lantana receiving 2.54 cm irrigation/per week having greater values as compared to plants receiving 3.81 cm irrigation/per week (Table 5.5.). Chlorophyll fluorescence was also significantly influenced by irrigation but the opposite trend was observed, plants receiving higher irrigation exhibited greater values than lantana under low irrigation. The main effects of fertilizer, soil amendment, and microbial inoculant did not significantly impact chlorophyll content nor chlorophyll fluorescence.

Physiological Parameters: 2017 Chlorophyll Content and Fluorescence

The main effect of fertilizer significantly influenced chlorophyll content with plants under high fertilizer treatment having greater chlorophyll content readings (Table 5.6.). The main effects of irrigation, soil amendment, and microbial inoculant were not significant for chlorophyll content and there were no significant interaction effects. Chlorophyll fluorescence was not significantly impacted by the main effects of irrigation, fertilizer, soil amendment, or microbial inoculant. Likewise, there were no significant interaction effects for chlorophyll fluorescence.

Plant Tissue Analysis: 2016 and 2017

Plant tissue analysis revealed that lantana grown under the various treatments (i.e. irrigation, fertilizer, soil amendment, and microbial inoculant) in this study were within acceptable ranges (refer to App., Table 5.8.).

Soil Temperature, Moisture, and pH: 2016 and 2017

Soil temperature was highest in September 2016 (33.8 °C) and in June 2017 (31.6 °C; Figs. 5.7. and 5.8.). Soil moisture content (% volumetric water content) was highest in August 2016 (15.2) and in September 2017 (28; Figs. 5.7. and 5.8.).

Discussion

With respect to the first research question of the study, we found that microbial inoculants significantly influenced GI and inflorescence number in lantana (Tables 5.1., 5.2., 5.4.). Effective Microorganims-1 (EM) and Companion Biological Fungicide (CM) both appeared to positively boost GI when compared to untreated plants in 2016. However, in 2017, GI and inflorescence count was higher in untreated plants and in those treated with CM. With regards to mode of application (i.e. drench or foliar), in 2016, we observed higher GI for foliar application (EM). However, in 2017, drench application resulted in larger plants (CM). However, SDW was not significantly impacted by microbial inoculants in either year (Tables 5.1. and 5.4.). This means that larger plants resulted from increased tissue water content.

These inconsistent results in microbial inoculant performance may be attributed to variation in environmental and climatic conditions from year to year. The weeks immediately following planting are critical for plant establishment and sustained growth throughout the season. Upon closer examination (Fig. 5.8.), there was an increased rainfall in June 2017 with soil water content rising to 24 (% volumetric water content) as compared to 13.6 for the same month in 2016 which may have affected the results. Further analysis revealed that microbial inoculant did not significantly impact GI for June 2017 (refer to App., Table 5.7.).

Similarly, several published reports have indicated limited or no effects of EM-1 to positively enhance yield or plant growth of sweet basil (*Ocimum basilicum* L.) and lettuce (*Lactuca sativa* L.) (Fraszczak et al., 2012; Szczech et al., 2016). Research observed the main strain of fungi *Bacillus subtilis* in the Companion Biological Fungicide has been variable in its effect on plant growth parameters including total fresh weight, plant height, and SPAD values for summer squash (*Cucurbita pepo* L.) and cantaloupe (*Cucumis melo* Ser.) (Zhang et al., 2011).

With respect to the second research question, namely existence of potential interactions between microbial inoculants and specific cultural effects, we observed that in 2016, microbial inoculant x soil amendment interactions significantly impacted GI and number of inflorescences (Tables 5.1. and 5.3.). Under the control (NM), higher GI was observed in plants in amended soil as compared to unamended soil. Similarly, lantana receiving the Effective Microorganisms (EM) treatment had increased GI when compared to those receiving EM and under unamended soil. This suggests enhancement of EM product performance when soils are amended with organic matter. The opposite trend in GI was seen for Companion Biological Fungicide (CM)-treated plants under amended vs. unamended soil (Fig. 5.4.). However, for inflorescence counts, plants treated with either microbial product growing in unamended soil developed larger number of inflorescences (e.g. CM, 122) as compared to those grown in amended soil (e.g. CM, 94). With regards to physiological parameters, although the same interaction (i.e. microbial inoculant x soil amendment) was significant for chlorophyll fluorescence (Table 5.4.), all values were within the acceptable range for unstressed plants (Baker, 2008; Bacarin et al., 2016).

Aside from microbial inoculants, cultural practices not surprisingly, influenced lantana growth during the first year of the study. In 2016, plants exhibited higher GI, inflorescence number, shoot dry weight, and chlorophyll content under 2.54 cm irrigation/per week (Tables 5.1., 5.3., 5.5.). *Lantana camara* is adapted to lower soil moisture being indigenous to Australia and the tropical regions of Africa and South America (Ow et al., 2011; MacDonald et al., 2018). Previous research has well documented increased growth (e.g. higher GI, inflorescence counts, increased fresh weight) under lower irrigation or dry conditions (Henley et al., 2000; Starman and Lombardini, 2006; Castillo et al., 2007; Bayer et al., 2013). SPAD values for chlorophyll content were in the acceptable range for annual bedding plants and in agreement with Turner and Wang et al. (2004), Wang et al. (2012a) and Dunn et al. (2015) studies. Although chlorophyll fluorescence (Fv/Fm) values were significantly higher under 3.81 cm irrigation/per week (Table 5.5.), the values for lower irrigation were within the acceptable range for non-stressed plants (Baker, 2008; Bacarin et al., 2016). In the second year of the study, irrigation did not significantly affect plant morphological or physiological parameters (Table 5.2., 5.4., 5.6.).

Fertilizer significantly influenced GI both in 2016 and 2017. There was higher GI (2016) and inflorescences (2017) under low fertilizer treatment. However, in 2017, plants under high fertilizer treatment had increased GI and SDW. Several studies have shown increases in number of inflorescences, shoot dry weight, growth index, and overall growth of annual bedding plants such as impatiens, petunia, salvia, and vinca grown under higher nitrogen levels (van Iersel et al., 1998; Shurberg et al., 2012; Combareto et al. 2013; Kumari and Prasad, 2017). Although chlorophyll content values were within acceptable range, increased chlorophyll content was observed in lantana under the high fertilizer treatment in 2017. Shurberg et al. (2012) and Wang et al. (2012b) reported higher SPAD (chlorophyll content) values with increased nitrogen fertilization rates and contributed this response to the nitrogen content in the leaves. In 2016, there was significant irrigation x fertilizer interactions for GI and chlorophyll content. Plants under low irrigation x low fertilizer and low irrigation x high fertilizer had increased growth and chlorophyll content (Tables 5.1. and 5.5.). This may be attributed to the reduced water requirement by *L. camara* and less nitrogen leaching under the low irrigation treatment (Erickson et al., 2001). Plant tissue analysis revealed that lantana grown under both fertilizer treatments were within acceptable ranges (refer to App., Table 5.8.).

With regards to soil amendment, inflorescence number (2016) and shoot dry weight (2017) was significantly impacted. However, the effect was inconsistent; *L. camara* grown in unamended soil exhibited higher inflorescence counts in 2016 and increased SDW when grown in amended soil in 2017. Pine bark is a widely-used soil amendment that has been reported to improve soil water retention, infiltration, and mineral content as well as aid in root development (Jackson et al., 2009; Taylor et al., 2012). Numerous studies have reported pine bark amendment to enhance plant growth in numerous horticultural crops (Pudelski and Pirog, 1984; Roeber and Leinfelder, 1997; Gruda et al., 2004; Wright and Browder, 2005; Wright et al., 2006; Boyer et al., 2008; Jackson et al., 2008a; Jackson et al., 2008b; Wright et al., 2008). While the current study indicated variable growth response regarding certain growth parameters (i.e. inflorescence counts) in unamended vs. amended soil, overall floral and plant performance was satisfactory.

In summary, although microbial inoculants appeared to boost certain plant growth parameters in lantana, the effect was significant only under favorable environmental conditions and was modest in practical terms. From the data, it appears that the microbial products, Effective Microorganims-1 (EM) and Companion Biological Fungicide (CM), may improve *L. camara* growth if plants are receiving higher irrigation than 2.54 cm irrigation/per week, however, if soil moisture content exceeds tolerance levels for healthy growth, this recommendation cannot be made. Based on this study, incorporation of microbial inoculants into a routine landscape maintenance program should only be considered after the economic costs of product and application and site-specific environmental conditions and cultural practices are evaluated.

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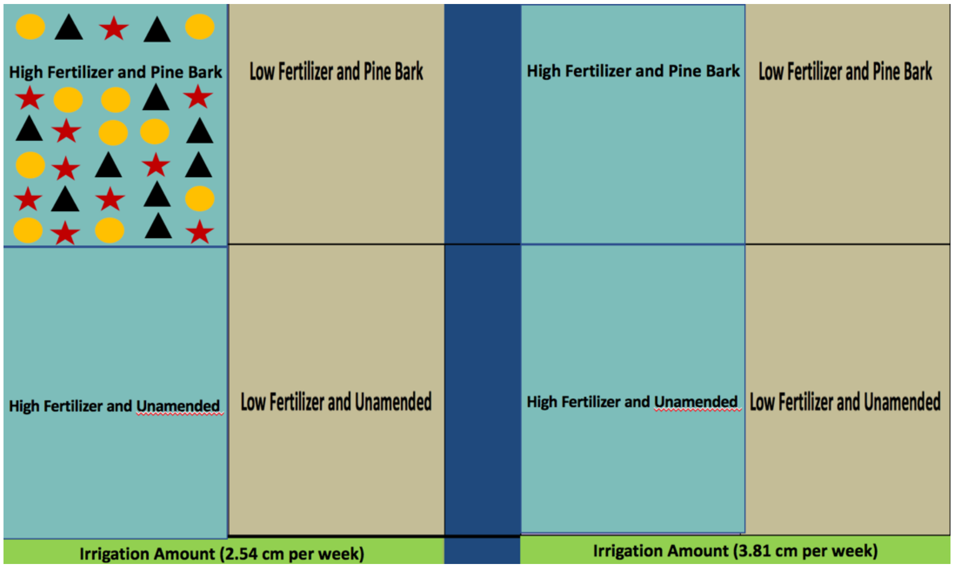


Figure 5.1. Field plots (232.3 m^2) with each irrigation treatment in Split-Strip Plot Design with vertical fertilizer strip (116.1 m^2 each) treatments and soil amendment subplots (58.0 m^2 each).

Figure 5.2. *Lantana camara* plants in field marked using color flags with respective microbial inoculant treatment.

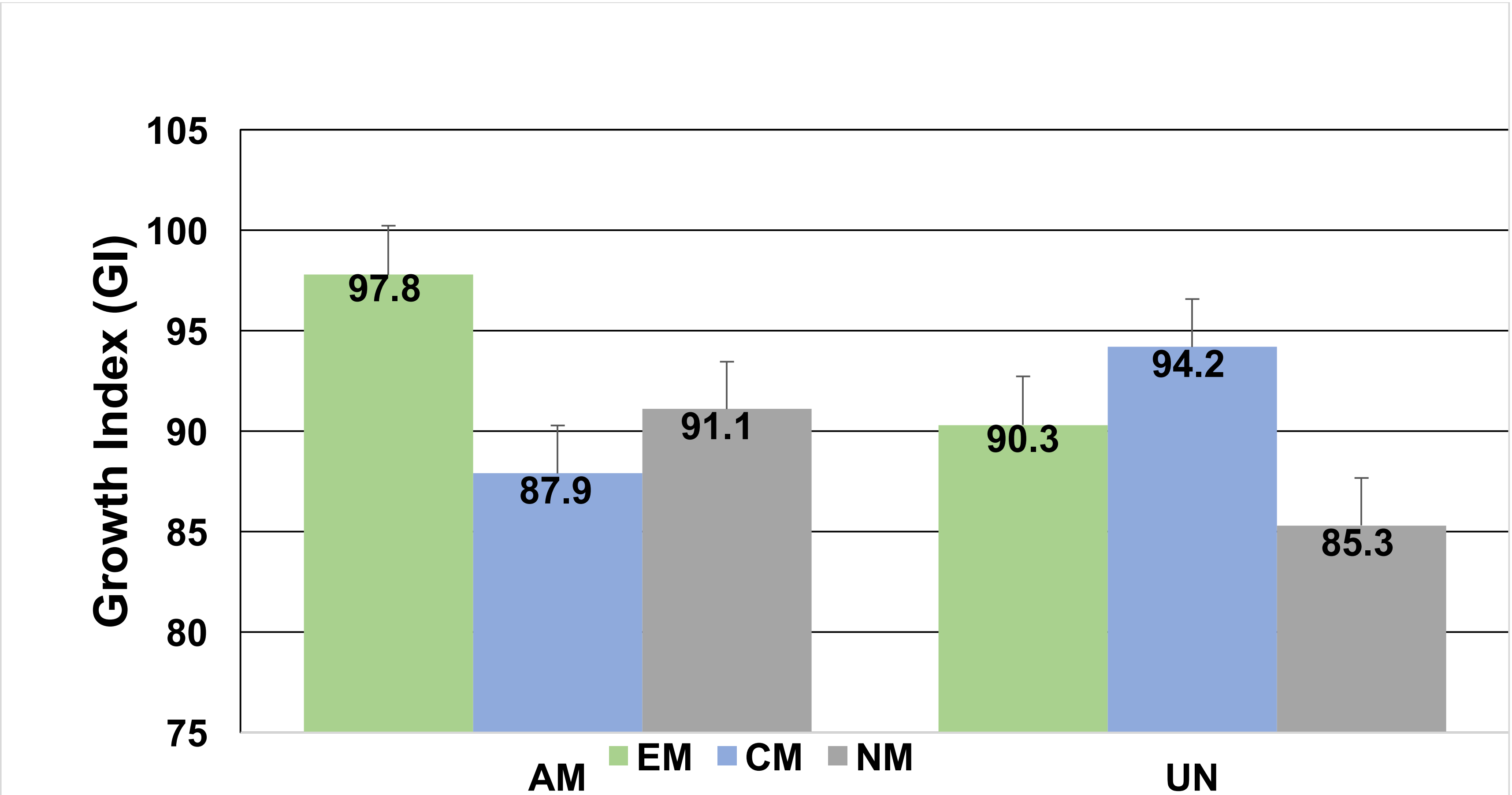
Figure 5.3. Effective Microorganisms-1 product being applied to the foliage of *L. camara*.

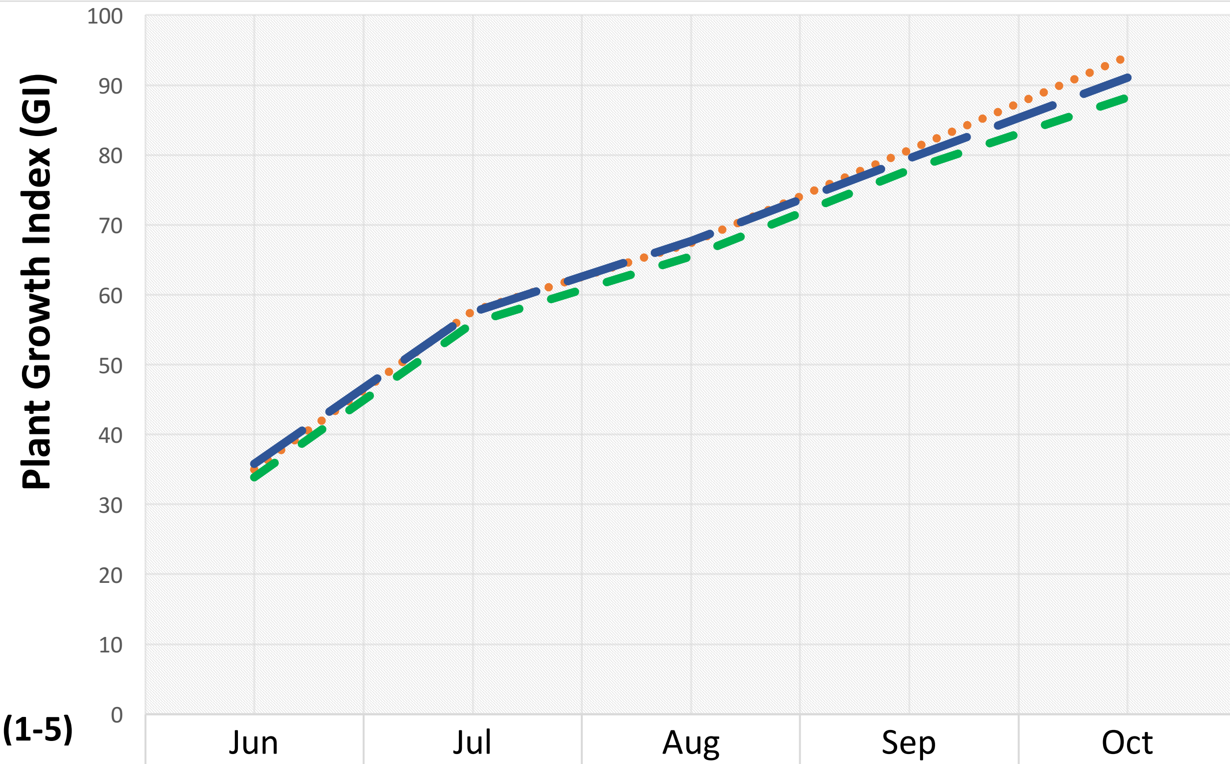
Table 5.1. Effect of microbial inoculant, fertilizer, irrigation, and soil amendment main factors and their interaction effects on 2016 lantana (*L. camara* L. 'Lucky Red Flame' 'Balandimfla') growth index (GI) and shoot dry weight (SDW). Abbreviations: Low Irrigation=LI; High Irrigation=HI; Low Fertilizer=LF; High Fertilizer=HF; No Soil Amendment=UN; Soil Amendment=AM; Effective Microorganisms-1=EM; Companion Biological Fungicide=CM; No Microbial Inoculant=NM.

Treatment	**p-value**		**Growth Index (GI) and Shoot Dry Weight (g)**					
	GI	**SDW**						
microbial inoculant	0.05*	0.27	**EM**		**CM**		**NM**	
			94.1a[Y] (1.73)[X]		91.1ab (1.71)		88.2b (1.69)	
fertilizer	0.0004***	0.07	**LF**			**HF**		
			94.7a (1.40)			87.5b (1.37)		
irrigation	0.001**	<0.001***	**LI (2.54 cm/per week)**			**HI (3.81 cm/per week)**		
			94.3a (1.39)	*183.6a (7.26)*		87.9b (1.40)	*122.3b (7.27)*	
soil amendment	0.24	0.51	N.S.					
irrigation*fertilizer	<.0001***	0.66	**LI*LF**	**LI*HF**		**HI*LF**	**HI*HF**	
			93.8a (1.98)	94.8a (r1.95)		95.6a (1.97)	80.2b (1.98)	
irrigation*amendment	0.04*	0.79	**LI*UN**	**LI*AM**		**HI*UN**	**HI*AM**	
			91.2b (1.95)	97.5a (1.98)		88.7b (1.96)	87.1b (1.99)	
irrigation*inoculant	0.03*	0.71	**LI*EM**	**LI*CM**	**LI*NM**	**HI*EM**	**HI*CM**	**HI*NM**
			94.3a (2.43)	93.8a (2.46)	94.8a (2.40)	93.8a (2.39)	88.3a (2.43)	81.5b (2.37)
fertilizer*amendment	0.55	0.87	N.S.					
fertilizer*inoculant	0.07	0.74	N.S.					
amendment*inoculant	0.009**	0.07	**UN*EM**	**UN*CM**	**UN*NM**	**AM*EM**	**AM*CM**	**AM*NM**
			90.3bc (2.43)	94.2ab (2.39)	85.3c (2.37)	97.8a (2.46)	87.9bc (2.43)	91.1abc (2.40)

N.S., *, **, *** indicates No statistical significance, significance at the P<0.05 level, P<0.01 level, or P<0.001 level, respectively.
[X]Values are averages of ten samples with standard error in parentheses.
[Y]Values followed by the same lowercase letter are not significantly different at P<0.05
Values in black indicate growth index (GI) values.
Values in ***red*** indicate shoot dry weight (g) values.

Figure 5.4. Microbial inoculant x soil amendment interaction of lantana (*L. camara* L. 'Lucky Red Flame' 'Balandimfla') growth index (GI) under two microbial inoculant treatments (EM, CM) and control (NM) and amended (AM) and unamended (UN) treatments in 2016.





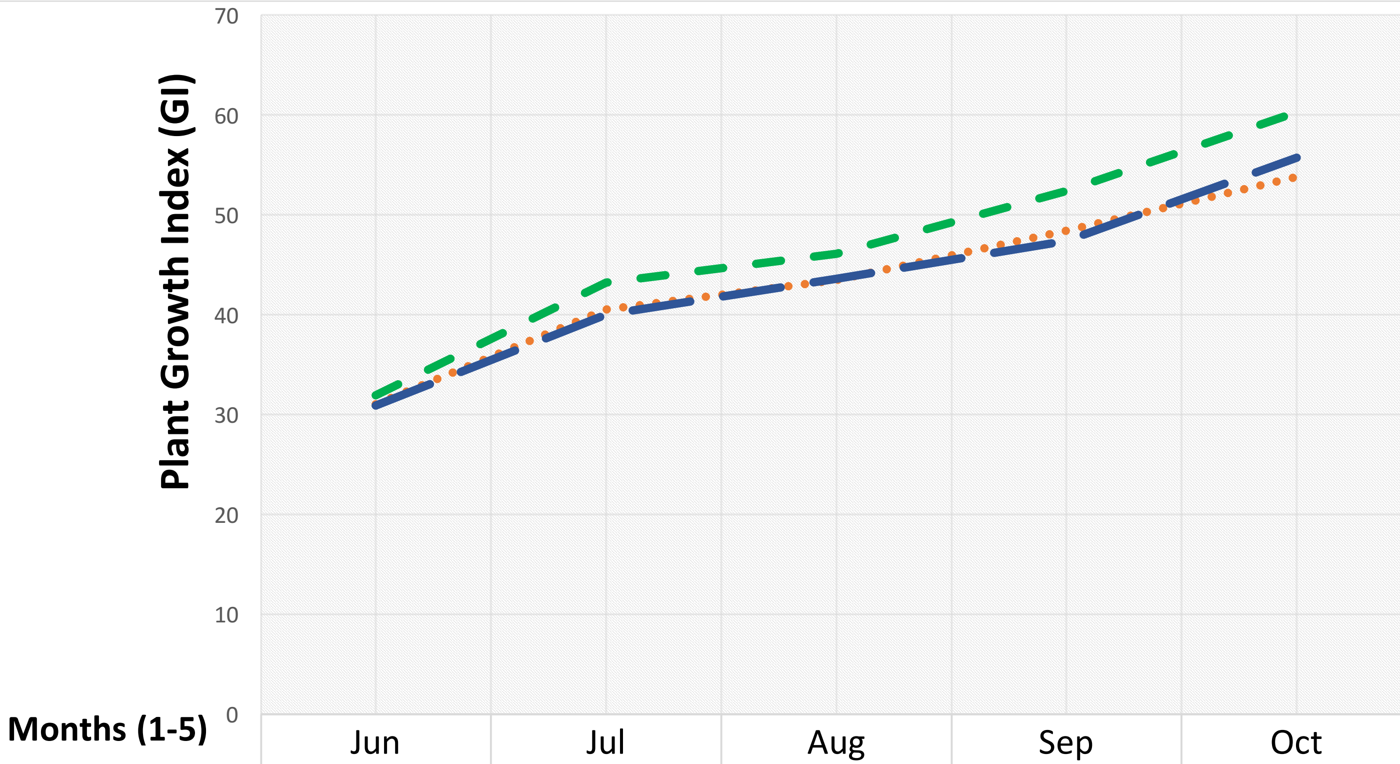
Months (1-5)	Jun	Jul	Aug	Sep	Oct
Effective Microorganisms-1 (EM)	35	57.7	67.4	80.7	94.1
Companion Biological Fungicide (CM)	35.8	57.5	67.7	79.5	91.1
Control	33.9	56	65.5	77.9	88.2

Figure 5.5. Lantana (*L. camara* L. 'Lucky Red Flame' 'Balandimfla') growth index (GI) under two microbial inoculant treatments (EM, CM) and control (NM) from June to October 2016. Values are averages of ten replicates.

Table 5.2. Effect of microbial inoculant, fertilizer, irrigation, and, soil amendment main factors and interaction effects on 2017 lantana (*L. camara* L. 'Lucky Red Flame' 'Balandimfla') growth index (GI) and shoot dry weight (SDW). Abbreviations: Low Irrigation=LI; High Irrigation=HI; Low Fertilizer=LF; High Fertilizer=HF; No Soil Amendment=UN; Soil Amendment=AM; Effective Microorganisms-1=EM; Companion Biological Fungicide=CM; No Microbial Inoculant=NM.

Treatment	**p-value**		**Growth Index (GI) and Shoot Dry Weight (g)**			
	GI	**SDW**				
microbial inoculant	0.04*	***0.64***	**EM**	**CM**	**NM**	
			53.2b[Y] (1.88)[X]	56.5ab (1.85)	58.8a (1.90)	
fertilizer	<.0001***	***0.003****	**LF**		**HF**	
			50.6b (1.66)	***60.6b (4.98)***	61.7a (1.62)	***79.9a (4.86)***
irrigation	0.94	***0.59***	N.S.			
soil amendment	0.93	***<.0001****	**UN**		**AM**	
			51.1b (4.95)		***89.4a (4.99)***	
irrigation*fertilizer	0.91	***0.16***	N.S.			
irrigation*amendment	0.94	***0.002****	**LI*UN**	**LI*AM**	**HI*UN**	**HI*AM**
			37.5c (6.95)	***98.9a (7.07)***	***64.7b (7.06)***	***79.9ab (7.07)***
irrigation*inoculant	0.99	***0.93***	N.S.			
fertilizer*amendment	0.77	***0.82***	N.S.			
fertilizer*inoculant	0.35	***0.16***	N.S.			
amendment*inoculant	0.41	***0.39***	N.S.			

N.S., *, **, *** indicates No statistical significance, significance at the $P<0.05$ level, $P<0.01$ level, or $P<0.001$ level, respectively.
[X]Values are averages of ten samples with standard error in parentheses.
[Y]Values followed by the same lowercase letter are not significantly different at $P<0.05$
Values in black indicate growth index (GI) values.
Values in ***red*** indicate shoot dry weight (g) values.



	Jun	Jul	Aug	Sep	Oct
Effective Microorganisms-1 (EM)	31	40.5	43.5	48.4	53.8
Companion Biological Fungicide (CM)	30.9	40	43.6	47.4	55.7
Control	31.9	43.2	46.1	52.4	60.3

Figure 5.6. Lantana (*L. camara* L. 'Lucky Red Flame' 'Balandimfla') growth index (GI) under two microbial inoculant treatments (EM, CM) and control (NM) from June to October 2017. Values are averages of ten replicates.

Table 5.3. Effect of microbial inoculant, fertilizer, irrigation, and soil amendment main factors and interaction effects on 2016 lantana (*Lantana camara* L. 'Lucky Red Flame' 'Balandimfla' inflorescence counts. Abbreviations: Low Irrigation=LI; High Irrigation=HI; Low Fertilizer=LF; High Fertilizer=HF; No Soil Amendment=UN; Soil Amendment=AM; Effective Microorganisms-1=EM; Companion Biological Fungicide=CM; No Microbial Inoculant=NM.

Treatment	p-value	Number of Inflorescences					
microbial inoculant	0.44	N.S.					
fertilizer	0.34	N.S.					
irrigation	<.0001***	**LI (2.54 cm/per week)**			**HI (3.81 cm/per week)**		
		131.9a[Y] (3.67)[X]			76.0b (3.70)		
soil amendment	0.0003***	**UN**			**AM**		
		111.3a (3.55)			96.6b (3.58)		
irrigation*fertilizer	0.93	N.S.					
irrigation*amendment	0.003**	**LI*UN**	**LI*AM**		**HI*UN**	**HI*AM**	
		131.9a (5.02)	131.8a (5.03)		90.7b (5.03)	61.3c (5.11)	
irrigation*inoculant	0.22	N.S.					
fertilizer*amendment	0.04*	**LF*UN**	**LF*AM**		**HF*UN**	**HF*AM**	
		108.4a (5.03)	103.9a (5.06)		114.2a (5.03)	89.2b (5.07)	
fertilizer*inoculant	0.31	N.S.					
amendment*inoculant	0.01*	**UN*EM**	**UN*CM**	**UN*NM**	**AM*EM**	**AM*CM**	**AM*NM**
		114.1ab (6.10)	122.0a (6.01)	97.8bc (5.94)	92.7c (6.09)	94.0c (6.09)	103.0bc (6.01)

N.S., *, **, *** indicates No statistical significance, significance at the P<0.05 level, P<0.01 level, or P<0.001 level, respectively.
[X]Values are averages of ten samples with standard error in parentheses.
[Y]Values followed by the same lowercase letter are not significantly different at P<0.05

Table 5.4. Effect of microbial inoculant, fertilizer, irrigation, and soil amendment main factors and interaction effects on 2017 lantana (*L. camara* L. 'Lucky Red Flame' 'Balandimfla') inflorescence counts. Abbreviations: Low Irrigation=LI; High Irrigation=HI; Low Fertilizer=LF; High Fertilizer=HF; No Soil Amendment=UN; Soil Amendment=AM; Effective Microorganisms-1=EM; Companion Biological Fungicide=CM; No Microbial Inoculant=NM.

Treatment	p-value	Number of Inflorescences			
microbial inoculant	0.04*	**EM**	**CM**	**NM**	
		12.9b[Y] (0.69)[X]	14.1ab (0.67)	15.3a (0.70)	
Fertilizer	<.0001***	**LF**	**HF**		
		17.0a (0.59)	11.3b (0.61)		
Irrigation	0.97	N.S.			
soil amendment	0.54	N.S.			
irrigation*fertilizer	0.77	N.S.			
irrigation*amendment	0.96	N.S.			
irrigation*inoculant	0.91	N.S.			
fertilizer*amendment	0.005**	**LF*UN**	**LF*AM**	**HF*UN**	**HF*AM**
		10.5c (0.81)	12.1c (0.79)	18.2a (0.77)	15.6b (0.78)
fertilizer*inoculant	0.32	N.S.			
amendment*inoculant	0.22	N.S.			

N.S., *, **, *** indicates No statistical significance, significance at the P<0.05 level, P<0.01 level, or P<0.001 level, respectively.
[X]Values are averages of ten samples with standard error in parentheses.
[Y]Values followed by the same lowercase letter are not significantly different at P<0.05.

Table 5.5. Effect of microbial inoculant, fertilizer, irrigation, and soil amendment main factors and interaction effects on 2016 lantana (*L. camara* L. 'Lucky Red Flame' 'Balandimfla') chlorophyll content and fluorescence. Abbreviations: Low Irrigation=LI; High Irrigation=HI; Low Fertilizer=LF; High Fertilizer=HF; No Soil Amendment=UN; Soil Amendment=AM; Effective Microorganisms-1=EM; Companion Biological Fungicide=CM; No Microbial Inoculant=NM.

Treatment	p-value		Chlorophyll Content and Fluorescence					
	Chl. content	Chl. fluorescence						
microbial inoculant	0.76	*0.63*	N.S.					
fertilizer	0.18	*0.08*	N.S.					
irrigation	<.0001***	*0.004***	LI (2.54 cm/per week)			HI (3.81 cm/per week)		
			46.4a[Y] (0.58)[X]	*0.59b (0.01)*		41.0b (0.59)	*0.64a (0.02)*	
soil amendment	0.41	*0.57*	N.S.					
irrigation*fertilizer	0.009**	*0.17*	LI*LF	LI*HF		HI*LF		HI*HF
			45.8a (0.83)	46.9a (0.83)		42.6b (0.84)		39.3c (0.84)
irrigation*amendment	0.13	*0.85*	N.S.					
irrigation*inoculant	0.35	*0.17*	N.S.					
fertilizer*amendment	0.23	*0.66*	N.S.					
fertilizer*inoculant	0.34	*0.94*	N.S.					
amendment*inoculant	0.07	*0.05**	UN*EM	UN*CM	UN*NM	AM*EM	AM*CM	AM*NM
			0.61ab (0.02)	*0.61ab (0.02)*	*0.64a (0.02)*	*0.61ab (0.02)*	*0.63ab (0.02)*	*0.59b (0.01)*

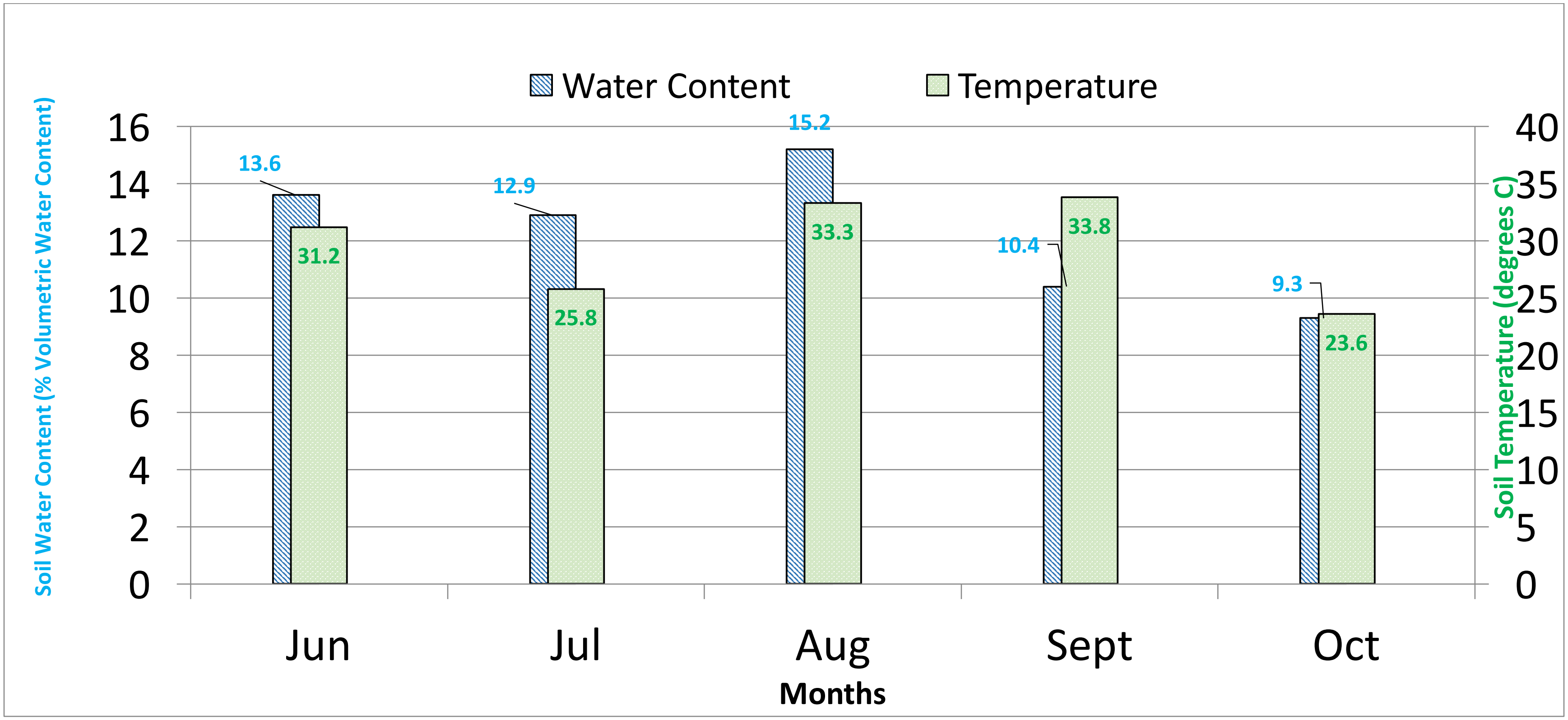
N.S., *, **, *** indicates No statistical significance, significance at the P<0.05 level, P<0.01 level, or P<0.001 level, respectively.
[X]Values are averages of ten samples with standard error in parentheses.
[Y]Values followed by the same lowercase letter are not significantly different at P<0.05.
Values in black indicate chlorophyll content values.
Values in ***red*** indicate chlorophyll fluorescence values.

Table 5.6. Effect of microbial inoculant, fertilizer, irrigation, and soil amendment main factors and interaction effects on 2017 lantana (*L. camara* L. 'Lucky Red Flame' 'Balandimfla') chlorophyll content and fluorescence. Abbreviations: Low Irrigation=LI; High Irrigation=HI; Low Fertilizer=LF; High Fertilizer=HF; No Soil Amendment=UN; Soil Amendment=AM; Effective Microorganisms-1=EM; Companion Biological Fungicide=CM; No Microbial Inoculant=NM.

Treatment	**p-value**		**Chlorophyll Content and Fluorescence**	
	Chl. Content	**Chl. fluorescence**		
microbial inoculant	0.72	***0.53***	N.S.	
Fertilizer	<.0001***	***0.36***	**LF**	**HF**
			40.8b[Y] (0.70)[X]	46.2a (0.67)
Irrigation	0.65	***0.30***	N.S.	
soil amendment	0.22	***0.38***	N.S.	
irrigation*fertilizer	0.66	***0.39***	N.S.	
irrigation*amendment	0.65	***0.34***	N.S.	
irrigation*inoculant	0.82	***0.37***	N.S.	
fertilizer*amendment	0.43	***0.39***	N.S.	
fertilizer*inoculant	0.71	***0.21***	N.S.	
amendment*inoculant	0.43	***0.32***	N.S.	

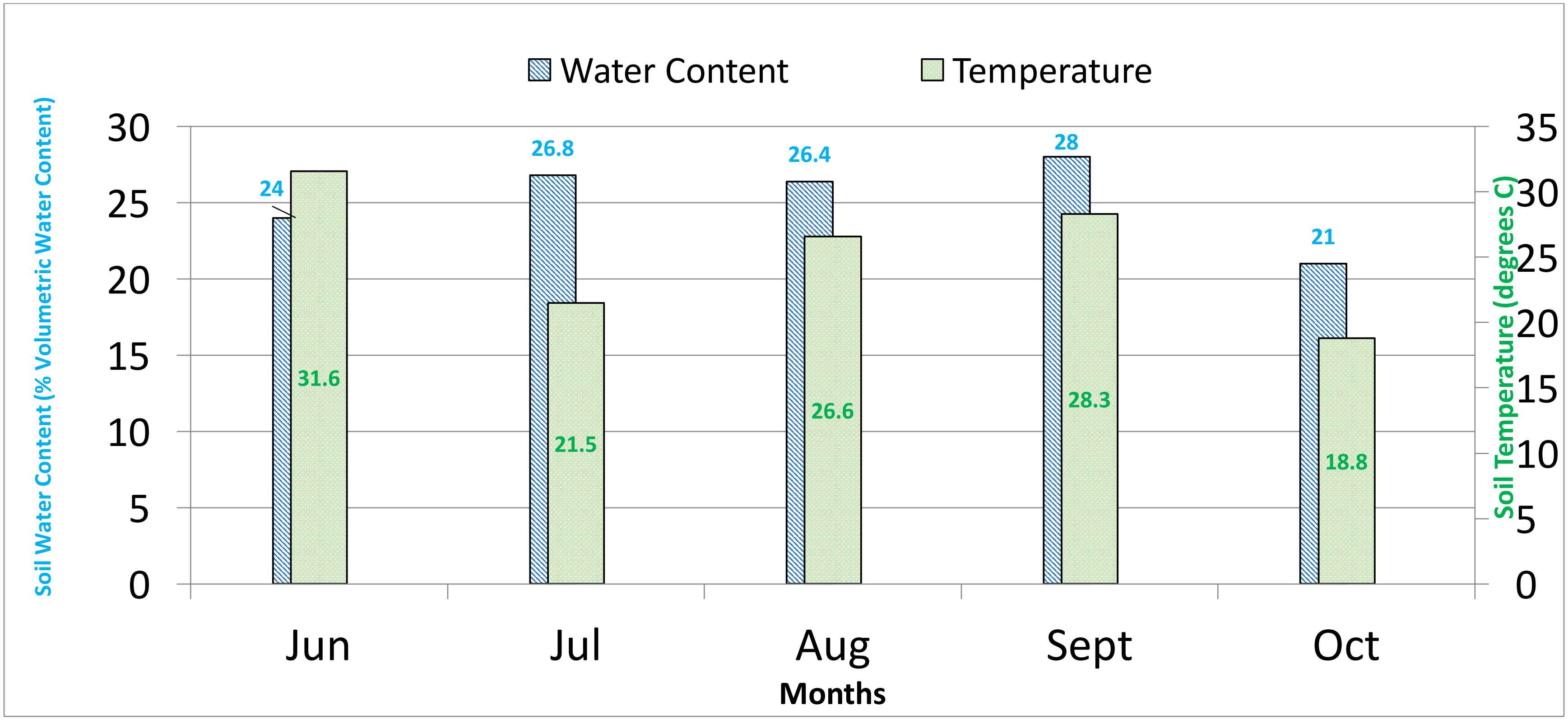
N.S., *, **, *** indicates No statistical significance, significance at the P<0.05 level, P<0.01 level, or P<0.001 level, respectively.
[X]Values are averages of ten samples with standard error in parentheses.
[Y]Values followed by the same lowercase letter are not significantly different at P<0.05.
Values in black indicate chlorophyll content values.
Values in ***red*** indicate chlorophyll fluorescence values.

Figure 5.7. Average soil temperature (°C) and moisture content (% volumetric water content) over from June to October 2016.



Values are averages of eight measurements per microbial inoculant, fertilizer, irrigation, and soil amendment treatment.

Figure 5.8. Average soil temperature (°C) and moisture content (% volumetric water content) from June to October 2017.



Values are averages of eight measurements per microbial inoculant, fertilizer, irrigation, and soil amendment treatment.

APPENDIX

Table 2.5. Container loss (%) as affected by container type and fertilizer treatment at two farm locations over ten months from 2015 to 2016. Abbreviations: F=Fertilized; NF=Non-Fertilized; Processed Cow Manure Container=PCM; Wood Pulp Fiber Container=WPF; Coconut Coir Container =CC.

Treatment	**Container Loss (%) (Bledsoe Farm)**					
Fertilizer	**F**			**NF**		
	16.2[X]			16.6		
Fertilizer* Container Type	**PCM*F**	**WPF*F**	**CC*F**	**PCM*NF**	**WPF*NF**	**CC*NF**
	23.4	16.2	11.0	18.2	18.9	13.0
Treatment	**Container Loss (%) (Dempsey Farm)**					
Fertilizer	**F**			**NF**		
	13.8			15.1		
Fertilizer *Container Type	**PCM*F**	**WPF* F**	**CC*F**	**PCM*NF**	**WPF*NF**	**CC*NF**
	15.8	13.8	12.0	20.4	13.8	12.3

[X]Values are averages of ten samples.

Table 2.6. Container loss (%) as affected by container type, irrigation level, soil amendment treatment, and fertilizer treatment over six months in 2017. Abbreviations: LI=Low Irrigation; HI=High Irrigation; AM= Soil Amendment; UN: Unamended; LF=Low Fertilizer; HF=High Fertilizer; Recycled Paper Sleeve=RPS; Processed Cow Manure =PCM; Wood Pulp Fiber =WPF; Coconut Coir =CC.

<table>
<tr><th>Treatment</th><th colspan="6">Container Loss (%)</th></tr>
<tr><td rowspan="2">Irrigation</td><td colspan="3">LI</td><td colspan="3">HI</td></tr>
<tr><td colspan="3">15.5[X]</td><td colspan="3">13.5</td></tr>
<tr><td rowspan="2">Amendment</td><td colspan="3">AM</td><td colspan="3">UN</td></tr>
<tr><td colspan="3">14.1</td><td colspan="3">15.5</td></tr>
<tr><td rowspan="2">Irrigation* Fertilizer</td><td colspan="2">LI*LF</td><td>LI*HF</td><td colspan="2">HI*LF</td><td>HI*HF</td></tr>
<tr><td colspan="2">19.5</td><td>12.6</td><td colspan="2">12.6</td><td>15.1</td></tr>
<tr><td rowspan="2">Irrigation* Amendment</td><td colspan="2">LI*AM</td><td>LI*UN</td><td colspan="2">HI*AM</td><td>HI*UN</td></tr>
<tr><td colspan="2">14.8</td><td>16.2</td><td colspan="2">13.2</td><td>14.5</td></tr>
<tr><td rowspan="2">Fertilizer* Amendment</td><td colspan="2">LF*AM</td><td>LF*UN</td><td>HF*AM</td><td colspan="2">HF*UN</td></tr>
<tr><td colspan="2">16.2</td><td>18.2</td><td>12.0</td><td colspan="2">12.9</td></tr>
<tr><td rowspan="2">Fertilizer* Container Type</td><td>LF*CC</td><td>LF*WPF</td><td>LF*RPS</td><td>HF*CC</td><td>HF*WPF</td><td>HF*RPS</td></tr>
<tr><td>8.71</td><td>15.5</td><td>38.0</td><td>6.92</td><td>10.0</td><td>28.2</td></tr>
<tr><td rowspan="2">Amendment* Container Type</td><td>AM*CC</td><td>AM*WPF</td><td>AM*RPS</td><td>UN*CC</td><td>UN*WPF</td><td>UN*RPS</td></tr>
<tr><td>6.46</td><td>13.8</td><td>31.0</td><td>9.33</td><td>11.0</td><td>34.7</td></tr>
</table>

[X]Values are averages of six samples.

Table 2.7. Average % Volumetric Water Content and soil temperature (°C) for months 3 through 6 in 2017. Averages presented are pooled from all irrigation, fertilizer, and amendment treatments.

Months	**% Volumetric Water Content**	**Soil Temperature (°C)**
3	27.9[X]	28.6
4	26.4	26.6
5	26.8	21.5
6	20.9	18.8

[X]Values are averages of eight sample measurements.

Table 3.7. Amount of carbon released (mg CO_2-C/100 g soil) over 182 days for recycled paper container. Means for non-significant main effects [recycled paper container (RPS, Ellepot®) and fertilizer] and two-way interactions are shown. Abbreviations: C = With Container Material; NC = Soil Only (Without Container Material); 40% Water Holding Capacity= 40WHC; 60% Water Holding Capacity= 60WC; Low Fertilizer = LF; High Fertilizer = HF; Unamended = UN; Soil Amendment = AM.

Main and Interaction Effects	Carbon Released (mg CO_2-C/100 g soil)			
Container	C		NC	
	5.83[X]		5.17	
Fertilizer	LF		HF	
	6.10		4.90	
Container *Fertilizer	C*LF	NC*LF	C*HF	NC*HF
	5.78	6.41	5.88	3.93
Container *WHC	C*40WHC	NC*40WC	C*60WC	NC*60WC
	6.22	7.14	5.45	3.20
Fertilizer * Amendment	LF*AM	LF*UN	HF*AM	HF*UN
	8.40	3.82	6.90	2.89
Fertilizer*WHC	LF*40WC	LF*60WC	HF*40WC	HF*60WC
	7.70	4.48	5.65	4.17

[X]Values are averages of five replicates.

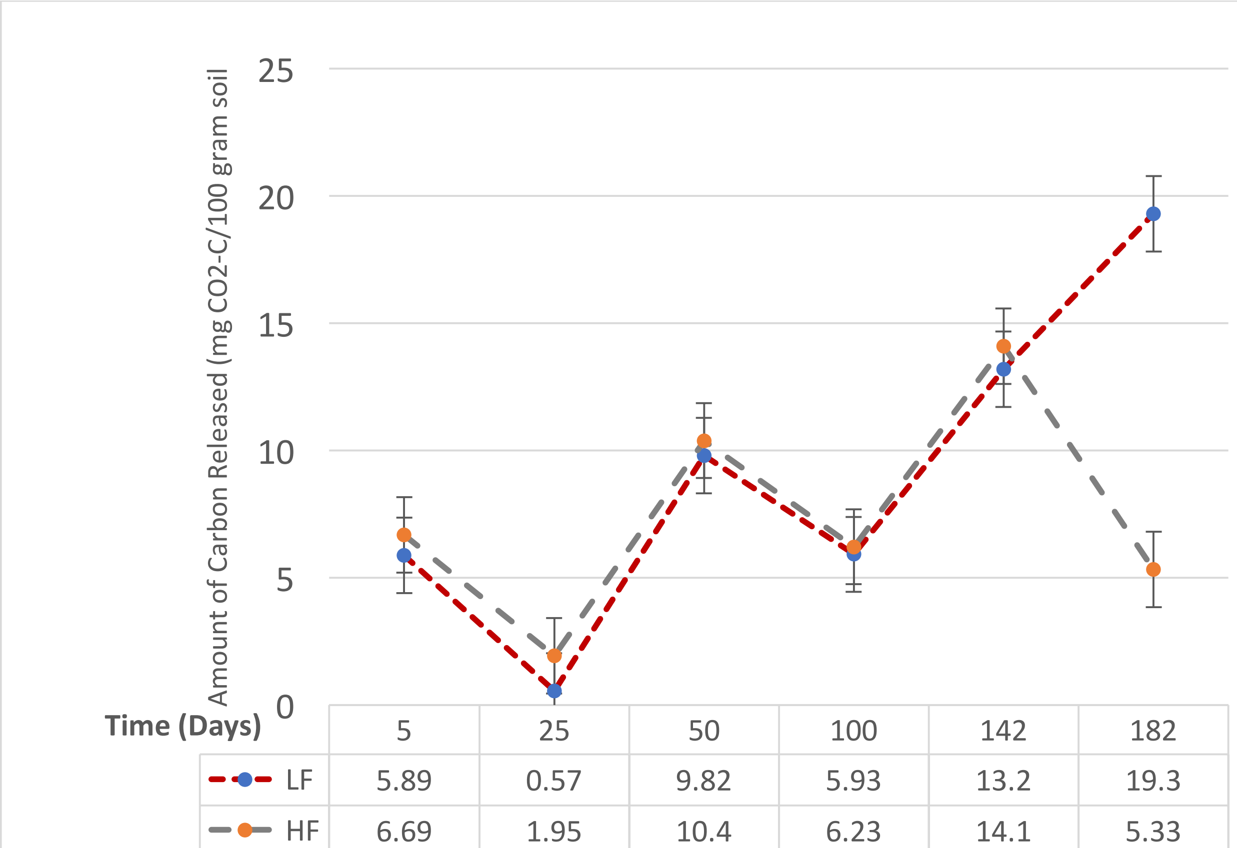


Figure 3.6. Mean (± S.E.) amount of carbon released (mg CO_2-C/100 g. soil) over 182 days with low (LF) and high (HF) fertilizer treatments for recycled paper sleeve container (RPS, Ellepot®).

Table 3.8. Amount of carbon released (mg CO_2-C/100 g soil) over 182 days for wood pulp fiber container. Means for non-significant main effects [fertilizer, amendment, and water holding capacity (WHC)] and two-way interactions are shown. Abbreviations: C = With Container Material; NC = Soil Only (Without Container Material); 40% Water Holding Capacity= 40WHC; 60% Water Holding Capacity= 60WHC; Low Fertilizer = LF; High Fertilizer = HF; Unamended = UN; Soil Amendment = AM.

Main and Interaction Effects	**Carbon Released (mg CO_2-C/100 g soil)**			
Fertilizer	**LF**		**HF**	
	3.52[X]		4.05	
Amendment	**AM**		**UN**	
	3.81		3.77	
Water Holding Capacity (WHC)	**40WHC**		**60WHC**	
	3.74		3.84	
Container *Fertilizer	**C*LF**	**NC*LF**	**C*HF**	**NC*HF**
	2.94	4.09	3.47	4.64
Container*Amendment	**C*AM**	**NC*AM**	**C*UN**	**NC*UN**
	2.94	4.67	3.48	4.06
Container *WHC	**C*40WHC**	**NC*40WHC**	**C*60WHC**	**NC*60WHC**
	3.03	4.46	3.40	4.27
Fertilizer * Amendment	**LF*AM**	**LF*UN**	**HF*AM**	**HF*UN**
	3.45	3.60	4.16	3.95
Fertilizer*WHC	**LF*40WHC**	**LF*60WHC**	**HF*40WHC**	**HF*60WHC**
	3.51	3.54	3.97	4.13
Amendment*WHC	**AM*40WHC**	**AM*60WHC**	**UN*40WHC**	**UN*60WHC**
	3.61	4.00	3.87	3.68

[X]Values are averages of five replicates.

Table 3.9. Amount of carbon released (mg CO_2-C/100 g soil) over 182 days. Means for non-significant main effects [fertilizer, amendment, and water holding capacity (WHC)] and two-way interactions are shown for coconut coir container. Abbreviations: C = With Container Material; NC = Soil Only (Without Container Material); 40% Water Holding Capacity = 40WHC; 60% Water Holding Capacity = 60WHC; Low Fertilizer = LF; High Fertilizer = HF; Unamended = UN; Soil Amendment = AM.

Main and Interaction Effects	**Carbon Released (mg CO_2-C/100 g soil)**			
Fertilizer	**LF**		**HF**	
	3.27[X]		3.87	
Amendment	**AM**		**UN**	
	3.98		3.16	
Water Holding Capacity (WHC)	**40WHC**		**60WHC**	
	3.61		3.53	
Container *WHC	**C*40WHC**	**NC*40WHC**	**C*60WHC**	**NC*60WHC**
	4.72	2.49	4.61	2.46
Fertilizer * Amendment	**LF*AM**	**LF*UN**	**HF*AM**	**HF*UN**
	2.98	3.57	3.35	4.38
Fertilizer*WHC	**LF*40WHC**	**LF*60WHC**	**HF*40WHC**	**HF*60WHC**
	2.89	3.65	4.32	3.41
Amendment*WHC	**AM*40WHC**	**AM*60WHC**	**UN*40WHC**	**UN*60WHC**
	3.22	3.99	3.10	3.97

[X]Values are averages of five replicates.

Table 4.10. Total revenue and number and type of employee positions hired by surveyed horticultural firms in 2016.

<table>
<tr><th>Company size by total 2016 revenue</th><th>Number of Respondents</th><th>Number of Employees</th><th><10</th><th>11-20</th><th>21-30</th><th>31-40</th><th>41-50</th><th>51-75</th><th>76-100</th><th><100</th></tr>
<tr><td>Less than $50,000</td><td>38/76%</td><td rowspan="2">Full-Time</td><td rowspan="2">112/79%</td><td rowspan="2">10/7%</td><td rowspan="2">8/6%</td><td rowspan="2">6/4%</td><td rowspan="2">3/2%</td><td rowspan="2">1/1%</td><td rowspan="2">1/1%</td><td rowspan="2">1/1%</td></tr>
<tr><td>$50,000-$100,000</td><td>18/9%</td></tr>
<tr><td>$100,001-$150,000</td><td>12/6%</td><td rowspan="2">Part-Time</td><td rowspan="2">61/95%</td><td rowspan="2">2/3%</td><td rowspan="2">-</td><td rowspan="2">-</td><td rowspan="2">1/1%</td><td rowspan="2">-</td><td rowspan="2">-</td><td rowspan="2">-</td></tr>
<tr><td>$150,001-$200,000</td><td>13/6%</td></tr>
<tr><td>$200,001-$350,000</td><td>16/8%</td><td rowspan="2">Seasonal Full-Time</td><td rowspan="2">40/83%</td><td rowspan="2">6/13%</td><td rowspan="2">-</td><td rowspan="2">2/4%</td><td rowspan="2">-</td><td rowspan="2">-</td><td rowspan="2">-</td><td rowspan="2">-</td></tr>
<tr><td>$350,001-$500,000</td><td>11/5%</td></tr>
<tr><td>$500,001-$750,000</td><td>7/3%</td><td rowspan="2">Seasonal Part-Time</td><td rowspan="2">63/95%</td><td rowspan="2">-</td><td rowspan="2">1/1%</td><td rowspan="2">2/3%</td><td rowspan="2">-</td><td rowspan="2">-</td><td rowspan="2">-</td><td rowspan="2">-</td></tr>
<tr><td>$750,001-$1,000,000</td><td>14/7%</td></tr>
<tr><td>$1,000,001-$1,500,000</td><td>8/4%</td><td rowspan="2">Number of total employees</td><td rowspan="2">125/74%</td><td rowspan="2">15/9%</td><td rowspan="2">13/8%</td><td rowspan="2">3/2%</td><td rowspan="2">7/4%</td><td rowspan="2">1/1%</td><td rowspan="2">2/1%</td><td rowspan="2">2/1%</td></tr>
<tr><td>$1,500,001 or more</td><td>27/13%</td></tr>
</table>

Table 4.11. Demographics regarding position in the horticultural firm, years of experience in the business area, gender, age, and years of schooling.

<table>
<tr><th>Position in Company</th><th>Number of Respondents</th><th rowspan="4">Years in Company</th><th>1-5</th><th>6-10</th><th>11-15</th><th>16-20.5</th><th>21-25</th><th>26-30</th><th>30.5-39</th><th>40-56</th></tr>
<tr><td>Administrative</td><td>7/6%</td><td rowspan="3">18/14%</td><td rowspan="3">19/15%</td><td rowspan="3">19/15%</td><td rowspan="3">17/13%</td><td rowspan="3">14/12%</td><td rowspan="3">12/11%</td><td rowspan="3">21/16%</td><td rowspan="3">7/6%</td></tr>
<tr><td>Other Managerial</td><td>5/4%</td></tr>
<tr><td>Owner/Manager</td><td>113/90%</td></tr>
<tr><th>Gender</th><th>Number of Respondents</th><th>Years of Schooling</th><td colspan="2">1-12
44/36%</td><td colspan="2">13-16
45/38%</td><td colspan="2">17-23
28/23%</td><td colspan="2">24-30
4/3%</td></tr>
<tr><td>Female</td><td>39/31%</td><th rowspan="2">Age</th><td rowspan="2"><30
1/1%</td><td rowspan="2">31-40
20/16%</td><td colspan="2" rowspan="2">41-50
29/23%</td><td rowspan="2">51-60
38/30%</td><td rowspan="2">61-70
33/27%</td><td colspan="2" rowspan="2">>71
4/3%</td></tr>
<tr><td>Male</td><td>85/69%</td></tr>
</table>

Table 4.12. Frequency of respondents whose county regulates plastic container disposal and number of pounds of plastic containers, trays, and liners disposed monthly.

Plastic Container Disposal	Number of Respondents	Pounds of plastic discarded monthly	1-5 pounds	6-10 pounds	11-20 pounds	21-25 pounds	26-40 pounds	41-70 pounds	71-79 pounds	100 pounds
No	102/51%		27/57%	6/13%	3/7%	3/6%	1/2%	1/2%	1/2%	5/11%
Yes	21/10%									
Don't Know	79/39%									

Table 4.13. Frequency of respondents regarding difficulty of storage of biodegradable containers and disposal of plastic containers, trays, and liners.

Difficulty of Storage of Biodegradable Containers	Number of Respondents		Discard Ways	Almost never	Seldom	Neither often, nor seldom	Often	Very Often
No	14/16%	Discarding Method of Plastic	With regular waste to landfill	39/48%	14/17%	8/10%	12/15%	9/11%
Yes	22/26%		Separated for recycling	24/31%	10/13%	8/10%	18/23%	18/23%
			In other way	33/49%	11/16%	11/16%	9/13%	3/4%
			Place plastic containers in bins with other waste	36/46%	15/19%	7/9%	13/17%	7/9%
			We reuse plastic containers	4/5%	2/2%	5/6%	10/12%	15/20%
Don't Know	50/58%		Place plastic containers in bins for recyclable waste	29/38%	14/18%	6/8%	12/16%	15/20%
			Discard them in other ways	41/56%	9/12%	12/16%	5/7%	4/6%

Table 4.14. Frequency of respondents using algaecides and their use of these products with regard of biodegradable containers.

<table>
<tr><th>Algaecide Use</th><th>Almost Never</th><th>Seldom</th><th>Neither often, nor seldom</th><th>Often</th><th colspan="2">Very Often</th></tr>
<tr><td>Clean greenhouse</td><td>42/53%</td><td>14/18%</td><td>7/8%</td><td>16/20%</td><td colspan="2">1/1%</td></tr>
<tr><td>Clean Containers, Trays, or Flats</td><td>38/48%</td><td>9/11%</td><td>15/19%</td><td>11/14%</td><td colspan="2">6/8%</td></tr>
<tr><th>Issue/Statement</th><th>Strongly disagree</th><th>Disagree</th><th>Neither agree, nor disagree</th><th>Agree</th><th>Strongly Agree</th><th>Don’t Know</th></tr>
<tr><td>Biodegradable containers contribute to higher algaecide application as compared to plastic containers</td><td>2/2%</td><td>4/5%</td><td>23/27%</td><td>2/2%</td><td>-</td><td>53/63%</td></tr>
<tr><td>Biodegradable containers contribute to higher fungicide application as compared to plastic containers</td><td>-</td><td>4/5%</td><td>24/28%</td><td>-</td><td>-</td><td>57/67%</td></tr>
</table>

Table 5.7. Effect of microbial inoculant, fertilizer, irrigation, and soil amendment main factors and their interaction effects on lantana (*L. camara* L. 'Lucky Red Flame' 'Balandimfla') growth index (GI) in June 2017. Abbreviations: Low Irrigation=LI; High Irrigation=HI; Low Fertilizer=LF; High Fertilizer=HF; No Soil Amendment=UN; Soil Amendment=AM; Effective Microorganisms-1=EM; Companion Biological Fungicide=CM; No Microbial Inoculant=NM.

Treatment	**p-value**	**Growth Index (GI) and Shoot Dry Weight (g)**	
	GI		
microbial inoculant	0.90	N.S.	
fertilizer	0.65	N.S.	
irrigation		**LI (2.54 cm/per week)**	**HI (3.81 cm/per week)**
	<.0001***	19.3a[Y] (0.84)[X]	32.0 (1.84)
soil amendment	0.97	N.S.	
irrigation*fertilizer	0.95	N.S.	
irrigation*amendment	0.42	N.S.	
irrigation*inoculant	0.84	N.S.	
fertilizer*amendment	0.78	N.S.	
fertilizer*inoculant	0.84	N.S.	
amendment*inoculant	0.74	N.S.	

N.S., *, **, *** indicates No statistical significance, significance at the P<0.05 level, P<0.01 level, or P<0.001 level, respectively.
[X]Values are averages of ten samples with standard error in parentheses.
[Y]Values followed by the same lowercase letter are not significantly different at P<0.05

Table 5.8. 2016 Post-experiment macronutrient plant tissue analysis of *Lantana camara* L. 'Lucky Red Flame' 'Balandimfla' under varying microbial inoculant, fertilizer, irrigation, and soil amendment treatments. Abbreviation: Low Irrigation=LI; High Irrigation=HI; Low Fertilizer=LF; High Fertilizer=HF; No Soil Amendment=UN; Soil Amendment=AM; Effective Microorganisms-1=EM; Companion Biological Fungicide=CM; No Microbial Inoculant=NM.

Sample	% Ca	% K	% Mg	% P	% N	% S
LI-LF-AM-NM	2.47[a]	2.01	0.65	0.22	2.97	0.26
LI-LF-AM-EM	2.30	1.85	0.71	0.21	3.01	0.25
LI-LF-AM-CM	2.51	2.08	0.72	0.24	2.92	0.28
LI-LF-UN-NM	2.01	1.97	0.71	0.29	2.96	0.26
LI-LF-UN-EM	2.03	1.92	0.64	0.23	3.19	0.27
LI-LF-UN-CM	2.29	2.24	0.69	0.29	3.06	0.27
LI-HF-AM-NM	2.04	2.26	0.64	0.28	3.17	0.28
LI-HF-AM-EM	2.13	1.99	0.71	0.23	2.98	0.27
LI-HF-AM-CM	2.18	2.29	0.64	0.27	2.96	0.28
LI-HF-UN-NM	1.42	1.83	0.49	0.25	1.86	0.26
LI-HF-UN-EM	2.19	1.82	0.75	0.24	2.61	0.27
LI-HF-UN-CM	2.17	2.07	0.69	0.25	2.91	0.26
LI-LF-AM-NM	2.53	2.19	0.57	0.35	2.61	0.24
HI-LF-AM-EM	1.91	1.85	0.46	0.40	1.40	0.37
HI-LF-AM-CM	2.00	2.17	0.39	0.35	2.29	0.27
HI-LF-UN-NM	2.41	2.27	0.71	0.40	2.80	0.31
HI-LF-UN-EM	2.25	2.01	0.61	0.33	2.58	0.26
HI-LF-UN-CM	2.15	2.09	0.58	0.32	2.71	0.26
HI-HF-AM-NM	2.16	2.17	0.59	0.35	3.08	0.28
HI-HF-AM-EM	2.32	2.29	0.67	0.34	3.53	0.28
HI-HF-AM-CM	2.46	2.29	0.77	0.32	3.48	0.27
HI-HF-UN-NM	2.15	2.16	0.60	0.33	2.82	0.28
HI-HF-UN-EM	1.75	1.90	0.52	0.24	2.26	0.23
HI-HF-UN-CM	2.17	1.94	0.70	0.27	2.54	0.25

[a]Values represent means pooled from ten samples. For *Lantana camara*, typical macronutrient concentrations are 1.5% N, 1.0% K, 0.5% Ca, 0.2% Mg, 0.2% P, and 0.1% S (Bryson et al., 2014).