4-4-2023

Evaluating Form and Function of Groundcovers and their Environmental Impacts in Louisiana Landscapes

Thomas Maxwell McKeown
Louisiana State University and Agricultural and Mechanical College

EVALUATING FORM AND FUNCTION OF GROUNDCOVERS AND THEIR ENVIRONMENTAL IMPACTS IN LOUISIANA LANDSCAPES

A Thesis

Submitted to the Graduate Faculty of the
Louisiana State University and
Agricultural and Mechanical College
in partial fulfillment of the
requirements for the degree of
Master of Science

in

The School of Plant, Environmental, and Soil Sciences

by
Thomas Maxwell McKeown
B.S., University of Arkansas at Fayetteville, 2021
May 2023

ACKNOWLEDGMENTS

They say it’s a village to raise a child, I argue it’s also true to complete a master’s degree. I had many people to help me along this journey to success. I would like to thank my parents for their support. They heard many panicked phone calls over upcoming tests and papers and gave me the idea for putting boxes over my wire connections. I thank my grandma as well for inspiring my love of horticulture. And my sister, Mady, thank you for calling out all those numbers.

My committee members were invaluable to me throughout my program. Dr. Damon Abdi put in hours of editing and improved my writing tremendously, and without Dr. Heather Kirk-Ballard and Dr. Jeff Kuehny’ s critical input to the project it would have not reached its full potential. While not on my committee, Dr. Lisa Fultz, thank you so much for allowing me to use your lab to run the FAME samples, as well as sitting down with me to explain how Microsoft Access works.

I want to acknowledge the LSU Hill Farm for allowing me to get cuttings of the Sandy Leaf Fig, as well as Dr. Rick Prewitt, for allowing me to get the Creeping Fig cuttings.

Jason Stagg was instrumental in assisting me choose the plant species for my projects. Like me, he is a plant savant and gave me many groundcover species recommendations. He also gave me numerous tips to survive grad school, along with his motto, “It’s only temporary.” Never thought it would end, but it did.

A huge shoutout to Mandy Clayton, as she helped me navigate the bureaucracy known as higher education. I would also like to thank the members of the crew, Kenny, Hunter, Destiny, and Missy for watering my plants while I was gone, helping me start the weed eater, and helping

me plant hundreds of plants in these projects. As well as Jonathon and Corey for helping with all the electrical and plumbing for my projects. You both taught me many lessons.

Kris Criscione should probably be a co-author on this paper because of all the statistics, sensor programming, and Excel shortcuts he taught me. Kris made me realize that I am not dumb, and that statistics are just hard. But thanks to him, I am a wizard at JMP.

Thank you, Maureen Thiessen, better known as Moshi, for standing at the data logger box with me in the beating sun, trying to figure out why the soil sensors weren't reading. You helped so much during this project, offering so many creative solutions. You still don't believe this, but you are one of the smartest people I know.

Ashely Edwards, the one who gave me my nickname, Fayettechill, the first day she met me. Thanks for being there for the whole process, keeping the camera guarded, keeping me sane, and never letting me win in the Facebook wars.

Thank you, Baileigh Snow and Amanda Mizell, for helping me move the tent for all the photographs of the groundcovers, this paper would not have happened without you both.

I may be a tiger now but, thank you to everyone at the University of Arkansas for preparing me for my education and career in horticulture. Woo Pig Sooie!

Above all, I would like to thank Dr. Jeb Fields, for assisting me through this entire process and pushing me to succeed in the highest capacity. The amount of time and dedication he demonstrated throughout the program is honorable. He was a port in the storm when I needed him. Thank you for your mentorship and improving my skills as a student, a scientist and above all, a horticulturist.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

ABSTRACT

Increasing environmental concerns are encouraging the adoption of sustainable landscapes that have environmental, social, and financial benefits. Ornamental groundcover systems are touted as sustainable landscape features due to the associated decreased demand of water, fertilizer, pesticide, and maintenance; however, limited research exists on soil property effects, planting density, weed density, or consumer preferences of groundcovers. This study was aimed to gain a more thorough understanding of ornamental groundcovers systems and their environmental impacts. The effects of groundcover growth habit (matting; bunching) and irrigation delivery (micro spray; overhead) on soil temperature, volumetric water content (VWC), and electric conductivity (EC) along with impacts on weed growth, soil microbial communities, and plant coverage were measured. Furthermore, twelve traditional and non-traditional groundcover species' vegetative coverage and visual quality were assessed under optimal and suboptimal planting densities. Soil temperatures were lowest under groundcover species with a matting growth habit, and to a lesser extent, bunching species, in comparison to fallow systems. Micro spray irrigation decreased VWC values with matting species exacerbating this decrease when compared to overhead irrigation delivery. Plant type did not influence EC values, however micro spray irrigation produced significantly increased EC values perhaps due to increased leaching of the overhead irrigation. Micro spray irrigation along with matting growth habits decreased weed density greater than bunching species or overhead irrigation. Annual and most tender perennial groundcover species can tolerate suboptimal planting densities to achieve vegetation coverage values analogous to optimal densities, while hardy perennials cannot. A consumer survey revealed non-traditional groundcover species were preferred over industry standards in both aesthetic and coverage quality. Plant species nor irrigation affected the

soil microbial communities. Groundcovers species with increased vegetative coverage along with a targeted irrigation regime can reduce soil temperature, moisture, and weeds. Suboptimal planting densities can accomplish comparable results to optimal densities, with plant spacing dependent on species selection, thus decreasing landscape plant material costs while maintaining consumer satisfaction. Residential and commercial landscapes can incorporate groundcovers to increase their sustainability while maintaining visual qualities associated with more traditional landscapes.

1. INTRODUCTION

Sustainable landscapes are increasingly trying to balance visual and functional satisfaction while preserving critical ecosystem functions. Humanity has altered Earth's climate with devasting effects, such as increased incidence of heat waves, altered precipitation patterns resulting in floods and droughts, and more frequent extreme weather events leading to the loss of human life and causing negative economic impacts. Precipitation patterns have become more irregular (Nearing et al., 2005; IPPC Working Group, 2013), increasing the prevalence of both flood and drought events and putting more pressure on water resources (Gosling, 2016). Designing and implementing landscapes that fulfill community functions while maintaining the natural environment in the era of climate change will be challenging (O'Farrell and Anderson, 2010); however, by incorporating a wide array of environmental disciplines communities can increase sustainability and in turn create social, economic, and financial gains. In response to these mounting environmental concerns, sustainable movements across many areas of the economy, including agriculture, have garnered attention (Piñeiro et al., 2020).

LITERATURE REVIEW

1.1. Green industry

Agriculture is comprised of several subfields, including horticulture or The Green Industry, which encompasses ornamental plant producers; landscape architects, designers/builders, contractors, and maintenance firms; retail garden centers, and big box stores with lawn and garden departments; and plant brokers and horticultural distribution centers (Hall et al., 2006.). In response to climate change concerns, industry standard production practices have been placed under greater scrutiny, including plastic consumption (Evans and Hensley, 2004; Dennis et al., 2010), water management (Berghage et al., 1999), fertilizer use (Carpenter et al., 1998; Hochmuth et al., 2009; Udawatta et al., 2011), and pesticide applications (Getter et al., 2016; Wollaeger et al., 2015). The increase in urban and suburban areas replace natural land features with landscapes often defined by turfgrass, exotic plant species and impervious surfaces (Groffman et al., 2016). Impervious surfaces alter water flow patterns, that can lead to disastrous environmental impacts (Walsh et al., 2012; Rose and Peters, 2001). Migration to urban areas is a global phenomenon, where in the United States a 6.4% increase in urban population from 2010 to 2020 was observed (U.S Census Bureau, 2022a). Urban land area use decreased by 2.4% from 2010 to 2020; however, changes in land area classification contributed to this decrease. Despite this, trends indicate urban land area increases every year and will continue (U.S Census Bureau, 2022b). Consumers have continued to demonstrate increased interest in the environmental impact of the Green Industry, encouraging the adoption of low environmental-impact production methods (Nambuthiri et al., 2015). Moreover, consumers are adopting sustainable practices into their own landscapes, such as including more native and adapted plant species and reducing chemical applications.

1.2. Sustainable Landscapes

Sustainability is defined as "enabling natural and built systems to work together to meet the needs of the present without compromising the ability of future generations to meet their own needs" (World Commission on Environment and Development, 1987). Implementation of sustainable practices in landscapes tends to follow other agricultural sectors, albeit with limited momentum (Doxon, 1996), and consumer perception (or lack thereof) is partially responsible for this slow adoption. Landscapes incorporating sustainable practices and features correlate with low aesthetic quality ratings from consumers; however, as knowledge of sustainable methods and elements increased, the subjective ratings improved (Huang and Sherk, 2014). Sustainable landscapes present as low input of resources (water, fertilizer, agrochemicals), use of native plant species, and encouragement of the proliferation of wildlife (Saksa et al., 2012).

1.2.1. Irrigation

Irrigating lawns and landscape beds is the largest sector of residential water use (St. Hilaire et al., 2008), thus water conservation strategies are heavily targeted to homeowners. Water conservation efforts such as reducing lawn sizes (City of El Paso, 2001), installing efficient irrigation (Cardenas-Lailhacar et al., 2008; Davis and Dukes, 2008), and landscaping with drought tolerant plant species (Paine et al., 1992) can reduce residential landscape water use.

1.2.2. Fertilizer

Mismanagement of fertilizer applications has detrimental effects on watershed quality, notably manifesting as eutrophication, the proliferation of aquatic algal blooms in response to fertilizer rich waters (Shober, et al., 2010). Extension programs educating consumers on best

management practices when using fertilizers are important to preserve landscape visual quality without sacrificing environmental protection (Warner et al., 2017). Education detailing sustainable fertilizer practices include soil testing (Shober and Mylavarapu, 2009), timing and placement of fertilizer applications (Hochmuth and Hanlon, 2010), and research-based fertilizer recommendations (Erickson, et al., 2001; Trenholm and Sartain, 2010).

1.2.3. Agrochemicals

Reducing the frequency in which agrochemicals are unnecessarily applied is a key aspect of sustainable landscape management, with integrated pest management (IPM) the most commonly employed method. IPM encompasses practices that incorporate routine monitoring of pests and their natural enemies, the use of economic thresholds when deciding pesticides applications, and integrated use of other non-pesticide control methods (Ehler, 2006). These non-chemical control methods include biological control methods (Jacobsen et al., 2004), trapping (Rhino et al., 2010), and planting disease and pest resistant cultivars (Stewart et al., 2002; Klingeman, et al., 2009).

1.2.4. Native Plants

The use of native plant species in the landscapes is commonly advocated by individuals interested in developing sustainable systems. Native plants are species that are naturally indigenous to a given geographic area and are adapted to an area's local climate and fauna (Owen, 2002). Native plants support native wildlife (Alam et al., 2017) increasing pollinator density and diversity (Palmersheim et al., 2022;), can subsist with reduced irrigation (Suleiman, et al., 2011), and are adapted to local nutrient levels (Haridasan, 2008).

1.2.5. Lawns

The lawn is a dominant feature in the American landscape, covering an estimated 1.9% of land (Milesi et al., 2005); however, lawns are one of the least sustainable aspects of a landscape given the requisite high rates of irrigation, pesticide, and fertilizer use (Blanco-Montero et al, 1995). Replacing turfgrass species with non-turfgrass alternatives can reduce maintenance inputs and achieve similar recreational benefits as those associated with turfgrass (Beard, 1999). Moreover, many non-turfgrass plant species can thrive in a wider array of landscape settings, including shaded areas, where turfgrass growth can be challenging (Sladek et al., 2009).

1.2.6 Turfgrass Alternatives

Low growing, non-turfgrass plant species that can be used to replace lawns are colloquially known as ornamental groundcovers, or groundcovers. Interest in incorporating groundcovers into landscapes has increased (Nambuthiri and Ingram, 2014) recently due to their ornamental qualities (Klett and Wilson, 2009), low maintenance, pest resistance, low water (Pittenger et al., 2001) and fertilizer requirements (Eom et al., 2005; Weston and Eom, 2008). Groundcovers can also suppress weed growth, reducing the reliance on herbicide use in landscapes (Quigley, 2003). Information on the benefits of groundcovers is generally comprised of anecdotal accounts and non-quantitative assessments; however, cover crops, plant species that cover the ground in agriculture environments, have been extensively studied with their environmental impacts well documented (Kaspar and Singer, 2011). Plant species suitable for cover crops systems are seldom suitable for landscape applications due to their low ornamental value; however, cover crops and ornamental groundcover systems function in a remarkably similar manner, and the same benefits offered in agriculture could be presented in the landscape. Groundcovers represent an option for consumers to increase sustainability in their urban and

suburban areas while maintaining landscape quality, improving perception of adopting "green" planting schemes.

1.3. Groundcovers

Cover crops and groundcovers provide vegetative cover for soils, that alters physical properties of the soil including temperature and moisture content. Soil fertility is often increased under groundcovers due to the buildup of organic matter from plant residues. Groundcover systems can create an inhospitable environment for weeds to grow and develop, thereby decreasing weed pressure in the landscape.

1.3.1. Soil Temperature

Soil temperature directly affects many biological processes, including plant growth and microbial communities, as well as physical properties including chemical reactions and water movement (Hillel, 2004). Solar radiation striking the soil surface is the main driver of changes in soil temperature (Onwuka, 2018). Vegetative cover influences soil temperature due to solar radiation interception (i.e., shading; Flerchinger and Pierson, 1991), with decreased vegetative cover increasing temperatures (Sándor and Fodor, 2012). Increased soil temperatures may indeed increase plant growth (Domisch et al., 2001) and microbial activity (Zogg, et al., 1997); however, supra-optimal temperatures can elicit negative responses in the plant and soil system, including reduced plant shoot growth (McMichael and Burke, 1994; Liu and Huang, 2005) and soil bacteria health (Biederbeck and Campbell, 1973).

Groundcovers or cover crops can significantly impact soil temperature at or near the surface of the profile. Groundcovers block and reflect solar radiation, maintaining lower soil temperatures during the summer months when compared to bare soil (Van Huyssteen et al.

2017). Increasing density of groundcover vegetation correlates with an increased capacity to mitigate temperature extremes and prevent excess soil moisture depletion (Song et al., 2013). In addition to reducing soil temperatures through blocking solar radiation, groundcovers can moderate temperatures by evaporative cooling of the plant cover (Bavougian and Read, 2018). Evaporative cooling and the high specific heat of groundcovers when compared to impervious surfaces reduces soil temperatures in urban areas, thus decreasing heat island effects (Wu et al., 2014). Groundcovers and their subsequent residue reduce diurnal changes in soil temperature, buffering temperature fluctuations and producing healthier soils (Wilhelm et al., 2004). However, groundcovers have been shown to insulate the soil and increase temperatures when air temperatures decrease in the autumn, perhaps leading to an increase in the duration of microbial activity (Yang et al. 2021).

1.3.2. Soil Hydrology

Groundcovers can influence water dynamics in soils, such as infiltration rate (Glenn and Welker, 1989), moisture content (Eilers et al., 1995), and evaporative water loss (Zhiming, et al., 2011). The effects of living vegetative covers on soil hydrology has been studied extensively in agricultural settings, and the subsequent impact on crop growth has been assessed (Haramoto and Brainard, 2012). While this topic has been investigated in agricultural crop settings, the interest has been lesser in landscape settings. Excess water or saturated soil conditions are harmful to soil health and detrimental to plant growth (Bedard-Haughn, 2009); thus, increasing interest in further employing groundcovers to remove water through transpiration (Kihumba et. al., 2008; Prasad, 1988).

When compared to bare or cultivated soil conditions, groundcover systems increased infiltration rates significantly when studied in nursery settings (Calkins and Swanson 1998) and

may have reduced winter root injury of the main crop through insulation. Mulching systems are used to conserve moisture and improve soil properties (Iles and Dosmann, 1999); however, groundcover systems can have different purposes, and are used to increase infiltration rates and reduce excess soil moisture (Merwin et al., 1994). Groundcovers increase infiltration rates by reducing soil crusting and sealing (Folorunso et al., 1992), and groundcover root biomass increases water infiltration, subsequently reducing runoff (Krohn and Ferree, 2005; Chalise et al. 2021) and erosion (Gabet and Dunne, 2003). Moreover, infiltration rates may increase due to a soil moisture gradient created by groundcover plants. (Horton, 1941: Turner and Sumner, 1978).

1.3.3. Weeds

Weed control is an expensive and high labor demand in landscape maintenance (Case, 2005). Applications of herbicides can reduce physical control methods, yet herbicide resistance is becoming more prevalent (Délye et al., 2013). Additionally, homeowners are searching for alternative methods for weed control due to environmental and health concerns (Matheny, 2009). An environmentally friendly and effective method for controlling weeds is mulching; however, organic mulches such as pine straw, tree bark, and leaves decompose (Duryea et al., 1999) and must be replaced periodically, increasing maintenance costs (Marble et al., 2017). Inorganic mulches do not need to be replaced as frequently; however, they do not increase organic matter of the soil, and may raise soil temperatures and reflect heat onto plants (Pramanik et al., 2015). Groundcover plantings are an underutilized low maintenance option for non-chemical weed control in landscapes (Marble et al., 2015).

Groundcovers can reduce weed prevalence by competiting for resources such as light, water, and nutrients with their dense canopies and fast growth (Workayehu et al., 2011; Yeganehpoora et al., 2015). Reducing light transmittance is a mechanism by which groundcovers

can decrease weed densities (Pons, 1991; Wesson and Wareing, 1969), and some groundcover species further suppress weed growth by exuding allelopathic compounds (Eom et al., 2006). Ornamental groundcovers with dense growth forms can suppress weeds and reduce maintenance (Foo et al., 2011). Furthermore, these ornamental groundcovers can be employed in landscapes where conditions are not optimal for turfgrass (Marble and Pickens, 2020) with the added benefit of ornamental value through aesthetically pleasing foliage or flowers.

1.3.4. Soil Health

Soil health is measured by several factors including microbial community, nitrogen and carbon quantity, and organic matter residues. Presence of plant residues has been linked to greater soil health compared to soils devoid of such residues (Fu et al., 2021). Groundcovers increase soil organic matter and carbon through their residues and serve as a sink for global CO_2 (Jian et al., 2020; Repullo-Ruibérriz de Torres et al., 2018). Increased levels of soil organic matter increase microbial community diversity (Sofo et al., 2014), indicating a healthier and more robust soil profile (Anderson, 2003). Nitrogen availability can be increased by the presence of groundcovers and has been shown to increase crop yields (Raffa et al., 2021). In addition to above ground plant residues, the rhizosphere is an area rich in nutrients produced by root exudates (Baudoin et al., 2003) when compared to fallow soil (Sasse et al., 2018).

1.4. Conclusion

Groundcovers are popular additions to landscapes due to low maintenance requirements, ease of care, and attractive foliage and flower forms. Groundcovers can serve as sustainable alternatives for turfgrass. Concerns for the environment and negative effects of human-induced climate change have sparked a revival of the green movement, leading environmentally

conscious consumers to implement groundcover systems to lower soil temperatures, optimize soil moisture, decrease weed populations, and increase soil health and resilience. However, there is limited data on underutilized groundcover species selection and planting density can have on these soil properties. By increasing the knowledge of the effects of various species, we can increase sustainability in our rapidly urbanizing world.

2. THE EFFECT OF ORNAMENTAL GROUNDCOVER HABIT AND IRRIGATION DELIVERY ON SOIL CONDITIONS

2.1. Introduction

Sustainable practices, such as reducing the use and reliance of critical inputs like water, energy, and chemicals, are gaining widespread adoption in the horticulture industry. Consumers are frequently requesting sustainable practices to be incorporated into their landscapes. Sustainable practices in landscapes may manifest as reduced water and fertilizer use, reduced or no pesticide use, less labor-intensive landscapes, and increased use of native plant species. Sustainable landscapes are increasingly being adopted and recognized for their potential to enhance ecological, social, and educational benefits in urban and suburban landscapes (Saksa et al., 2012) Across the globe urban areas are increasing exponentially every year with the majority occurring in developing countries, which are predicted to harbor 80% of the urban population of the world by 2030 (Goddard et al., 2010). Urban areas are similarly expanding within the United States, increasing the need to adopt sustainable practices within our landscapes. With landscapes currently occupying millions of acres of land in the United States (Steinberg, 2005), it is critical that we continue to develop and implement new sustainable landscape practices to maximize the ecological value of this land. A popular component in the American landscape is the lawn, a notoriously high input feature of the landscape. The lawn is ubiquitous in the American landscape (Larson et al., 2014), making up approximately 25 to 40 million acres of land (Steinberg, 2005). Lawns have long been associated with high rates of water, fertilizer, and maintenance (Yue, 2021). Reducing lawn areas, either through conversion to native planting schemes or replacing turfgrass species with turfgrass alternatives is a sustainable practice to reduce water, fertilizer, and maintenance requirements. These non turf grass species are

popularly known as ornamental groundcovers. Planting and maintaining ornamental groundcovers, may be used to reduce water use compared to turfgrass (Burayu et al. 2021), reduce pesticide use (Garber and Bondari, 1996) reduce labor (Roka et al., 2003), and used as forage by pollinators (Masierowska et al., 2018).

An ornamental groundcover is defined as a plant species that has a dense prostrate growth habit, often with adventitious roots, and can survive where turfgrass cannot. Incorporating ornamental groundcover systems into landscapes can reduce labor cost, maintenance, lower water, and fertilizer usage, and reduce runoff water (Marble and Pickens, 2020). Trends in suburban landscapes have been shifting from a more traditional, input intensive management style to a more sustainable model.

Encouraging the installation of landscapes that require fewer inputs (e.g., irrigation, fertilizer, and maintenance) may decrease negative environmental outcomes. This is particularly true in cities, where limited water supplies are generating more interest in identifying plants for the landscape that do not require as much water as some that are currently in widespread use (Staats and Klett, 1995). Fertilization mismanagement in urban landscapes represents a potential source of nutrients that may contribute to water quality impairment (Carey et al., 2012). Fertilizing lawns can contribute to non-point source pollution, produce algal blooms, and degrade water resources (Campbell et al., 2020).

Removing the societal expectation to incorporate turfgrass in these sites and supporting the use of alternative groundcovers, native plants, or landscape beds may help reduce the need for frequent water and chemical applications and mitigate water contamination (Marble et al., 2015).

Public and private gardens are a major component of this urban green space and can provide considerable biodiversity benefits (Goddard et al., 2010). However, landscapes are often slower to adopt sustainable practices than production agriculture (Doxon, 1996). However, with increased urbanization, ornamental plantings in these areas are expected to increase as cities continue to beautify public and private places. It is imperative to promote biodiversity as well as be economically, environmentally, and socially minded in what comprises our urban landcover. As our land is converted from areas traditionally covered by vegetation into a built environment, groundcovers could be an essential tool in maintaining the vegetative cover of the land. Groundcovers planted in the urban environment are used for purposes like cover crops planted in agricultural fields; however, research into groundcovers is not as well documented.

Cover crops have similar environmental functions to ornamental groundcovers. Cover crops are well studied in production agriculture, with vast research quantifying their benefits on crop productivity and soil health. However, there has been little research in documenting the benefits of ornamental groundcover systems beyond aesthetics and ecosystem services such as pollinator and wildlife support. Cover crops to manage soil erosion, runoff, soil nutrients, soil physical properties, soil water, soil organic carbon, soil chemical properties, and soil biology (Kaspar and Singer 2011). Cover crops work to reduce soil erosion by mitigating rainfall impact. Cover crops have traditionally been planted to protect soils from wind and water erosion during fallow periods by enhancing soil structure and intercepting rainfall (Rosario-Lebron et al., 2019). A growing crop canopy has a significant potential to modify distribution of water applied during irrigation (Li and Rao, 2000). Growing cover crops remove water and nitrogen from the soil profile through transpiration and nitrogen uptake (Strock et al., 2004). Excess water in the soil profile is not conducive to plant growth because of reduced soil oxygen levels which impede root

growth (Pezeshki and DeLaune, 2012). Cover crops are used to reduce weed pressure in many cropping systems. By changing residue amounts and competition for water nutrients, weed volume is greatly reduced (Teasdale et al., 2007). We understand the similarities between cover crops and ornamental groundcover exist; however, there are also some unique differences. This research will quantify groundcovers for the same benefits that cover crops provide.

Many ornamental groundcovers are perennial species that can survive for many growing seasons. These ornamental groundcovers systems do not have to be replanted unlike annual cover crops systems. Annual labor costs can be lowered through installation of ornamental groundcover management systems. Mowing turfgrass is an expense that can be reduced or eliminated by integrating groundcovers into landscapes, public or private. Many ornamental groundcover species do not require the routine maintenance that turfgrass requires.

Water movement under different groundcover management systems (GMSs) has been well-studied under orchards. Several comprehensive reviews assessing the relative advantages and disadvantages of various GMSs have emphasized the need for additional information on the physiological, economic, and edaphic impacts of alternative orchard GMSs (Merwin et al., 1994). These are systems where various material or vegetation is used to cover bare soil to prevent erosion, add nutrients to the soil or cool soil temperature. Many studies cite groundcovers increasing water infiltration rates of soil (Folorunso et al., 1992, Krohn and Ferree, 2005). Impervious surfaces accompany urban development (Arnold and Gibbons, 1996), such as roofs, parking lots, and roads (Shuster et al., 2005). These impervious surfaces have dramatic effects on water movement, such as stormwater flow (Brabec et al. 2002). By substituting impervious surfaces with permeable surfaces such as groundcover plantings, water infiltration and stormwater mitigation could be accomplished.

Groundcovers have been shown to reduce high soil temperatures, which factor into the rates of biochemical reactions and have strong influences on plant and root growth (Song et al. 2013, Michelsen-Correa and Scull, 2005). The effects of groundcover canopies have been studied widely in vineyard management systems and orchards. Temperatures were found to be consistently cooler under a living groundcover system, Wimmera ryegrass (*Lolium multiflorum*), and vetch (*Vicia sativa*) in vineyards in South Africa (Van Huyssteen et al., 2017). Temperatures were also found to be lower under living mulch systems in vineyards than under conventional mulch systems. The groundcover treatments may have reduced soil temperatures because of the evaporative demand of the vegetation (Bavougian and Read, 2018). One study found that vegetation heights have an inverse relationship to soil temperatures, and soil temperatures are lower under groundcover systems than bare soil. (Song et al., 2013, Wu et al., 2014). Soil temperatures are lower under grass groundcover systems than bare soil. Mulches have traditionally been used to modify soil temperatures in landscapes. Ornamental groundcover systems have distinct advantages over mulches. All mulches, organic or synthetic, must be replaced periodically, adding to labor and maintenance requirements. Although many organic materials can exclude light if applied at sufficient depth, they degrade over time and certain materials potentially attract unwanted pests (Marble et al., 2017).

Plant cover or cover crops have a sizeable impact on soil microbial populations. Planted systems increase organic matter in soil which in turn increases microorganism numbers. Cover crops increase organic residue and humic substances that increase microbial activity vs. non cropped systems (Reddy et al., 2003). The rhizosphere of plants, the immediate zone around the plant’s roots, has an impact on microbial activity as well. Plant roots produce exudates that contribute to the microbiome (Baudoin et al., 2003). The rhizosphere is an area rich in nutrient

for microorganisms compared to bulk soil (Sasse et al., 2018) Bulk soil is defined as the soil not colonized by plant roots. (Vukicevich et al. 2016) concluded that plant diversity increases soil microorganism diversity which reduces soil pathogens, and native plants may further promote beneficial soil microbes. Moreover, traditional cultivation harms microbial populations and leads to a proliferation of pathogens and crop decline.

As landscapes cover such a vast quantity of land, it is important to quantify the environmental benefits of ornamental groundcovers. GMS have been used to improve agronomic crop fields, tree fruit orchards, and other production agriculture; however, they have not been studied to the same extent in the landscape. Therefore, the objective of this experiment was to study the influence of ornamental groundcover on soil health and conditions, and quantify any other environmental, cultural, or economic benefits that may be associated with groundcover plantings. Additionally, this research aims to understand how groundcover growth habits and irrigation application methods influence the outcome and benefits with groundcovers in the landscape**.**

2.2. Materials and Methods

2.2.1. Site preparation and establishment

An 80 m^2 area plot (4 m x 20 m) was prepared at the Louisiana State University Agricultural Center Hammond Research Station located in Hammond, LA (30.5044° N, 90.4612° W).Wherein, the soil, Cahaba fine sandy loam, was tilled to a depth of 10 cm and amended with a locally sourced landscape mix consisting of pine bark, sand, dolomitic lime, Agri-AFC micro-nutrient blend, and magnesium sulfate (Phillips Bark Processing Company; Brookhaven, MS**)**. Twenty individual 1 m^2 plots were partitioned, with 50 cm between plots

north to south and 1 meter between the two rows of plot east to west, meanwhile three meters were placed between irrigation treatment. The plots were subdivided into two separate irrigation regimes, where half the plot was designed for overhead irrigation and the other half plot was designed for micro-irrigation.

2.2.2. Irrigation

The overhead irrigation consisted of sprayers (Model 15 UH; U15Q, Rainbird, Azusa, CA) on 6, 1 m risers with 4 corner risers and 2 middle risers located 4.5 m toward the center of the overhead plot. The micro-irrigation plots were designed with a 360-degree sprayer (Model XS360TS Adj True Spray, Rainbird, Azusa, CA) on a 30 cm riser with barb .16 adapter (Antelco, Longwood, FL) positioned in the center of each plot. Distribution uniformity (DU) tests were conducted in each zone following (Merriam and Keller 1978). The overhead DU was 77%, and the micro-irrigation had a DU of 89.5%.

Irrigation was applied to each plot twice a week (Monday at 9AM & Thursday at 9AM), with plots in both irrigation delivery treatments receiving 6.8 L/m^3 of water per irrigation event. To ensure equal irrigation applications, the overhead plots were irrigated for 15 min and the micro-irrigation plots were irrigated for 22 min every event.

2.2.3. Soil Properties

A soil moisture sensor (Teros 12; METERGROUP, Pullman, WA) was buried in the center of each plot at a depth of 15 cm to monitor soil volumetric water content, temperature electric conductivity (EC). The sensors were attached to a data logger (CR1000x; Campbell Scientific, Logan, UT) along with a tipping bucket rain gauge (TR-525I; Texas Electronics, Dallas, TX), which collected data every 10 minutes. The data logger was programmed to record

hourly averages of each sensor. The entire research plot was mulched with pine straw at a depth of 7.5 cm. Within each irrigation system, three randomly selected plots were planted with *Sphagneticola trilobata* (Wedelia), three were planted with *Liriope muscari* ‘Big Blue’ (Liriope), and the remaining three were left fallow.

The wedelia was selected as a quick-growing groundcover with a matting habit, which would spread across the surface of the plot representing an established groundcover planting, potentially intercepting water, while the liriope was selected as a bunching groundcover that would direct water into the soil. Nine individual plants were spaced 30cm with a cardboard bracket and transplanted in each respective plot. After planting, each plot received 100 g of controlled release fertilizer (Osmocote Plus 15-9-12, 5-6 months; ICL Specialty Fertilizers, Dublin, OH), which was spread uniformly across the entire plot.

2.2.4. Coverage analysis

Overhead photographs of each plot were collected every 30 d ± 3 d utilizing a Sony A6000 camera (Sony Group Corporation, Minato City, Tokyo, Japan). A 1 m x 1m bracket with a stand was constructed to ensure the camera was positioned 150 cm high above the center of the plots, so each photograph was taken from the same height with the entire 1 m^2 plot within the frame, plus it served as a boarder for further analysis. A portable canopy (10' x 10' Venture, White, Z-Shade Company. Ltd., Baldwin Park, California) was placed over the plots to ensure that sunlight levels were consistent for every photo. Individual photographs were cropped using Adobe Photoshop (Adobe Inc., San Jose, California) to only include the materials within the bracket. Photos were analyzed using WinCAM Color Area Meter Software (Regent Instruments, Québec City, Quebec, Canada), wherein the plot coverage of the plants was calculated. This

involved assigning color classes were assigned to the groundcover and background. These classes were analyzed by the software and percentage was determined.

2.2.5. Weed Density and Biomass

Weed suppression was assessed by collecting individual weeds every two weeks starting on May 25, 2022. The bracket was placed around each plot. Weeds were only collected in the 1 m^2 plot. Weeds were severed at the soil level to minimize soil disturbance. Weeds were counted and organized as either a monocotyledon or dicotyledonous species. Weeds were dried at 70 º C for 7 d and the dry weight was recorded. This was a modified protocol following (Cardina et al. 1997). There were no herbicide treatments within the plots. Glyphosate herbicide was applied to the lawn edge of the study area every three weeks.

2.2.6. Microbial Communities

Analysis of the microbial community in this project was completed using the FAMEs (Fatty Acid Methyl-Ester) technique described by Quideau et al. (2016). Soil cores approximately 30 cm in length were extracted from each plot 30 cm from the center of each plot in the southwest corner on 17 June 2022 (Week 6), and again on 23 September 2022 (Week 19). The samples were frozen immediately after removal from the soil. On the day of the extraction, each sample was mixed in each collection bag to form a homogeneous mixture. The fatty acid methyl-esters were extracted from each 3 g sample. These were then processed through a gas chromatograph (7890B, Agilent), which measured the relative and absolute abundance of each class of soil microorganisms. The peaks were measured using software (MIDI, Microbial ID, Inc., Newark, DE)

2.2.7. Canopy Interception

Canopy interception was measured on 26 September 2022 by arranging four petri dishes (100mm x 15mm; Fisher Scientific, Waltham, MA) on the soil surface of each plot. Petri dishes were placed 20 cm from the center of each plot on the diagonal. Irrigation was applied for four min. The volume of water retained in each petri dish was measured via graduated cylinder. This process was repeated three times (the 2 consecutive days after 26 September 2022). Canopy interception was calculated as the difference between the planted plots and the fallow plots (Li and Rao 2000).

$$\frac{(Fallow - Planted\ Plots)}{Fallow} * 100 = Interception\ \%$$

2.2.8. Data Analysis

The data presented in tables and figures with associated statistics were analyzed in JMP Pro (16.1.0; SAS Institute, Inc.; Cary, NC, U.S.) utilizing Tukey's Honestly Significant Difference ($\alpha = 0.05$) to separate plant coverage means, VWC means, temperature means, EC means, soil microbial community abundance means, canopy interception means, and weed density and biomass means across 3 plot treatment responses across both irrigation deliveries. Analysis of variance (ANOVA) was further utilized to determine any statistically significant differences between the means of the 3 plots.

2.3. Results and Discussion

2.3.1. Volumetric Water Content

Wedelia plots had lower weekly average volumetric water content (VWC) values across irrigation treatments throughout the entire study with limited exceptions (Figure 2.1.).

Ornamental groundcovers function similarly to cover crops, where more total plant biomass produces a higher transpiration rate resulting in less water in the soil profile. (Kihumba et. al., 2008) demonstrated that cover crops can reduce excess soil moisture, moreover Yunusa et. al., (2012) demonstrated that greater root biomass and leaf area index (LAI) results in increased transpiration rates. Groundcover biomass was not measured during this study; however, an alternative metric, vegetative cover, measured that wedelia plots had a range of 9%-52% more vegetative coverage than liriope plots (Table 2.1.), yielding lower VWC values for plots with wedelia (Figure 2.2.).

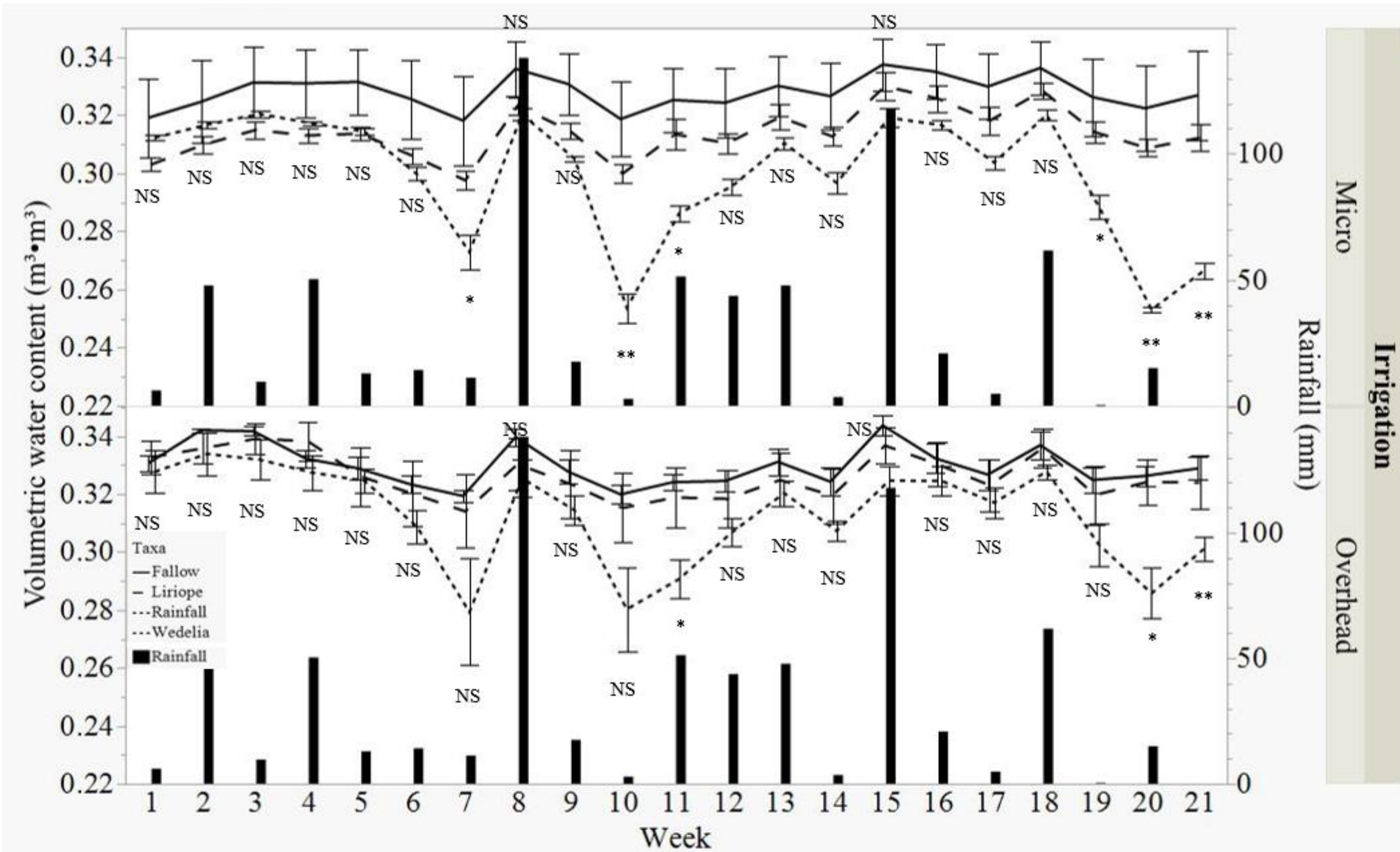

Figure 2.1. Average volumetric water content (15cm below the surface) and weekly rainfall totals were recorded over a 21-week period in summer 2022. Not significant (NS), * P ≤ 0.05, **P ≤ 0.01, ***P ≤ 0.001 denote differences among the means using Tukey honestly difference test (α = 0.05). Each error bar is constructed using 1 standard error from the mean.

Table 2.1. Groundcover percentage of two different species (Liriope; Wedelia) measured five times over a 21- week period during Summer 2022.

Weeks after Planting	0 WAP	5 WAP	9 WAP	13 WAP	18 WAP
Irrigation	% plant cover	% plant cover	% plant cover	% plant cover	% plant cover
Micro	32.5 a[i]	42.0 a	57.5 a	68.4 a	67.3 a
Overhead	31.2 a	43.2 a	56.2 a	63.0 a	60.4 a
p-value $_{irr}$	0.7593[ii]	0.7694	0.9021	0.3809	0.0860
Taxa					
Liriope	26.0 b	37.3 b	40.1 b	58.5 b	65.5 b
Wedelia	37.8 a	47.9 a	73.6 a	72.9 a	62.1 a
p-value $_{\text{taxa}}$	**0.0001**	**0.0002**	**<.0001**	**0.0058**	0.4319
Interaction					
Wedelia-Micro	40.6 a	48.8 a	75.5 a	78.4 a	67.4 a
Wedelia-Overhead	35.0 a	47.0 ab	71.1 a	67.3 ab	67.1 a
Liriope-Overhead	27.5 b	39.3 bc	40.7 b	58.6 b	63.9 a
Liriope-Micro	24.5 b	35.2 c	39.6 b	58.3 b	56.9 a
p-value $_{irr*plot}$	**0.0211**	0.1366	0.1096	0.1620	0.3525

[i]Letters denote detected differences among means of a full factorial including from three planting treatments (Wedelia; Liriope; Fallow) and two irrigations (Micro spray; Overhead) utilizing Tukey's HSD ($\alpha = 0.05$) approximately. Values with the same letters denote no significant difference.
[ii]Measures of overall treatment effects utilizing ANOVA analysis utilizing a significance level ($\alpha = 0.05$)

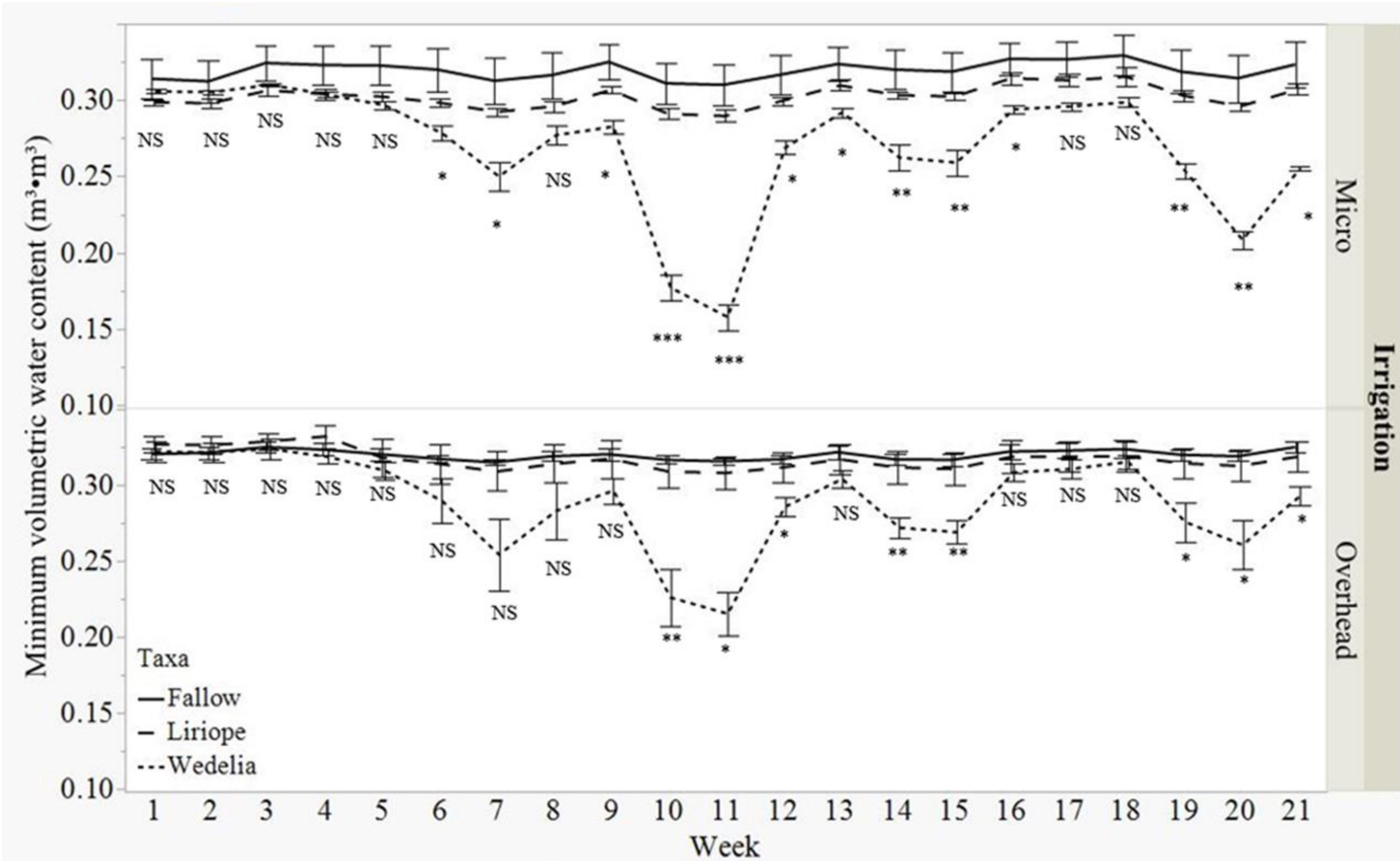

Figure 2.2. Average weekly volumetric water content minimum values (15cm below the surface) were recorded over a 21-week period in summer 2022. Not significant (NS), * $P \leq 0.05$, **$P \leq 0.01$, ***$P \leq 0.001$ denote differences among the means using Tukey honestly difference test ($\alpha = 0.05$). Each error bar is constructed using 1 standard error from the mean.

VWC was greatest under the fallow plots (Figure 2.3.), as there were no plant roots to remove water (Prasad, 1988) from the soil profile. Considerable variation was observed under the fallow plots, likely due to the lack of vegetation increasing water entry into soil (Gerrits et al. 2010). Liriope is a plant species that has a relatively low water demand, thus maintaining higher VWC values than plots with wedelia (Holmes, 2001).

The average VWC of the soil was lower in plots receiving micro spray irrigation compared to plots receiving overhead irrigation, despite identical volumes of water being applied. Similar results were observed by Rowe et al. (2014), where areas receiving overhead irrigation had greater VWC values when compared to other irrigation methods. Over the first five weeks of the study, plots receiving micro spray irrigation exhibited increases in the maximum VWC values while the overhead irrigated plots remained stable (Figure 2.3.). During weeks 6 and 7, VWC in all plots decreased due to an irrigation malfunction resulting in no irrigation applied for an estimated 2 weeks.

Flux (VWC_{Max}-VWC_{Min}) average values were observed to be greatest in both irrigation deliveries for wedelia plots, noting a greater change in VWC for wedelia versus both liriope and fallow plots following rainfall events. (Figure 2.4.). Moreover, during periods of rainfall greater or equal to 50 mm during the week, VWC values increased for all treatments, but most dramatically for plots with wedelia receiving micro irrigation, and to a slightly lesser extent plots with wedelia receiving overhead irrigation, which was likely attributed to root growth increasing the infiltration rates (Krohn and Ferree, 2005; Chalise et al. 2021). Interspace areas between micro spray irrigation plots may have been drier than overhead irrigated areas due to the higher water application efficiency of micro spray irrigation (Irmak et al., 2011), unlike overhead irrigation where water was applied intentionally to the plots and unintentionally to the plot

interspaces. The low moisture interspaces, along with the drier soil created by the high-water demand of the plots planted with wedelia, may have increased the infiltration rate due to the soil's initial lower soil moisture values (Horton, 1941: Turner and Sumner, 1978).

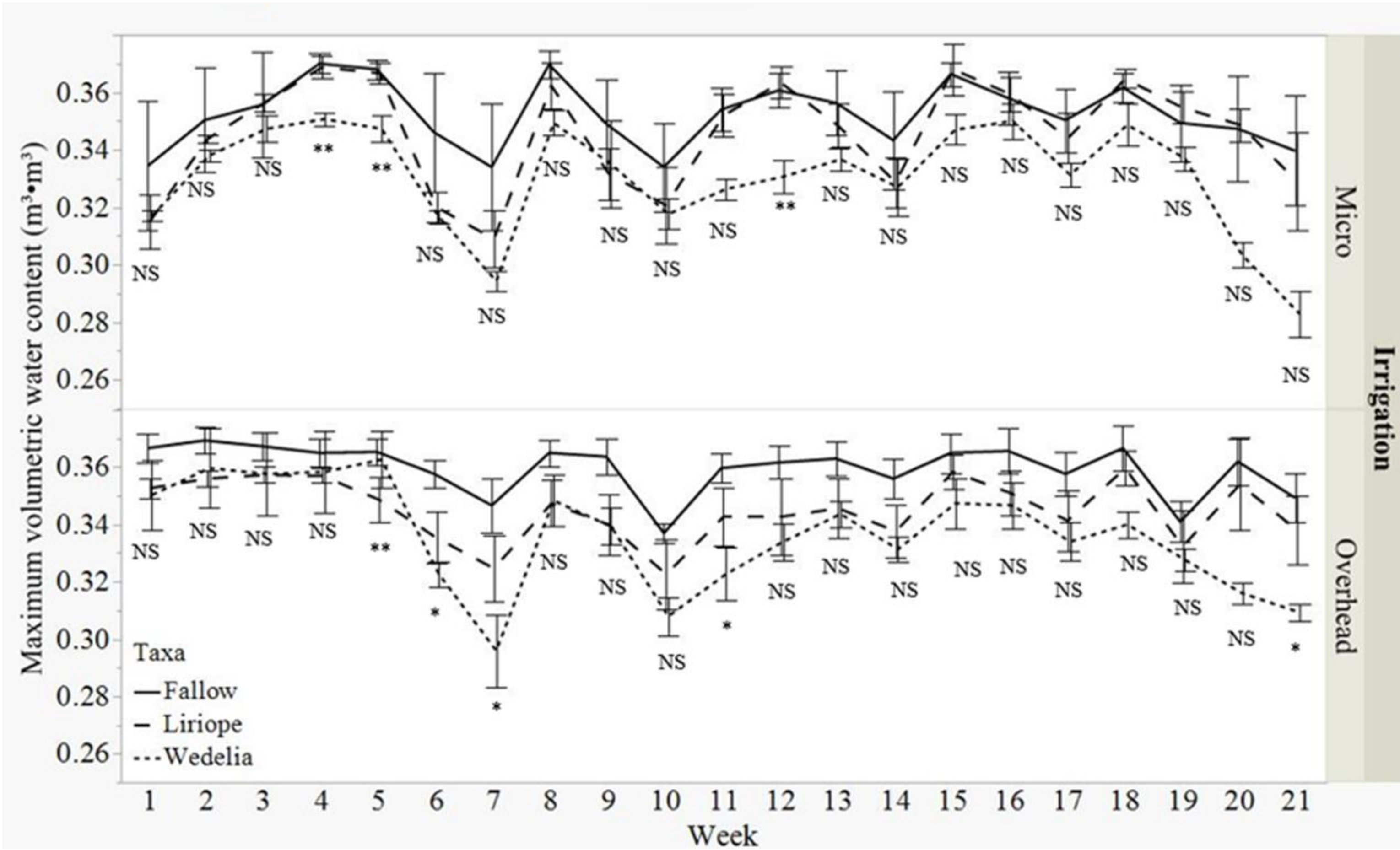

Figure 2.3. Average weekly volumetric water content maximum values (15cm below the surface) were recorded over a 21-week period in summer 2022. Not significant (NS), * $P \leq 0.05$, **$P \leq 0.01$, ***$P \leq 0.001$ denote differences among the means using Tukey honestly difference test ($\alpha = 0.05$). Each error bar is constructed using 1 standard error from the mean.

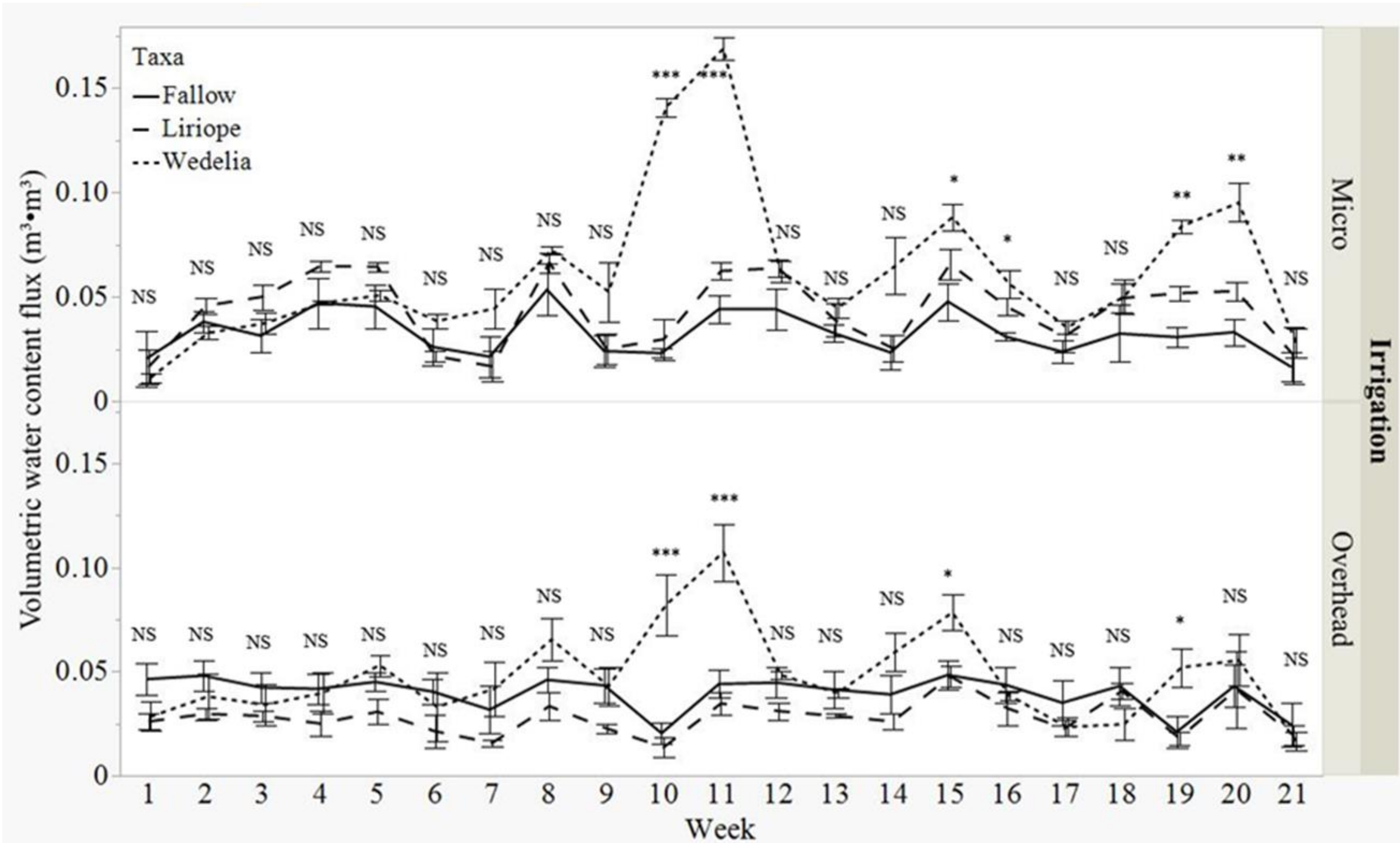

Figure 2.4. Average weekly volumetric water content flux (VWCmax-VWCmin) (15cm below the surface) was recorded over a 21-week period in summer 2022. Not significant (NS), * P ≤ 0.05, **P≤ 0.01, ***P ≤ 0.001 denote differences among the means using Tukey honestly difference test (α = 0.05). Each error bar is constructed using 1 standard error from the mean.

2.3.2. Soil Temperature

The plots with wedelia had the lowest temperatures under both irrigation delivery systems, followed by plots planted with liriope and finally plots left fallow. (Figure 2.4.). Wedelia had a greater coverage percentage (Table 2.1.) which likely contributed to more reflected solar radiation from the soil surface, which would be similar to results observed by Van Huyssteen et al. (2017). The increased shading caused by the greater plot coverage provided by the dense wedelia canopy likely contributed to the lower temperatures in soils under both irrigation systems (Song et al., 2013). A higher evaporative demand from the plants may have also lowered the soil temperature under plots planted with wedelia (Bavougian and Read, 2018). This is mirrored by the lower soil moisture content within the wedelia plots. (Figure 2.2.). The fallow plots had the highest temperature when compared to plots planted with liriope or wedelia under both irrigation deliveries, which was consistent with results from Calkins and Swanson (1998) and Wu et al. (2014). During weeks of rainfall greater than or equal to 50 mm, ambient air temperatures were lower or equal to soil temperatures in all treatments. This increased water content within the treatments may have raised the specific heat of the soil (Zhang et al., 2022). As average ambient temperatures decreased below 26^{o} C during the fall, soil temperatures under all treatments were greater than air temperature, which is consistent with observations from a study by Yang et al. (2021).

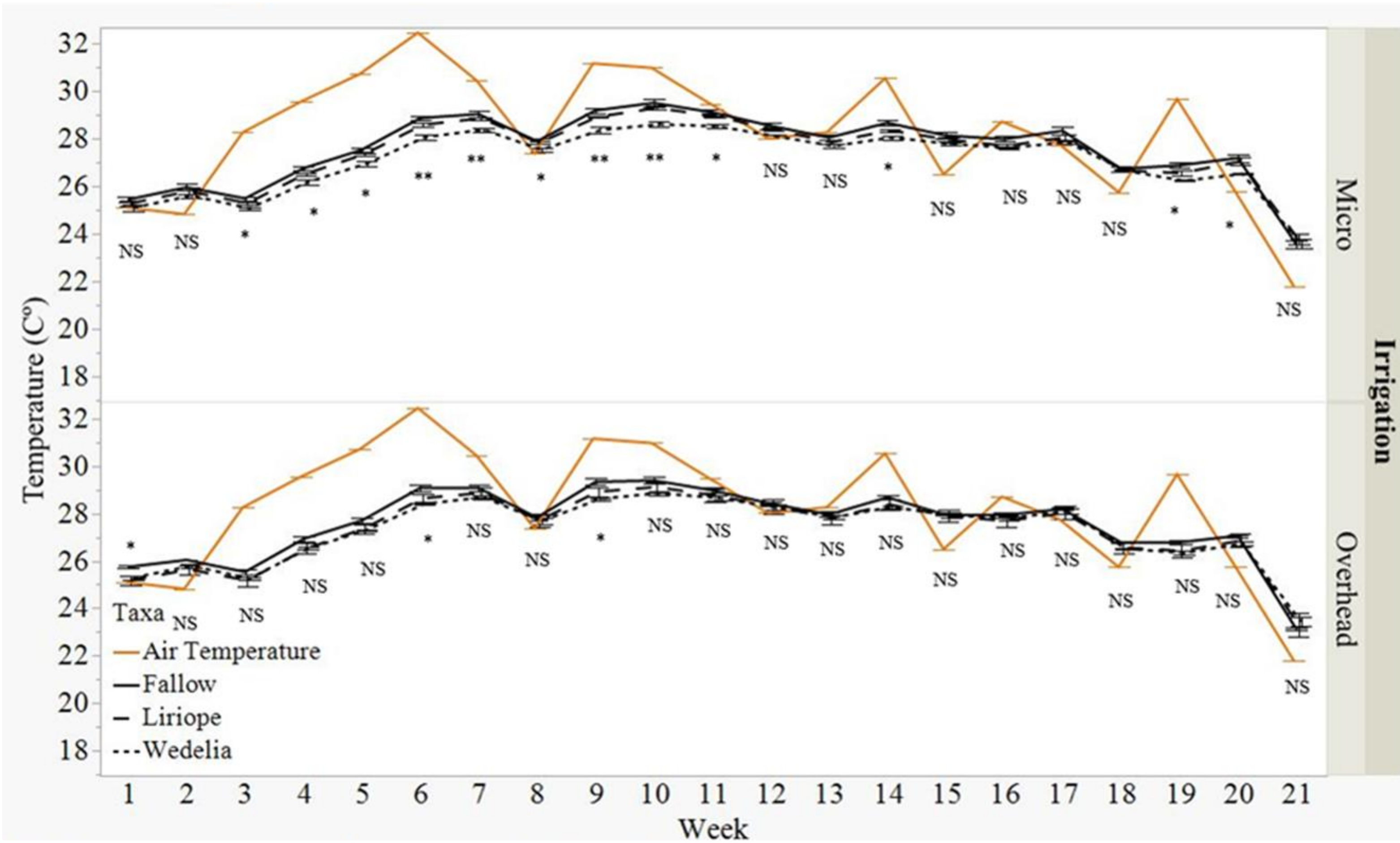

Figure 2.5. Average weekly soil temperatures (15cm below the surface) and weekly average air temperatures were recorded over a 21-week period in summer 2022. Not significant (NS), * P ≤ 0.05, **P≤ 0.01, ***P ≤ 0.001 denote differences among the means using Tukey honestly difference test (α = 0.05). Each error bar is constructed using 1 standard error from the mean.

2.3.3. Electronic Conductivity

Electrical conductivity (EC) is the measure of soluble salts in a soil (Verma et al., 2015). Measuring EC is a fast and cost-effective method EC to determine several chemical properties of soil including leaching, irrigation patterns and can correlate to crop yields (Grisso et al., 2005). There were no significant differences between the planting treatments receiving micro spray or overhead irrigation (Figure 2.6.). Micro irrigated plots had significantly lower EC values ($p<.0001$) than plots receiving overhead irrigation indicating that overhead irrigation more than likely leached more nutrients than micro spray irrigation due to irrigation efficiency and distribution (Li et al., 2018; Machado and Serralheiro, 2017). Variability in the composition of the soil (Corwin and Lesch, 2005) could have led to an increased EC value under micro spray irrigation but was not measured because of the small zone of influence of the soil sensors (1010 ml). Plots planted with liriope had significantly higher EC values ($p<.0001$) in comparison to wedelia plots or fallow plots presumably due to the roots of liriope increasing the EC values (Ni et al., 2019).

2.3.4. Vegetative Coverage

Wedelia had significantly more coverage than liriope on three of the five dates this metric was measured during the study (Table 2.1.). Wedelia has a more rapid growth rate and spreading growth form than liriope, contributing to the observed greater coverage (Nesom, 2010; Si et al., 2014). Irrigation delivery method did not influence the coverage percentage of the two species. Differences in the growth habits of wedelia and liriope were most likely attributable to the innate form of each species, and less so towards the irrigation application method.

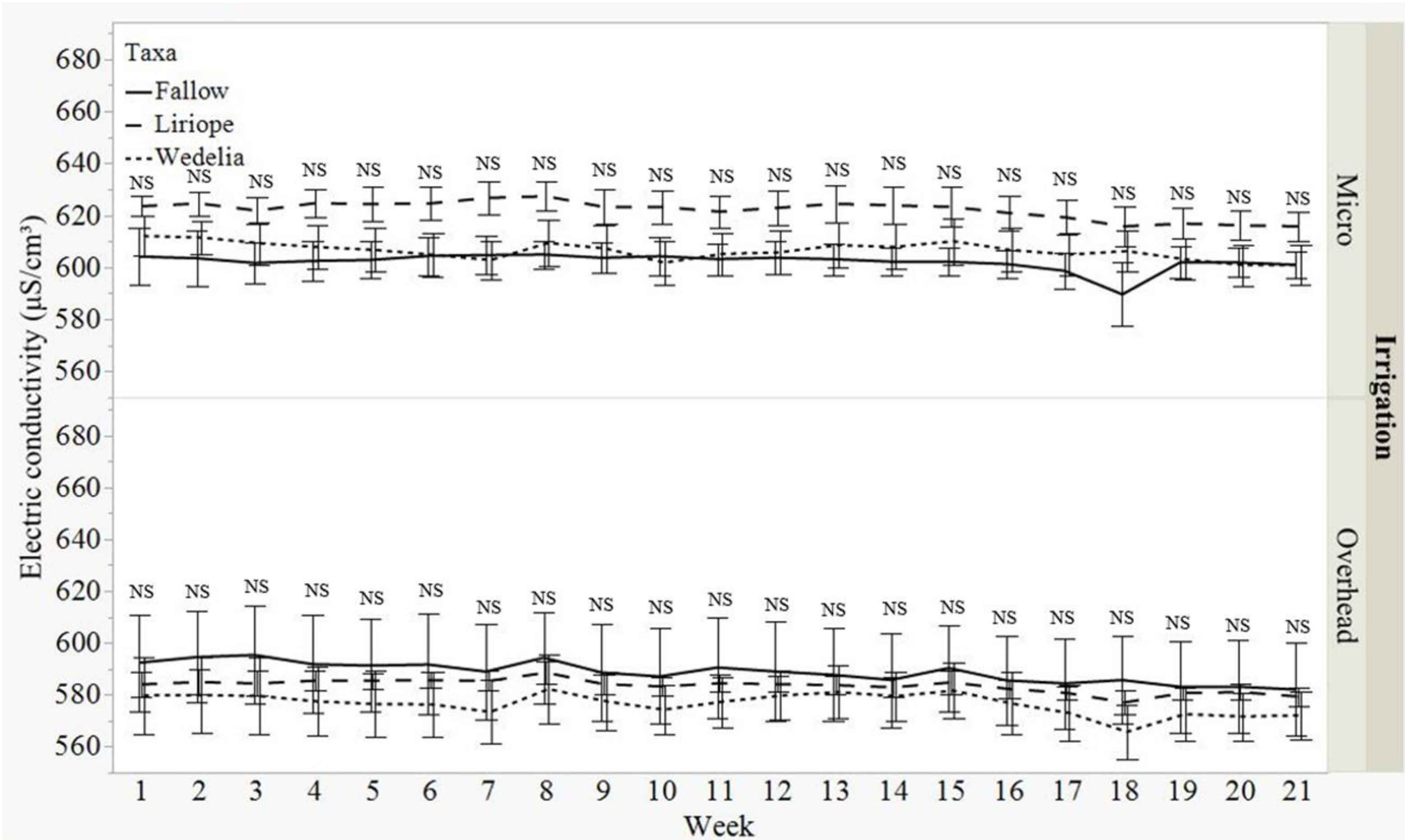

Figure 2.6. Average weekly electric conductivity values (15cm below the surface) were recorded over a 21-week period in summer 2022. Not significant (NS), * P ≤ 0.05, **P≤ 0.01, ***P ≤ 0.001 denote differences among the means using Tukey honestly difference test (α = 0.05). Each error bar is constructed using 1 standard error from the mean.

2.3.5. Weed Biomass and Density

Fallow plots irrigated via overhead systems exhibited increased levels of weed density and weed biomass when compared to plots planted with wedelia or liriope (Table 2.1.), which is consistent with results demonstrated in other agricultural systems (Clement and DeFrank, 1998; Haramoto and Brainard, 2012). The wedelia and liriope planted plots provided coverage with their respective canopies, with wedelia providing more coverage than the plots planted with liriope. Wedelia has a horizontal growth pattern with less erect growth than liriope (Figure 2.7.), decreasing light transmittance to the soil and likely contributing to decreased weed biomass and density (Workayehu et al., 2011; Yeganehpoora et al., 2015). The combination of and interaction between the increased shading and lower moisture content (Figure 2.2.) created by the wedelia plants produced an environment that was less conducive to weed germination and growth (Pons, 1991; Wesson and Wareing, 1969; Foo, 2011).

Plots planted with wedelia, liriope, or left fallow receiving micro spray irrigation had less weed density and biomass than overhead irrigated plots; however, the fallow plots did not have consistently higher levels of weed density and biomass as is demonstrated in the overhead irrigation. Taking into account that both irrigation systems delivered the same volume of irrigation water, and that coverage percentages did not differ between irrigation delivery systems (Table 2.1.), it is possible that irrigation distribution influenced differences in weed density and biomass (Xi et al., 2022; Stewart et al., 2017).

Table 2.2. Weed density and biomass recorded in three planting treatments: Fallow, Liriope, Wedelia under two irrigation treatments (Overhead and Micro spray irrigation) over a 21-week period in summer 2022.

Irrigation	Plot	2 WAP[i]	4 WAP	7 WAP	10 WAP	13 WAP	17 WAP	19 WAP
		no./m^2	no./m^2	no./m^2	no./m^2	no./m^2	no./m^2	no./m^2
Overhead	Fallow	12.5 ab[ii]	25.5 a	28.6 a	23.8 a	23.8a	15.8 a	21.0 a
	Liriope	5.3 ab	11.5 a	11.5 a	9.8 a	11.3a	9.0 a	6.1 a
	Wedelia	4.6 b	7.0 a	7.5 a	6.0 a	7.5a	3.0 a	3.3 a
Micro	Fallow	2.5 a	2.1 a	5.6 a	2.8a	5.1 a	3.3 a	6.0 a
	Liriope	5.8 ab	11.8 a	9.8 a	7.3a	7.3 a	4.0 a	2.6 a
	Wedelia	5.3 ab	8.3 a	2.6 a	5.5a	5.5 a	3.1 a	3.6 a
Irrigation $_{\text{p-value}}$		.1106[iii]	.2510	.1516	.1300	.0680	.0600	.2856
Plot $_{\text{p-value}}$		.4491	.7125	.3487	.4850	.3263	.2160	.2839
Irr*plot $_{\text{p-value}}$		**.0317**	.1986	.3838	.2162	.2475	.2293	.5121
		g/m^2	g/m^2	g/m^2	g/m^2	g/m^2	g/m^2	g/m^2
Overhead	Fallow	10.5 a	2.5 a	5.5 a	3.7 a	10.9 a	8.1 a	3.2 a
	Liriope	8.1 a	1.3 a	2.5 a	4.0 a	7.1 ab	4.0 a	1.1 a
	Wedelia	7.5 a	1.0 a	1.9 a	1.9 a	4.3 b	0.7 a	0.8 a
Micro	Fallow	8.2 a	0.4 a	1.5 a	0.7 a	4.2 b	5.5 a	1.5 a
	Liriope	8.0 a	0.6 a	2.3 a	2.6 a	5.5 ab	3.9 a	0.4 a
	Wedelia	7.5 a	0.3 a	2.1 a	1.4 a	4.2 b	1.0 a	0.8 a
Irrigation $_{\text{p-value}}$		.3036	**.0222**	.2020	**.0445**	**.0139**	.6862	.2808
Plot $_{\text{p-value}}$		.1156	.3900	.4678	.2259	.0523	.0748	.1201
Irr*plot $_{\text{p-value}}$		.3308	.3723	.1928	.4080	**.0415**	.8125	.6365

[i]Weeks after planting

[ii]Letters denote detected differences among means of a full factorial including from three planting treatments (Wedelia; Liriope; Fallow) and two irrigations (Micro spray; Overhead) utilizing Tukey's HSD ($\alpha = 0.05$) approximately. Values with the same letters denote no significant difference.

[iii]Measures of overall treatment effects utilizing ANOVA analysis utilizing a significance level ($\alpha = 0.05$)

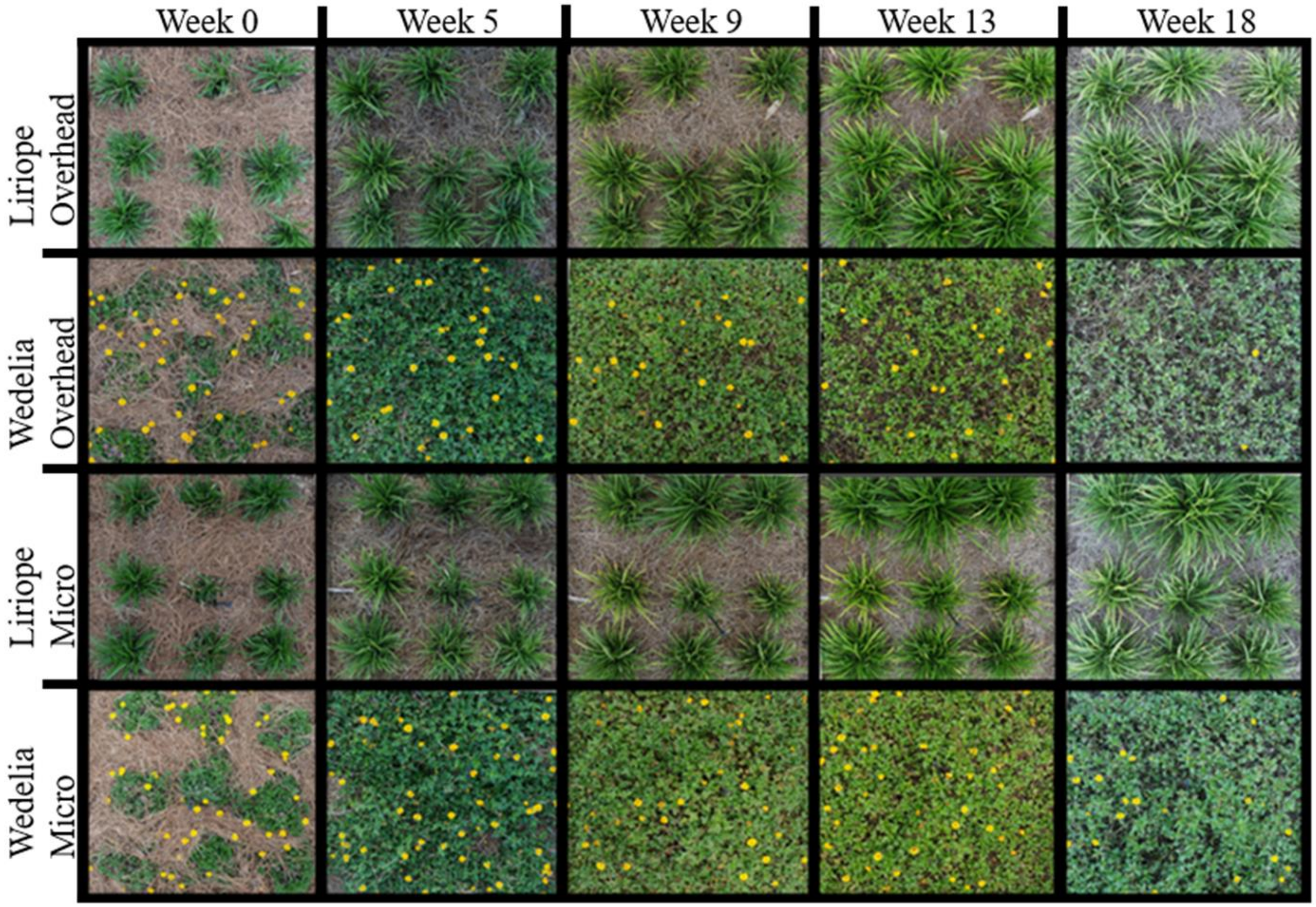

Figure 2.7. Photos taken of two groundcover species (Liriope; Wedelia) under two irrigation treatments (overhead; micro spray irrigation) every 4 weeks over a period of 20 weeks.

2.3.6. Microbial Communities

The rhizosphere is the area immediately surrounding plant roots and their associated microbial community (Morgan et al., 2002). The rhizosphere is often rich with microbial life due to root photosynthate secretions (Bais et al., 2006). Consistent with findings by Buyers et al. (2002), no significant differences were observed in relative or absolute abundance among the microbial communities between plant species when soils were sampled during week 6 or week 20 (Table 2.3.; Table 2.4.). Buyers et. (2002) observed the rhizosphere of plants only affects a small fraction of the microbial community, and any changes in root biomass and species would be insufficient to significantly alter the community. Additionally, no significant differences were observed in relative or absolute abundance among the microbial communities between irrigation methods. Soil moisture has been found to influence microbial communities (Cregger et al., 2012), however applied irrigation did not differ between delivery systems nor was it or rainfall deficit enough to influence the communities. Ignoring all treatment variables (plot, irrigation method, interaction), Gram-negative bacteria and arbuscular mycorrhizae were more relatively abundant when soil was sampled during week 20, however eukaryotes were more abundant during week 6. Ignoring all treatment variables (plot, irrigation method, interaction), arbuscular mycorrhizae were more abundant when soil was sampled during week 20 (Table 2.3.; Table 2.4.).

Table 2.3. Absolute abundance of microbial communities quantified by fatty acid methyl ester analysis (FAMEs) utilizing gas chromatography.

Week 6		Actinomycetes	Arbuscular Mycorrhizae	Eukaryotes	Fungi	Gram (+) bacteria	GM (-) bacteria	Protozoa
Irrigation	Plot	nmol/g	nmol/g	nmol/g	nmol/g	nmol/g	nmol/g	nmol/g
Micro	Fallow	2.95 a[i]	6.63 a	42.58 a	57.94 a	37.07 a	12.93 a	1.62 a
	Liriope	4.23 a	14.36 a	57.45 a	96.03 a	53.07 a	22.90 a	2.84 a
	Wedelia	3.22 a	9.93 a	70.32 a	199.16 a	64.80 a	28.00 a	0.89 a
Overhead	Fallow	3.68 a	7.23 a	50.72 a	82.88 a	41.71 a	18.66 a	2.11 a
	Liriope	1.40 a	9.14 a	63.05 a	73.04 a	34.58 a	14.75 a	0.31 a
	Wedelia	3.87 a	12.63 a	63.24 a	114.81 a	62.78 a	29.43 a	0.65 a
	Irrigation p-value	0.7005	0.9343	0.8818	0.3455	0.6377	0.9537	0.2683
	Plot p-value	0.8854	0.5356	0.5359	0.0568	0.1951	0.1824	0.3969
	Irr*plot p-value	0.4236	0.6083	0.9024	0.3138	0.6826	0.5940	0.1857

Week 20		Actinomycetes	Arbuscular Mycorrhizae	Eukaryotes	Fungi	Gram (+) bacteria	GM (-) bacteria	Protozoa
Irrigation	Plot	nmol/g	nmol/g	nmol/g	nmol/g	nmol/g	nmol/g	nmol/g
Micro	Fallow	3.23 a	9.91 a	19.79 a	38.32 a	33.22 a	13.18 a	2.30 a
	Liriope	2.75 a	43.89 a	40.07 a	172.81 a	44.28 a	29.78a	2.98 a
	Wedelia	2.95 a	23.69 a	19.49 a	70.00 a	34.99 a	28.59a	2.91 a
Overhead	Fallow	2.25 a	7.75 a	23.89 a	5.21 a	36.93 a	17.05 a	8.88×10^{-16} a
	Liriope	4.83 a	35.74 a	77.56 a	108.33 a	57.50 a	34.49 a	2.94 a
	Wedelia	7.50 a	58.42 a	71.48 a	179.46 a	83.01 a	73.81 a	6.53 a
	Irrigation p-value	0.2679[ii]	0.6031	0.2887	0.6816	0.2786	0.2004	0.8763

Table cont'd

	Actinomycetes	Arbuscular Mycorrhizae	Eukaryotes	Fungi	Gram (+) bacteria	GM (-) bacteria	Protozoa
Plot $_{p\text{-value}}$	0.4785	0.1899	0.5686	0.2849	0.5949	0.1255	0.5705
Irr*plot $_{p\text{-value}}$	0.4067	0.4827	0.7793	0.3804	0.6195	0.3757	0.6714
Date $_{p\text{-value}}$	0.5012	**0.0170**	0.3271	0.9987	0.9512	0.116	0.2766
Date*irr $_{p\ value}$	0.2554	0.5949	0.3695	0.4029	0.9512	0.2155	0.6718
Date*plot$_{p\text{-value}}$	0.6580	0.2774	0.8112	0.3860	0.8839	0.4277	0.4008
Date*irr*plot$_{p\text{-value}}$	0.3731	0.6012	0.7202	0.2051	0.6371	0.4286	0.5914

[i]Letters denote detected differences among means of a full factorial including from three planting treatments (Wedelia; Liriope; Fallow) and two irrigations (Micro spray; Overhead) utilizing Tukey's HSD (α = 0.05) approximately. Values with the same letters denote no significant difference.
[ii]Measures of overall treatment effects utilizing ANOVA analysis utilizing a significance level (α = 0.05)

Table 2.4. Relative abundance of microbial communities quantified by fatty acid methyl ester analysis (FAMEs) utilizing gas chromatography.

Week 6		Actinomycetes	Arbuscular Mycorrhizae	Eukaryotes	Fungi	Gram (+) bacteria	GM (-) bacteria	Protozoa
Irrigation	Plot	(mol %)	(mol %)	(mol %)	(mol %)	(mol %)	(mol %)	(mol %)
Micro	Fallow	0.79 a	2.01 a	12.88 a	17.90 a	12.14 a	4.02 a	0.42 a
	Liriope	0.92 a	2.73 a	13.33 a	21.80 a	11.84 a	4.81 a	0.61 a
	Wedelia	0.53 a	1.41 a	10.64 a	28.93 a	9.75 a	4.17 a	0.14 a
Overhead	Fallow	0.96 a	1.88 a	13.07 a	20.84 a	10.45 a	5.67a	0.53 a
	Liriope	0.43 a	3.06 a	13.82 a	19.75 a	8.66 a	4.36a	0.21 a
	Wedelia	0.55 a	2.22 a	11.69 a	19.63 a	12.30 a	5.18a	0.24 a
	Irrigation $_{p\text{-value}}$	0.6814	0.5821	0.6204	0.2610	0.4982	0.3732	0.6916
	Plot $_{p\text{-value}}$	0.5258	0.3080	0.2347	0.2679	0.7318	0.9657	0.3111
	Irr*plot $_{p\text{-value}}$	0.4924	0.8107	0.9514	0.1550	0.1328	0.5646	0.3307

Week 20		Actinomycetes	Arbuscular Mycorrhizae	Eukaryotes	Fungi	Gram (+) bacteria	GM (-) bacteria	Protozoa
Irrigation	Plot	(mol %)	(mol %)	(mol %)	(mol %)	(mol %)	(mol %)	(mol %)
Micro	Fallow	1.12 a	4.53 a	7.22 a	13.47 a	11.92 a	5.05 a	0.80 a
	Liriope	0.38 a	6.07 a	5.00 a	25.94 a	6.39 a	5.83 a	0.74 a
	Wedelia	1.28 a	4.22 a	3.52 a	19.52 a	11.42 a	7.13 a	0.75 a
Overhead	Fallow	0.73 a	2.59 a	9.11 a	21.45 a	14.54 a	6.39 a	2.77×10^{-16} a
	Liriope	1.10 a	6.11 a	9.49 a	18.99 a	11.84 a	8.40 a	0.22 a
	Wedelia	1.03 a	5.70 a	8.28 a	20.58 a	11.27 a	8.55 a	0.41 a
	Irrigation $_{p\text{-value}}$	0.9323	0.9467	0.0954	0.8284	0.2826	0.1776	0.1386

Table cont’d

	Actinomycetes	Arbuscular Mycorrhizae	Eukaryotes	Fungi	Gram (+) bacteria	GM (-) bacteria	Protozoa
Plot $_{p\text{-value}}$	0.6185	0.6190	0.6732	0.4544	0.3936	0.3936	0.9132
Irr*plot $_{p\text{-value}}$	0.3727	0.7990	0.8224	0.1959	0.6382	0.9050	0.8586
Date $_{p\text{-value}}$	0.2438	**0.0215**	**<.0001**	0.4578	0.7772	**0.0069**	0.5104
Date*irr $_{p\ value}$	0.7589	0.8263	0.1927	0.3819	0.2036	0.4871	0.2082
Date*plot$_{p\text{-value}}$	0.4583	0.7940	0.8638	0.4855	0.6375	0.4398	0.5990
Date*irr*plot$_{p\text{-value}}$	0.1861	0.8956	0.9098	0.3014	0.2234	0.6350	0.7003

[i]Letters denote detected differences among means of a full factorial including from three planting treatments (Wedelia; Liriope; Fallow) and two irrigations (Micro spray; Overhead) utilizing Tukey's HSD ($\alpha = 0.05$) approximately. Values with the same letters denote no significant difference.

[ii]Measures of overall treatment effects utilizing ANOVA analysis utilizing a significance level ($\alpha = 0.05$)

It is hypothesized the plots were too close in proximity to achieve differences, considering spatial variability can directly influence microbial community structures and similar communities become dissimilar with increasing distance (Ettema, and Wardle 2002). The entire study site was 80 m^2 with 50 cm between plots within irrigation treatments with 20 m being the furthest distance between two plots and distances of at least 25 m apart were observed to detect any differences in soil microbes (Packer and Clay, 2000). Plant roots, moisture levels, and distance can influence soil microbial life, yet these factors did not vary sufficiently to alter community structures.

2.3.7. Canopy Interception

Canopy interception is defined as the amount of water remaining on a plant after rainfall or irrigation (Kang et al., 2005). Canopy interception was not significantly different between planting treatments or irrigation delivery systems (Table 2.5.).

Table 2.5. Canopy interception of two groundcover species (Liriope, Wedelia) under two irrigation treatments (overhead and micro spray)

Irrigation	Plot	Canopy Interception (%)
Micro	Liriope	-19.5 a
	Wedelia	-22.7 a
Overhead	Liriope	23.7 a
	Wedelia	27.1 a
	$Irrigation_{p\text{-value}}$	0.0913
	$Plot_{p\text{-value}}$	0.9984
	$Irr*plot_{p\text{-value}}$	0.9033

[i]Letters denote detected differences among means of a full factorial including from two planting treatments (Wedelia; Liriope) and two irrigations (Micro spray; Overhead) utilizing Tukey's HSD (α = 0.05) approximately. Values with the same letters denote no significant difference.
[ii]Measures of overall treatment effects utilizing ANOVA analysis utilizing a significance level (α = 0.05)

Micro spray irrigation produced a negative value for canopy interception indicating higher values of net irrigation than gross irrigation (Bartik et al., 2016) while overhead produced

positive values perhaps due to irrigation application rates differing between irrigation delivery systems, with micro spray irrigation applying less water than overhead irrigation in the same time frame. Liriope and wedelia receiving overhead irrigation had positive canopy interception percentages (23.7%, 27.1%), which was similar to a study performed by Li and Rao (2000) who observed that 24-28% of total seasonal water was intercepted by wheat canopies under sprinkler irrigation. Plots receiving micro spray irrigation had negative percentages (-19.5%, -22.7%).

These negative percentages could be explained by the measurement of the canopy interception of low growing plants. Collection pans were located within millimeters of plant leaves, perhaps leading to a larger throughfall through the canopy. This was particularly evident for liriope, where the tips of the leaves were pointed into the collection pan (Figure 2.8.).

Figure 2.8. Photo displaying the funneling plant architecture of Liriope muscari into a collection pan.

Plant architecture is defined as the organization of the leaves, buds, and stems, as well as the size and morphology of these plant parts (Reinhardt and Kuhlemeier, 2002). Lower plant

capture values were recorded for *Agapanthus africanus*, a plant with a similar plant architecture to *Liriope muscari* (Million and Yeager, 2015). Banana, a species with a similar, albeit larger plant architecture to liriope, was observed to channel water towards one location instead of transferring water over an equal distribution (Sansoulet et al., 2008). Collection pans were in contact with the multiple stems of the wedelia plants, possibly increasing the canopy interception value by stemflow channeling. Liriope and wedelia had similar canopy interceptions when compared across irrigation deliveries, despite wedelia plots having greater coverage throughout the study period. This is observed elsewhere in nature, where forests with greater tree density intercept more rainfall than less dense forests (Sun et al., 2022).

2.4. Conclusion

Soil conditions can be influenced by ornamental groundcover systems, with the selected plant species and irrigation delivery methods as contributing factors. Ornamental groundcover systems can yield multiple benefits such as increasing the temperature buffering effect of soils in addition to lowering soil temperatures during summer. These systems can also increase soil temperatures during fall and reduce soil moisture levels. Including these benefits in the selection criteria of ornamental groundcover species, an increased compatibility between plant species and planting sites can be achieved. Furthermore, this research demonstrates that ornamental groundcover species with a matting habit and rapid growth, along with targeted irrigation is effective in reducing weed pressures in the landscape. Recognizing the impact that ornamental groundcovers can have on weed pressures can allow residential and commercial municipalities to incorporate ornamental groundcover planting systems, thereby decreasing the reliance on chemical and physical weed control methods and enhancing the ecological sustainability of landscapes. Further research quantifying the benefits of groundcovers including studying other

ornamental groundcover species and their suitability for erosion control, pollution abatement, pollinator forage, as well as multi-year, longitudinal studies is required. Selection of groundcover species that are appropriate for site conditions and installation of efficient irrigation delivery systems are effective tools in developing and maintaining ideal soil and environmental conditions in the landscape.

3. EVALUATING ORNAMENTAL AND COVERAGE QUALITY OF TRADITIONAL AND NOVEL GROUNDCOVER SPECIES UNDER OPTIMAL AND SUBOPTIMAL PLANTING DENSITIES

3.1. Introduction

The United States environmental horticulture industry, also known as the Green Industry, is comprised of ornamental plant producers; landscape architects, designers/builders, contractors, and maintenance firms; retail garden centers, home centers, and mass merchandisers with lawn and garden departments; and plant brokers and horticultural distribution centers (Hall et al., 2006). The value of the green industry is manifested in urban tree plantings, lawns, ornamental beds, and various other greenspaces which contribute to an aesthetically pleasing and beneficial environment.

The Green Industry as whole had a direct and indirect economic impact of $159.57 and $348.08 billion in 2018 according to U.S. *IMPLAN* economic model (Hall, 2018). The largest sector in the Green Industry is landscape and horticulture services. In Louisiana alone, landscape and horticulture services generated an estimated $2.21 billion in gross sales, $1.19 billion in total personal income, $1.68 billion in gross state product, and 56,686 jobs created in (Hinson et al., 2003) and is estimated to have increased since. Trends in the landscape and horticultural services have undergone shifts as of recently and have resulted in consumers being more aware of the labor, economic and environmental cost of their landscapes (Saksa et al., 2012), increasing demand for sustainable planting schemes, such as ornamental groundcovers.

Installing groundcovers can lower maintenance required in landscapes, as groundcovers are often used as a replacement for turfgrass or mulched areas (Hartin et al., 2022; Marble et al., 2017). Lawns represent one of the largest fertilizer sinks, with 1.9% of the total continental U.S. devoted to lawns (Milesi et al., 2005). While only a small portion of U.S lawns are fertilized, this

intensive practice can have significant environmental impacts and can lead to non-point pollution which degrades waterways and leads to algal blooms (Campbell et al., 2020).

Conversely, many groundcover species are perennial and do not have to be mowed or fertilized (Eom et al., 2005). Planting and maintaining ornamental groundcovers may be an effective tool to reduce water use compared to turfgrass (Burayu et al. 2021; Sapkota et al. 2023), as well as reduce pesticide use (Garber and Bondari, 1996) labor (Roka et al., 2003), and incidence of weeds (Weston and Eom, 2008). Groundcovers also provide ecological benefits, as they can be used as forage by pollinators (Masierowska et al., 2018).

The demand for ornamental groundcover plants in residential and commercial landscapes is increasing; however, widespread adoption is limited due to the up-front costs of large quantities of plants that standard groundcover installation practice require (Nambuthiri and Ingram 2014). Landscape groundcovers are a diverse group of matting, rhizomatous, or bunching ornamental plant species that naturally form a continuous soil covering. They can vary in height (typically 7.5 cm-1.0 m) and may be woody, herbaceous, or succulent (Dennis et al., 2001). Despite the variety of groundcovers available, landscape applications utilize but a few common species (Marble and Pickens 2020), limiting efforts to decrease the homogenization already present in landscapes across the country (Wheeler et al., 2017; Groffman et al., 2014; Larson et al., 2014). A review of scientific literature revealed limited studies on ornamental groundcover use in the landscape, particularly pertaining to the planting densities of ornamental groundcover species (Stafne et al., 2005; Dennis et al., 2001;).

The objective of this research was to evaluate twelve groundcover species, comprised of both industry standards as well as underutilized species, and the effect that planting density has on their establishment rate in the landscape. Plant coverage percentages were assessed under

planting densities that were considered optimal (planted at recommended densities) and suboptimal (less than commonly recommended densities). Results from this study can be used to provide contractors, clients, and consumers with more information on a wider range of groundcover species and efficient planting densities to increase diversity and reduce costs in the landscape.

3.2. Materials and Methods

3.2.1. Site preparation and establishment

A 535 m^2 area plot (5m x 107m) was prepared at the Louisiana State University Agricultural Center Hammond Research Station located in Hammond, LA (30.5044° N, 90.4612° W). The soil, Cahaba fine sandy loam, was tilled to a depth of 10 cm and amended with 5cm of a locally sourced landscape mix consisting of pine bark, sand, dolomitic lime, Agri-AFC micro-nutrient blend, and magnesium sulfate (Philips Bark Processing Company, Brookhaven, MS). The Anderson's Weed & Grass Preventer preemergent herbicide (Maumee, OH) was applied one week after plants were installed.

3.2.2. Irrigation

The plot was divided into 72 individual 1 m^2 plot, irrigated via micro sprayers (360º Jet Sprayer, Antelco, Longwood, FL) on 30 cm riser with barb .16 adapter (Antelco, Longwood, FL). Irrigation was applied to each plot twice per week (Monday at 9:37AM & Thursday at 9:37AM), for 20 minutes via micro spray irrigation. Distribution uniformity (DU) tests were conducted on the research plots following practices described by Merriam and Keller (1978), with DU for the plot measured at 48%. All planting treatments received the same irrigation throughout the duration of the study.

3.2.3. Plant Material Preparation

All cuttings were propagated and planted in a locally sourced greenhouse substrate mix consisting of sphagnum peat moss, perlite, pine bark, dolomitic lime, micronutrients (Micromax 0-0-0; ICL Specialty Fertilizers, Dublin, OH) and slow-release fertilizer (Osmocote Plus 15-9-12, 5-6 months; ICL Specialty Fertilizers, Dublin, OH).

The twelve groundcover species investigated were classified into three subgroups reflecting their hardiness and landscape application. Annuals, which would be replanted every year and do not survive below 0 ºC in most cases; tender perennials, which do not have to be replanted in Zones 8b (-6.7 ºC) and above; and perennials, which do not have to be replanted every year and are hardy to USDA Hardiness Zone 7a (-15 ºC) (Table 3.1.).

Table 3.1. Showing the twelve groundcover species and associated cultivars with number of plants used for optimal and suboptimal densities.

Scientific Name	Common Name	Plant Classification	Optimal[i]	Suboptimal[ii]
Asystasia gangetica 'Variegata'	Ganges Bellflower	Annual	9	5
Evolvulus glomeratus 'Blue Daze'	Evolvulus	Annual	16	9
Ipomoea batatas 'Sweet Caroline Kiwi'	Ornamental Sweet Potato	Annual	9	5
Arachis pintoi 'Golden Glory'	Ornamental Peanut	Tender Perennial	9	5
Ficus pumila	Creeping Fig	Tender Perennial	16	9
Ficus tikoua	Sandy Leaf Fig	Tender Perennial	16	9
Sedum mexicanum 'Lemon Ball'	Sedum	Tender Perennial	25	16
Sphagneticola trilobata	Wedelia	Tender Perennial	9	5
Liriope muscari 'Isabella'	Liriope	Perennial	9	5
Ophiopogon japonicus	Mondo grass	Perennial	25	16
Trachelospermum asiaticum	Asian Jasmine	Perennial	16	9
Verbena canadensis 'Homestead Purple'	Verbena	Perennial	9	5

[i]Number of plants in 1 m^2 based on recommended plant spacing in extension publications
[ii]Number of plants in 1 m^2 based on recommended plant spacing multiplied by 1.5

Asystasia g. ‘Variegata’ cuttings (8cm) were taken in November 2021 in 606 trays (Grower’s Solution; Cookeville, TN). Cuttings were placed under a mist system for 4 weeks, then were transplanted into 1801 trays (Grower’s Solution; Cookeville, TN).

Evolvulus g. ‘Blue Daze’ was ordered as 128 cell plugs and transplanted into 1801 trays in December 2021.

Ipomoea b. ‘Sweet Caroline Kiwi’ cuttings (10cm) were taken in November 2021 in 606 trays. The cuttings were placed in a greenhouse and watered once a week for 4 weeks, before transplanting into 1801 trays. Plants in 1801 trays were subsequently transplanted into trade 1-gallons after 4 weeks.

Arachis p. ‘Golden Glory’ was ordered as (5cm) plugs and transplanted into trade 1-gallons (The HC Companies; Twinsburg, OH) trays in January 2022.

Ficus p. cuttings (8 cm) were taken in November 2021 from a residence in Baton Rouge, LA and were stuck in 72 plug trays (Growers Supply; Dyersville, IA). Trays were placed under a mist system for 4 weeks, then were transplanted into 1801 trays.

Ficus t. cuttings (10cm) were taken in November 2021 from Louisiana State University campus in Baton Rouge, LA and were stuck in 72 plug trays. Trays were placed under a mist system for 2 weeks before transplanting into 1801 trays. In March 2022, plants were placed on the nursery pad where they received irrigation for 20 minutes. Plants were placed back in the greenhouse after 2 weeks because of concerns of excess moisture loss.

Sphagneticola t. cuttings (8cm) were taken from landscape beds at the Hammond Research Station in November 2021 and were stuck in 72 plug trays. Trays were placed under a mist system for a period of 4 weeks before transplanting into 1801 trays.

Sedum m. 'Lemon Ball' cuttings (5cm) were taken in November 2021 from landscape beds at the Hammond Research Station and stuck in 72 plug trays. Cuttings were placed in a greenhouse and watered once per week for 4 weeks before transplanting into 1801 trays. Cuttings were trimmed to the edge of the pot on the day of planting.

Liriope m. 'Isabella' was dug from landscape beds and cut into 10cm-wide divisions in March 2022. Divisions were potted into trade 1-gallons.

Ophiopogon j. was ordered as (5 cm) plugs and transplanted into 1801 trays in January 2022.

T*rachelospermum a.* cuttings (8 cm) were taken from landscape beds at the Hammond Research Station in November 2021 and were stuck in 72 plug trays. Trays were placed under a mist system for a period of 8 weeks and then transplanted into 1801 trays.

Verbena c. 'Homestead Purple' was ordered as 128 cell plugs. and were transplanted into 1801 trays in December 2021.

All species were placed on a nursery pad apart from *Ficus t.* where they received irrigation daily for 20 minutes in March 2022 until they were planted into the landscape. *Asystasia g.* 'Variegata' and *Ipomoea b.* 'Sweet Caroline Kiwi' were pruned by 50% in April 2022. *Asystasia g.* 'Variegata' and *Ipomoea b.* 'Sweet Caroline Kiwi' were also pinched when transplanted to their final respective containers.

3.2.4. Planting Treatments

Plants were installed on 25 April 2022 within 1 m^2 plots using a cardboard bracket to ensure uniform plant spacing. Plot locations were randomly assigned using a random number

generator. There were two planting density treatments investigated, with 3 replicates for each treatment. The first treatment, or the control, was the optimal planting density of each species, which was determined from extension publications. The second treatment was the suboptimal density, or 1.5 times the distance between plants as used in the first treatment/control. For example, optimal density was 30 cm between plants, then a sub-optimal planting density was 45 cm between plants. Total plant numbers for optimal and suboptimal planting densities were adjusted for practicality in landscape operations.

Plants were pruned periodically to the edge of the 1 m^2 plots only when they began to grow into other plots. *Arachis p*. 'Golden Glory', *Ficus t*. and *Sphagneticola t.* plots were trimmed once during the study period, while *Ipomoea b.* 'Sweet Caroline Kiwi' plots were pruned twice.

3.2.5. Coverage analysis

Overhead photographs of each plot were collected every 40 d ± 3 d utilizing a Sony A6000 camera (Sony Group Corporation, Minato City, Tokyo, Japan). A 1m x 1m bracket with a stand was constructed to ensure the camera was positioned 150 cm above the center of the plots, so each photograph was taken from a consistent height with the entirety of the 1 m^2 plot within frame. This served to delineate a border for coverage analysis. A portable canopy (3 x 3 m Venture, White, Z-Shade Company. Ltd., Baldwin Park, California) was placed over the plots to ensure that sunlight levels were consistent for all photos.

Individual photographs were cropped using Adobe Photoshop (Adobe Inc., San Jose, California) to only include the materials within the bracket. Photos were analyzed using WinCAM Color Area Meter Software (Regent Instruments, Québec City, Quebec, Canada),

wherein the plot coverage of the plants was calculated. Flower quantity was calculated for species cultivated for their blooms, such as *Verbena c.* 'Homestead Purple' (Burnett et al., 2000), *Evolvulus g.* 'Blue Daze' (Hooks and Niu, 2019), *Sphagneticola t.* (Gilman, 1999), *Arachis p.* 'Golden Glory' (Hensley et al., 1997). This involved assigning color classes to the foliage, flowers, white area from cropping the photos, and background. These classes were analyzed by the software and the percentage of coverage was determined by the following equations:

$$Foliage\ \% = \frac{Foliage\ class\ area}{(Foliage\ class\ area + (Background\ area - White\ class\ area) + Flower\ class\ area)}$$

$$Flower\ \% = \frac{Flower\ class\ area}{(Foliage\ class\ area + (Background\ area - White\ class\ area) + Flower\ class\ area)}$$

Rate of coverage was also calculated for each respective plant species by the following equation:

$$Coverage\ Rate\ \% = \frac{Previous\ Week\ Foliage\ Percentage - Current\ Week\ Foliage\ Percentage}{(6)}$$

Beginning with week 6, the current foliage percentage was subtracted by the previous week foliage percentage and then divided by 6 for the six weeks in between each time foliage was measured.

3.2.6. Quality Ratings

Evaluations were performed by members of the public (89 evaluators) on 16 September 2022. Groundcover replicates were rated for ornamental quality (overall aesthetic appearance) and coverage quality (amount of soil covered) on a scale from 1-5. Ornamental quality ratings were applied on the following scale: 1 = poor (few to no flowers, and/or substantial chlorosis), 2 = below average (significant dieback or chlorosis, reduced flowering), 3 = average or acceptable (moderate dieback, limited chlorosis, adequate form, and flowering), 4 = above average (minimal

dieback, healthy plant), and 5 = outstanding (outstanding flower quantity, no nutrient deficiencies or dieback). Coverage quality rating were applied on the scale 1 = poor (low canopy density), 2 = below average (lower density), 3 = average or acceptable (adequate canopy density), 4 = above average (above average density and form), and 5 = outstanding (dense leaf canopy), like ratings described by Moore et al. (2014**)** with scores averaged between participants and replicates.

3.2.7. Data analysis

The data presented in tables and figures with associated statistics were analyzed in JMP Pro (16.1.0; SAS Institute, Inc.; Cary, NC, U.S.) utilizing Tukey's Honestly Significant Difference ($\alpha = 0.05$) to separate coverage means, flower quantity means, coverage rate means, ornamental quality means, coverage quality means across twelve groundcover species responses across all planting density treatments. Analysis of variance (ANOVA) was further utilized to determine any statistically significant differences between the means of the planting density.

3.3. Results and Discussion

3.3.1. Annual Plant Species Coverage

Evolvulus g. 'Blue Daze', *Asystasia g.* 'Variegata', and *Ipomoea b.* 'Sweet Caroline Kiwi' were classified as annuals. Planting density did not influence coverage among annual groundcover species, with no significant differences in coverage between planting densities at any point during the study period (Table 3.2.).

Table 3.2. The percentage of plot vegetatively covered throughout the duration of the study. Twelve groundcover species were planted at optimal and suboptimal densities in separate plots, with percent of plot covered measured over five separate dates.

	Trachelospermum a.	*Ficus p.*	*Evolvulus g.* 'Blue Daze'	*Asystasia g.* 'Variegata'	*Liriope m.* 'Isabella'	*Ophiopogon j.*	*Arachis p.* 'Golden Glory'	*Ficus t.*	*Sedum m.* 'Lemon Ball'	*Ipomoea b.* 'Sweet Caroline Kiwi'	*Verbena canadensis* 'Homestead Purple'	*Sphagneticola trilobata*
Week 0												
Optimal	16.5 a[i]	19.7 a	13.1 a	13.1 a	10.4 a	20.6 a	52.2 a	10.6 a	17.1 a	61.6 a	3.4 a	10.1 a
Suboptimal	11.6 a	11.8 b	11.5 a	11.5 a	6.7 a	14.4 a	31.2 b	10.6 a	13.6 b	35.3 b	4.3 a	5.7 b
p-value$_{density}$	0.0521[ii]	**0.0176**	0.1487	0.1503	0.0808	0.0722	**0.0029**	0.9845	**0.0114**	**0.0007**	0.327	**0.0029**
Week 6												
Optimal	31.4 a	29.6 a	57.5 a	30.1 a	29.6 a	22.2 a	73.7 a	37.8 a	26.4 a	92.3 a	24.4 a	61.8 a
Suboptimal	20.4 b	19.5 b	52.2 a	23.8 a	24.1 b	16.8 b	65.7 a	34.2 a	22.5 b	93.5 a	25.3 a	45.8 a
p-value$_{density}$	**0.0026**	**0.0230**	0.3505	0.0733	**0.0419**	**0.0041**	0.3979	0.4173	**0.0302**	0.3055	0.9643	0.0879
Week 12												
Optimal	45.0 a	45.7 a	66.2 a	65.0 a	35.1 a	27.3 a	79.5 a	71.1 a	43.9 a	92.1 a	41.3 a	68.2 a
Suboptimal	26.2 b	14.2 b	65.0 a	52.6 a	24.7 b	21.2 b	68.7 a	70.5 a	30.4 a	90.4 a	37.0 a	63.5 a
p-value$_{density}$	**0.0016**	**0.0044**	0.7433	0.1860	**0.0200**	**0.0122**	0.4148	0.9318	0.0926	0.3162	0.5103	0.2690
Week 18												
Optimal	64.1 a	66.6 a	51.7 a	87.0 a	60.1 a	39.1 a	86.7 a	91.2 a	53.1 a	73.4 a	46.4 a	71.3 a
Suboptimal	42.0 b	29.4 b	62.3 a	87.5 a	40.2 b	27.0 b	65.7 a	88.9 a	38.2 a	73.4 a	46.4 a	62.2 a
p-value$_{density}$	**0.0061**	**0.0029**	0.4118	0.8582	**0.0022**	**0.1103**	0.1933	0.3873	0.2287	0.3867	0.9981	0.0805
Week 24												
Optimal	65.9 a	75.8 a	67.1 a	77.1 a	73.5 a	42.6 a	71.2 a	91.8 a	46.8 a	36.3 a	35.0 a	57.6 a
Suboptimal	43.9 b	31.3 b	67.9 a	79.1 a	45.0 b	29.3 b	51.0 a	90.5 a	37.5 a	43.5 a	34.8 a	52.9 a
p-value$_{density}$	**0.0068**	**0.0027**	0.8563	0.7862	**<.0001**	**0.0402**	0.2308	0.5635	0.4327	0.5997	0.9714	0.2492

[i]Letters denote significant differences between coverage percentage means under planting density and p-value of planting density main effect for each groundcover species using Tukey's honestly significant difference (α = 0.05) within columns.
[ii]Measures of overall treatment effects utilizing ANOVA analysis utilizing a significance level (α = 0.05)

Planting density did not significantly influence the coverage rates of *Evolvulus g.* 'Blue Daze' or *Asystasia g.* 'Variegata' (Figure 3.1.), but it did influence the coverage rate for *Ipomoea b.* 'Sweet Caroline Kiwi' during weeks 6 and 12 (Table 3.3.), despite no significant differences between, coverage among optimal and suboptimal planting densities. At week 18, coverage rates for *Ipomoea b.* 'Sweet Caroline Kiwi' and *Evolvulus g.* 'Blue Daze' were negative due to plant senescence (Hodel and Pittenger 1994) (Figure 3.2; Figure 3.3). *Evolvulus g.* 'Blue Daze' was the only annual plant where flowering was assessed, and planting density had no effect on the flower amount (Table 3.4.).

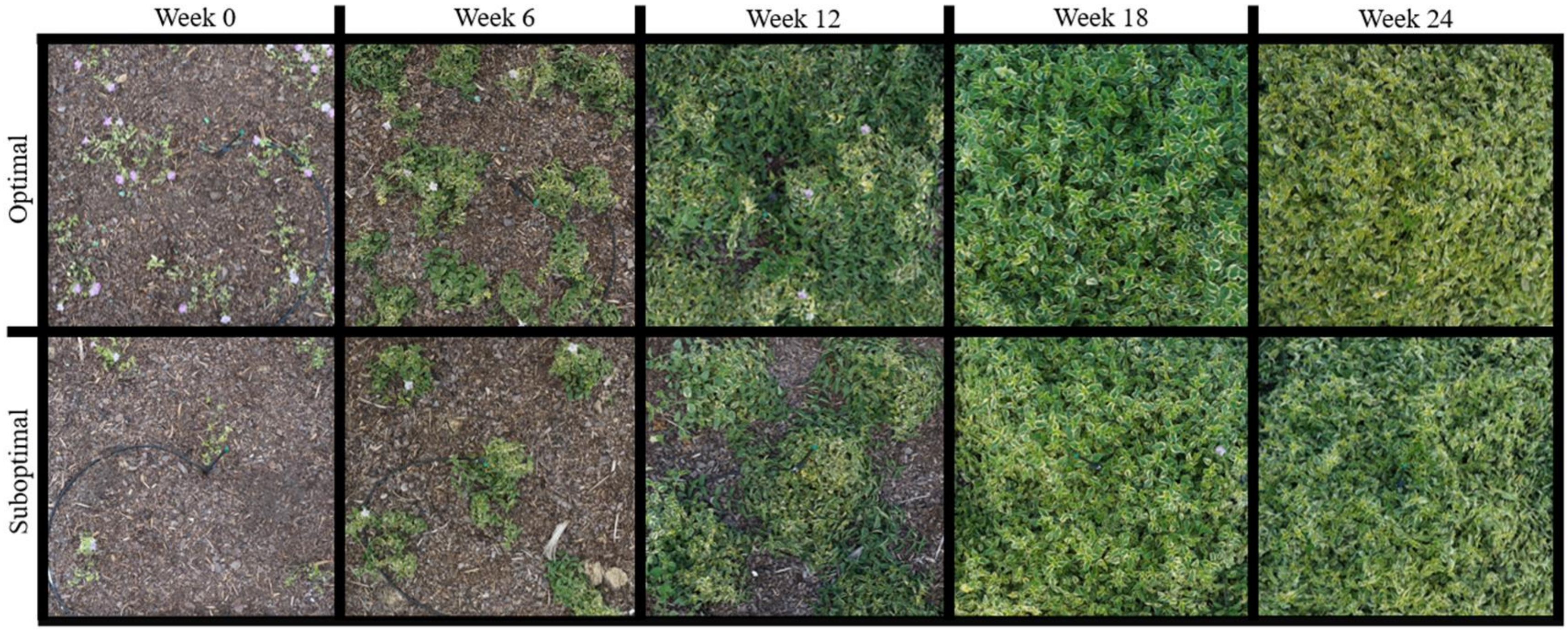

Figure 3.1. Showing the differences in plant coverage between optimal and suboptimal planting densities in *Asystasia g.* 'Variegata'

Table 3.3. Rate percentage of plot vegetatively covered throughout the duration of the study. Twelve groundcover species were planted at optimal and suboptimal densities in separate plots, with the percentage of plot covered measured over five separate dates. Rate percentage was found following an equation described in material and methods.

	Trachelospermum a.	*Ficus p.*	*Evolvulus g.* 'Blue Daze'	*Asystasia g.* 'Variegata'	*Liriope m.* 'Isabella'	*Ophiopogon j.*	*Arachis p.* 'Golden Glory'	*Ficus t.*	*Sedum m.* 'Lemon Ball'	*Ipomoea b.* 'Sweet Caroline Kiwi'	*Verbena canadensis* 'Homestead Purple'	*Sphagneticola trilobata*
Week 6												
Optimal	2.48 a[i]	1.64 a	5.43 a	2.84 a	3.19 a	0.39 a	3.57 a	4.52 a	2.12 a	5.12 b	3.66 a	8.63 a
Suboptimal	1.46 a	1.28 a	4.64 a	2.04 a	2.90 a	0.27 a	5.74 a	3.93 a	0.90 b	9.70 a	3.51 a	6.68 a
p-value$_{density}$	0.0568[ii]	0.5649	0.5039	0.0694	0.4125	0.7394	0.2855	0.5654	**0.0116**	**0.0005**	0.6387	0.2081
Week 12												
Optimal	2.25 a	2.69 a	2.69 a	5.80 a	0.91 a	0.83 a	0.96 a	6.14 a	2.92 a	-0.03 a	1.93 a	1.06 b
Suboptimal	0.95 b	-0.88 b	2.14 a	4.79 a	0.09 b	0.73 b	0.51 a	5.44 a	1.32 a	-0.51 b	2.66 a	2.94 a
p-value$_{density}$	**0.0104**	**0.0112**	0.2510	**0.3135**	**0.1868**	**0.6835**	0.5784	0.4319	0.1336	**0.0384**	0.4671	**0.0453**
Week 18												
Optimal	3.18 a	3.47 a	-2.40 a	3.68 a	4.63 a	1.96 a	1.20 a	3.46 a	1.52 a	-7.27 a	1.56 a	0.39 a
Suboptimal	2.63 a	2.52 a	-0.46 a	5.82 a	2.12 a	0.96 a	-0.51 a	2.98 a	1.29 a	-2.82 a	0.83 a	0.09 a
p-value$_{density}$	0.4867	0.5029	0.4424	0.0982	0.0609	0.2995	0.3313	0.6628	0.8124	0.3598	0.5633	0.5829
Week 24												
Optimal	2.10 a	1.53 a	2.56 a	-1.65 a	3.08 a	0.59 a	-2.44 a	0.09 a	-1.04 a	-2.02 a	-1.89 a	-1.95 a
Suboptimal	-1.49 a	0.31 a	0.94 a	1.40 a	-0.05 a	0.38 a	-2.59 a	0.26 a	-0.12 a	-4.98 a	-1.92 a	-1.87 a
p-value$_{density}$	0.1101	0.0784	0.3106	0.7832	0.1156	0.6336	0.9190	0.2424	0.0904	0.5407	0.9871	0.9462

[i]Letters denote significant differences between rate percentage means under planting density and p-value of planting density main effect for each groundcover species using Tukey's honestly significant difference (α = 0.05) within columns
[ii]Measures of overall treatment effects utilizing ANOVA analysis utilizing a significance level (α = 0.05)

The results indicate that the annual plants investigated in this study may be planted at suboptimal densities and achieve equivalent coverage and flowering as if they were planted to optimal densities, thus allowing the potential to reduce landscape installation costs, as consumer purchases of annual plant species are subject to fluctuation based on market price (Hovhannisyan and Khachatryan, 2017). The plant form of these species was matting or stoloniferous probably aiding in their ability to cover areas quickly. Furthermore, comparing the cost of St. Augustine grass and an ornamental peanut groundcover, establishment costs are often higher for groundcovers, but maintenance costs are greatly reduced after (Roka et al., 2003). An ornamental peanut groundcover system cost 57% less to maintain annually when compared to a lawn of equal size. There are few examples of replacing entire lawns with other species of groundcovers like ornamental peanut, nevertheless, landscape costs could be lowered with partial lawn replacement in other areas of the country where the climate is optimal for other groundcover species.

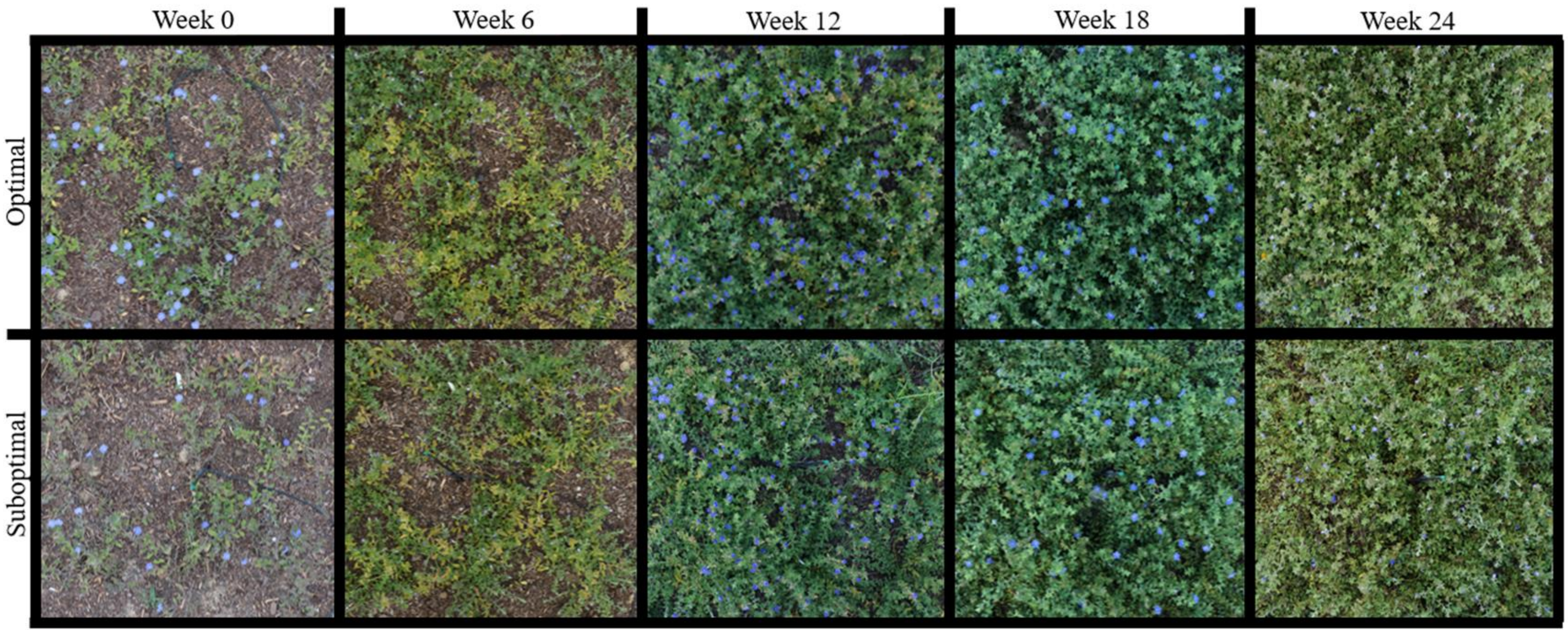

Figure 3.2. Showing the differences in plant coverage between optimal and suboptimal planting densities in *Evolvulus g.* ‘Blue Daze’

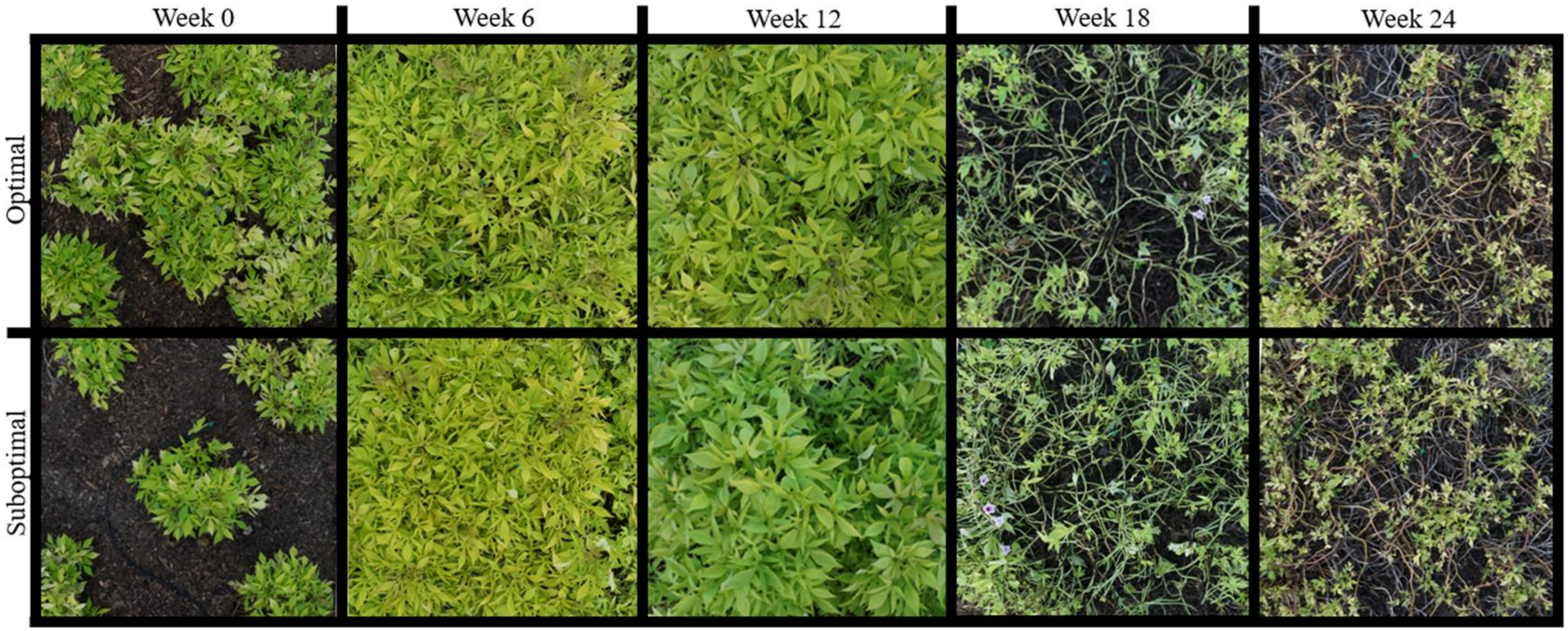

Figure 3.3. Showing the differences in plant coverage between optimal and suboptimal planting densities in *Ipomoea b.* 'Sweet Caroline Kiwi'

Table 3.4. Percentage of flowers throughout the duration of the study. Twelve groundcover species were planted at optimal and suboptimal densities in separate plots, with four species chosen to measure the percentage of flowers measured over five separate dates.

	Evolvulus g. 'Blue Daze'	*Arachis p.* 'Golden Glory'	*Verbena canadensis* 'Homestead Purple'	*Sphagneticola trilobata*
Week 0				
Optimal	1.70 a[i]	1.13 a	0.49 a	0.18 a
Suboptimal	1.32 a	0.38 b	0.59 a	0.15 a
$\text{p-value}_{density}$	0.2684[ii]	**0.0037**	0.2825	0.7285
Week 6				
Optimal	0.54 a	2.75 a	0.66 a	1.12 a
Suboptimal	0.35 a	0.96 a	1.14 a	0.59 b
$\text{p-value}_{density}$	0.2070	0.3161	0.2816	**0.0318**
Week 12				
Optimal	3.50 a	1.42 a	2.12 a	2.68 a
Suboptimal	3.00 a	0.94 a	2.34 a	3.07 a
$\text{p-value}_{density}$	0.0529	0.5007	0.8414	0.6540
Week 18				
Optimal	2.58 a	1.09 a	0.30 a	1.09 a
Suboptimal	2.65 a	1.00 a	0.17 a	1.29 a
$\text{p-value}_{density}$	0.9376	0.8345	0.5463	0.4933
Week 24				
Optimal	0.52 a	0.39 a	0.11 a	1.92 a
Suboptimal	1.30 a	0.36 a	0.04 a	1.67 a
$\text{p-value}_{density}$	0.1355	0.9165	0.4283	0.5117

[i]Letters denote detected differences among means of a full factorial including from four groundcover species and two planting densities (Optimal; Suboptimal) utilizing Tukey's HSD (α = 0.05) approximately. Values with the same letters denote no significant difference.
[ii]Measures of overall treatment effects utilizing ANOVA analysis utilizing a significance level (α = 0.05)

3.3.2. Tender Perennial Plant Species Coverage

Ficus p., *Arachis p.* 'Golden Glory', *Ficus t.*, *Sedum m.* 'Lemon Ball' and *Sphagneticola t.* were classified as tender perennials. Planting density did not influence coverage among tender perennials, such *Arachis p.* 'Golden Glory', *Sphagneticola t.* and *Ficus t.* (Table 3.3.). *Sedum m.*

'Lemon Ball' coverage under suboptimal planting density was significantly lower at week 6, but equivalent at other weeks during the study period (Table 3.3.). Coverage under suboptimal planting density was significantly lower for *Ficus p.* throughout the study period (Table 3.3.) as well as final coverage for suboptimal planting density was 58.7% lower than optimal planting density. Planting density did not affect the coverage rates of *Arachis p.* 'Golden Glory' or Ficus *t.* Rates of coverage were significantly greater for optimal spaced *Sedum m.* 'Lemon Ball' during week 6 and *Ficus p.* during week 12. Coverage rate was significantly greater in suboptimal spaced plants for *Sphagneticola t.* during week 12. Flowering was accessed for *Arachis p*. 'Golden Glory' and *Sphagneticola t.* and planting density did not have an effect.

Planting density does not seem to affect total coverage, coverage rate, or flowering among tender perennial groundcover species apart from *Ficus p.* A suboptimal planting density can achieve comparable results in landscape applications using tender perennial species (Figure 3.4.; Figure 3.5.; Figure 3.6.; Figure 3.7.; Figure3.8.), decreasing material costs for consumers, homeowners, and landscape managers.

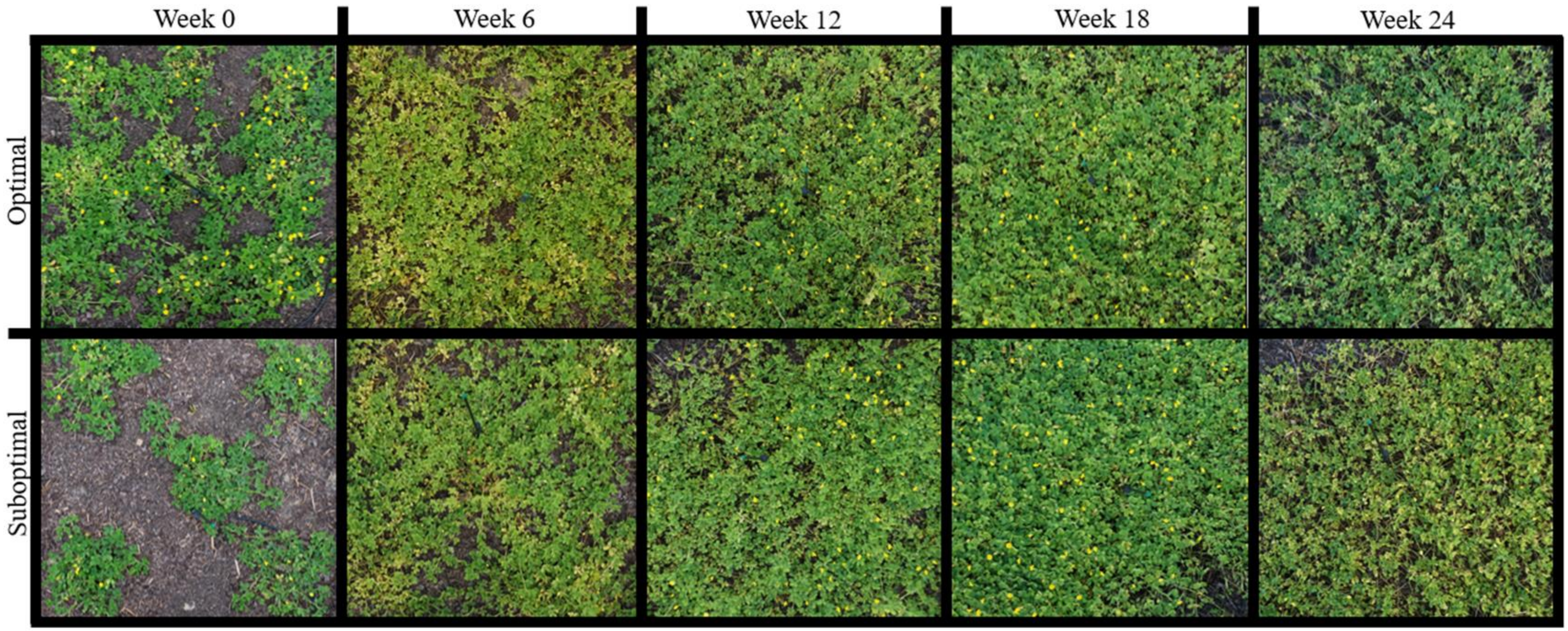

Figure 3.4. Showing the differences in plant coverage between optimal and suboptimal planting densities in *Arachis p.* ‘Golden Glory’

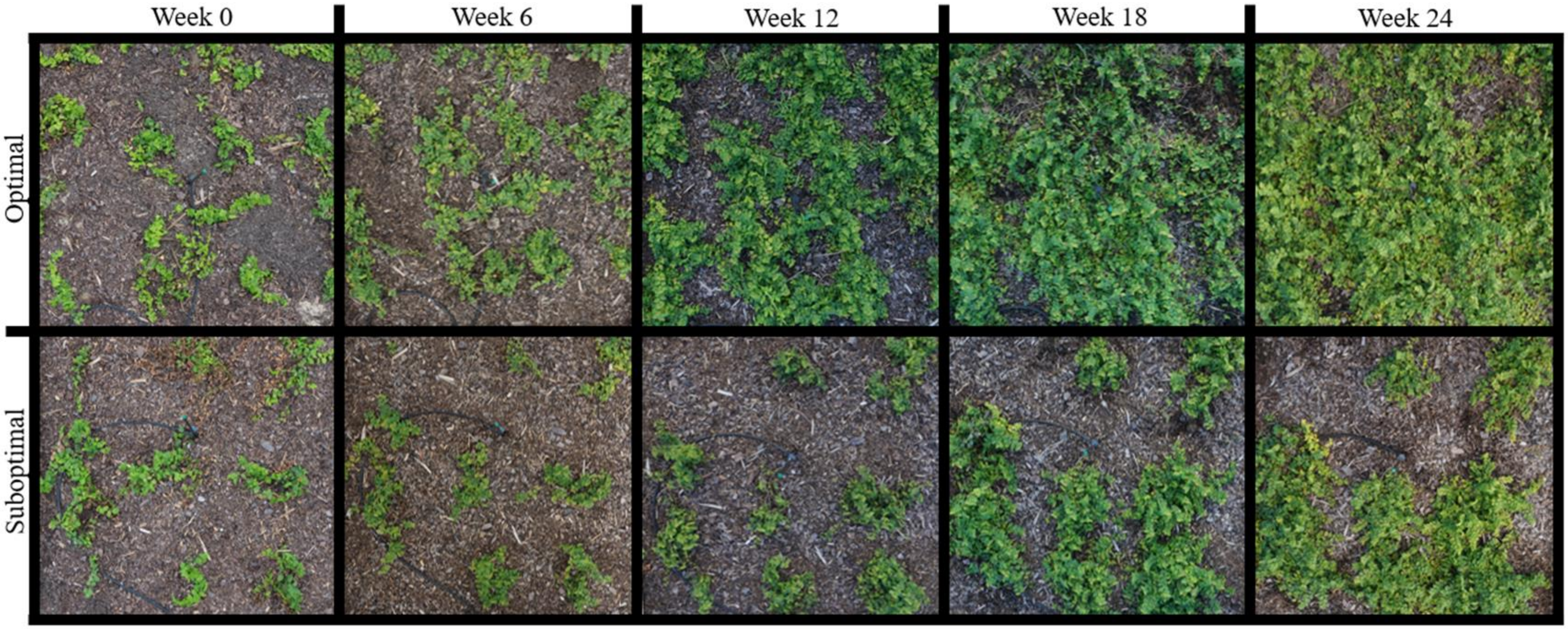

Figure 3.5. Showing the differences in plant coverage between optimal and suboptimal planting densities in *Ficus p.*

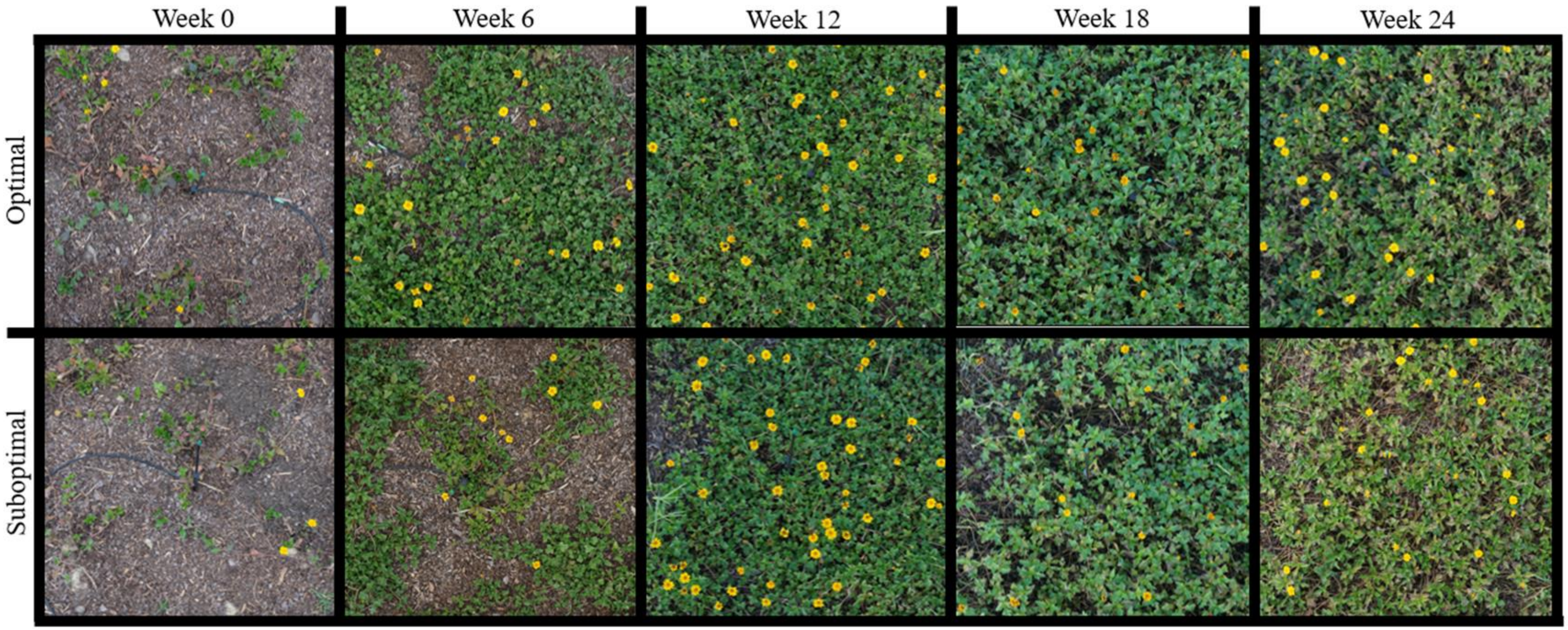

Figure 3.6. Showing the differences in plant coverage between optimal and suboptimal planting densities in *Sphagneticola t*.

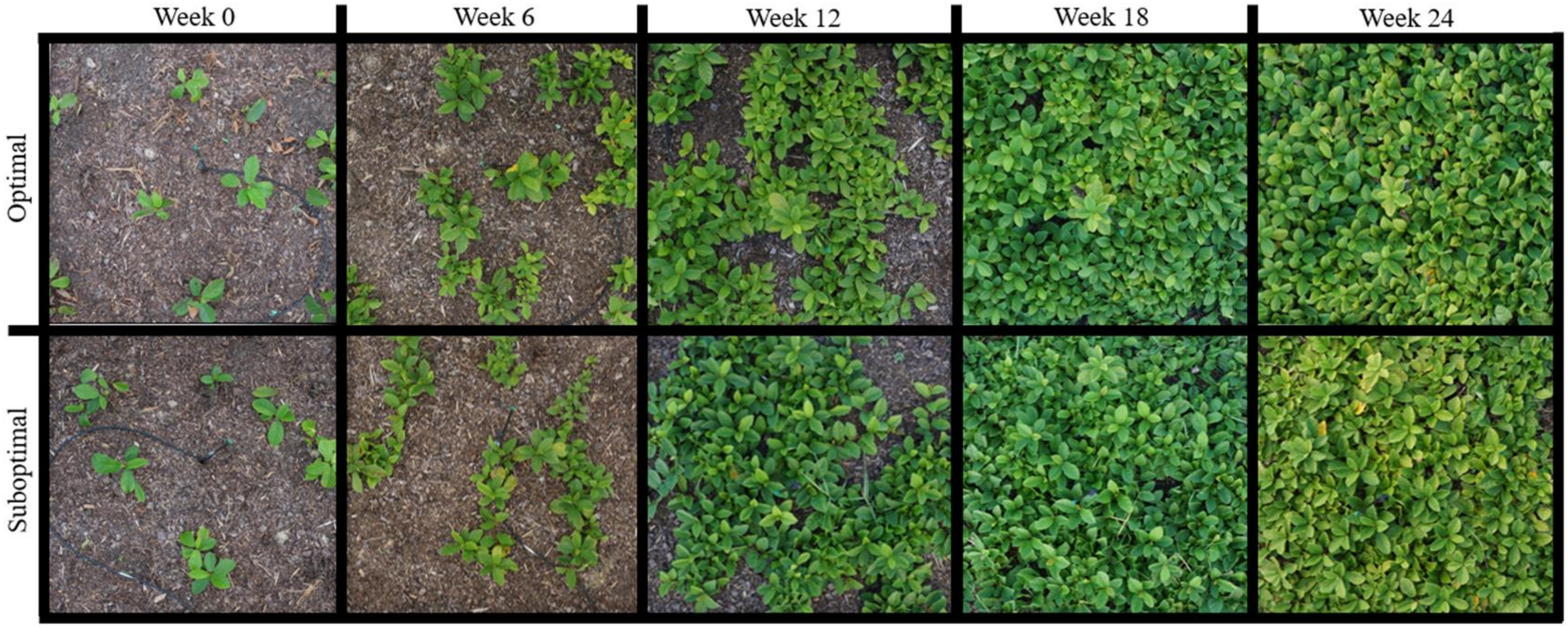

Figure 3.7. Showing the differences in plant coverage between optimal and suboptimal planting densities in *Ficus t.*

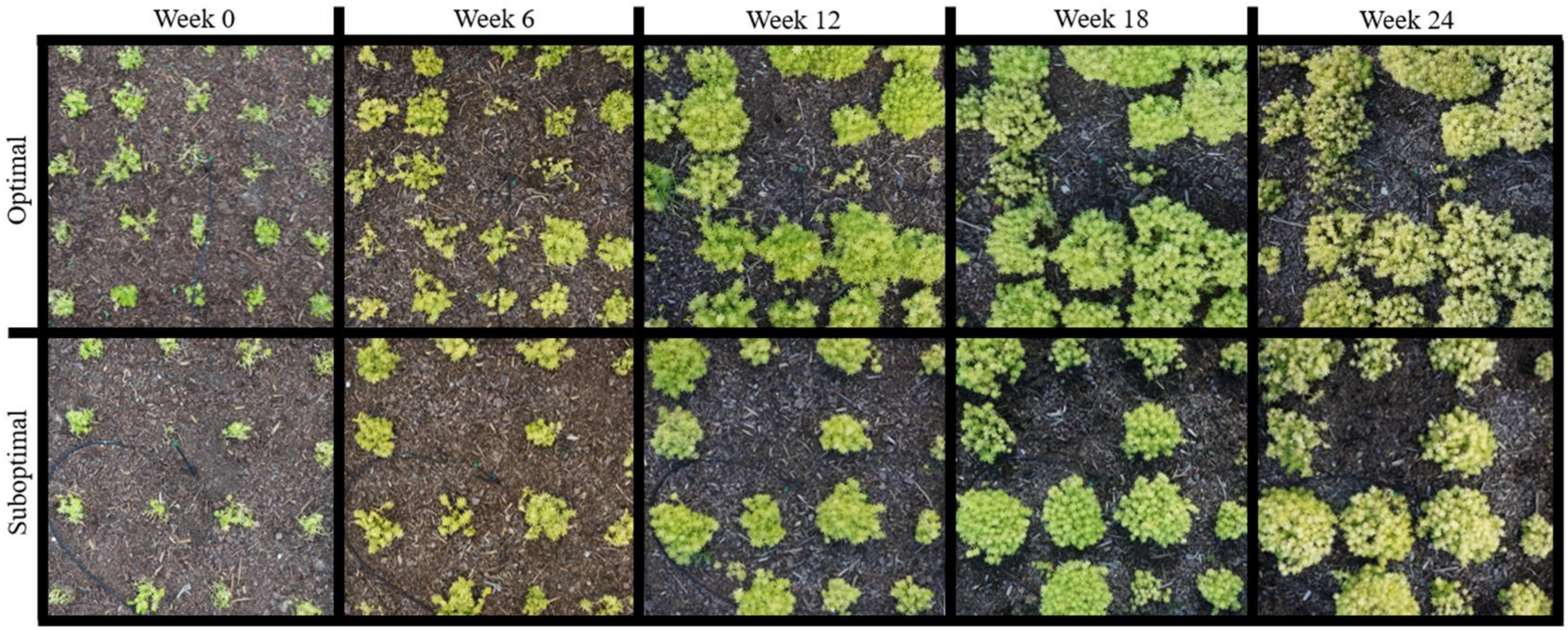

Figure 3.8. Showing the differences in plant coverage between optimal and suboptimal planting densities in *Sedum m.* ‘Lemon Ball’

3.3.3. Perennial Plant Species Coverage

Trachelospermum a., *Liriope m.* 'Isabella', *Ophiopogon j.,* and *Verbena c*. 'Homestead Purple' were classified as perennials. The final coverage was significantly greater in optimally spaced than sub optimally spaced hardy perennials; *Trachelospermum a.* (65.9 optimal, 43.9 suboptimal) *Liriope m.* 'Isabella' (73.5 optimal, 45.0 suboptimal), Ophiopogon *j.* (42.6 optimal ,29.3 suboptimal), and reflected a planting density effect. *Verbena c*. 'Homestead Purple' final coverage was not significantly greater (35.0 optimal, 34.8 suboptimal). Sub optimally spaced planting densities yielded less coverage versus optimal planting densities for Liriope *m.* 'Isabella' (38.8% lower), *Trachelospermum a.* (33.4%), and *Ophiopogon j.* (31.2%), respectively.

Planting density did not influence the coverage rates of *Trachelospermum a.*, *Liriope m.* 'Isabella', *Ophiopogon j.* except during week 12 where optimally spaced plots had significantly greater rates of coverage. (Table 3.3.). *Verbena c.* 'Homestead Purple' was the only perennial where flowering was assessed, and planting density did not influence flower amount (Table 3.4.).

Perennial groundcover species, with the exception of *Verbena* 'Homestead Purple', may benefit from an optimal planting density to achieve higher total coverage; however, a longer time frame may be warranted if a suboptimal planting density is employed, considering optimal coverage rates were only significantly greater during one point in the study (Figure 3.9.; Figure 3.10.; Figure 3.11.; Figure 3.12.).

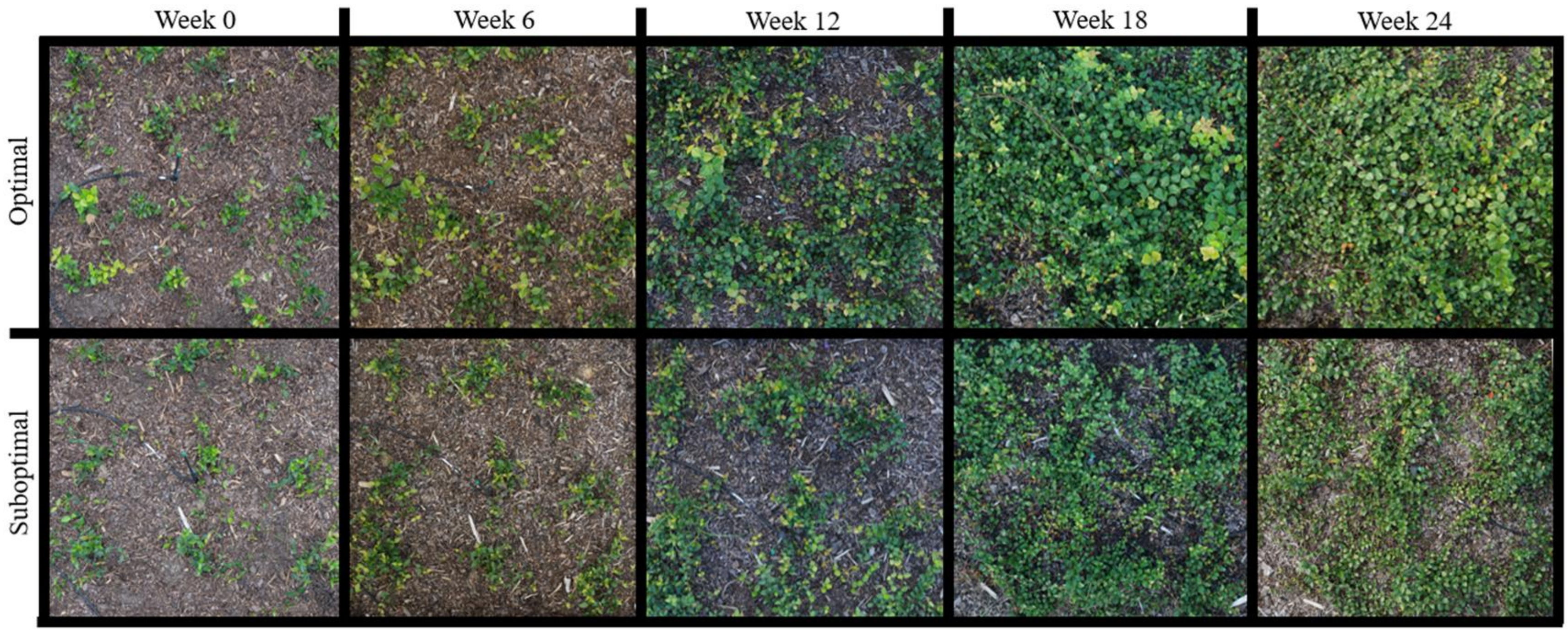

Figure 3.9. Showing the differences in plant coverage between optimal and suboptimal planting densities in *Trachelospermum a.*

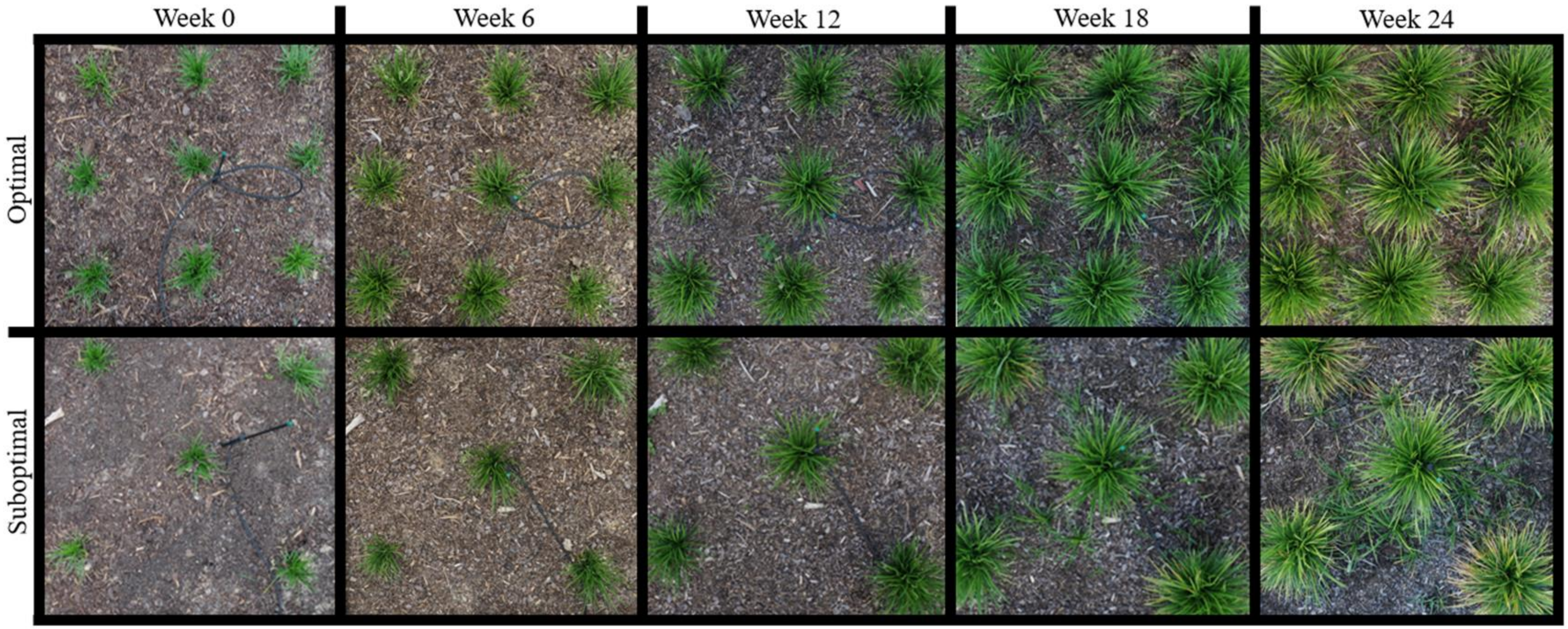

Figure 3.10. Showing the differences in plant coverage between optimal and suboptimal planting densities in *Liriope m.* 'Isabella'

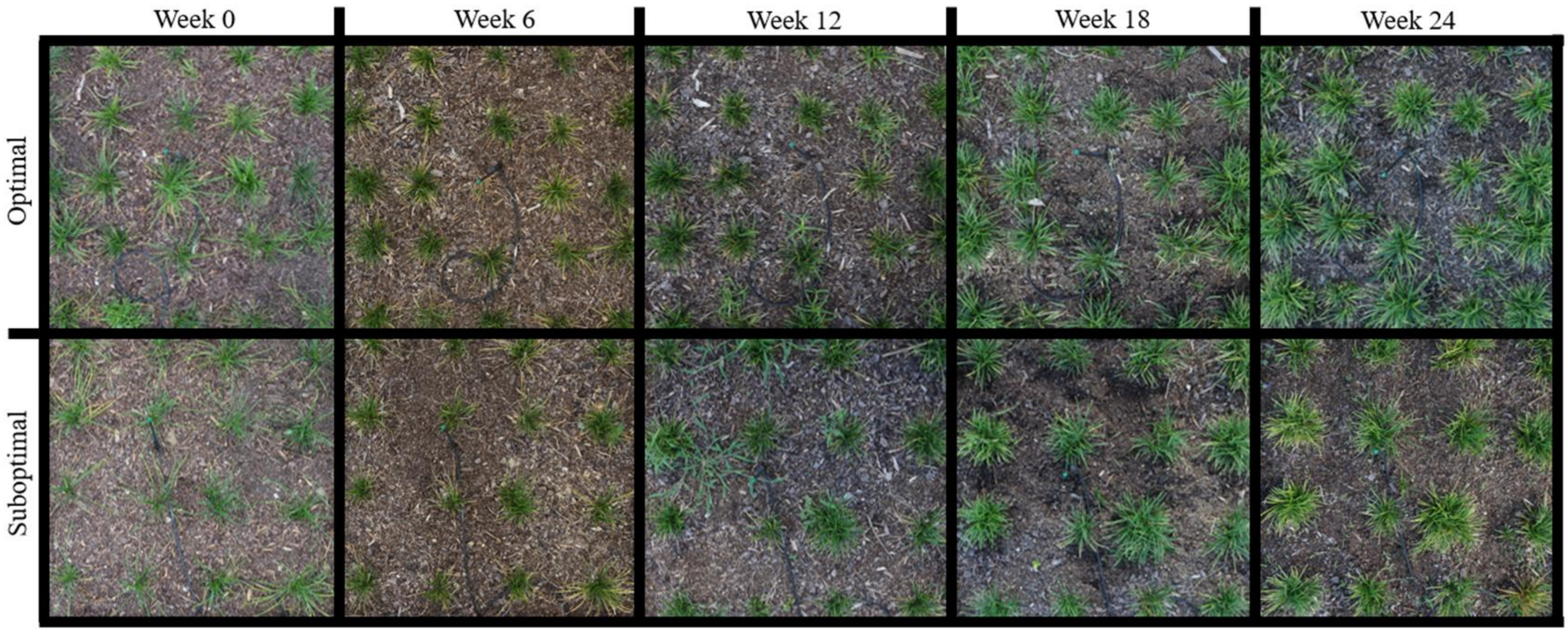

Figure 3.11. Showing the differences in plant coverage between optimal and suboptimal planting densities in *Ophiopogon j*.

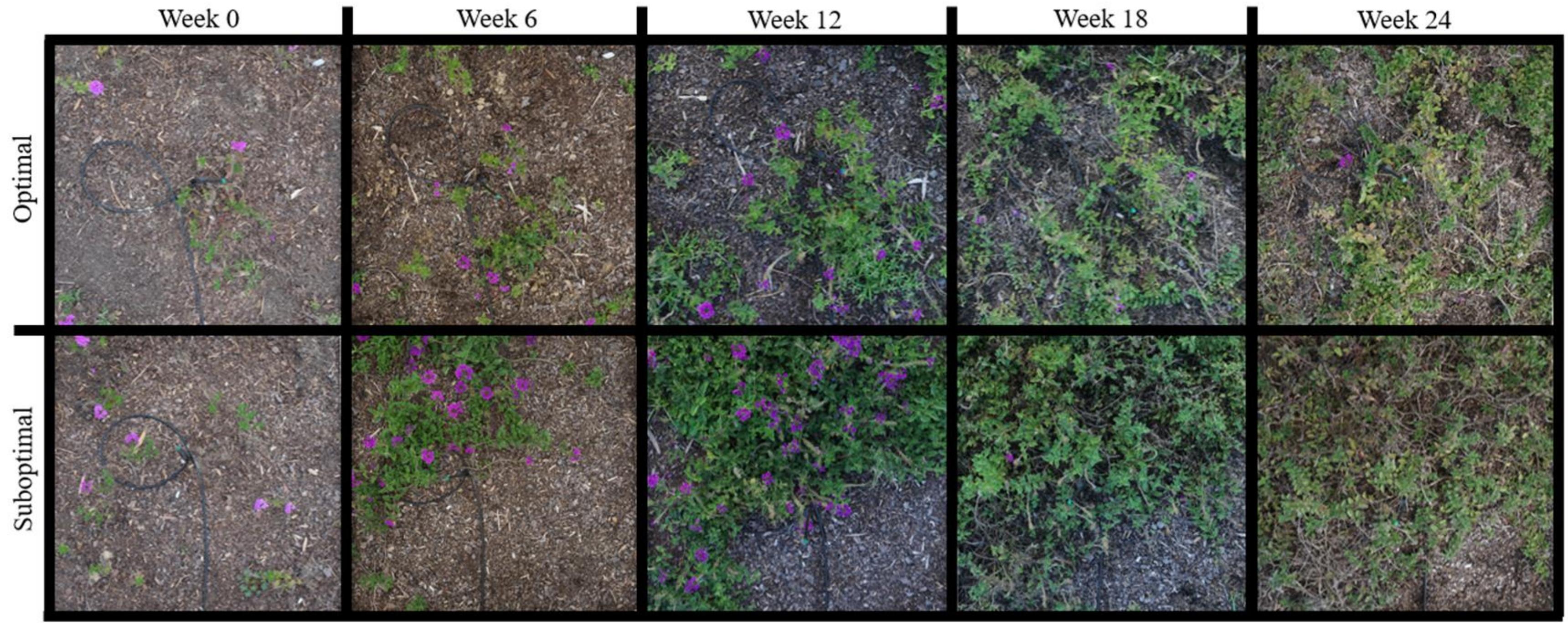

Figure 3.12. Showing the differences in plant coverage between optimal and suboptimal planting densities in *Verbena c.* ‘Homestead Purple’

Many of the species evaluated achieved similar coverage results planted with decreased quantities of plants. Decreasing initial plant material cost would reduce cost prohibitive barriers to incorporating groundcover systems into landscapes, thus increasing sustainability. If species are planted employing a suboptimal planting density, then plant material costs can be reduced by roughly 45% (Table 3.5.)

Table 3.5. Comparing the cost of twelve groundcovers planted at optimal and suboptimal densities in 1000 ft^2. Unit prices of the groundcovers were determined through commercially available price data.

Species	Pot Size[i]	Optimal[ii]	Suboptimal[iii]	Unit Price	Company	Optimal Cost[iv]	Suboptimal Cost[v]	Savings[vi]
Trachelospermum a.	4"	1488	837	2.49	Clegg's	$3705.12	$2084.13	$1620.99
Ficus p.	4"	1488	837	2.49	Clegg's	$3705.12	$2084.13	$1620.99
Evolvulus g. 'Blue Daze'	4.5"	1488	837	5.99	Clegg's	$8913.12	$5013.63	$3899.49
Asystasia g. 'Variegata'	3.5"	837	465	9.99	Almost Eden	$8361.63	$4645.35	$3716.28
Liriope m. 'Isabella'	4"	837	465	2.49	Clegg's	$2084.13	$1157.85	$926.28
Ophiopogon j.	4"	2325	1488	2.49	Clegg's	$5789.25	$3705.12	$2084.13
Arachis p. 'Golden Glory'	6.5"	837	465	13.99	Gene's Greenhouse	$11709.63	$6505.35	$5204.28
Ficus t.	4"	837	465	2.99	Far Reaches Farm	$2502.63	$1390.35	$1112.28
Sedum m. 'Lemon Ball'	3.5"	1488	837	18	Cleggs	$26784	$15066	$11718
Ipomoea b. 'Sweet Caroline Kiwi'	4"	2325	1488	2.99	Clegg's	$6951.75	$4449.12	$2502.63
Verbena c. 'Homestead Purple'	4.5"	837	465	4.99	Clegg's	$4176.63	$2320.35	$1856.28
Sphagneticola t.	4"	837	465	9.99	Almost Eden	$8361.63	$4645.35	$3716.28

[i]Diameter of plant container
[ii]Number of plants in 1000 ft^2 based on recommended plant spacing in extension publications
[iii]Number of plants in 1000 ft^2 based on recommended plant spacing multiplied by 1.5
[iv]Optimal cost determined by multipliying the unit price by the optimal number of plants
[v]Suboptimal cost determined by multipliying the unit price by the suboptimal number of plants
[vi]Savings equals the optimal cost subtracted by the suboptimal cost

3.3.4. Ornamental Rating

When subjectively grading groundcovers using a scale from 1-5, participants preferred groundcover species planted with an optimal density, such as, *Trachelospermum a., Ficus p., Liriope m.* 'Isabella', *Ophiopogon j., Arachis p.* 'Golden Glory'; however, participants preferred *Ipomoea b.* 'Sweet Caroline Kiwi' planted with a suboptimal density (Table 3.6.). Consumers prefer larger plant sizes in the landscape, which may explain the higher rating received by the optimal density plantings (Hardy et al., 2000). Planting density did not influence participant preference among *Evolvulus g.* 'Blue Daze', *Asystasia g.* 'Variegata', *Ficus t., Sedum m.* 'Lemon Ball', *Verbena c.* 'Homestead Purple', and *Sphagneticola t.* due to the coverage and flowering not differing between planting densities during week 18 when the survey was completed.

Table 3.6. Comparing the means in ornamental value rating among optimal and suboptimal planting densities among 12 groundcover species.

Species	Density		
	Optimal	Suboptimal	p-value$_{density}$
Trachelospermum a.	3.15 d[i]	2.87 d	**0.0233**[ii]
Ficus p.	2.96 d	2.60 de	**0.0027**
Evolvulus g. 'Blue Daze'	4.01 a	4.15 a	0.1555
Asystasia g. 'Variegata'	3.84 ab	3.88 ab	0.6755
Liriope m. 'Isabella'	3.79 ab	3.48 c	**0.0038**
Ophiopogon j.	2.97 d	2.68 de	**0.0133**
Arachis p. 'Golden Glory'	3.28 cd	2.87 d	**0.0006**
Ficus t.	3.99 a	4.04 a	0.6279
Sedum m. 'Lemon Ball'	3.67 ab	3.50 c	0.1434
Ipomoea b. 'Sweet Caroline Kiwi'	2.49 e	3.67 bc	**<.0001**
Verbena c. 'Homestead Purple'	2.38 e	2.35 e	0.7902
Sphagneticola t.	3.61 bc	3.45 c	0.1657

[i]Letters denote detected differences among means of a full factorial including from twelve species and two planting densities utilizing Tukey's HSD (α = 0.05) approximately. Values with the same letters denote no significant difference.
[ii]Measures of overall treatment effects utilizing ANOVA analysis utilizing a significance level (α = 0.05)

(Table 3.6.; Table 3.2.; Table 3.4.). Prescence of flowers (Figure 3.2.; Figure 3.12.; Figures 3.6.) may have contributed to the higher ratings of suboptimal planting densities, giving rise to similar ratings compared to optimal densities (Yang et al., 2019). *Evolvulus g.* 'Blue Daze' received the highest rating for both optimal and suboptimal planting densities perhaps due to coverage and flowering, meanwhile *Verbena c.* 'Homestead Purple' received the lowest rating (Table 3.5.) as plant species is the most important criteria when consumers are selecting plant material (Getter and Behe, 2013) Additionally, novel plant species can enjoy equal or greater consumer preference to traditional species (Lampert and Menrad, 2012), considering *Verbena canadensis* and associated cultivars have been used in gardens for over a century (Chappell, 2000)

3.3.5. Coverage Rating

On a subjectively graded scale from 1-5, participants believed that coverage was greater for *Trachelospermum a.* , *Ficus p.*, *Liriope m.* 'Isabella', *Ophiopogon j.* , *Arachis p.* 'Golden Glory', *Sedum m.* 'Lemon Ball', and *Sphagneticola t.* under an optimal planting density; however, participants believed coverage was greater for sub optimally planted *Evolvulus g.* 'Blue Daze', *Ipomoea b.* 'Sweet Caroline Kiwi', *Ficus t.* despite plant coverage only being significantly greater for *Trachelospermum a.* , *Ficus p.*, *Liriope m.* 'Isabella', and *Ophiopogon j.* during week 18 when the survey was completed. (Table 3.7.; Table 3.2.). Participants may have given a higher score to *Evolvulus g.* 'Blue Daze' as a result of foliar disease pressure reducing plant coverage in the optimal density replicates, an occurrence observed by Gilman and Meerow (1999). Planting density influenced participant perceptions of coverage among *Asystasia g.* 'Variegata', *Ipomoea b.* 'Sweet Caroline Kiwi', and *Verbena*. E*volvulus g.* 'Blue Daze' received the highest rating for optimal planting density; meanwhile, *Ficus t.* received the highest rating

under suboptimal planting density. *Verbena c.* 'Homestead Purple' and *Ficus p.* received the lowest rating under optimal and suboptimal densities respectively, likely due to their low coverage (Table 3.2.).

Table 3.7. Comparing the means in coverage rating among optimal and suboptimal planting densities among 12 groundcover species.

Species	Density		
-	Optimal	Suboptimal	p-value$_{density}$
Trachelospermum a.	3.53 c	2.65 ef	**<.0001**
Ficus p.	3.18 d	2.11 g	**<.0001**
Evolvulus g. 'Blue Daze'	4.29 a	4.32 ab	0.0737
Asystasia g. 'Variegata'	4.13 ab	4.28 ab	0.1033
Liriope m. 'Isabella'	3.48 cd	2.88 de	**<.0001**
Ophiopogon j.	2.77 e	2.42 fg	**0.0031**
Arachis p. 'Golden Glory'	3.88 b	3.00 d	**<.0001**
Ficus t.	4.19 ab	4.44 a	**0.0032**
Sedum m. 'Lemon Ball'	3.15 d	2.64 ef	**<.0001**
Ipomoea b. 'Sweet Caroline Kiwi'	2.74 e	4.00 bc	**<.0001**
Verbena c. 'Homestead Purple'	2.26 f	2.44 fg	0.0729
Sphagneticola t.	4.14 ab	3.76 c	**0.0001**

[i]Letters denote detected differences among means of a full factorial including from twelve species and two planting densities utilizing Tukey's HSD (α = 0.05) approximately. Values with the same letters denote no significant difference.
[ii]Measures of overall treatment effects utilizing ANOVA analysis utilizing a significance level (α = 0.05)

3.4. Conclusion

Interest in ornamental groundcovers is increasing due to their ease of maintenance, low resource input, aesthetic qualities, and environmental benefits; however, initial plant material costs may discourage many consumers from installing groundcovers into their landscape. Landscape architects, designers/builders, contractors, and maintenance firms have a wide array of ornamental groundcover species to choose from; however, only a few industry standards are commonly selected for installation into the landscape. This research demonstrates that a wider

array of groundcover species should be considered in planting schemes due to their ability to rapidly cover the ground and provide attractive foliage and flowers. Furthermore, planting densities for many species should be re-evaluated, especially for annual and tender perennial groundcovers, given that comparable coverage can be achieved despite using less initial plant material. Overall, groundcovers with matting growth habits achieved similar plant coverage despite planting sub optimally possibly reducing initial weed pressure. Some perennial species could replace areas of turf, reducing overall maintenance costs for landscapes. Further studies should be undertaken, perhaps evaluating planting densities in shade environments, determining what groundcovers tolerate foot traffic like turfgrass, and comparing pollinator activity across turf and ornamental groundcover systems. Achieving plant coverage goals with less plant material would lower installation costs, chiefly plant material, labor, fertilizer requirements, and plastic pot waste, thus increasing the sustainability of our landscapes.

Appendix. Chapter 2’s Inputted Program for CR-1000x data logger (Campbell Scientific, Logan, Utah, USA).

```
'CR1000X Series


'Wiring:

'Teros12

'Brown wire (power) -> 12V

'Orange wire (data) -> C7

'Bare wire (ground) -> G


'Program records precipitation from one TE525 or TE525WS Rain Gage once a

'second and stores the total every 60 minutes

'Wiring Diagram

'==============

'TE525 or TE525WS

' Wire

' Color     Function        CR1000X

' -----     --------        -------

' Black     Pulse Output     P1

' White     Ground           □

' Clear     Shield           □

'Declare the variables and units for the rain measurement
```

```
'Honeywell 26PC pressure transducers on Soil Measurement Systems Tensiometers
'The colors below use the following pin connections
'Pin 1 (Vs +) is Red
'Pin 2 (Output +) is Green
'Pin 3 (Ground) is Black
'Pin 4 (Output -) is White

'black p1 OR p2
'white AND clear go To ground (symbol)

'Declare Variables and Units
Public Flag(1) As Boolean: Alias Flag(1) = ReadNow
Public BattV, PTemp_C
Public Rain_mm
Dim LCount As Long 'Counter used for bookkeeping

'Teros12 variables
Const NumTeros12 = 18
Public Teros12Out(NumTeros12,3)
Public VWC(NumTeros12)

Alias Teros12Out(1,1) = CountsVWC_1: Alias Teros12Out(1,2) = Tsoil_C_1: Alias
Teros12Out(1,3) = EC_1
```

Alias Teros12Out(2,1) = CountsVWC_2: Alias Teros12Out(2,2) = Tsoil_C_2: Alias Teros12Out(2,3) = EC_2

Alias Teros12Out(3,1) = CountsVWC_3: Alias Teros12Out(3,2) = Tsoil_C_3: Alias Teros12Out(3,3) = EC_3

Alias Teros12Out(4,1) = CountsVWC_4: Alias Teros12Out(4,2) = Tsoil_C_4: Alias Teros12Out(4,3) = EC_4

Alias Teros12Out(5,1) = CountsVWC_5: Alias Teros12Out(5,2) = Tsoil_C_5: Alias Teros12Out(5,3) = EC_5

Alias Teros12Out(6,1) = CountsVWC_6: Alias Teros12Out(6,2) = Tsoil_C_6: Alias Teros12Out(6,3) = EC_6

Alias Teros12Out(7,1) = CountsVWC_7: Alias Teros12Out(7,2) = Tsoil_C_7: Alias Teros12Out(7,3) = EC_7

Alias Teros12Out(8,1) = CountsVWC_8: Alias Teros12Out(8,2) = Tsoil_C_8: Alias Teros12Out(8,3) = EC_8

Alias Teros12Out(9,1) = CountsVWC_9: Alias Teros12Out(9,2) = Tsoil_C_9: Alias Teros12Out(9,3) = EC_9

Alias Teros12Out(10,1) = CountsVWC_10: Alias Teros12Out(10,2) = Tsoil_C_10: Alias Teros12Out(10,3) = EC_10

Alias Teros12Out(11,1) = CountsVWC_11: Alias Teros12Out(11,2) = Tsoil_C_11: Alias Teros12Out(11,3) = EC_11

Alias Teros12Out(12,1) = CountsVWC_12: Alias Teros12Out(12,2) = Tsoil_C_12: Alias Teros12Out(12,3) = EC_12

Alias Teros12Out(13,1) = CountsVWC_13: Alias Teros12Out(13,2) = Tsoil_C_13: Alias

```
Teros12Out(13,3) = EC_13
Alias Teros12Out(14,1) = CountsVWC_14: Alias Teros12Out(14,2) = Tsoil_C_14: Alias
Teros12Out(14,3) = EC_14
Alias Teros12Out(15,1) = CountsVWC_15: Alias Teros12Out(15,2) = Tsoil_C_15: Alias
Teros12Out(15,3) = EC_15
Alias Teros12Out(16,1) = CountsVWC_16: Alias Teros12Out(16,2) = Tsoil_C_16: Alias
Teros12Out(16,3) = EC_16
Alias Teros12Out(17,1) = CountsVWC_17: Alias Teros12Out(17,2) = Tsoil_C_17: Alias
Teros12Out(17,3) = EC_17
Alias Teros12Out(18,1) = CountsVWC_18: Alias Teros12Out(18,2) = Tsoil_C_18: Alias
Teros12Out(18,3) = EC_18

Units BattV=Volts
Units PTemp_C=Deg C
Units Rain_mm=mm
'Define Data Tables

DataTable(Hourly,True,-1)
  DataInterval(0,60,Min,10)
  Average (1,VWC(1),FP2,False)
  Average (1,EC_1,FP2,False)
  Average (1,Tsoil_C_1,FP2,False)
  Average (1,VWC(2),FP2,False)
```

Average (1,EC_2,FP2,False)

Average (1,Tsoil_C_2,FP2,False)

Average (1,VWC(3),FP2,False)

Average (1,EC_3,FP2,False)

Average (1,Tsoil_C_3,FP2,False)

Average (1,VWC(4),FP2,False)

Average (1,EC_4,FP2,False)

Average (1,Tsoil_C_4,FP2,False)

Average (1,VWC(5),FP2,False)

Average (1,EC_5,FP2,False)

Average (1,Tsoil_C_5,FP2,False)

Average (1,VWC(6),FP2,False)

Average (1,EC_6,FP2,False)

Average (1,Tsoil_C_6,FP2,False)

Average (1,VWC(7),FP2,False)

Average (1,EC_7,FP2,False)

Average (1,Tsoil_C_7,FP2,False)

Average (1,VWC(8),FP2,False)

Average (1,EC_8,FP2,False)

Average (1,Tsoil_C_8,FP2,False)

Average (1,VWC(9),FP2,False)

Average (1,EC_9,FP2,False)

Average (1,Tsoil_C_9,FP2,False)

```
Average (1,VWC(10),FP2,False)

Average (1,EC_10,FP2,False)

Average (1,Tsoil_C_10,FP2,False)

Average (1,VWC(11),FP2,False)

Average (1,EC_11,FP2,False)

Average (1,Tsoil_C_11,FP2,False)

Average (1,VWC(12),FP2,False)

Average (1,EC_12,FP2,False)

Average (1,Tsoil_C_12,FP2,False)

Average (1,VWC(13),FP2,False)

Average (1,EC_13,FP2,False)

Average (1,Tsoil_C_13,FP2,False)

Average (1,VWC(14),FP2,False)

Average (1,EC_14,FP2,False)

Average (1,Tsoil_C_14,FP2,False)

Average (1,VWC(15),FP2,False)

Average (1,EC_15,FP2,False)

Average (1,Tsoil_C_15,FP2,False)

Average (1,VWC(16),FP2,False)

Average (1,EC_16,FP2,False)

Average (1,Tsoil_C_16,FP2,False)

Average (1,VWC(17),FP2,False)

Average (1,EC_17,FP2,False)
```

```
  Average (1,Tsoil_C_17,FP2,False)
  Average (1,VWC(18),FP2,False)
  Average (1,EC_18,FP2,False)
  Average (1,Tsoil_C_18,FP2,False)
  EndTable

DataTable (VWC_Counts,True,-1 )
  DataInterval (0,1,Hr,3)
  Sample (1,CountsVWC_1,FP2)
  Sample (1,CountsVWC_2,FP2)
  Sample (1,CountsVWC_3,FP2)
  Sample (1,CountsVWC_4,FP2)
  Sample (1,CountsVWC_5,FP2)
  Sample (1,CountsVWC_6,FP2)
  Sample (1,CountsVWC_7,FP2)
  Sample (1,CountsVWC_8,FP2)
  Sample (1,CountsVWC_9,FP2)
  Sample (1,CountsVWC_10,FP2)
  Sample (1,CountsVWC_11,FP2)
  Sample (1,CountsVWC_12,FP2)
  Sample (1,CountsVWC_13,FP2)
  Sample (1,CountsVWC_14,FP2)
  Sample (1,CountsVWC_15,FP2)
```

```
 Sample (1,CountsVWC_16,FP2)
 Sample (1,CountsVWC_17,FP2)
 Sample (1,CountsVWC_18,FP2)
EndTable

DataTable(Daily,True,-1)
 DataInterval(23,24,Hr,0) 'Outputs the values as of the END of the day (11pm), before values
are reset for next day
 Minimum (1,VWC(1),FP2, False, True)
 Minimum (1,Tsoil_C_1,FP2, False, True)
 Minimum (1,VWC(2),FP2, False, True)
 Minimum (1,Tsoil_C_2,FP2, False, True)
 Minimum (1,VWC(3),FP2, False, True)
 Minimum (1,Tsoil_C_3,FP2, False, True)
 Minimum (1,VWC(4),FP2, False, True)
 Minimum (1,Tsoil_C_4,FP2, False, True)
 Minimum (1,VWC(5),FP2, False, True)
 Minimum (1,Tsoil_C_5,FP2, False, True)
 Minimum (1,VWC(6),FP2, False, True)
 Minimum (1,Tsoil_C_6,FP2, False, True)
 Minimum (1,VWC(7),FP2, False, True)
 Minimum (1,Tsoil_C_7,FP2, False, True)
 Minimum (1,VWC(8),FP2, False, True)
```

Minimum (1,Tsoil_C_8,FP2, False, True)

Minimum (1,VWC(9),FP2, False, True)

Minimum (1,Tsoil_C_9,FP2, False, True)

Minimum (1,VWC(10),FP2, False, True)

Minimum (1,Tsoil_C_10,FP2, False, True)

Minimum (1,VWC(11),FP2, False, True)

Minimum (1,Tsoil_C_11,FP2, False, True)

Minimum (1,VWC(12),FP2, False, True)

Minimum (1,Tsoil_C_12,FP2, False, True)

Minimum (1,VWC(13),FP2, False, True)

Minimum (1,Tsoil_C_13,FP2, False, True)

Minimum (1,VWC(14),FP2, False, True)

Minimum (1,Tsoil_C_14,FP2, False, True)

Minimum (1,VWC(15),FP2, False, True)

Minimum (1,Tsoil_C_15,FP2, False, True)

Minimum (1,VWC(16),FP2, False, True)

Minimum (1,Tsoil_C_16,FP2, False, True)

Minimum (1,VWC(17),FP2, False, True)

Minimum (1,Tsoil_C_17,FP2, False, True)

Minimum (1,VWC(18),FP2, False, True)

Minimum (1,Tsoil_C_18,FP2, False, True)

Maximum (1,VWC(1),FP2, False, True)

Maximum (1,Tsoil_C_1,FP2, False, True)

Maximum (1,VWC(2),FP2, False, True)

Maximum (1,Tsoil_C_2,FP2, False, True)

Maximum (1,VWC(3),FP2, False, True)

Maximum (1,Tsoil_C_3,FP2, False, True)

Maximum (1,VWC(4),FP2, False, True)

Maximum (1,Tsoil_C_4,FP2, False, True)

Maximum (1,VWC(5),FP2, False, True)

Maximum (1,Tsoil_C_5,FP2, False, True)

Maximum (1,VWC(6),FP2, False, True)

Maximum (1,Tsoil_C_6,FP2, False, True)

Maximum (1,VWC(7),FP2, False, True)

Maximum (1,Tsoil_C_7,FP2, False, True)

Maximum (1,VWC(8),FP2, False, True)

Maximum (1,Tsoil_C_8,FP2, False, True)

Maximum (1,VWC(9),FP2, False, True)

Maximum (1,Tsoil_C_9,FP2, False, True)

Maximum (1,VWC(10),FP2, False, True)

Maximum(1,Tsoil_C_10,FP2, False, True)

Maximum (1,VWC(11),FP2, False, True)

Maximum (1,Tsoil_C_11,FP2, False, True)

Maximum (1,VWC(12),FP2, False, True)

Maximum (1,Tsoil_C_12,FP2, False, True)

Maximum (1,VWC(13),FP2, False, True)

Maximum (1,Tsoil_C_13,FP2, False, True)

Maximum (1,VWC(14),FP2, False, True)

Maximum (1,Tsoil_C_14,FP2, False, True)

Maximum (1,VWC(15),FP2, False, True)

Maximum (1,Tsoil_C_15,FP2, False, True)

Maximum (1,VWC(16),FP2, False, True)

Maximum (1,Tsoil_C_16,FP2, False, True)

Maximum (1,VWC(17),FP2, False, True)

Maximum (1,Tsoil_C_17,FP2, False, True)

Maximum (1,VWC(18),FP2, False, True)

Maximum (1,Tsoil_C_18,FP2, False, True)

Average (1,VWC(1),FP2, False)

Average (1,Tsoil_C_1,FP2, False)

Average (1,VWC(2),FP2, False)

Average (1,Tsoil_C_2,FP2, False)

Average (1,VWC(3),FP2, False)

Average (1,Tsoil_C_3,FP2, False)

Average (1,VWC(4),FP2, False)

Average (1,Tsoil_C_4,FP2, False)

Average (1,VWC(5),FP2, False)

Average (1,Tsoil_C_5,FP2, False)

Average (1,VWC(6),FP2, False)

Average(1,Tsoil_C_6,FP2, False)

Average (1,VWC(7),FP2, False)

Average (1,Tsoil_C_7,FP2, False)

Average (1,VWC(8),FP2, False)

Average (1,Tsoil_C_8,FP2, False)

Average (1,VWC(9),FP2, False)

Average (1,Tsoil_C_9,FP2, False)

Average (1,VWC(10),FP2, False)

Average (1,Tsoil_C_10,FP2, False)

Average (1,VWC(11),FP2, False)

Average (1,Tsoil_C_11,FP2, False)

Average (1,VWC(12),FP2, False)

Average (1,Tsoil_C_12,FP2, False)

Average (1,VWC(13),FP2, False)

Average (1,Tsoil_C_13,FP2, False)

Average (1,VWC(14),FP2, False)

Average (1,Tsoil_C_14,FP2, False)

Average (1,VWC(15),FP2, False)

Average (1,Tsoil_C_15,FP2, False)

Average (1,VWC(16),FP2, False)

Average (1,Tsoil_C_16,FP2, False)

Average (1,VWC(17),FP2, False)

Average (1,Tsoil_C_17,FP2, False)

Average (1,VWC(18),FP2, False)

```
  Average (1,Tsoil_C_18,FP2, False)
  EndTable

DataTable(Rain,True,-1)
DataInterval(0,60,Min,0)
Totalize(1,Rain_mm,FP2,0)
EndTable

DataTable(tmin,True,-1)
  DataInterval(0,10,Min,10)
  Sample (1,VWC(1),FP2)
  Sample (1,EC_1,FP2)
  Sample (1,Tsoil_C_1,FP2)
  Sample (1,VWC(2),FP2)
  Sample (1,EC_2,FP2)
  Sample (1,Tsoil_C_2,FP2)
  Sample (1,VWC(3),FP2)
  Sample (1,EC_3,FP2)
  Sample (1,Tsoil_C_3,FP2)
  Sample (1,VWC(4),FP2)
  Sample (1,EC_4,FP2)
  Sample (1,Tsoil_C_4,FP2)
  Sample (1,VWC(5),FP2)
```

Sample (1,EC_5,FP2)

Sample (1,Tsoil_C_5,FP2)

Sample (1,VWC(6),FP2)

Sample (1,EC_6,FP2)

Sample (1,Tsoil_C_6,FP2)

Sample (1,VWC(7),FP2)

Sample (1,EC_7,FP2)

Sample (1,Tsoil_C_7,FP2)

Sample (1,VWC(8),FP2)

Sample (1,EC_8,FP2)

Sample (1,Tsoil_C_8,FP2)

Sample (1,VWC(9),FP2)

Sample (1,EC_9,FP2)

Sample (1,Tsoil_C_9,FP2)

Sample (1,VWC(10),FP2)

Sample (1,EC_10,FP2)

Sample (1,Tsoil_C_10,FP2)

Sample (1,VWC(11),FP2)

Sample (1,EC_11,FP2)

Sample (1,Tsoil_C_11,FP2)

Sample (1,VWC(12),FP2)

Sample (1,EC_12,FP2)

Sample (1,Tsoil_C_12,FP2)

```
  Sample (1,VWC(13),FP2)
  Sample (1,EC_13,FP2)
  Sample (1,Tsoil_C_13,FP2)
  Sample (1,VWC(14),FP2)
  Sample (1,EC_14,FP2)
  Sample (1,Tsoil_C_14,FP2)
  Sample (1,VWC(15),FP2)
  Sample (1,EC_15,FP2)
  Sample (1,Tsoil_C_15,FP2)
  Sample (1,VWC(16),FP2)
  Sample (1,EC_16,FP2)
  Sample (1,Tsoil_C_16,FP2)
  Sample (1,VWC(17),FP2)
  Sample (1,EC_17,FP2)
  Sample (1,Tsoil_C_17,FP2)
  Sample (1,VWC(18),FP2)
  Sample (1,EC_18,FP2)
  Sample (1,Tsoil_C_18,FP2)
  EndTable

'Main Program
BeginProg
```

```
  'Main Scan
  Scan(10,Min,1,0)
    'Default CR1000X Datalogger Battery Voltage measurement 'BattV'
    Battery(BattV)
    'Default CR1000X Datalogger Wiring Panel Temperature measurement 'PTemp_C'
    PanelTemp(PTemp_C,60)
    If IfTime (0,10,Min) Then ReadNow = True
    If ReadNow = True Then

PulseCount(Rain_mm,1,P1,1,0,0.254,0)
'For TE525MM Rain Gage, use multiplier of 0.1 in PulseCount instruction

        'Teros12 readings
      'Query each sensor for 3 SDI-12 outputs.  Default address for all Decagon Digital sensors is
0.
      SDI12Recorder (Teros12Out(1,1),C1,1,"M!",1.0,0,-1)
      SDI12Recorder (Teros12Out(2,1),C1,2,"M!",1.0,0,-1)
      SDI12Recorder (Teros12Out(3,1),C7,3,"M!",1.0,0,-1)
      SDI12Recorder (Teros12Out(4,1),C7,4,"M!",1.0,0,-1)
      SDI12Recorder (Teros12Out(5,1),C7,5,"M!",1.0,0,-1)
      SDI12Recorder (Teros12Out(6,1),C7,6,"M!",1.0,0,-1)
      SDI12Recorder (Teros12Out(7,1),C7,7,"M!",1.0,0,-1)
      SDI12Recorder (Teros12Out(8,1),C7,8,"M!",1.0,0,-1)
```

```
    SDI12Recorder (Teros12Out(9,1),C1,9,"M!",1.0,0,-1)
    SDI12Recorder (Teros12Out(10,1),C1,"J","M!",1.0,0,-1)
    SDI12Recorder (Teros12Out(11,1),C1,"K","M!",1.0,0,-1)
    SDI12Recorder (Teros12Out(12,1),C1,"L","M!",1.0,0,-1)
    SDI12Recorder (Teros12Out(13,1),C7,"N","M!",1.0,0,-1)
    SDI12Recorder (Teros12Out(14,1),C7,"O","M!",1.0,0,-1)
    SDI12Recorder (Teros12Out(15,1),C7,"P","M!",1.0,0,-1)
    SDI12Recorder (Teros12Out(16,1),C1,"Q","M!",1.0,0,-1)
    SDI12Recorder (Teros12Out(17,1),C7,"R","M!",1.0,0,-1)
    SDI12Recorder (Teros12Out(18,1),C7,"S","M!",1.0,0,-1)
    'Apply calibration to calibrated counts for volumetric water content(VWC) for mineral soil
(VWCmineral), soilless media (VWCsoilless), and dielectric permittivity (VWCdielectric)
    For LCount = 1 To NumTeros12
      VWC(LCount) = 3.879E-4*Teros12Out(LCount,1) - 0.6956 'mineral soil calibration
    Next LCount

   ReadNow = False
   EndIf 'End of Flag = true condition
   'Call Data Tables and Store Data
   CallTable Hourly
   CallTable tmin
   CallTable VWC_Counts
   CallTable Daily
```

```
CallTable(Rain)


  NextScan
EndProg
```

LITERATURE CITED

Alam, H., J. Z. Khattak, S. B. Ppoyil, S. S. Kurup, and T. Ksiksi. 2017. Landscaping With Native Plants in the UAE: A Review. Emir. J. Food Agric. 2910, 729-41. https://doi.org/10.9755/ejfa.2017.v29.i10.319.

Anderson, T.H. 2003. Microbial eco-physiological indicators to asses soil quality. Agric., Ecosyst. & Environ. 98:285–293.

Arnold Jr., C.L and C.J. Gibbons. 1996. Impervious surface coverage: the emergence of a key environmental indicator. J. Am. Planning Assoc. 62:2, 243-258. DOI: 10.1080/01944369608975688.

Bais, H.P., T.L. Weir, L.G. Perry, S. Gilroy, and J.M. Vivanco. 2006. The role of root exudates in rhizosphere interactions with plants and other organisms. Annu. Rev. Plant. Biol. 57:1, 233-266.

Bartik, M., M. Jančo, K. Střelcová, J. Škvareninová, S. Jaroslav, M. Mikloš, J. Vido, and P. Waldhauserova. 2016. Rainfall interception in a disturbed montane spruce (Picea abies) stand in the West Tatra Mountains. Biol. 71. DOI: 10.1515/biolog-2016-0119.

Baudoin, E., E. Benizri, and A. Guckert. 2003. Impact of artificial root exudates on the bacterial community structure in bulk soil and maize rhizosphere. Soil Biol. Biochem. 35:9, 1183-1192. ISSN 0038-0717. https://doi.org/10.1016/S0038-0717(03)00179-2.

Bavougian, C.M., and, Read, P.E. 2018. Mulch and groundcover effects on soil temperature and moisture, surface reflectance, grapevine water potential, and vineyard weed management. Peer. 6:e5082. DOI: 10.7717/peerj.5082.

Beard, J.B. 1999. Turfgrass benefits and the golf environment fate and management of turfgrass chemicals. 36-44. DOI:10.1021/bk-2000-0743.ch002.

Bedard-Haughn, A. 2009. Managing excess water in Canadian prairie soils: A review. Can. J. Soil Sci. 89:2, 157-168. https://doi.org/10.4141/CJSS07071.

Berghage, R.D., E.P. MacNeal, E.F. Wheeler, and W.H. Zachritz. 1999. "Green" water treatment for the green industries: opportunities for biofiltration of greenhouse and nursery irrigation water and runoff with constructed wetlands. Hort. Sci. 34:1, 50-54.

Biederbeck, V. O. and C. A. Campbell. 1973. Soil microbial activity as influenced by temperature trends and fluctuations. Can. J. Soil Sci. 53:363-376

Blanco-Montero, C., T. Bennett, P. Neville, C. Crawford, B. Milne, and C. Ward. 1995. Potential environmental and economic impacts of turfgrass in Albuquerque, New Mexico (USA). Landscape Ecol. 10:121-128. DOI: 10.1007/BF00153829.

Brabec, E., S. Schulte and P.L. Richards. 2002. Impervious surfaces and water quality: a review of current literature and its implications for watershed planning. J. Planning Literature. 16:4, 499-514. https://doi.org/10.1177/088541202400903563.

Burayu, W. and K. Umeda. 2021. Versatile native grasses and a turf-alternative groundcover for the arid southwest United States. J. Environ. Hortic. 39:4, 160–167. https://doi.org/10.24266/0738-2898-39.4.160.

Burnett, S. E., G. J. Keever, J. R. Kessler, and C.H. Gilliam. 2000. Growth regulation of Mexican sage and 'Homestead Purple' verbena during greenhouse and nursery production. J. Environ. Hortic. 18:3, 166–170. https://doi.org/10.24266/0738-2898-18.3.166.

Buyer, J.S., D.P. Roberts, and E. Russek-Cohen. 2002. Soil and plant effects on microbial community structure. Can. J. Microbiol. 48:955–964.

Calkins, J.B. and B.T. Swanson. 1998. Comparison of conventional and alternative nursery field management systems: soil physical properties. J. Environ. Hortic. 16:2, 90–97. https://doi.org/10.24266/0738-2898-16.2.90.

Campbell, J., A. Rihn, and H. Khachatryan. 2020. Factors influencing home lawn fertilizer choice in the United States. Hort. Tech. 30, 296-305.

Cardenas-Lailhacar, B., M.D. Dukes, and G.L. Miller. 2008. Sensor-based automation of irrigation on bermudagrass, during wet weather conditions. J. Irrig. Drainage Eng. 134:2, 120-128.

Cardina J., D.H. Sparrow, and E.L. McCoy. 1996. Spatial relationships between seedbank and seedling populations of common lambsquarters (Chenopodium album) and annual grasses. Weed Sci. 44:2, 298–308. http://www.jstor.org/stable/4045682.

Carey, R. O., G.J. Hochmuth, C.J. Martinez, T.H. Boyer, V.D. Nair, M.D. Dukes, G.S. Toor, A.L. Shober, J.L. Cisar, L.E. Trenholm, and J.B. Sartain. 2012. A review of turfgrass fertilizer management practices: implications for urban water quality. Hort. Tech. 22: 280-291. https://doi.org/10.21273/HORTTECH.22.3.280.

Carpenter, S.R., N.F. Caraco, D.L. Correll, R.W. Howarth, A.N. Sharpley, and V.H. Smith. 1998. Nonpoint pollution of surface waters with phosphorus and nitrogen. Ecol Applic. 8:559-568. https://doi.org/10.1890/1051-0761(1998)008[0559:NPOSWW]2.0.CO;2

Case, L.T., H.M. Mathers, and A.F. Senesac. 2005. A review of weed control practices in container nurseries. Hort. Tech. 15:535–545.

Chalise, K.S.; S.; Singh, B.R.; Wegner, S.; Kumar, J.D Pérez-Gutiérrez,.; S.L.; Osborne, T.; Nleya, J.; Guzman, and J.S. Rohila, 2018. Cover crops and returning residue impact on soil organic carbon, bulk density, penetration resistance, water retention, infiltration, and soybean yield. Publications from USDA-ARS / UNL Faculty. 2139. https://digitalcommons.unl.edu/usdaarsfacpub/2139

Chappell, G.W., Ed. Southern Plant Lists. 2000. The Herbarium of Louisiana and Mississippi of John C. Jenkins, A.D. 1836-37.

City of El Paso, 2001 Turf grass prohibited No. 14805. 4 Jan. 2023

Clement, C. R., and J. DeFrank. 1998. The use of ground covers during the establishment of heart-of-palm plantations in Hawaii. Hort. Sci. 33:5, 814-815

Corwin, D. L., and S. M. Lesch. 2005. Apparent soil electrical conductivity measurements in agriculture. Computers and Electronics in Agriculture. 46, 11-43.

Cregger MA, C.W Schadt, N.G McDowell, W.T Pockman, and A.T Classen. 2012. Response of the soil microbial community to changes in precipitation in a semiarid ecosystem. Appl. Environ. Microbiol. 78:24, 8587-8594. DOI: 10.1128/aem.02050-12.

Davis, S. L., and M. D. Dukes. 2012. Landscape irrigation with evapotranspiration controllers in a humid climate. Trans. ASABE. 55:2, 571-580.

Délye C., M. Jasieniuk, and V.L. Corre. 2013. Deciphering the evolution of herbicide resistance in weeds. Trends Genet.. 29:11, 649-658. ISSN 0168-9525. DOI: 10.1016/j.tig.2013.06.001.

Dennis, J. H., R.G. Lopez, B.K. Behe, C.R. Hall, C. Yue, and B.L. Campbell. 2010. Sustainable production practices adopted by greenhouse and nursery plant growers. Hort. Sci. horts. 45:8, 1232-1237.

Domisch, T., L. Finér, and T. Lehto. 2001. Effects of soil temperature on biomass and carbohydrate allocation in Scots pine (Pinus sylvestris) seedlings at the beginning of the growing season. Tree Physiol. 21:465-72. DOI: 10.1093/treephys/21.7.465.

Doxon, L. E. 1996. Landscape sustainability: environmental, human, and financial factors. Hort. Tech. 6, 362-365.

Duryea, Mary L., R.J. English, and L.A. Hermansen. 1999. A comparison of landscape mulches: chemical, allelopathic, and decomposition properties. J. Arboric. 88-97.

Ehler, Lester E. 2006. Integrated pest management (IPM): definition, historical development and implementation, and the other IPM. Pest Manage. Sci. 62:9, 787-789.

Eilers, R. G., W.D. Eilers, W.W. Pettapiece, and G. Lelyk. 1995. Salinization of soil. Pages 77-86 in D. F. Acton and L. J. Gregorich, eds. The health of our soils: Toward sustainable agriculture in Canada. Research Branch, Agri. and Agri-Food C., Ottawa, ON.

Eom, S.H., A.F. Senesac, I. Tsontakis-Bradley, and L.A. Weston. 2005. Evaluation of herbaceous perennials as weed suppressive groundcovers for use along roadsides or in landscapes. J. Environ. Hortic. 23:4, 198–203. https://doi.org/10.24266/0738-2898-23.4.198.

Eom, S.H., H.S. Yang, and L.A. Weston. 2006. An evaluation of the allelopathic potential of selected perennial groundcovers: foliar volatiles of catmint (*Nepeta* × *faassenii*) Inhibit seedling growth. J. Chem. Ecol. 32, 1835–1848. https://doi.org/10.1007/s10886-006-9112-1.

Erickson, J.E., J.L. Cisar, J.C. Volin, and G.H. Snyder. 2001. Comparing nitrogen runoff and leaching between newly established st. augustinegrass turf and an alternative residential landscape. Crop Sci. 41:1889-1895. https://doi.org/10.2135/cropsci2001.1889.

Ettema, C. H., and D.A. Wardle. 2002. Spatial soil ecology, trends in ecology & evolution. 17:4, 177-183. ISSN 0169-5347. https://doi.org/10.1016/S0169-5347(02)02496-5.

Evans, M.R., and D.L. Hensley. 2004. Plant growth in plastic, peat, and processed poultry feather fiber growing containers. Hort. Sci. 39:5, 1012-1014.

Flerchinger, G.N. and F.B. Pierson. 1991. Modeling plant canopy effects on variability of soil temperature and water. Agric. Meteorol. 56:227-246.

Folorunso, O., D.E Rolston, T. Prichard, and D.T. Louie. 1992. Cover crops lower soil surface strength, may improve soil permeability. Hilgardia. 46:6:26-27. DOI:10.3733/ca. v046n06p26.

Foo, C. L., K.C. Harrington, and M.B MacKay. 2011. Weed suppression by twelve ornamental ground cover species. N. Z. Plant Prot. 64:149-154.

Fu, B. L. Chen, H. Huang, P. Qu and Z. Wei 2021. Impacts of crop residues on soil health: a review. Environ. Pollut. Bioavailability. 33:1, 164-173, DOI: 10.1080/26395940.2021.1948354.

Gabet, E. J., and T. Dunne. 2003. Sediment detachment by rain power, Water Resour. Res. 39:1, 1002. DOI:10.1029/2001WR000656.

Garber M.P., and K. Bondari. 1996. Landscape maintenance firms: ii. pest management practices. J. Environ. Hortic. 14:2, 58–61. https://doi.org/10.24266/0738-2898-14.2.58.

Gerrits, A.M.J., L. Pfister, and H.H.G. Savenije. 2010. Spatial and temporal variability of canopy and forest floor interception in a beech forest. Hydrol. Process. 24, 3011-3025. https://doi.org/10.1002/hyp.7712

Getter, K. L., and B. K. Behe. 2013. Consumer willingness to purchase impatiens walleriana alternatives. Hort. Sci. 48:11, 1370-1377.

Getter, K. L., B.K. Behe, and H.M. Wollaeger. 2016. Comparative consumer perspectives on eco-friendly and insect management practices on floriculture crops. Hort. Tech. 26:1, 46-53.

Gilman, E. F. and A. Meerow. 1999. Evolvulus glomeratus. Fact Sheet FPS-207. Florida Cooperative Extension Service, University of Florida.

Gilman, E. F. 1999. Wedelia trilobata. Fact Sheet FPS-612, Florida Cooperative Extension Service, University of Florida.

Glenn, D.M. and W. Welker. 1989. Orchard soil management systems influence rainfall infiltration. J. Amer. Soc. Hort. Sci. 114:10-14. DOI: 10.21273/JASHS.114.1.10.

Goddard M.A., A.J. Dougill, and T.G. Benton. 2010. Scaling up from gardens: biodiversity conservation in urban environments. Trends Ecol. & Evol. 25:2, 90-98. ISSN 0169-5347. https://doi.org/10.1016/j.tree.2009.07.016.

Gosling, S.N., and N.W. Arnell. 2016. A global assessment of the impact of climate change on water scarcity. Climatic Change 134, 371–385. https://doi.org/10.1007/s10584-013-0853-x.

Grisso, R. D., M.M. Alley, D.L. Holshouser, and W.E. Thomason. 2005. Precision farming tools. soil electrical conductivity. Virginia Tech Cooperative Extension. Pub. 442-508

Groffman, P.M, J. Cavender-Bares, N.D. Bettez, J.M. Grove, S.J. Hall, J. B. Heffernan, S.E. Hobbie, K.L. Larson, J.L. Morse, C. Neill, K. Nelson, J. O'Neil-Dunne, L. Ogden, D.E. Pataki, C. Polsky, R.R. Chowdhury, and M. K. Steele. 2014. Ecological homogenization of urban USA. Front. Ecol. Environ. 12, 74-81. https://doi.org/10.1890/120374.

Hall, C. R., A.W. Hodges, and J.J. Haydu. 2006. The economic impact of the green industry in the United States. Hort. Tech. 16:2, 345-353.

Hall, C.R., A.W. Hodges, H. Khachatryan, and M.A. Palma. 2020 Economic contributions of the green industry in the united states in 2018. J. Environ. Hortic. 38:3, 73–79. https://doi.org/10.24266/0738-2898-38.3.73.

Haramoto, E. R., and D. C. Brainard, 2012. Strip tillage and oat cover crops increase soil moisture and influence N mineralization patterns in cabbage. Hort. Sci. 47:11, 1596-1602.

Hardy J., B.K. Behe, S.S. Barton, T.J. Page, R.E. Schutzki, K. Muzii, R.T. Fernandez, M.T. Haque, J. Brooker, C.R. Hall, R. Hinson, P. Knight, R. McNiel, D.B. Rowe, and C. Safley. 2000. Consumers preferences for plant size, type of plant material and design sophistication in residential landscaping. J. Environ. Hortic. 18:4, 224–230. https://doi.org/10.24266/0738-2898-18.4.224.

Haridasan, M. 2008. Nutritional adaptations of native plants of the Cerrado biome in acid soils. Brazilian J. Plant Physiol. 20:183-195.

Hensley, D., J. Yogi, and J. DeFrank. 1997. Perennial peanut ground cover. Coop. Ext. Serv., College of Trop. Agr. Human Resour., Univ. of Hawaii at Manoa, Ornamentals and Flowers OF-23.

Hilaire St., Rolston, M.A. Arnold, D.C. Wilkerson, D.A. Devitt, B.H. Hurd, B.J. Lesikar, V.I. Lohr, C.A. Martin, G.V. McDonald, R.L. Morris, D.R. Pittenger, D.A. Shaw, and D.F. Zoldoske. 2008. Efficient water use in residential urban landscapes. Hort. Sci. 43:7, 2081-2092, https://library.municode.com/tx/el_paso/codes/code_of_ordinances?nodeId=TIT15PUSE_CH15.13WACO_15.13.130TUGRPR.

Hillel, D. 2004. Soil temperature and heat flow, p. 215-233. Introduction to Environmental Soil Physics. Elsevier Academic Press, San Diego, CA.

Hinson, R.A., R. Pinel, and D.W. Hughes. 2003. Louisiana's green industry: evaluation of its economic contribution. Research Information Sheet 108, Louisiana State University Agricultural Center, Baton Rouge, LA, 16 p. https://www.lsuagcenter.com/NR/rdonlyres/BFEE68F0-DC32-4837-9AC1-A200BD57C973/4111/RIS108GreenIndustry6.pdf.

Hochmuth, G., and E. Hanlon. 2010. Principles of sound fertilizer recommendations. SL315/SS527, 2/2010." EDIS 2010.2.

Hochmuth, G., T. Nell, J. Sartain, J.B. Unruh, C. Martinez, L. Trenholm, and J. Cisar. 2009. Unintended consequences associated with certain urban fertilizer ordinances. Univ. Florida Coop. Ext. Serv. SL283.

Hodel, D.R., and D.R. Pittenger. 1994. Responses of eight groundcover species to renovation by mowing. J. Environ. Hortic. 12:1, 4–7. https://doi-org.libezp.lib.lsu.edu/10.24266/0738-2898-12.1.4.

Holmes, R. 2001. Taylor's master guide to gardening. Houghton Mifflin Harcourt.

Hooks, T., and G. Niu. 2019. Relative salt tolerance of four herbaceous perennial ornamentals. Hortic. 5:2, 36. https://doi.org/10.3390/horticulturae5020036.

Horton, R.E. 1941. An approach toward a physical interpretation of infiltration capacity. Soil Sci. Soc. Amer. Proc. 5:399.

Hovhannisyan, V. and H. Khachatryan, H. 2017. Ornamental plants in the United States: an econometric analysis of a household-level demand system. Agribusiness. 33:226-241. https://doi.org/10.1002/agr.21488.

Huang, X., and J.T. Sherk. 2014. Evaluation and comparison of sustainability performance and visual preference of residential landscape elements. Hort. Tech. 24:3, 318-324.

Iles, J.K., and M.S. Dosmann 1999. Effect of organic and mineral mulches on soil properties and growth of Fairview Flame® red maple trees. Arboric. Urban For. 25:3.

Irmak, S., L.O. Odhiambo, W. L. Kranz, and D.E. Eisenhauer. 2011. Irrigation efficiency and uniformity, and crop water use efficiency. Biol. Syst. Eng.: Papers and Publications. 451. https://digitalcommons.unl.edu/biosysengfacpub/451.

Jacobsen B. J., N. K. Zidack, and B. J. Larson. 2004. The role of bacillus-based biological control agents in integrated pest management systems. Plant Dis. Phytopathol. 94:11, 1272-1275.

Jian, J. X. Du, M.S. Reiter, and R.D. Stewart. 2020. A meta-analysis of global cropland soil carbon changes due to cover cropping, Soil Biol. and Biochem. 143:107735. ISSN 0038-0717. https://doi.org/10.1016/j.soilbio.2020.107735.

Kahimba, F.C., R., Sri Ranjan, J., Froese, M., Entz, and R. Nason, 2008. Cover crop effects on infiltration, soil temperature, and soil moisture distribution in the Canadian prairies. Appl. Eng. Agric. 24: 321-333.

Kaspar, T., and J. Singer. 2011. The use of cover crops to manage soil. Soil Manage.: Building a Stable Base Agric. https://doi.org/10.2136/2011.soilmanagement.c21.

Khachatryan, H., D.H. Suh, G. Zhou, and M. Dukes. 2017. Sustainable urban landscaping: consumer preferences and willingness to pay for turfgrass fertilizers. C. J. Agric. Econ. 65, 385-407. https://doi.org/10.1111/cjag.12129.

Klett, J.E. and C.R. Wilson. 2009. Xeriscaping: ground cover plants. Colorado State Univ. Ext. Fact Sheet No. 7.230.

Klingeman, W. E., G.V. Pettis, and S.K. Braman. 2009. Lawn care and landscape maintenance professional acceptance of insect- and disease-resistant ornamental plants. Hort. Sci. 44:6, 1608-1615.

Krohn, N.G., and D.C. Ferree, 2005. Effects of low-growing perennial ornamental groundcovers on the growth and fruiting of `Seyval Blanc' grapevines. Hort. Sci. 40:561-568.

Lampert, P., and K. Menrad. 2012. Consumer attitudes for new plant species using the example of Trachycarpus wagnerianus. J. Hortic. For. 4:8: 129-135.

Larson, K.L. and J. Brumand. 2014. Paradoxes in landscape management and water conservation: examining neighborhood norms and institutional forces. Cities Environ. (CATE). 7:1:6. https://digitalcommons.lmu.edu/cate/vol7/iss1/6.

Li, J., and M. Rao. 2000. Sprinkler water distributions as affected by winter wheat canopy. Irrig. Sci. 20, 29–35. https://doi.org/10.1007/PL00006715.

Li, Y., Li J., Gao L., and Tian Y. 2018. Irrigation has more influence than fertilization on leaching water quality and the potential environmental risk in excessively fertilized vegetable soils. PLOS ONE 13:9. e0204570. https://doi.org/10.1371/journal.pone.0204570.

Liu, X., and B. Huang. 2005. Root physiological factors involved in cool-season grass response to high soil temperature. Environ. Exp. Bot. 53:3, 233-24. ISSN 0098-8472. https://doi.org/10.1016/j.envexpbot.2004.03.016.

Machado, R.M.A., and R.P. Serralheiro. 2017. Soil salinity: effect on vegetable crop growth. management practices to prevent and mitigate soil salinization. Hortic. 3:2, 30. https://doi.org/10.3390/horticulturae3020030.

Marble S.C., and J.M. Pickens. 2020. Tolerance of three deep south non-turf ornamental groundcovers to applications of postemergence herbicides. J. Environ. Hortic. 38:3, 91–100. https://doi.org/10.24266/0738-2898-38.3.91.

Marble, S. C., A. K. Koeser, G. Hasing, D. McClean, and A. Chandler. 2017. Efficacy and estimated annual cost of common weed control methods in landscape planting beds. Hort. Tech. 27:2, 199-211.

Marble, S. C., A. K. Koeser, and G. Hasing. 2015. A review of weed control practices in landscape planting beds: part ii—chemical weed control methods, Hort. Sci. 50:6, 857-862.

Marble, S. C., A.K. Koeser, and G. Hasing. 2015. A review of weed control practices in landscape planting beds: part i–nonchemical weed control methods. Hort. Sci. 50:6, 851-856.

Marble, S. C., A.K. Koeser, G. Hasing, D. McClean, and A. Chandler. 2017. Efficacy and estimated annual cost of common weed control methods in landscape planting beds. Hort. Tech. 27:2, 199-211.

Masierowska M., E. Stawiarz, and R. Rozwałka. 2018. Perennial ground cover plants as floral resources for urban pollinators: A case of Geranium species. Urban For. & Urban Greening. 32, 185-194. ISSN 1618-8667. https://doi.org/10.1016/j.ufug.2018.03.018.

Matheny, A.L. 2009. Home gardener preferences, perceptions, knowledge and behaviors associated with pest management strategies and information acquisition (Thesis). University of Maryland, College Park, MD. 114.

McMichael, B.L., and J.J. Burke. 1994. Metabolic activity of cotton roots in response to temperature. Environ. and Exp. Bot. 34:2, 201-206. ISSN 0098-8472. https://doi.org/10.1016/0098-8472(94)90039-6.

Merriam, J. L., and J. Keller. 1978. Farm irrigation system evaluation: A guide for management. Dept. of Agric. and Irrig. Eng. Utah State Univ., Logan, Utah.

Merwin, I. A., W.C., Stiles, and H. M. van Es, 1994. Groundcover management impacts on soil physical properties. J. Amer. Soc. Hortic. Sci. 119:216-222.

Michelsen-Correa, S., and P. Scull. 2005. The impact of reforestation on soil temperature. Middl. States Geograp. 38:39-44.

Milesi, C., S.W. Running, C.D. Elvidge, J.B. Dietz, B.T. Tuttle and R.R. Nemani. 2005. Mapping and modeling the biogeochemical cycling of turf grasses in the United States. Environ. Manage. 36:426–438. https://doi.org/10.1007/s00267-004-0316-2.

Million, J. B., and T.H. Yeager. 2015. Capture of sprinkler irrigation water by container-grown ornamental plants. Hort. Sci. 50:3, 442-446.

Moore, K. A., A.L. Shober, G.S. Hasing, C.L. Wiese, G.C. Denny, and G.W. Knox. 2014. Effects of nitrogen fertilization rate on aesthetic quality of landscape-grown annuals and perennials. HortTechnology hortte. 24:5, 597-603.

Morgan, J.A.W., G. D. Bending, and P. J. White 2005. Biological costs and benefits to plant–microbe interactions in the rhizosphere. J. Exp. Bot. 56:417, 1729–1739. https://doi.org/10.1093/jxb/eri205.

Nambuthiri, S. S., and D.L. Ingram. 2014. Evaluation of plantable containers for groundcover plant production and their establishment in a landscape. Hort. Tech. 24:1, 48-52.

Nambuthiri, S., A. Fulcher, A.K. Koeser, R. Geneve, and G. Niu. 2015. Moving toward sustainability with alternative containers for greenhouse and nursery crop production: a review and research update. Hort. Tech. 25:1, 8-16.

Nearing, M.A, V. Jetten, C. Baffaut, O. Cerdan, A. Couturier, M. Hernandez, Y. Le Bissonnais, M.H. Nichols, J.P. Nunes, C.S. Renschler, V. Souchère, and K. van Oost. 2005. Modeling response of soil erosion and runoff to changes in precipitation and cover. Catena. 61:2–3, 131-154. ISSN 0341-8162. DOI: 10.1016/j.catena.2005.03.007

Nesom, G.L. 2010. Overview of Liriope and Ophiopogon (Ruscaceae) naturalized and commonly cultivated in the USA. Phytoneuron. 56:1–31.

Ni, J.-J., Y.F. Cheng, S. Bordoloi, H. Bora, Q.H. Wang, C.W. Waing, and A. Garg. 2019. Investigating plant root effects on soil electrical conductivity: An integrated field monitoring and statistical modelling approach. Earth Surf. Process Landforms. 44, 825– 839. https://doi.org/10.1002/esp.4533.

O'Farrell, P. J., and P.M. Anderson. 2010. Sustainable multifunctional landscapes: a review to implementation. Curr. Opin. Environ. Sustain. 2:1-2, 59-65.

Onwuka, B., and B. Mang. 2018. Effects of soil temperature on some soil properties and plant growth. Adv. Plants Agric. Res. 8:1, 34-37.

Owen, Wayne. 2002. The history of native plant communities in the south. The southern forest resource assessment: technical report. US Forest Service general technical report SRS-53: 47-62.

Packer, A., and K. Clay. 2000. Soil pathogens and spatial patterns of seedling mortality in a temperate tree. Nat. 404, 278–281. https://doi.org/10.1038/35005072.

Paine, T.D., C.C. Hanlon, D.R. Pittenger, D.M. Ferrin, and M.K. Malinoski. 1992. Consequences of water and nitrogen management on growth and aesthetic quality of drought-tolerant woody landscape plants. J. Environ. Hortic. 10:2, 94–99. https://doi.org/10.24266/0738-2898-10.2.94.

Palmersheim, M.C., R. Schürch, M.E. O'Rourke, J. Slezak, and M.J. Couvillon. 2022. If you grow it, they will come: ornamental plants impact the abundance and diversity of pollinators and other flower-visiting insects in gardens. Hortic. 8:11, 1068. https://doi.org/10.3390/horticulturae8111068.

Pezeshki, S. R., and R.D. DeLaune. 2012. Soil oxidation-reduction in wetlands and its impact on plant functioning. Biol. 1:2, 196–221. https://doi.org/10.3390/biology1020196

Piñeiro, V., J. Arias, J. Dürr, P. Elverdin, A.M. Ibáñez, A. Kinengyere, C.M. Opazo, N. Owoo, J.R. Page, S.D. Prager, and M. Torero. 2020. A scoping review on incentives for adoption of sustainable agricultural practices and their outcomes. Nat. Sustain. 3, 809–820. https://doi.org/10.1038/s41893-020-00617-y.

Pittenger, D.R., D.A. Shaw, D.R. Hodel, and D.B. Holt. 2001. Responses of landscape groundcovers to minimum irrigation. J. Environ. Hortic. 19:2, 78–84. doi: https://doi.org/10.24266/0738-2898-19.2.78

Pons, T. L. 1991. Induction of dark dormancy in seeds: its importance for the seed bank in the soil. Funct. Ecol. 5:5, 669–675. https://doi.org/10.2307/2389487

Pramanik, P., K. K. Bandyopadhyay, D. Bhaduri, R. Bhattacharyya, and P. Aggarwal. 2015. Effect of mulch on soil thermal regimes-a review. Int. J. Agric., Environ. Biotech. 8:3, 645-658.

Prasad, R. 1998. A linear root water uptake model. J. Hydrology. 99:3–4, 297-306. ISSN 0022-1694. https://doi.org/10.1016/0022-1694(88)90055-8.

Qi, Zhiming, M.J. Helmers, and A.L. Kaleita. 2011. Soil water dynamics under various agricultural land covers on a subsurface drained field in north-central Iowa, USA. Agric. Water Manage. 98:4, 665-674.

Quideau, S.A., A.C. McIntosh, C.E. Norris, E. Lloret, M.J. Swallow, and K. Hannam. 2016. Extraction and analysis of microbial phospholipid fatty acids in soils. J. Visualized Experiments: JoVE. 114. 54360. https://doi.org/10.3791/54360.

Quigley, M. F. 2003. Reducing weeds in ornamental groundcovers under shade trees through mixed species installation. Hort. Tech. 13:1, 85-89.

Raffa, D.W., D. Antichi, S. Carlesi, C. Frasconi, S. Marini, S. Priori, and P. Bàrberi. 2021. Groundcover Mulching in Mediterranean Vineyards Improves Soil Chemical, Physical and Biological Health Already in the Short Term. Agron. 11:4, 787. https://doi-org.libezp.lib.lsu.edu/10.3390/agronomy11040787.

Reddy, K., R. Zablotowicz, M. Locke, and C. Koger. 2003. Cover crop, tillage, and herbicide effects on weeds, soil properties, microbial populations, and soybean yield. Weed Sci. 51:6, 987-994. DOI:10.1614/P2002-169.

Reinhardt, D., and C. Kuhlemeier. 2002. Plant architecture. EMBO reports, 3:9, 846–851. https://doi.org/10.1093/embo-reports/kvf177.

Repullo-Ruibérriz de Torres, M.A., R. Ordóñez-Fernández, M. Moreno-García, J. Márquez-García, and R.M. Carbonell-Bojollo. 2018. Carbon sequestration by grass, crucifer and legume groundcovers in olive orchards. J. Water Clim. Change. 4:748–763. DOI: 10.2166/wcc.2018.371.

Rhino, B., M. Dorel, P. Tixier, and J.M. Risède. 2010. Effect of fallows on population dynamics of Cosmopolites sordidus: toward integrated management of banana fields with pheromone mass trapping. Agric. and For. Entomol. 12:195-202. https://doi.org/10.1111/j.1461-9563.2009.00468.x.

Roka, F.M., R.E. Rouse, and E. Miavitz-Brown. 2003. Economic considerations from using perennial peanut in urban landscapes. In Proceedings of the Florida State Horticultural Society. 116, 339-341.

Rosario-Lebron, A., A.W. Leslie, V.L. Yurchak, G. Chen, and C.R.R. Hooks. 2019. Can winter cover crop termination practices impact weed suppression, soil moisture, and yield in no-till soybean [Glycine max (L.) Merr.]?, Crop Prot. 116, 132-141. ISSN 0261-blok2194. https://doi.org/10.1016/j.cropro.2018.10.020.

Rose, S., and N.E. Peters. 2001. Effects of urbanization on streamflow in the Atlanta area (Georgia, USA): a comparative hydrological approach. Hydrol. Process. 15:1441-1457. https://doi.org/10.1002/hyp.218.

Rowe, D.B. M.R. Kolp, S.E. Greer, and K.L. Getter. 2014. Comparison of irrigation efficiency and plant health of overhead, drip, and sub-irrigation for extensive green roofs. Ecol. Eng. 64:306-313. ISSN 0925-8574. https://doi.org/10.1016/j.ecoleng.2013.12.052.

Saksa, K. A., T. W. Ilvento, and S.S. Barton. 2012. Interpretation of sustainable landscapes affects student perception of sustainable landscape features. Hort. Tech. 22:3, 402-409.

Sándor, R., and N. Fodor. 2012. Simulation of soil temperature dynamics with models using different concepts. Sci. World J. 2012.

Sansoulet, J., Y.M. Cabidoche, P. Cattan, S. Ruy, and J. Šimůnek. 2008. Spatially distributed water fluxes in an andisol under banana plants: experiments and three-dimensional modeling. Vadose Zone J. 7, 819-829. https://doi.org/10.2136/vzj2007.0073.

Sapkota, A., Haghverdi, A., Merhaut, D., Singh, A., and Iradukunda, J. C. 2023. Response of landscape groundcovers to deficit irrigation: an assessment based on normalized difference vegetation index and visual quality rating, Hort. Sci. 58:3, 274-285

Sasse, J., E. Martinoia, and T. Northern. 2018. Feed your friends: do plant exudates shape the root microbiome? Trends Plant Sci. 23:1, 25-41. ISSN 1360-1385. https://doi.org/10.1016/j.tplants.2017.09.003.

Shober, A. L., G.C. Denny, and T.K. Broschat. 2010. Management of fertilizers and water for ornamental plants in urban landscapes: current practices and impacts on water resources in Florida. Hort. Tech. 20:1, 94-106.

Shober, A.L., and R.S. Mylavarapu. 2009. Soil sampling and testing for the home landscape or vegetable garden. SL 281/SS494, 3/2009. EDIS 2009.2.

Shuster, W., J. Bonta, H. Thurston, E. Warnemuende, and D. Smith. 2005. Impacts of impervious surface on watershed hydrology: a review. Urban Water Journal - Urban Water. 2:263-275. DOI: 10.1080/15730620500386529.

Si, C.C., ZC., Dai, Y. Lin, S.S. Qi, P. Huang, S.L. Miao, and D.L. Du. 2014. Local adaptation and phenotypic plasticity both occurred in Wedelia trilobata invasion across a tropical island. Biol. Invasions. 16:2323–2337. https://doi.org/10.1007/s10530-014-0667-4.

Sladek, B. S., G.M. Henry, and D.L. Auld. 2009. Evaluation of zoysiagrass genotypes for shade tolerance. Hort. Sci. 44:5, 1447-1451.

Sofo, A., A. Ciarfaglia, A. Scopa, I. Camele, M. Curci, C. Crecchio, C. Xiloyannis, and A.M. Palese. 2014. Soil microbial diversity and activity in a Mediterranean olive orchard using sustainable agricultural practices. Soil Use Manage. 30, 160-167. https://doi.org/10.1111/sum.12097.

Song, Y.T., D.W., Zhou, and H.X. Zhang, 2013. Effects of vegetation height and density on soil temperature variations. Chin. Sci. Bull. 58:907-912, DOI: 10.1007/s11434-012-5596-y.

Staats, D., and J.E. Klett, 1995. Water conservation potential and quality of non-turf groundcovers versus Kentucky bluegrass under increasing levels of drought stress. . 13:4, 181–185. https://doi.org/10.24266/0738-2898-13.4.181.

Stafne, R.A., A.E. Einert, and G.L. Klingaman. 2005. Fertilizer applications on establishment and growth of three groundcover species in sun and shade. J. Environ. Hortic. 23:3, 157–161. https://doi-org.libezp.lib.lsu.edu/10.24266/0738-2898-23.3.157

Steinberg, T. 2005. Lawn and landscape in world context, 1945-2000. OAH Magaz. Hist. 19, 62-68. DOI:10.1093/maghis/19.6.62.

Stewart, C. J., C.S. Marble, B.J. Pearson, and P.C. Wilson, P. C. 2017. Impact of container nursery production practices on weed growth and herbicide performance. Hort. Sci. 52:11, 1593-1600.

Stewart, C.D., S.K. Braman, B.L. Sparks, J.L. Williams-Woodward, G.L. Wade, and J.G. Latimer. 2002. Comparing an IPM pilot program to a traditional cover spray program in

commercial landscapes. J. Econ. Entomol. 95:4, 789–796. https://doi.org/10.1603/0022-0493-95.4.789.

Stocker, T.F., D. Qin, G.-K. Plattner, M. Tignor, S.K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex and P.M. Midgley eds. IPCC, 2013: Climate Change 2013: The physical science basis. contribution of working group I to the fifth assessment report of the intergovernmental panel on climate change. Cambridge University Press. 1535 pp.

Strock J.S., P.M Porter, and M.P Russelle. 2004. Cover cropping to reduce nitrate loss through subsurface drainage in the northern U.S. corn belt. J. Environ. Qual. 33.3, 1010-1016. DOI: 10.2134/jeq2004.1010.

Suleiman, M. K., N. R. Bhat, S. Jacob, R. R. Thomas, and G. D'Cruz. 2011. Performance of selected native plants under deficit irrigation. World J. Agric. Sci. 7:1, 19-25.

Sun, S., W. Xiang, S. Ouyang, Y. Hu, Z. Zhao, X. Xu, K. Yue, L. Chen, Y. Zeng, P. Lei, X. Deng, J. Wang, and K. Wang, 2022. Higher canopy interception capacity of forests restored to the climax stage in subtropical China. Hydrol. Processes, 36:3. https://doi-org.libezp.lib.lsu.edu/10.1002/hyp.14538.

Teasdale, J.R., L.O Brandsaeter, A. Calegari, and F. S. Neto. 2007. Cover crops and weed management. Non-Chemical Weed Management: Principles, Concepts and Technology.

Trenholm, L. E., and J.B Sartain. 2010. Turf nutrient leaching and best management practices in Florida. Hort. Tech. 20:1, 107-110.

Turner, D.P., and M.E. Sumner. 1978. The influence of initial soil moisture content on field measured infiltration rates. Water SA, 4:1, 18-24.

U.S. Census Bureau. 2022a. 2020 Census Urban Areas Facts. Retrieved from [https://www.census.gov/programs-surveys/geography/guidance/geo-areas/urban-rural/2020-ua-facts.html].

U.S. Census Bureau. 2022b. Nation's Urban and Rural Populations Shift Following 2020 Census. Retrieved from [https://www.census.gov/newsroom/press-releases/2022/urban-rural-populations.html].

Udawatta, R.P., H.E Garrett, and R. Kallenbach. 2011. Agroforestry buffers for nonpoint source pollution reductions from agricultural watersheds. J. Environ. Qual. 40:800-806. https://doi.org/10.2134/jeq2010.0168.

Van Huyssteen, L., J.L., Van Zyland, and A. P. Koen, 2017. The effect of cover crop management on soil conditions and weed control in a Colombar vineyard in Oudtshoorn. S. Afri. J. Enolog. Viticul. 5:1. https://doi.org/10.21548/5-1-2364.

Verma J.K., A. Sharma, and P. K.K. 2015. To evaluate the values of electrical conductivity and growth parameters of apple saplings in nursery fields. Int. J. Appl. Sci. Eng. Res. 4:3, 321-332.

Vukicevich, E., T. Lowery, P. Bowen, J. Ramon Urbez and M. Hart. 2016. Cover crops to increase soil microbial diversity and mitigate decline in perennial agriculture. A review. Agron. Sustain. Dev. 36, 48. https://doi.org/10.1007/s13593-016-0385-7.

Walsh C.J., T.D. Fletcher, and M.J. Burns. 2012. Urban stormwater runoff: a new class of environmental flow problem. PLOS ONE 7:, e45814. DOI: 10.1371/journal.pone.0045814.

Warner, L. A., A. D. Ali, and A.K. Chaudhary. 2017. Perceived landscape benefits influence engagement in urban landscape irrigation and fertilizer best practices. Hort. Tech. 27:3, 424-430.

Wesson, G., and P.F. Wareing. 1969. The induction of light sensitivity in weed seeds by burial. J. Exp. Bot. 20:63, 414–425. http://www.jstor.org/stable/23688401.

Weston, L.A., and S.H. Eom. 2008. Utilization of stress tolerant, weed suppressive groundcovers for low maintenance landscape settings. In: Zeng, R.S., Mallik, A.U., Luo, S.M. (eds) Allelopathy in Sustain. Agric. For. https://doi.org/10.1007/978-0-387-77337-7_18.

Wheeler, M.M., C. Neill, P.M. Groffman, M. Avolio, N. Bettez, J. Cavender-Bares, R.R Chowdhury, L. Darling, J.M. Grove, S.J. Hall, J.B. Heffernan, S.E. Hobbie, K.L. Larson, J.L. Morse, K.C. Nelson, L.A. Ogden, J. O'Neil-Dunne, D.E. Pataki, C. Polsky, M. Steele, and T.L.E. Trammell. 2017. Continental-scale homogenization of residential lawn plant communities. Landscape and Urban Planning. 165, 54-63. ISSN 0169-2046. https://doi.org/10.1016/j.landurbplan.2017.05.004.

Wilhelm, W. W., J.M.F Johnson, J.L. Hatfield, W.B. Voorhees, and D.R. Linden. 2004. Crop and soil productivity response to corn residue removal: a literature review. Publications from USDAARS / UNL Faculty. 1343. https://digitalcommons.unl.edu/usdaarsfacpub/1343.

Wollaeger, H. M., K.L. Getter, and B.K. Behe. 2015. Consumer preferences for traditional, neonicotinoid-free, bee-friendly, or biological control pest management practices on floriculture crops. Hort. Sci. 50:5, 721-732.

Workayehu, T., W. Mazengia, and L. Hidoto, 2011. Growth habit, plant density and weed control on weed and root yield of sweet potato (Ipomoea batatas L.) Areka, Southern Ethiopia. J. Hortic. For. 3.

World Commission on Environment and Development 1987. Our common future: Report of the World Commission on Environment and Development. <http://www.un-documents.net/our-common-future.pdf>

Wu, J., C. S. Tang, B. Shi, L. Gao, H.T. Jiang, and J. Daniels, 2014. Effect of ground covers on soil temperature in urban and rural areas. Environ. Engineer. Geosci. 20:225-237. DOI: 10.2113/gseegeosci.20.3.225.

Xi, N., Y. Wu, J. Weiner, and D.Y. Zhang. 2022. Does weed suppression by high crop density depend on crop spatial pattern and soil water availability? Basic and Appl. Ecol. 61, 20-29. ISSN 1439-1791. https://doi.org/10.1016/j.baae.2022.03.001.

Yang, F., M. Ignatieva, A. Larsson, S. Zhang, and N. Ni. 2019. Public perceptions and preferences regarding lawns and their alternatives in China: A case study of Xi'an. Urban For. & Urban Greening. 46:12647. ISSN 1618-8667.https://doi.org/10.1016/j.ufug.2019.126478.

Yang, X.M., W.D. Reynolds, C.F. Drury, and M.D. Reeb. 2021. Cover crop effects on soil temperature in a clay loam soil in southwestern Ontario. C. J. Soil Sci. 101:4, 761-770. https://doi.org/10.1139/cjss-2021-0070.

Yeganehpoora F., S.Z. Salmasi, G. Abedi, F. Samadiyanc, and V. Beyginiyad. 2015. Effects of cover crops and weed management on corn yield. J. Saudi Soc. of Agric. Sci. 14:2, 178-181. ISSN 1658-077X. https://doi.org/10.1016/j.jssas.2014.02.001.

Yue, C., M. Cui, E. Watkins, and A. Patton. 2021. Investigating factors influencing consumer adoption of low input turfgrasses, Hort. Sci. 56:10, 1213-1220.

Yunusa, I., S., M. Zolfaghar, Z. Zeppel, L.A. Palmer, and D. Eamus, 2012. Fine root biomass and its relationship to evapotranspiration in woody and grassy vegetation covers ecological restoration of waste storage and mining landscapes. Ecosyst. 15:113-127. DOI: 10.1007/s10021-011-9496-9.

Zhang, M., Y., Li, J., Liu, J., Wang, Z., Zhang, and N. Xiao, 2022. Changes of soil water and heat transport and yield of tomato (Solanum lycopersicum) in greenhouses with micro-sprinkler irrigation under plastic film. Agron. 12:664. https://doi.org/10.3390/agronomy12030664.

Zogg, G.P., Zak, D.R., Ringelberg, D.B., White, D.C., MacDonald, N.W. and Pregitzer, K.S. 1997. Compositional and Functional Shifts in Microbial Communities Due to Soil Warming. Soil Sci. Soc. Amer. J. 61: 475-481. https://doi.org/10.2136/sssaj1997.03615995006100020015x.

VITA

Thomas M. McKeown, better known as Max, was born in Pine Bluff, Arkansas, and raised in the small rural community of Rock Springs. Max grew up exploring the natural areas surrounding his home, helping in the family vegetable garden, and planting flowers everywhere he went. This led him to attend the University of Arkansas in Fayetteville to study horticultural science to further cultivate his love of all things' plants. After an extremely successful undergraduate career, he furthered his education with a Master's degree in horticulture at Louisiana State University under the direction of Dr. Jeb S. Fields, while working at the Hammond Research Station. Max anticipates graduating in May 2023, after which he plans to pursue a career in public gardens.