How Can The Greenhouse Industry Benefit From Changing The Materials Used For Making Growing Containers?

Jessica C. Weller

(Johnny's Selected seeds, n.d.)

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"A beautiful plant is like having a friend around the house" – Beth Ditto


(Weller J., 2023. J Weller)

Previous Course Experience:

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Professor Stevie Famulari
Senior capstone.

Autumn 2023, Landscape History 1900, Hort 3050
Professor Stevie Famulari
History of past landscapes and how they came to be.

Autumn 2023, Urban Landscape I: Forestry, Hort 3040
Professor David Gamstetter
Horticulture in the legal system and pruning techniques.

Autumn 2023, Horticultural Entomology, Hort 3020
Professor Gene Kritsky
Insect Identification.

Autumn 2023, Urban Landscape II: Agriculture, Hort 3042
Professor Brian Grubb
What it takes to tend and care for a community garden.

Summer 2023, Herbaceous Ornamentals III, Hort 2033
Professor James Hansel
Plant identification of herbaceous plants.

Summer 2023, Urban Landscapes V: Interiors, Hort 3045
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Designing indoor rooms with plants.

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Autumn 2022, Woody Ornamentals I, Hort 2030
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Autumn 2022, Permaculture I, DAAP 5061/DAAP 6061
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Autumn 2022, Plant Pathology and Microbiology, Hort 2020
Professor James Hansel, and Dr. Dan Petersen
Identifying pests and diseases on plants.

Autumn 2022, Sustainable Landscape Design I, Hort 2040
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Chapter 1
Introduction and Case Studies

Abstract

The overuse of plastic containers in greenhouse and nursery production surpasses the amount being recycled. A solution to this issue involves a shift in the materials used for making containers. Specifically, containers employed for plant growth are single-use due to the higher costs associated with reusing them in production. Due to chemicals used during the growing process recycling containers is challenging. Transitioning to eco-friendly alternatives holds the promise of positively impacting the environment and curbing plastic waste generated in growing containerized plants. This research delves into the types of plastics currently utilized, their purposes, and the recycling processes involved. This is compared to new eco-friendly container options, analyzing their advantages and disadvantages. The significance of this study is exploring potential materials for manufacturing containers in greenhouse and nursery production. The result of this paper finds alternatives to plastic, fostering sustainability and reducing reliance on plastic for containers, thereby contributing to a more sustainable industry.

Keywords: Horticulture, Container Growing, Eco-friendly, Bio-degradable pots, Plastic waste, Bio-containers, Recycling horticultural plastics, plastic containers

Project Statement

How can the greenhouse industry benefit from changing the materials used for making planting containers?

Project Justification

Plastic pollution is a global crisis affecting ecosystems, wildlife, and human health. I have observed that the containers commonly used in greenhouse and nursery production are often disposed of after a single use due to the higher costs associated with reusing them in production. Transitioning to eco-friendly alternatives, such as biodegradable materials, this project can help change the environmental damage caused by plastic. While there are initial costs associated with transitioning to more sustainable alternatives, the long-term benefits may outweigh these expenses. For example, investing in biodegradable pots may be more expensive up front, but if enough companies invest in them the prices will go down as more competition starts to create them.

Also, as awareness of environmental issues grows, consumers are increasingly demanding sustainable products. By aligning this project with consumer preferences for eco-friendly options, it can connect with the values of a market that wants sustainability and attract environmentally conscious consumers. Embracing sustainability initiatives also reflects positively on companies' reputations and enhances their corporate social responsibility profile. Leading the transition to eco-friendly practices, this project can position companies as responsible stewards of the environment and improve their brand image. Sustainable practices are essential for the long-term viability of industries. Reducing reliance on finite resources like plastic and embracing renewable materials, this project can contribute to the industry's resilience and longevity in the face of evolving environmental challenges.

Project Goals

Theoretical

To develop a system that reduces the amount of single use annual plastic containers used in the greenhouse industry.

Physical

To examine plant growth and watering requirements of tomato and basil seeds in plastic and bio-containers.

Social

To encourage the consumer market and greenhouse industry to adopt growing containers made from eco-friendly materials.

Project solution

Theoretical

Through researching the physical properties of bio-containers and their compatibility in commercial greenhouse production.

Physical

Performing an experiment that tests 3 different types of bio-containers and taking note of how the seeds germinate and grow compared to ones grown in plastic containers.

Social

Through research of the different kinds of materials, their sizes, costs, and the physical properties needed to be compatible with commercial use and appeal to consumers.

Major project elements

Containers

The focus for this project is looking into different types of materials that can be used for making bio-containers.

Storing

It is important to know how to store the bio-containers properly to extend their longevity.

Consumer appeal

For bio-containers to become more common in greenhouse production consumers need to like them for them to sell and make a profit.

Recycling

Where does recycling take place and how long is the process?

Project Requirements

Containers

Investigating different materials for bio-containers to be used in greenhouse production to reduce the overuse of single-use plastic containers and lessen plastic waste in the environment. Materials such as fiber-based, paper-based, or a blend of materials can be used to create durable containers that can withstand greenhouse production and decompose after the plant has been sold. These containers will be compostable instead of plantable to achieve the required durability.

Storing

One challenge greenhouses face is determining where to store the containers they have purchased. While plastic containers can be stored almost anywhere, they will degrade if exposed to the elements such as sun or rain for an extended period. Bio-containers, on the other hand, need to be stored in a secure location away from the elements to preserve their durability and quality.

Consumer appeal

Consumers play a crucial role in driving markets and determining the success of a product. It is important to investigate consumer preferences to understand which materials used for bio-containers will be most appealing to consumers and have a positive impact on sales.

Recycling

Greenhouses currently use a large quantity of single-use plastic containers for annual plants. Some customers return these containers to be recycled by the retailers after the plants are sold. It is important to investigate the recycling process for plastic containers, including the duration and methods used for recycling, to assess the practicality of continuing their use. Another crucial aspect to consider is the impact of chemicals used during the growing process on the recyclability of these plastic containers.

User client description

Greenhouse growers

Greenhouse growers can benefit from this project by evaluating the advantages and disadvantages of purchasing decomposable containers. By weighing these factors, they can make informed decisions about whether to transition to eco-friendly alternatives. If they opt to make the change, they will contribute to environmental preservation by replacing plastic single-use annual containers with ones that can decompose naturally. This shift towards sustainability not only benefits the environment but also aligns with growing consumer demand for eco-friendly products.

Nursery owners

Depending on the material, nurseries could utilize decomposable containers, especially when planting herbaceous perennials. However, there are considerations to be made regarding the extended time nurseries hold onto their plants. While using decomposable containers might pose challenges with woodie shrubs due to their longer cultivation periods, it remains feasible for herbaceous perennials. Perennials typically have shorter cultivation cycles, often being ready for sale within two years, depending on the plant species and variety. Therefore, adopting decomposable containers for perennials can be a viable option for nurseries seeking to reduce their environmental impact while accommodating their specific cultivation timelines.

Landscape Workers

By encountering decomposable containers during plant purchases, landscape workers will gain firsthand exposure to sustainable alternatives. Introducing landscape companies to different types of decomposable containers will expand their knowledge about available options. They will learn about various materials used and their respective benefits for the environment. This paper can provide information on the proper way to deal with decomposable containers, ensuring their effectiveness. Clear instructions on handling will facilitate the adoption of sustainable practices. As landscape companies adopt sustainable practices, they can also influence their clients.

Customers

Customers also indirectly encounter decomposable containers when purchasing plants from retailers or nurseries. This exposure may lead customers to become more environmentally conscious and inclined to request eco-friendly solutions. As a result, there is potential for a ripple effect of positive change within the industry, with increased demand for sustainable options driving adoption and innovation in the use of decomposable containers.

Site Information- Inventory and Analysis

1. Size of containers in greenhouses.
   Container sizes vary from 3 inches to 2 gallons in some greenhouses and in nurseries they use larger containers ranging from 1 gallon to 30+ gallon containers.

Pot Sizes (inches)	Pot Equivalent (U.S. Gallons) *	Suitable Plants	Soil Needed (cu. Ft.) and Weight (lbs.) *
4” pot	0.125 gallon	Nursery plants / Seedlings	0.01 ft3 / 0.137 lbs.
5-6” pot	0.25 gallon	Small succulents / 1 annual	0.03 ft3 / 0.27 lbs.
7-8” pot	1 gallon	Larger succulents / 2 annuals	0.13 ft3 / 1.1 lbs.
10” pot	3 gallons	Small herbs, such as chives / up to 3 annuals	0.40 ft3 / 3.3 lbs.
12” pot	5 gallons	Lettuce / spinach / strawberries	0.66 ft3 / 5.5 lbs.
14” pot	7 gallons	Larger herbs such as rosemary	0.94 ft3 / 7.7 lbs.
16” pot	10 gallons	Small shrubs / small fruit such as raspberry	1.33 ft3 / 11lbs
18” pot	15 gallons	Vegetables such as tomato plants / mix of annuals	2.00 ft3 / 16.5 lbs.
24” pot	25 gallons	Evergreen shrubs / dwarf trees	3.34 ft3 / 27.5 lbs.
30” pot	30 gallons	Larger plants: Orchard fruit trees such as apple	4.01 ft3 / 30 lbs.

***All figures are estimates and exact specifications largely depend on the manufacture**

(Jay Scotts Collection, 2021)

2. Materials used for making bio-containers.
   The material used for the containers can affect both the rate of decomposition and their durability during production.
3. Different plastics used.
   Various types of plastics possess distinct properties, influencing how containers are utilized. The specific plastic employed dictates the container's intended use and functionality.
4. Storage areas.
   When storing containers, it is crucial to place them in locations where their quality will not degrade. Ideally these spaces should be fully protected from the elements or partially shielded from major environmental factors that could accelerate product degradation.

Experiment inventory and analysis

(Weller J. February 20, 2024. Experiment set up)

1. 1- 1 cubic foot bag Berns Potting Soil
   The Berns potting soil is used for its consistency and quality of materials used in its formulation.
2. GooingTop LED Grow Light
   6000K Full Spectrum Clip Plant Growing Lamp with White and Red LEDs.
3. 8- EcoGrown Standard Round Pot, size 5 inches
   Will be used as a test for different materials. Made from recycled newspaper and a plant-based binding agent.
4. 8- 3" biodegradable Seed Starting JIFFY-POT
   Will be used as a test for different materials. Made from harvested peat.
5. 8- Jiffy Seed Starting Expanding Peat Pellets
   Will be used as a test for different materials. Made from peat with netting derived from cornstarch.
6. 3" plastic pots
   Will be used as a constant in the experiment to replicate what is currently being used.
7. 2- pot holding trays
   The trays hold the containers in place to keep things organized.
8. 1- small watertight tray
   This tray holds the peat pellets.
9. Tomato, Roma VF seeds, *Solanum lycopersicum* 'Roma'
   Seeds that I planned to grow this year.
10. Basil, Everleaf Emerald Towers seeds Ocimum *basilicum* 'Everleaf Emerald Towers'
    Seeds that I planned to grow this year.
11. Plant tags
    These keep track of what is planted in each row.

(Weller J. 2024. Containers used in experiment. (Left to right: 5" EcoGrow Standard Round Pot, 3" Biodegradable Seed Starting JIFFY -POT, 3" plastic pot, Jiffy Seed Starting Expanding Peat Pellet))

Experiment summary

This experiment tests germination rate, water holding longevity, and durability between plastic and biodegradable containers. Starting off with planting everything on the same day and using a uniform soil mix to ensure consistency. The seeds used are tomato and basil which have around a week for germinating. The variable under observation will be the type of container utilized. Through observation and data collection, this experiment aims to evaluate how different containers withstand watering regimens and whether plants benefit from growing within specific container materials.

Summary

The greenhouse and nursery industry uses an abundance of plastic pots, ranging in size from quarts to 25+ gallons. These various sizes often correspond to different plastics based on specific requirements. To explore alternative materials for container production, it is essential that they are compatible across size variations, resilient throughout the entire growing process, and capable of decomposing after the plant is purchased. Additionally, an evaluation of container storage methods is needed to ensure their durability is maintained over extended periods when not in use. Finally, the cost of adopting bio-containers plays a significant role in influencing whether companies are willing to transition away from traditional plastic materials.

GOLF BALLS THAT ARE SAFER FOR THE ENVIRONMENT

Biodegradable golf balls are a thing. Pela Case. (2020), Biodegradable Golf Canada Inc. (2022), Causeartist. (2023), Dekate, N., Navarrette, D., & Gardon, R., Golf balls as pollution. Oregon Courses, Jarzecki, K., Zhao, B., Nakamura, K., & Wu, P. (2018)

Introduction

Golf is a widely enjoyed sport, whether on an expansive 18-hole course or a casual game of putt-putt. However, the golf ball, a common denominator in both forms of the game, poses an environmental challenge. Playing golf near water can be challenging because of the placement of a course making it a hazard to avoid, unexpected events such as wind, or the grade of the land can cause the ball to go unwanted destinations. Due to intentional or unexpected events bodies of water often claim these golf balls, making retrieval difficult and contributing to a significant accumulation of non-biodegradable waste in the environment. The materials used in traditional golf balls exacerbate this issue, prompting some companies to explore the development of biodegradable alternatives. Eco-friendly golf balls aim to mitigate environmental harm by utilizing sustainable materials and reducing the time a ball lingers in the environment. This case study delves into the environmental problem posed by conventional golf balls, examines the innovative solutions currently being developed, and explores the materials and life cycle of these new, eco-conscious golf balls.

The Problem With Golf Balls

Golf balls used in the sport are crafted from a diverse range of materials, including rubbers, resins, plastics, and metals, among others. Typically, these balls consist of a core and an outer layer or cover, with the option of adding additional layers to modify performance aspects such as spin and distance travel (Golf balls as pollution, n.d.). However, a significant issue arises with golf balls when they are lost or end up in bodies of water, making retrieval challenging. This poses a substantial environmental problem as golf balls, composed of materials that do not readily decompose, can persist for many decades or even centuries, contributing to pollution in the surrounding areas (Causeartist, 2023). Even during the decomposition process, these balls release toxic materials into the environment, further exacerbating the harm caused over an extended period.

Biodegradable Golf Balls

There are several companies venturing into the production of golf balls designed to disintegrate upon contact with water. One North American company, Biodegradable Golf Balls, manufactures its product from compressed cornstarch with a polyvinyl alcohol (PVA) coating, offering an 80% performance rate. These balls are specifically tailored for players near bodies of water and are not intended for professional green use (Biodegradable Golf Canada Inc., 2020).

(Causeartist, 2023)

The University of Maine takes a unique approach by repurposing lobster shells to create golf balls that disintegrate within a week of submersion in water. Not only do these balls break down rapidly, but they also release calcium and nutrients, contributing to environmental benefits.

(Dekate, N., Navarrette, D., & Gardon, R., n.d.)

Another innovative company addressing both environmental concerns and wildlife welfare is AlbusGolf Eco-Balls. Their golf balls transform into fish food upon entering the water, thanks to their dissolvable exterior and a center filled with fish food. These golf balls are designed to disintegrate in approximately 48 hours or less (Biodegradable Golf Balls Are a Thing, 2022).

Manufacturing and Life Cycle

Biodegradable golf balls can be crafted from a variety of materials, including biopolymers, natural rubber, and other organic substances carefully chosen to strike a balance between durability, performance, and biodegradability (Causeartist, 2023). Ensuring these golf balls meet high-quality and performance standards is crucial, as golfers are more likely to embrace these environmentally friendly options, particularly when playing near water.

The decomposition process begins when the balls are exposed to natural elements such as water, heat, and microseisms. The speed of decomposition depends on these factors, influencing how quickly the balls break down. The ultimate goal is to create golf balls that disintegrate within a few months to a few years, aligning with sustainability objectives (Causeartist, 2023).

Conclusion

In conclusion, golf is not exempt from environmental challenges, notably the impact of non-biodegradable golf balls on ecosystems. As explored in this short case study, the issue of lost golf balls, particularly in bodies of water, has led to a concerning accumulation of pollution. Recognizing the ecological implications, various companies are investigating the development of biodegradable golf balls. These eco-friendly alternatives, crafted from materials such as biopolymers, natural rubber, and other organic substances, signify a promising shift toward sustainability in the sport. Companies like Biodegradable Golf Balls, the University of Maine, and AlbusGolf Eco-Balls, each contribute to a greener future. By shortening the lifespan of golf balls in the environment and incorporating environmentally friendly materials, these biodegradable options aim to strike a balance between the enjoyment of the sport and its ecological footprint.

How It Relates

The relevance of biodegradable golf balls to my paper is the exploration of various materials for product development, specifically aiming to enhance environmental sustainability. Examining the efforts of others in designing these eco-friendly golf balls provides a foundational understanding of strategies that can be applied to create decomposable containers. This investigation not only discusses the environmental benefits during the decomposition process but also addresses an often-overlooked issue of pollution associated with the sport. Many of these products contribute positively to the environment as they break down, making it a good area of study for sustainable design ideas

(Causeartist, 2023)

Case Study on “Evaluating Biodegradable containers as Alternatives to Plastic Pots”
by Renee L. Conneway

Introduction

This comprehensive report goes into various aspects of horticulture, including insect and weed control, fertilizers, and irrigation. However, its primary focus lies in examining biodegradable containers as viable alternatives to traditional plastic pots. The report meticulously evaluates the potential use, performance, and durability of the containers across different settings, ranging from greenhouse production to landscape applications. In their experiments, key factors such as plant growth rates, substrate composition, and watering frequencies are examined. Additionally, he looked at algal growth and container strength within greenhouse environments. Furthermore, the report investigates the performance of both plants and containers in landscape settings, providing valuable insights into the practical implications of adopting biodegradable alternatives. By examining plant growth, substrate interactions, and container durability, this report offers a comprehensive analysis of the feasibility and effectiveness of bio-pots. Such insights not only inform horticultural practices but also contribute to the broader conversation on sustainable solutions within the industry.

The horticultural industry

Numerous factors contribute to assessing the industry's sustainability efforts, including insect control, fertilizer use, water conservation, potting mix composition, container materials, plant selection, and recycling practices. Each of these elements is explored in depth, providing insights into the industry's progress towards a more environmentally conscious future. Conneway lays the foundation for understanding the industry's evolution by delving into its history. He begins by tracing its origins and highlights significant milestones such as the construction of the first glass greenhouse. Throughout the narrative, he discusses historical events that impeded the industry's growth and examines the pivotal role played by nurseries and organizations in driving forward progress and instigating major changes. Furthermore, Conneway dedicates sections to critical aspects such as insect control,

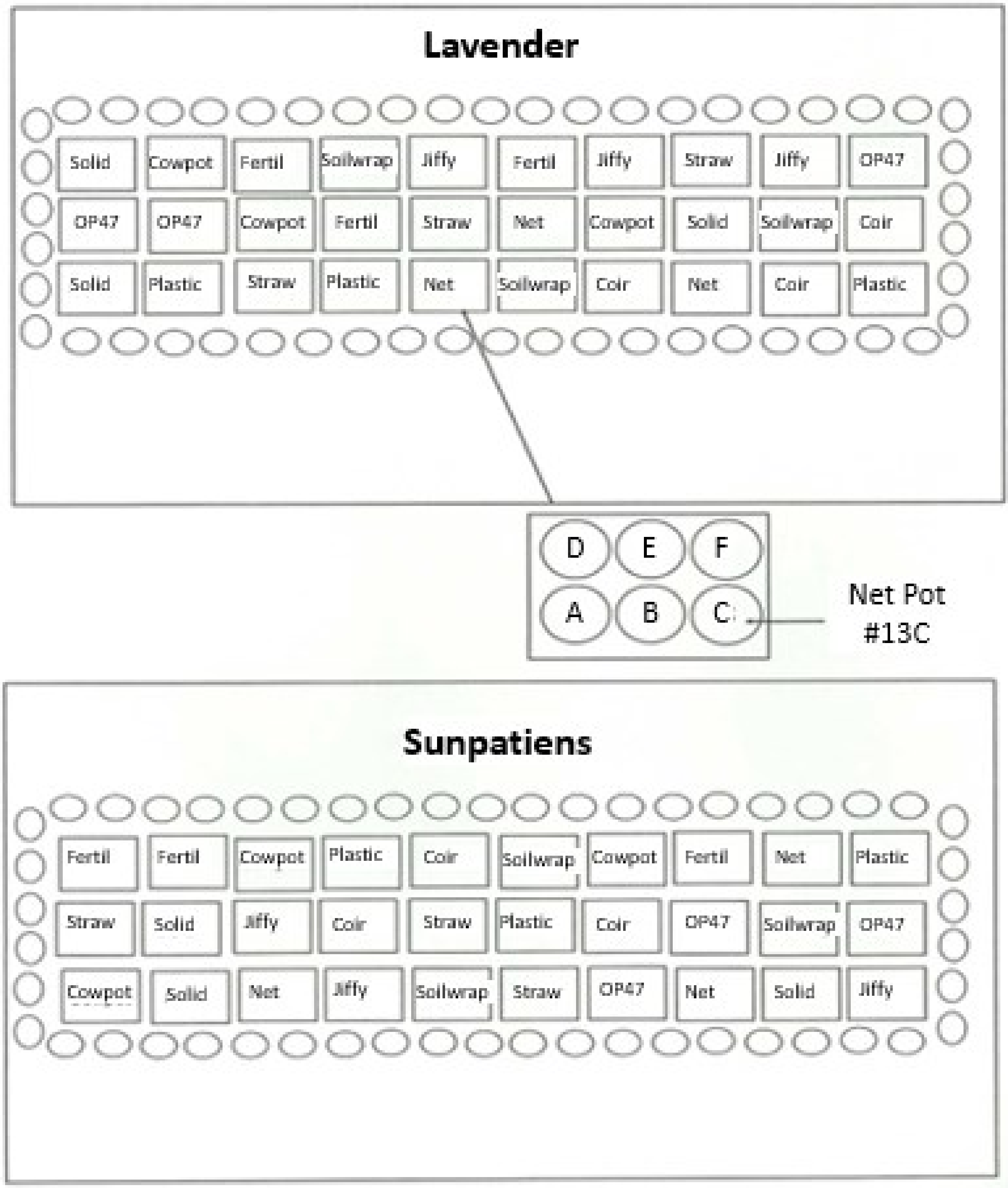
Figure 2.3. Photographs depicting visual ratings of *Lavendula angustifolia ‘Elgans Ice’* in 2011. Figure left to right, “1”, “3”, and “5”.

(Conneway, 2013)

fertilization, and irrigation, noting their impact on the horticultural industry. The concluding sections of the first chapter delve into container materials and the trend of bio-containers, underscoring the industry's continuous adaptation to more sustainable practices.

When discussing containers in the industry, Conneway initially reflects on significant shifts, noting that while plants were traditionally grown in the ground and balled-and-burlapped for transportation, this method has become less common due to labor intensity and health concerns for workers. He proceeds to explore the array of container types predating the advent of plastic containers. Transitioning to plastic containers, Conneway

Figure 2.2. Experimental design of the greenhouse experiment



(Conneway, 2013)

highlights two primary drawbacks: limited root penetration leading to circling roots and concerns regarding disposal. Addressing these challenges, he proposes two solutions. Firstly, he talks about the reuse of plastic containers, promoting sustainability through extended product lifespan. Secondly, he suggests recycling plastic containers to repurpose collected materials, thereby minimizing environmental impact, and promoting circularity in the industry's supply chain.

Different types of bio-pots are used.

Conneway starts this section by listing various materials utilized for manufacturing bio-containers, then goes into detailed explanations of their sourcing origins. He then highlights specific companies engaged in bio-pot production and points out their differences as these products resemble one another. Following the exploration of material types, Conneway shifts focus to customer perceptions of bio-containers, noting the disconnection between consumer willingness to purchase plants in bio-pots and producers' reluctance to adopt them. He poses the question, "If consumers are willing to buy plants in bio-pots, then why are producers not willing to use them?" (Conneway, 2013), and proceeds to offer insights into potential reasons for this discrepancy, drawing on supporting studies. Additionally, Conneway addresses the challenges associated with utilizing bio-containers, before outlining his intended trajectory for the paper's subsequent sections.

Evaluating the containers

In the experiment conducted to assess potential material use, nine different materials were employed: coir, manure, wood fiber, peat, slot rice hull, PLA bioplastic, PHA bioplastic, solid rice hull, and straw. Plastic was also

Table 3.1. The pot treatments used in this experiment, including product name, container component, and manufacturer information.

Product Name	Container Component	Manufacturer
Dillen 04.00 Standard Thinwall Green (plastic)	Injection molded Plastic	Myers Industries Lawn & Garden Group, Middlefield, OH
Coir 4.0" Std Fiber Gro Pot (Coir)	Pressed coconut fiber	Dillen Products, Middlefield, OH
#4 Square CowPot (Manure)	Composted Manure Fiber	CowPots Manufacturing and Sales, East Canaan, CT
10 X 10 cm Round Individual Fertilpot (Wood Fiber)	Steam-Pressed Spruce Wood Fiber	Fertil SAS, Boulogne Billancourt, France
4" Jiffy Pot (Peat)	Peat and Recycled Paper	Jiffy Products of America Inc., Lorain, OH
4.5" NetPot (Slotted Rice Hull)	Slotted Rice Hull	Summit Plastic Company, Akron, OH
4.5" Standard Assembled SoilWrap® (PHA bioplastic)	PHA (polyhydroxyalkanoate) Bioplastic Sleeve	Ball Horticultural Company, West Chicago, IL
n/a (Straw)	80:20 Rice Straw:Coconut Fiber with Latex Binder	Ivy Acres, Baiting Hollow, NY

(Conneway, 2013)

included as a constant reference point throughout the experiment. The chosen plants for the experiment were *Impatiens spp.* 'Sunpatiens Compact' and *Lavandula angustifolia* 'Elegans Ice'. The experiment spanned six and twelve weeks in a greenhouse setting, during which observations were made regarding the growth of the plants in each container type. Despite minimal disparities in plant growth, notable differences were observed in irrigation requirements, as well as significant variations in algal growth and pot strength among the different containers.

When assessing the performance of containers in a landscape setting, Conneway used seven plantable bio-pots to evaluate the growth of annuals over a fifteen-week growing season. His plant selection comprised *Lantana camara* 'Luscious Citrus', *Cleome hassleriana* 'Senorita Rosalita', and *Impatiens spp.* 'Sunpatiens Compact'. In addition to monitoring plant growth, the experiment also documented the decomposition of the pots upon conclusion. Conneway noted minimal differences in plant growth and visual quality at the end of the experiment. However, a significant disparity was observed in the decomposition rates of the pots, indicating variations in the longevity and environmental impact of different container materials.

Conclusion

The study indicates promising potential in the utilization of biodegradable containers. Conneway establishes this by synthesizing past research on bio-containers and conducting his own experiments. His findings underscore the significance of factors tested in influencing greenhouse managers' inclination towards adopting bio-containers. Notably, he highlights cost as a pivotal determinant in the decision-making process, potentially serving as a barrier to widespread industry transition. Concluding his paper, Conneway advocates for further research to address lingering concerns and challenges associated with bio-containers. He emphasizes the need for comprehensive investigation and innovation to overcome existing limitations and facilitate the broader adoption of sustainable container solutions within the horticultural industry.

How it relates

This case study is directly relevant to my project as it focuses on the evaluation of biodegradable containers, aligning with my own research objectives. By reviewing this paper, I can gain valuable insights into potential methodologies and approaches for my study, as well as additional resources for information and analysis. Furthermore, comparing the findings of my experiment with those presented in the report will allow me to identify similarities or differences, providing a deeper understanding of the efficacy and implications of using biodegradable containers in greenhouse and nursery settings. This comparative analysis will enrich the findings of my research and contribute to the broader conversation surrounding sustainable practices in the industry.

Case study on "Physical Properties of Biocontainers for Greenhouse Crop Production" by Michael R Evans, Matt Taylor, and Jeff Kuehuy

Introduction

This paper delves into the physical properties of bio-containers used in crop production within a greenhouse. It begins by discussing how the size of the container influences the final size of the plant at the end of production. The type of bio-container chosen determines whether it will be planted in the ground along with the plant or removed prior to planting. Evans et al. (2010) outlined two main categories: "Plantable bio-containers," which are meant to remain intact around the root ball and be planted directly into the field or final container, allowing roots to penetrate the container walls and decompose post-planting; and "Compostable bio-containers," designed to be removed before planting, broken apart, and composted (p. 549). In their experiment, the researchers tested ten different types of pots: 4-inch plastic, 5-inch plastic, OPA47, fertile, cowpot, coconut fiber, peat, rice hull, paper, and rice straw. The tests conducted on these various containers included assessments of wet and dry vertical, lateral, and puncture strength, as well as the volume of water required to produce a marketable geranium, average irrigation intervals for geraniums, cumulative water loss,

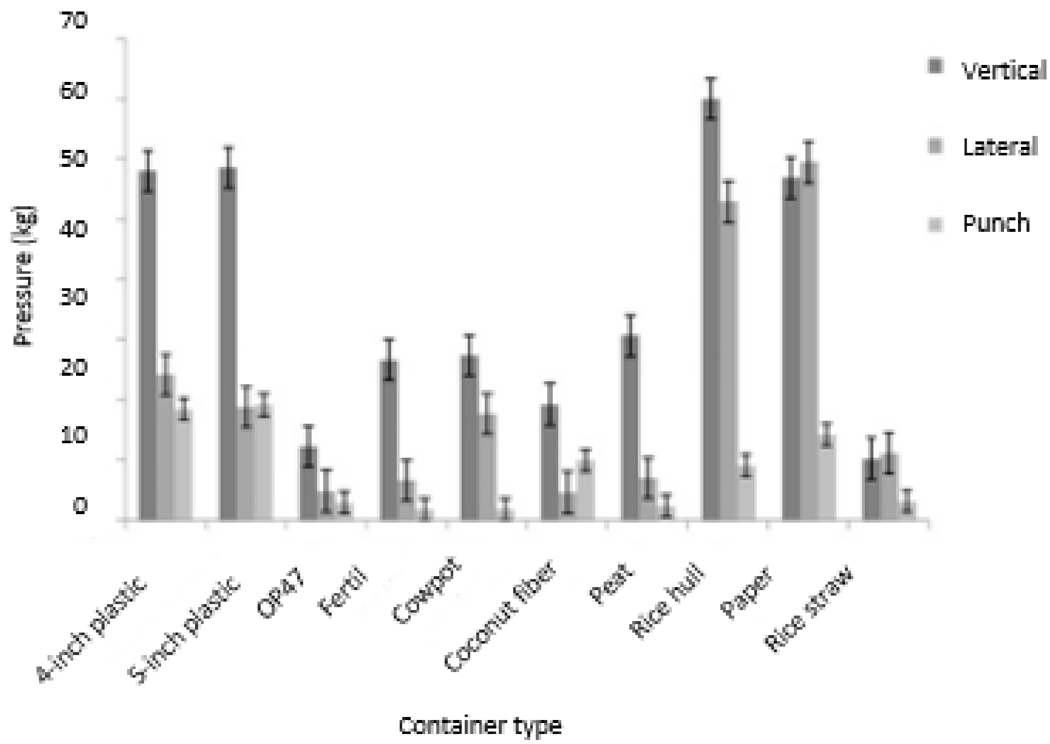


Fig. 1. Dry vertical, lateral, and punch strength of plastic containers and various biocontainers. Vertical strength was tested with pressure applied to the top of the container and lateral strength was tested with pressure applied to the side of the container. Punch strength was tested by forcing a 5-mm (0.2 inch) ball probe through the container wall. Error bars represent ± least significant difference value (a = 0.05) for each strength test; OP47 (Summit Plastic Co., Tallmadge, OH), Fertil (Fertil International, Boulogne Billancourt, France), Cowpot (CowPots Co., Brodheadsville, PA); 1 kg = 2.2046 lb, 1 inch = 2.54 cm.

(Evans, et. al. 2010)

algal and fungal growth on the containers, and decomposition measured as a percentage of the unused container weight.

Materials and methods

When testing for wet and dry vertical, lateral, and puncture strength, the containers were filled with LCI root substrate. For wet strength testing, the containers were placed in a glass-glazed greenhouse and watered daily for four consecutive weeks. Throughout this period, the greenhouse temperature was maintained at a constant level, and the amount of incoming light was recorded. Strength testing involved applying pressure to the containers from top to bottom and from the sides. Additionally, the strength of the container walls was assessed by puncturing them with a 5-mm ball probe.

The assessment of water usage in the containers by geraniums spanned over an eight-week period. Initially, the containers were filled with substrate, and six-leaf plugs of geraniums were planted. Following transplantation, the containers were positioned on drainage trays within a greenhouse environment. Initially, the plants received watering with a water-soluble fertilizer solution at 200mL. Subsequently, as the containers began to dry out, and watering was adjusted to 150 mL of water. Excess water from watering sessions was collected and recorded.

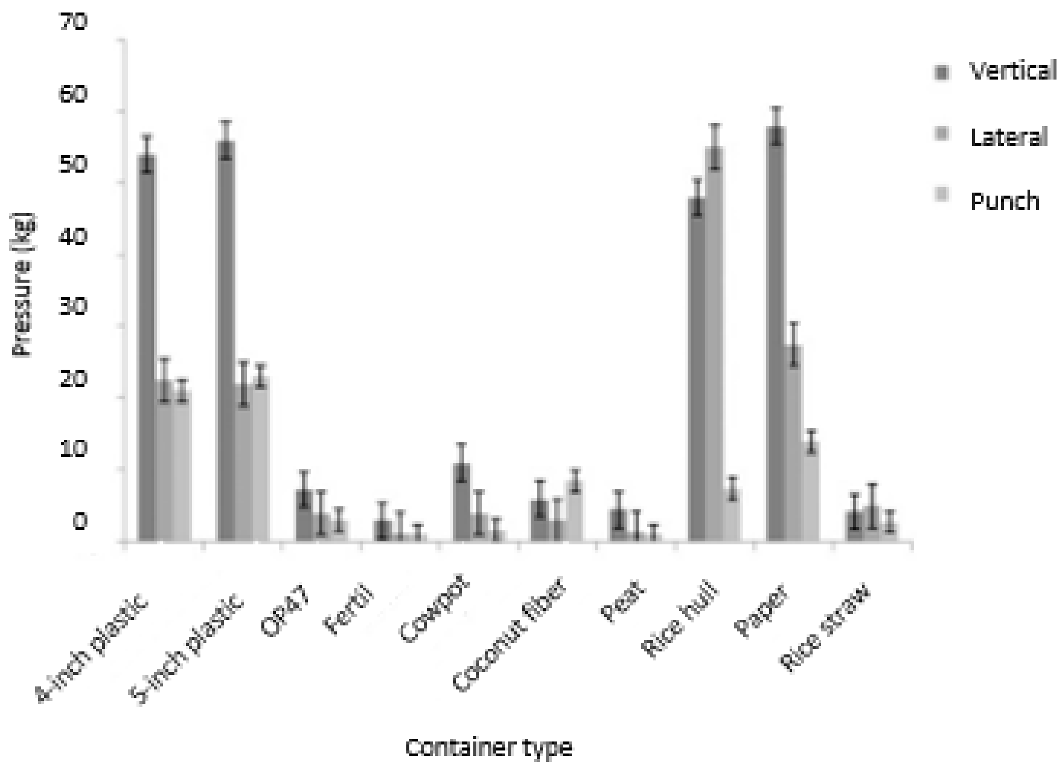


Fig. 2. Wet vertical, lateral, and punch strength of plastic containers and various biocontainers 4 weeks after being filled with wet substrate in a greenhouse environment. Vertical strength was tested with pressure applied to the top of the container and lateral strength was tested with pressure applied to the side of the container. Punch strength was tested by forcing a 5-mm ball probe through the container wall. Error bars represent ± least significant difference value (a = 0.05) for each strength type; OP47 (Summit Plastic Co., Tallmadge, OH), Fertil (Fertil International, Boulogne Billancourt, France), Cowpot (CowPots Co., Brodheadsville, PA); 1 kg = 2.2046 lb, 1 inch = 2.54 cm.

(Evans, et. al. 2010)

> Evans et al. (2010) stated, "The total water used by the crop during the production cycle (water retained in the container) and the average irrigation interval (required frequency of irrigation) was determined" (p. 551).

To assess water loss through the container walls, the containers were filled with substrate up to their rims, and watering was done where the walls were not saturated. The drainage holes at the bottom were sealed with wax, and the containers were weighed before placement in the greenhouse. Observations on water loss through the walls were conducted over a week while the containers remained in the greenhouse.

The growth of algae and fungi was observed by placing containers pot-to-pot in a greenhouse for six weeks and irrigating them using overhead watering.

After the six-week period, the substrate in the containers was allowed to dry, and examination for discoloration indicating algae and fungal growth was conducted.

Lastly, decomposition was measured based on the original dry weight. This was accomplished by cultivating vinca plants in

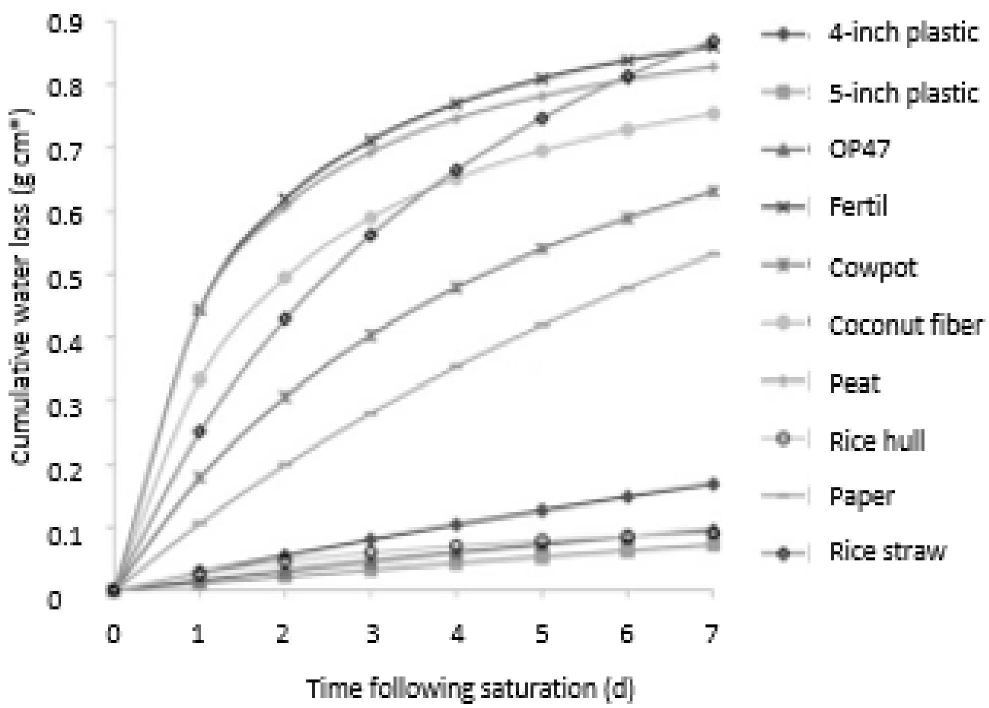


Fig. 5. Cumulative water loss as milliliters per square centimeter of container surface area over a 7-d period for traditional plastic and various biocontainers. The equations for each container type were: 4-inch (10.2 cm) plastic, y = 0 + 0.025x, (R2 = 0.98); 5-inch (12.7 cm) plastic, y = 0 + 0.011x, (R2 = 0.97); OP47 (Summit Plastic Co., Tallmadge, OH), y = 0 + 0.014x, (R2 = 0.96); Fertil (Fertil International, Boulogne Billancourt, France), y = [(1.02x)/(1.302 + x)], R2 = 0.98; Cowpot (CowPots Co., Brodheadsville, PA), y = [(1.093x)/(5.129 + x), R2 = 0.97; coconut fiber, y = [(0.9542x)/(1.859 + x)]; R2 = 0.98; peat, y = [(0.9692x)/(1.196 + x)], R2 = 0.98; rice hull, y = 0 + 0.014x, (R2 = 0.93); paper, y = 0 + 0.075x (R2 = 0.98); straw, y = [(1.475x)/(4.877x)], R2 = 0.99; 1 gcm22 = 0.2276 oz/inch2

(Evans, et. al. 2010)

containers within greenhouses at two separate locations: for five weeks in Louisiana and for seven weeks in Pennsylvania. Subsequently, the plants were transplanted outdoors and left undisturbed for eight weeks before being excavated and examined.

Conclusion

The study concluded that the various types of bio-containers exhibited differing physical properties compared to plastic containers. It was noted that the importance of these properties varied depending on the specific location and circumstances. For instance, certain bio-containers exhibited lower wet strength, potentially making them more challenging to handle, while others allowed water to permeate through their walls, creating increased water usage compared to plastic containers.

The research suggests that greenhouse managers considering a transition to bio-containers will need to carefully consider the specific physical attributes required for their production operations. This decision should be based on factors such as handling ease, water retention capabilities, and overall suitability for the intended growing conditions.

How it relates

This study relates to my research as it examines the physical attributes of containers during greenhouse production. In my paper, I aim to investigate whether materials used for bio-containers can endure everything that goes into growing plants in production and with frequent handling before reaching retail centers for customer purchase. By referencing this study, I can gain insights into their methodology for assessing the properties of bio-containers, allowing for a comprehensive analysis of the advantages and disadvantages of utilizing these containers in production environments.

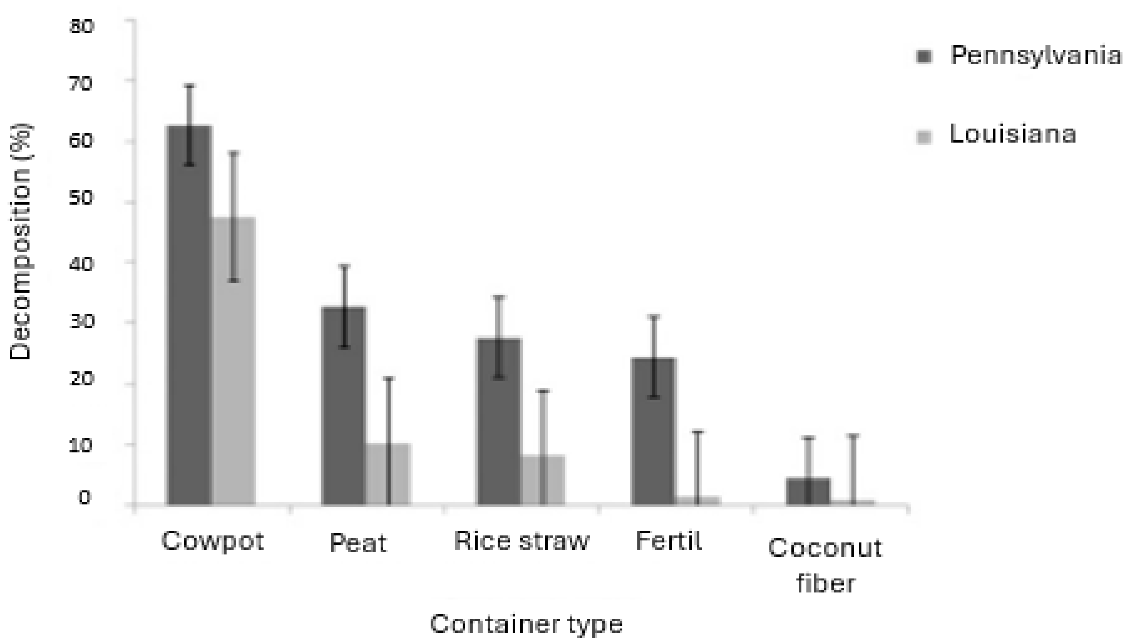


Fig. 7. Decomposition as a percentage of unused container weight after 8 weeks planted out-of-doors in plant beds in Baton Rouge, LA, and Kennett Square, PA. Error bars represent ± least significant difference value (a = 0.05); Cowpot (CowPots Co., Brodheadsville, PA), Fertil (Fertil International, Boulogne Billancourt, France); 1 inch = 2.54 cm (Evans, et. al. 2010)

Chapter 2
Literature review

What is horticulture?

Horticulture, derived from the Latin words "hortus" (garden) and "cultura" (culture), encompasses the art and science of cultivating fruits, vegetables, herbs, nuts, and ornamental plants such as trees, shrubs, flowering plants, and turf (Baeyer, E. von. 2010). The roots of horticulture in the United States trace back to the arrival of the first settlers, who initially prioritized growing crops for sustenance and profit (Abate, A. 2018). However, as leisure time increased, gardening with ornamental plants became more prevalent.

The nursery industry in the United States took root in 1737 when Robert Prince established the first nursery, known as the Botanic Garden and Nurseries (Abate, A. 2018). Initially, Prince cultivated plants for personal use in his garden. However, in the 1720s, he wrote a letter requesting plants from overseas, laying the groundwork for introducing new plant varieties to American gardens. This exchange facilitated by Prince and other nurseries allowed customers access to a diverse array of plant species from around the world. Approximately one-fourth of the plants in American gardens were native to the United States, while half originated from Asia, with the remaining quarter coming from Europe (Abate, A. 2018). Prince Nursery remained under family management for four generations until its closure in 1865 (Abate, A. 2018), marking a significant chapter in the early history of horticulture in the United States.

History of containers in the industry

Before the widespread use of plastics, plants were typically sold and shipped bare-root. During transportation, the roots would often be coated in a clay-based slurry to maintain moisture levels (Association of Professional Landscape Designers, 2020). Burlap was also commonly used to wrap and transport plant material, although these practices are still employed for certain plants, they are no longer the sole method. Over time, growers began using ceramic pots, despite their weight and susceptibility to breakage, as they provided an effective means of transporting plant material to retailers. Subsequently, in the 1940s and 50s, paper and food cans were utilized as containers for housing plants (Association of Professional Landscape Designers, 2020). However, the post-World War II era saw the emergence of plastic pots, which rapidly became the predominant container type in the United States by the 1980s, revolutionizing the horticultural industry (Association of Professional Landscape Designers, 2020).

Today's containers

Plastic containers offer numerous advantages, including being lightweight, easy to handle, flexible, sturdy, and non-porous (Goldammer T., 2019). These characteristics have contributed to plastic containers becoming the dominant choice in the industry. Horticultural plastics are classified based on their plastic type, which includes High-Density Polyethylene (HDPE; #2), Low-Density Polyethylene (LDPE; #4), Polypropylene (PP; #5), and High Impact Polystyrene (HIPS; #6) (Heidi Lindberg, 2022). This categorization helps in understanding the properties and applications of different types of plastic containers used in horticulture.

Association of Professional Landscape Designers
Plastics used in horticulture.

High-Density Polyethylene (HDPE; #2) is commonly utilized for manufacturing durable, rigid plastic containers suitable for housing woody ornamental plants such as trees and shrubs. Due to their extended usage period, HDPE containers are resistant to degradation from UV light exposure and possess thermal and chemical resistance, which is crucial for outdoor production environments where exposure to various chemicals may occur.

Low-Density Polyethylene (LDPE; #4) is cost-effective and often employed for covering greenhouses and as mulching material. However, LDPE containers have specific requirements when encountering pesticides, posing challenges in some situations.

Polypropylene (PP; #5) is the plastic of choice for greenhouse containers. Known for their durability, lightweight nature, and resistance to breakage, PP containers are preferred for their reliability and minimal leaching tendencies.

High Impact Polystyrene (HIPS; #6) is commonly used for flats and trays due to its affordability and lightweight properties.

PLASTICS USED IN HORTICULTURE				
Plastic	**Resin Identification Code**	**Pros**	**Cons**	**Recycled Uses**
High Density Polyethylene (HDPE)	#2	Rigid durable plastic used for outdoor trees and shrubs. Resists breakage, does not degrade quickly under UV light; thermally and chemically resistant.		Plastic timber, picnic tables, railroad ties.
Low Density Polyethylene (LDPE)	#4	Relatively inexpensive; used to cover greenhouses; mulching material.	Requires special recycling if in contact with pesticides; some companies offer wash line systems for cleaning.	Plastic composite lumber for decks; floor tiles; reusable grocery bags; compost bins and trash cans.
Polypropylene (PP)	#5	Plant containers for greenhouse production; durable; lightweight and resists breakage; not prone to leaching.	Yield losses are pretty high and standardized packaging in PP is low.	Typically not recycled.
High Impact Polystyrene (HIPS)	#6	Flats and trays for seedlings and small plants; inexpensive and lightweight.	Most often discarded or recycled rather than reused.	Can be recycled back into trays.

(Association of Professional Landscape Designers, 2020)

Bio-containers

Bio-containers can be created from a diverse range of materials, including peat, paper, coconut fiber, rice hulls, poultry feathers, rice straw, dairy manure, and bioplastics (Evans et al., 2010). However, many bio-containers encounter durability issues and may not withstand the rigors of crop production. Evans et al. (2010) classify bio-containers into two primary types: "Plantable bio-containers," which are meant to remain intact around the root ball and can be directly planted into the field or final container, allowing roots to penetrate the container walls and decompose post-planting; and "Compostable bio-containers," designed to be removed before planting, disassembled, and composted (p. 549). This categorization provides growers with clarity on the different types of bio-containers available and helps them choose the most suitable option based on their preferences and requirements for eco-friendly alternatives.

Different Materials

Peat

Peat containers, such as JIFFY seed starting products, are typically small and can be in the form of expanding peat pellets. Peat can also be condensed into solid containers, making them easier to handle. However, when peat containers become wet, they tend to tear or break easily, making handling difficult (Evans et al., 2004). These containers require more water than plastic containers, and algae can grow on their outer walls (Evans et al., 2004). Peat containers are best suited for plants that will be directly planted into the ground or transferred into larger containers. They can help reduce transplant shock, and their structure allows roots to break through easily.

Different kinds of fiber

Fiber containers are beneficial for promoting water and air exchange due to their semi-porous walls (Nambuthiri et al., 2015). The decision between whether a container is plantable or compostable depends on the material used. Various fibers can provide structural support independently, while others require a binding material, which can be natural or synthetic. Examples of binding agents include resins, glue, wax, latex, or even cow manure (Nambuthiri et al., 2015).

Poultry feathers

Containers made from poultry byproducts can retain water better than peat containers, requiring less frequent watering. Additionally, they decompose quickly when planted in the field. In greenhouse settings, these containers exhibit less algae and fungal growth compared to other materials (Evans et al., 2004).

Bioplastics

Similar to traditional plastics, bioplastics are made from biopolymers (non-petroleum-based) or a blend of biopolymers and petrochemical-based polymers (Nambuthiri et al., 2015). "Biopolymer-based plastics are produced using renewable raw materials" (Nambuthiri et al., 2015). One of the advantages of using bioplastics is that they offer similar benefits to traditional plastic containers, such as being lightweight and

Paper

Paper pots are commonly used for seed plugs and cutting propagation of ornamental, vegetable, and forestry species (Goldammer, T., 2019). These pots are typically intended for short-term use, but if the container wall is thickened, they can be used for a longer period since they are more durable.

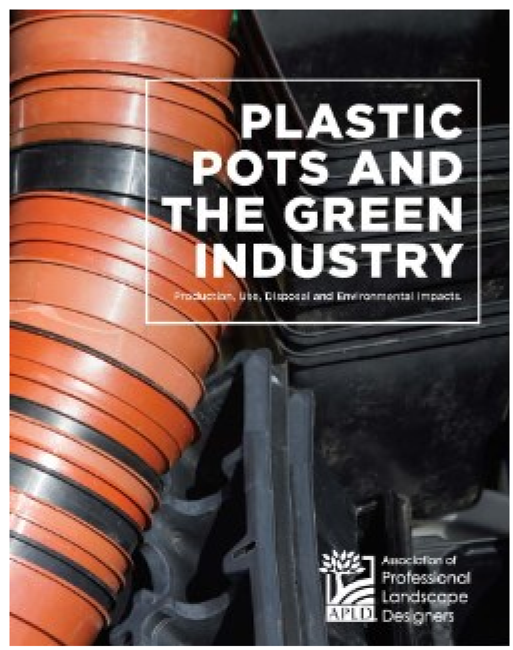
Literature review

Introduction

Despite its perception as a "green" industry, the horticultural sector heavily relies on plastics, contributing to significant waste generation. Plastic pots have emerged as the industry standard due to their convenience, leading to widespread adoption. While research into alternative options exists, their uptake remains limited as growers prioritize the convenience, flexibility, durability, and cost-effectiveness offered by traditional plastic containers. As environmental awareness grows, consumers increasingly seek out more eco-friendly choices when purchasing, with biodegradable containers emerging as a viable option to mitigate plastic usage in the industry. Although bio-containers present a promising alternative, they come with higher costs and certain challenges. However, they signify the beginning of a potential revolution in the industry, with ongoing research exploring new materials and refining existing solutions to address environmental concerns and promote sustainability.

The issue with plastic containers

Plastic containers are extensively utilized in the horticultural industry, particularly in greenhouse and nursery production. Currently, most of these containers are single-use and petroleum-based (Association of Professional Landscape Designers, 2020). Large companies produce tens of millions of plastic pots each season, resulting in substantial amounts of plastic waste that eventually degrades in both freshwater and marine ecosystems, as well as in landfills. This degradation process releases plastics and harmful chemicals into the environment (Association of Professional Landscape Designers, 2020). The sheer volume of plastic production overwhelms recycling efforts, with much of the waste ending up disposed of rather than recycled. Cleaning and sorting plastic containers for recycling are costly processes, often resulting in companies paying for their disposal (Chieppo M., 2021). Moreover, only 8.5% of plastic waste is recycled in the U.S., and many containers fail to undergo proper recycling due to difficulties in identification caused by carbon pigment, and some are even composed of mixed plastics, rendering them unprocessable (Chieppo M., 2021).



(Association of Professional Landscape Designers, 2020)

Alternatives

With the escalating use of plastic containers in the industry, researchers have turned their attention to exploring new materials for constructing plant containers. These innovative bio-containers can be crafted from a diverse array of materials, including peat, paper, coconut fiber, rice hulls, poultry feathers, rice straw, dairy manure, and bioplastics (Evans et al., 2010). By embracing these new materials for container production, the industry aims to reduce its reliance on plastic and enhance its environmental sustainability. However, it is important to note that many bio-containers face a durability challenge (Evans et al., 2010). Often, these biodegradable alternatives may not withstand the rigors of production processes. Evans et al. (2010) categorize bio-containers into two main types: "Plantable bio-containers," intended to remain intact around the root ball and be directly planted into the field or final container, allowing roots to penetrate the container walls and decompose post-planting; and "Compostable bio-containers," designed to be removed before planting, disassembled, and composted (p. 549). This classification highlights the variability in durability based on the material used. Given these considerations, greenhouse production may lean towards utilizing more compostable bio-containers, as they tend to withstand production processes better than their plantable counterparts and offer improved durability during plant production.

Hypothesize on what you except to see and/or read about.

The prevalent overuse of plastic in greenhouse and nursery production exacerbates the challenge of recycling, with many containers ending up as single-use items. Addressing this issue requires a shift towards more sustainable materials that can decompose without leaving behind waste. In my research, I aim to investigate the current plastics utilized in the industry, as well as the alternatives being explored, along with their respective advantages and drawbacks. By understanding the current container materials, I can identify the necessary requirements for new bio-containers to gain acceptance in the industry. This approach will contribute to the development of more sustainable practices and materials within the horticultural sector.

Summary

Transitioning to environmentally friendly alternatives, such as biodegradable materials, through this project can mitigate the environmental harm caused by plastic waste. Recycling proves difficult due to chemical, dirt, and plant debris contamination from the growing process. Embracing eco-friendly alternatives holds promise for mitigating environmental impact and minimizing plastic waste. Although there may be initial expenses associated with adopting more sustainable options, the long-term advantages can surpass these costs. For instance, while investing in biodegradable pots may incur higher upfront costs, increased market demand and competition can eventually drive prices down. As environmental awareness grows, consumers are increasingly seeking sustainable products. Aligning this project with consumer preferences for eco-friendly choices allows it to resonate with a market that prioritizes sustainability and attract environmentally conscious consumers. Embracing sustainability initiatives enhances companies' reputations and strengthens their corporate social responsibility profiles. My research will investigate existing plastic types, their functions, and recycling protocols, compared with new sustainable container options, assessing their pros and cons. This study's significance lies in exploring viable materials for greenhouse and nursery containers, aiming to minimize plastic dependence, thus promoting a more eco-conscious industry.

Chapter 3
Assessing the possible utilization of bio-containers

Greenhouse practices

Sizes used in greenhouses

Depending on the crop species and target market greenhouse and containerized nursery crops are commonly grown in plastic containers of varying sizes (Evans et al., 2004). Common types of plastic containers include round or square pots, decorative containers, hanging baskets, trays, flats, or sheets. These containers range in size from 3 inches to 12 inches or more in diameter. Containers are typically named based on either the diameter of the top of the container or the number of gallons it can hold; for example, a container with a 10-inch diameter is referred to as a 10-inch container. It is important to note that while containers may be labeled as the same size, they can vary in actual dimensions. For instance, a 10-inch Azalea round pot has a diameter of 9.87 inches, and a 10-inch non-attachable saucer has a diameter of 9 inches (Leader in Horticultural Containers. n.d.). This variation in size can make it challenging to purchase containers from different vendors, as containers labeled with the same size may have different actual dimensions.

Number of containers used by greenhouses

The greenhouse industry utilizes a significant amount of plastic containers annually. During the spring and summer, considered the "busy season," small greenhouses alone can go through over 263,841 containers (personal connection, March 29, 2024). If we were to total all the plastic containers used for one year's production, the total would be approximately 303,264 containers. A medium-sized greenhouse in the busy season could use no less than five times that amount, totaling around 1,319,205 containers. Large wholesale greenhouses, in turn, would use no less than five times the amount of a medium-sized greenhouse, equating to roughly 6,596,025 containers. Considering the volume of plastic containers used in a single greenhouse, multiplying that by the number of greenhouses in a city or even the state could result in millions of containers used a city or state alone. In the broader context of the containers crop industry, the USDA reported in 2009 that 4 billion containers were produced, utilizing 1.66 billion pounds of plastic (Association of Professional Landscape Designers, 2020).

(Association of Professional Landscape Designers, 2020)

Where are plastic pots recycled

Recycling plastic containers can become tricky in finding places to accept them. Many of the companies will not accept plastic that is not clean, sorted, and in some cases forklift ready. To justify the cost of labor and transportation many companies also require a minimum weight and/or quantity of plastic before considering recycling them (Heidi Lindberg, 2022). This is one of the reasons why a greenhouse may choose to not recycle its plastic containers. The labor that goes into cleaning and sorting them along with the price for the recycling company to come out and collect the containers is far too great to justify doing it from a business standpoint. Another issue is the chemicals used during the growing process. Depending on what is used can cause the plastics to be denied by companies for safety reasons even if the containers are cleaned.

Environmental effects

Transitioning to bio-containers would benefit the environment in several ways, notably by reducing the number of plastic containers destined for landfills. Plastic containers are a significant contributor to the global plastic pollution problem, with only about 8.5% of plastics being recycled in the United States (Association of Professional Landscape Designers, 2020). Even when black containers commonly used in greenhouse production are recycled, they often fail to be sorted by recycling machines because the carbon pigment is undetectable to the readers (Association of Professional Landscape Designers, 2020). Consequently, a substantial amount of plastic containers end up in water bodies and landfills. As these single-use plastic containers degrade, a process that can take hundreds of years, they release chemicals that can harm surrounding vegetation and waterways (Association of Professional Landscape Designers, 2020).

Compatibility in greenhouse production

Plastic containers remain the primary choice for greenhouse production due to their reliability. However, as the industry considers transitioning to bio-containers, understanding their compatibility and performance in commercial settings is crucial. Bio-containers can vary in integrity and strength during production and marketing as the industry explores alternative options (Nambuthiri, et al., 2015).

A study by Evans, et al. (2010) investigated the physical characteristics of bio-containers in a greenhouse setting. They evaluated wet and dry strength, water usage, algal and fungal growth, and decomposition rates. The study highlighted that the suitability of bio-containers depends on the specific conditions they encounter. Bio-containers with stronger wet and dry strength are more suitable for growers. However, transitioning to bio-containers can be challenging as they often require more frequent watering and may not be as durable as plastic containers.

(Koeser, et. at., 2013)

Despite these challenges, the industry is gradually shifting towards bio-containers. J. Hughes (personal communication, January 27, 2024) expressed confidence in this shift, stating, "This is the better way to go for the industry, and at some point, it will come whether we are ready for it or not."

Appeal to consumers

There are various consumer markets, and while some individuals may not favor the idea of bio-containers, many others are receptive to them. Despite bio-containers being more expensive than traditional plastic containers, there is a segment of consumers willing to pay premium prices for eco-friendly products (Hall, et. al. 2010). The material used for bio-containers can significantly influence consumer opinion. A study from (Yue, et. al. 2010) explored consumers' willingness to pay for different types of bio-containers. It revealed that consumers are willing to pay premium prices for containers made from wheat starch, rice hulls, straw, coir, and peat. However, containers made from chicken feathers and cow manure did not show much difference in consumer willingness to pay compared to recycled plastics (Yue, et. al. 2010). For bio-containers to succeed, they must outperform non-green competing products, as consumers are hesitant to purchase low-quality items (Hall, et. al. 2010).

Chapter 4
Assessing the durability of bio-containers

Introduction

This experiment aimed to assess the performance of different bio-containers for greenhouse production, focusing on their watering requirements and impact on plant growth. The containers tested included 8- plastic, 8- EcoGrown Standard Round Pot, 8- 3" biodegradable Seed Starting JIFFY-POT, and 8- Jiffy Seed Starting Expanding Peat Pellets. The seeds used were tomato Solanum lycopersicum 'Roma' and Ocimum basilicum 'Everleaf Emerald Towers'. The experiment was conducted indoors, on a shelf under a grow light, to simulate greenhouse conditions. Observations were made over a nine-week period. This setup allowed for the comparison of the containers' performance in terms of seed germination, watering needs, and overall plant growth, providing insights into their suitability for greenhouse production.

Methods and materials

CONTAINERS: This experiment examines the performance of four different containers, including one control (a 3-inch plastic container) and three bio-containers: EcoGrown Standard 5-inch Round Pot, 3-inch biodegradable seed starting JIFFY pot, and JIFFY seed starting expanding peat pellets. These containers are utilized to observe the growth of Roma tomato seeds (Solanum lycopersicum 'Roma') and sweet basil seeds (Ocimum basilicum).

SEEDS: In each container, three seeds are planted and watered. The Roma tomato seeds have a germination time of 7-10 days and a maturation period of 85-90 days, while the sweet basil seeds typically germinate in 7-14 days and mature in 60-90 days.

FILLING: All containers, except for the JIFFY expanding peat pellets, are manually filled with Berns potting soil up to the rim and lightly packed down.

LOCATION: The containers are positioned on a shelf under a grow light set to an 8-hour interval for nine weeks.

(Weller J. February 27, 2024. Experiment set up)

Observations

During the germination period, it was observed that the overall germination rate of the seeds was lower than expected, with less than 50% of the seeds germinating. This lower germination rate may have been influenced by factors such as poor seed quality, improper planting depth, or other conditions regarding where they were placed. Due to this lower germination rate, the experiment was not able to continue for the full nine-week period as originally intended.

Conclusions

The experiment aimed to evaluate the performance of four different containers (one plastic and three bio-containers) in supporting the growth of Roma tomato seeds (Solanum lycopersicum 'Roma') and sweet basil seeds (Ocimum basilicum). Despite attempts to ensure consistency in filling and environmental conditions, including the use of a grow light, the experiment encountered a lower-than-expected germination rate, which impacted the ability to assess the containers' performance over the planned nine-week period.

Expanding the experiment to a commercial greenhouse with plug trays for germination and transplanting would enhance the control over environmental factors, enabling a more precise comparison between different containers. This setup would also facilitate the observation of the full production cycle, offering valuable insights into the long-term performance of the bio-containers. Such an expansion would provide a clearer understanding of the containers' suitability for greenhouse production and contribute significantly to the research on sustainable alternatives to plastic containers.

Response to Research Question

Greenhouses can benefit by aligning the industry with environmentally friendly practices, reduce their environmental impact, and open new marketing opportunities, such as environmentally conscious consumers and areas for growth.

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