EVALUATION OF SPENT TEA GRINDS AS AN ALTERNATIVE HORTICULTURAL SUBSTRATE COMPONENT

Except where reference is made to the work of others, the work described in this thesis is my own or was done in collaboration with my advisory committee. This thesis does not contain proprietary or classified information.

____

Daniel Evan Wells

Certificate of Approval:

Charles H. Gilliam Professor Horticulture	Jeff L. Sibley, Chair Professor Horticulture
William A. Dozier, Jr. Professor Horticulture	George T. Flowers Dean Graduate School

EVALUATION OF SPENT TEA GRINDS AS AN ALTERNATIVE HORTICULTURAL SUBSTRATE COMPONENT

Daniel Evan Wells

A Thesis

Submitted to

the Graduate Faculty of

Auburn University

in Partial Fulfillment of the

Requirements for the

Degree of

Master of Science

Auburn, Alabama
December 19, 2008

EVALUATION OF SPENT TEA GRINDS AS AN ALTERNATIVE

HORTICULTURAL SUBSTRATE COMPONENT

Daniel Evan Wells

____

Signature of Author

____

Date of Graduation

VITA

Daniel Evan Wells, son of Larry and Vickie Wells of Headland, Alabama, was born April 22, 1983 in Opelika, Alabama. He has one younger brother named Wesley. He graduated in May 2001 from Headland High School in Headland, Alabama. He entered Auburn University Spring Semester of 2003 and graduated with a Bachelor of Science degree in Landscape Horticulture in May 2006. Upon graduation, Daniel continued his studies at Auburn University pursuing a Master of Science degree in Horticulture under the direction of Dr. Jeff Sibley. In December 2008, he received his Master of Science degree in Horticulture from Auburn University. He married Alexandrea Anne Williams on March 24, 2007.

THESIS ABSTRACT

EVALUATION OF SPENT TEA GRINDS AS AN ALTERNATIVE

HORTICULTURAL SUBSTRATE COMPONENT

Daniel Evan Wells

Master of Science, December 19, 2008
(Bachelor of Science, Auburn University, 2006)

123
Typed Pages

Directed by Jeff L. Sibley

Spent Tea Grinds (STG) is the by-product of the rapidly growing tea brewing industry. Published research to date provides few alternatives for beneficial uses of STG. However, the physical and chemical properties of STG indicate a possibility for use as a suitable substrate component. In response to a request for proposals from the Milo's Tea Company, Inc., Bessemer, AL, a series of studies were proposed and subsequently funded to evaluate STG as a substrate component for greenhouse and nursery crops. In a greenhouse study, *Lantana camara* 'New Gold' and *Nephrolepis exaltata* 'Bostoniensis' were grown for 10 weeks in seven substrate blends. Substrate components included a commercial greenhouse substrate (Fafard® 3B), pine bark (PB), STG, perlite and a composted product (PB:STG ; 50:50) referred to as TBC. Plant performance was evaluated for leaf chlorophyll content, growth indices, and dry weights. Substrate

leachates were collected weekly to determine substrate chemical properties. PB:STG and TBC substrates produced similar or superior plants than Fafard® 3B. An additional greenhouse study determined the effect of pre-plant incorporated elemental sulfur on foliar chlorosis symptoms in petunia. *Petunia* x *hybrida* 'Dreams Mix' and *Begonia* x *semporflorens-cultorum* 'Harmony Mix' were grown for 10 weeks in a greenhouse. Plant performance was evaluated by comparing leaf chlorophyll content, visual quality, and dry weights. Petunias grown in a substrate containing up to 20% (by volume) STG were similar to those grown in substrates containing peat moss (PM). Incorporated elemental sulfur eliminated foliar chlorosis of petunia grown in STG substrates. In a container-plant production study, *Lagerstroemia indica* 'Tuscarora', *Loropetalum chinense* 'Chang's Ruby', *Nandina domestica* 'Fire Power', and *Rhododendron* x 'Micrantha Pink' were grown in five substrate blends containing various PB:STG ratios. Leaf chlorophyll content and growth indices were used to determine plant performance. Substrate leachates were collected every four weeks in order to monitor pH and electrical conductivity. Crapemyrtle, loropetalum, nandina, and azalea, grown in substrates containing up to 50% (by volume) STG, had similar or greater growth than those grown in 100% PB. An additional container-plant production study evaluated *Zantadeschia* hybrids 'Elliottiana' and *Hosta* hybrids 'T-Rex' and 'Wide Brim' were grown in five substrate blends containing various ratios of STG:PB. Plant performance was evaluated by comparing root quality and foliar weight. Calla lily and hosta grown in substrates containing up to 50% (by volume) STG were similar to those grown in 100% PB.

ACKNOWLEDGEMENTS

The author would like to express his sincerest gratitude for the guidance, insight, and patience extended to him over the past two years by Dr. Jeff Sibley. The author would also like to thank Dr. Charles Gilliam and Dr. William Dozier for lending support and wisdom while serving on his advisory committee. He would also like to thank Drs. Glenn Fain, Wheeler Foshee, and Joe Eakes for their support and help during the completion of this research. Sincere appreciation is also expressed to Mr. Jay Evers, VP and COO of Milo's Tea Company, Inc., for initiating the concepts investigated in this project, and for providing financial and material support for this research.

The author would like to thank B.J. Brymer, Diana Cochran, Chris Marble, Matt Wilkin, and Matt Wilson for their unique friendship that has developed over the past two years. The author would also like to extend a special thanks to Jeremy Pickens for the extraordinary help he has provided and for being a truly incomparable friend.

To his parents, thank you for being wonderful role models and for providing unconditional love. The author wishes to thank his brother Wesley for his friendship and love, and for always providing comic relief whether he means to or not. He especially thanks his wife Andrea for being his best friend, soul mate, and the love of his life.

Most importantly, the author wishes to thank the Lord Jesus Christ for saving him, an imperfect, undeserving sinner.

Styled after the following journal:

Journal of Environmental Horticulture and HortTechnology

Computer software used:
Microsoft Word 2003, Microsoft Excel 2003, and SAS v. 9.1

TABLE OF CONTENTS

LIST OF TABLES

CHAPTER II

CHAPTER III.

APPENDIX A.

LIST OF FIGURES

CHAPTER I

Introduction and Literature Review

The practice of using waste materials as a substrate component in the nursery and greenhouse industry has been studied extensively in recent years. Much focus has been placed on composting agricultural or industrial waste products before use as substrate components. Several composted materials have been researched for their suitability as substrate components (Lu, 2008). Use of a fresh waste material as a substrate component, without composting, has not been researched as extensively. In many cases waste products are simply not suitable substrate components, physically or chemically, prior to the composting process. Because of the costs associated with large scale composting, it is likely desirable for growers to find a waste product that does not have to be composted to become a suitable substrate component. Very little research has been done to investigate the possibility of using spent tea grinds (STG), composted or not composted, as a substrate component. This review will discuss current practices and issues facing the horticulture industry with respect to substrates.

Spent Tea Grinds

The majority of tea consumed worldwide is brewed from leaves of *Camellia sinensis* (Harler, 1966). Tea is the second most popular beverage worldwide, behind only water, and is produced in India, Sri Lanka, Indonesia, Argentina, Turkey, Kenya, China, and many other countries with Mediterranean-type climates (Hicks, 2001). Tea plant production thrives in areas that receive a minimum annual rainfall of 45 inches per year. A mild winter is desirable and an acidic soil is crucial. An optimum soil pH range for tea plantations is 5.4 to 5.8 (Harler, 1966). In the United States, the market for refrigerated, ready-to-drink tea has grown tremendously in recent years. Since 1990, domestic sales of ready-to-drink tea have increased by $2.6 billion annually and are expected to continue climbing for the next several years (Simarny, 2007). This has led to increased outputs of residual materials from commercial tea brewing companies.

Spent Tea Grinds (STG) are finely ground tea leaves that are the byproduct of the tea-brewing process. Since commercial tea production is steadily increasing over time, STG is a renewable resource. Tea brewing companies are faced with the challenge of disposing of their waste products. Several avenues for this disposal have been pursued such as using STG as a livestock feed, but in many cases this is not economical for livestock producers. As a result, some tea brewers have been forced to dump STG into landfills. This is not a desired course of action because of potential environmental drawbacks. Some states, such as Illinois, have banned green wastes, such as landscape debris, from being dumped into landfills (Walker et al., 2006). Costs incurred from dumping STG into landfills also presents an economic dilemma to tea brewers. In many cases, the tea brewers are searching for ways to recover these costs. Finding a suitable alternative for the recovery or reuse of STG would also be environmentally beneficial.

STG's high water holding capacity and organic nature make it a potential replacement for currently used substrate components, such as peat moss (PM) and pine bark (PB).

Current Standards for Horticultural Substrates

Several factors influence the quality and suitability of a substrate for use in horticulture. Growers desire substrate components that are consistent, reproducible, available, easy to handle and mix, cost effective, and that possess suitable physical and chemical properties for a desired crop (Klock-Moore et al., 2000; Hartmann et al., 2002). For every type of grower there is a different consensus as to what constitutes a suitable substrate component. Therefore, the number of materials that can be successful substrate components is as large as the number of source materials available.

The major substrate components used in the southeastern United States are pine bark (PB), sphagnum peat moss (PM), rice hulls, and sand (Yeager et al., 2007). PM is the most widely used substrate component for the production of greenhouse crops due to the fact that PM has desirable water holding capacity and cation exchange capacity (CEC) (Arenas et al., 2002). PM is light weight, has a predictable pH, and lacks harmful chemicals and salts (Papafotiou et al., 2001). Furthermore, PM is a desired substrate component due to its low degradation rate (Garcia-Gomez et al., 2002). However, the cost of PM has increased in recent years due to transportation costs incurred from importing from Canada (Yu et al., 1990). Rising fuel costs will surely escalate this problem. The future availability of PM is also questionable due to environmental concerns (Garcia-Gomez et al., 2002).

PB is another major substrate component used in the nursery and greenhouse industries. However, the future availability of PB for the horticulture industry is of concern. Due to rising energy costs PB has become an increasingly attractive fuel source for many industries. The relocation of timber processing mills to locations abroad has also threatened to decrease the horticulture industry's already small market share of PB (Lu et al., 2006).

Physical and Chemical Properties of Substrates

According to Yeager et al. (2007), a substrate used for nursery production should possess the following properties after irrigation and drainage (% volume basis): a total porosity of 50 to 80%, air space of 10 to 30%, water holding capacity of 45 to 65%, a bulk density of 0.19 to 0.70 g/cm^3, a pH between 5.0 to 6.0, and an EC between 0.2 and 0.5 dS/cm. Recommended physical and chemical characteristics for propagation substrates are similar. Air space should range between 15 to 40% and container capacity should range from 20 to 60%. Substrates should possess a bulk density between 0.3 and 0.8 g/cm3, pH should range from 4.5 to 6.5 and substrate EC should range from 0.6 to 1.5 mS/cm (Maronek et al., 1985).

Many different methods can be used to determine chemical characteristics of potential substrate components. The Virginia Tech Extraction Method (VTEM) can be used to collect leachates to determine pH and EC of substrates containing actively growing plants (Wright, 1984). The Saturation Extraction Method (SEM) can be used to determine many chemical properties of a substrate by analyzing a sample of the substrate

(Warncke, 1986). The North Carolina State University Porometer is a common method used to determine physical characteristics of substrates (Fonteno et al., 1981).

Waste Products as Substrate Components

Several waste products have been evaluated as substrate components for nursery and greenhouse production in recent years. Many of these products have been shown to produce marketable plants. Many of these waste products were composted or processed in some other fashion prior to being utilized as a substrate component. Composted products that have been used include: sewage sludge (Olive et al., 2005), yard trimmings (Klock, 1997), municipal garbage (Lu et al., 2005), green waste (Spiers and Feitje, 2000), and grape marc (Chen et al., 1988). Some waste products have been used as substrate components without being composted such as, construction debris (Sibley et al., 2005), animal wastes (Sibley et al., 2004), biosolids (Klock-Moore, 1999), coconut fibre (Hernandez-Apaolaza et al., 2005), and processed poultry feather fiber (Evans, 2004). All of these waste products have been shown to produce marketable plant material and may be able to alleviate some reliance on common substrate components such as PM and PB.

STG as a Substrate Component

Tatum and Owings (1992) conducted a study using "ground tea leaves" as a bedding plant substrate amendment. They grew tomatoes, marigolds, and verbena in various substrate blends. Ground tea leaves were used alone and were mixed with perlite and vermiculite. These substrates were tested against similar PM-based substrates and a commercial greenhouse substrate mix. It was reported that the blend of ground tea leaves:perlite:vermiculite (1:1:1, v:v:v) produced the highest quality tomatoes along with the commercial greenhouse substrate. For all three species, when combined with perlite and vermiculite, ground tea leaves produced similar plants to those grown in PM-based substrates. However, no further known research was conducted.

Project Objectives

According to available literature many waste products have been used to produce viable plants. Similar research should be conducted to determine if STG is a suitable substrate component. Since the future availability of major substrate components, such as, PM and PB are predictably low, a continued search for a potential replacement for these components is needed.

Several areas of interest should be pursued. These areas include: greenhouse crop production, nursery crop production, and stem cutting propagation. Physical and chemical characteristics of STG should be determined and appropriate avenues for the reuse of STG will be explored. All research should be conducted under the assumption that STG will perform comparably to its previously investigated counterparts.

Finding a suitable use for STG as a substrate component will alleviate multiple problems. First, tea brewing companies may be able to recover disposal costs and become more environmentally friendly. Secondly, a portion of current substrate components may be replaced. This will possibly help lower costs for nursery and greenhouse growers, while also obtaining a sustainable system for the recapture and reuse of STG.

Literature Cited

Arenas, M., C.S. Vavrina, J.A. Cornell, E.A. Hanlon, and G.J. Hochmuth. 2002. Coir as an alternative to peat in media for tomato transplant production. HortScience 37:309-312.

Chen, Y., Y. Inbar, and Y. Hadar. 1988. Composted agricultural wastes as potting media for ornamental plants. Soil Science145: 298-303

Evans, M. R. 2004. Processed poultry feather fiber as an alternative to peat in greenhouse crops substrates. HortTechnology 14:176-179.

Fonteno, W.C., D.K. Cassel, and R.A. Larson. 1981. Physical properties of three container media and their effect on poinsettia growth. J. Amer. Soc. Hort. Sci. 106:736-741.

Garcia-Gomez A., M.P. Bernal, and A. Roig. 2002. Growth of ornamental plants in two composts prepared from agroindustrial wastes. Bio Tech. 83:81-87.

Harler, C.R. 1966. Tea growing. Oxford University Press.

Hartmann, H.T., D.E. Kester, F.T. Davies, Jr., and R.L. Geneve. 2002. *Plant Propagation: Principles and Practices.* 7th ed. Prentice Hall, Upper Saddle River, N.J.

Hernandez-Apaolaza, L., A.M. Gasco, J.M. Gasco, and F. Guerroro. 2005. Reuse of waste materials as growing media for ornamental plants. Bioresource Tech. 96:125-131.

Hicks, A. 2001. Review of global tea production and the impact on industry of the asian economic situation. FAO http://www.journal.au.edu/au_techno/2001/oct2001/article4.pdf

Klock, K. A., 1997. Growth of dianthus and petunia in media amended with composted urban waste. J. Environ. Hort. 15:135-137.

Klock-Moore, K. 1999. Growth of impatiens 'accent orange' in two compost products. Compost Sci. & Util. 7:58-62.

Klock-Moore, K.A., G.E. Fitzpatrick, and G. Zinati. 2000. Container production of ornamental horticultural crops. Biocycle 41(11):58-60.

Lu, W. 2008. Municipal waste compost as an alternative substrate. Dissertation, Auburn University, Auburn, AL.

Lu, W., J.L. Sibley, C.H. Gilliam, J.S. Bannon, and Y. Zhang. 2006. Estimation of U.S. bark generation and implications for horticultural industries. J. Environ. Hort. 24:29-34.

Lu, W., J.L. Sibley, M. Schaefer, and X. Yang. 2005. Nursery use of municipal garbage compost. Proc. SNA Res. Conf. 50:68-72.

Maronek, D.M., D. Studebaker, and B. Oberly. 1985. Improving media aeration in liner and container production. Comb. Proc. Intl. Plant Prop. Soc. 35:591-597.

Nelson, P.V. 2003. *Greenhouse Operation and Management.* 6th ed. Prentice Hall, Upper Saddle River, N.J.

Olive, J.W. Sibley, J.L., R.A. Price and J.C. Stephenson. 2005. Landscape application of a manufactured topsoil comprised of harbor dredge and biosolids. Proc. SNA Res. Conf. 50:484-485.

Papafotiou, M. J. Chronopoulos, G. Kargas, M. Voreakou, N. Leodaritis, O. Lagogiani, and S. Gazi. 2001. Cotton gin trash compost and rice hulls as growing medium components for ornamentals. J. Hort. Sci. Biotech. 76:431-435.

Sibley, J.L., C.H. Gilliam, W.G. Foshee, III, A.N. Wright, and G.B. Fain. 2005. Development of nursery crop substrates from recycled materials and composted poultry litter. Proc. SNA Res. Conf. 50:127-130.

Sibley, J.L., D.M. Cole, and W. Lu. 2004. Waste is a terrible thing to mind. Com. Proc. Int. Plant Prop. Soc. 54:596-603.

Simarny, J. P., 2007. The state of the U.S. tea industry. Tea Association of the U.S.A., Inc. http://www.teausa.com/general/002ga.cfm

Spiers, T.M., and G. Fietje. 2000. Green waste compost as a component in soilless growing media. Compost Sci. & Util. 8(1):19-23.

Tatum, D. H., and Owings, A. D. 1992. Ground tea leaves as a bedding plant medium amendment. Proc. SNA Res. Conf. 37:75-76.

Walker, P., D. Williams, and T. M. Waliczek. 2006. An analysis of the horticulture industry as a potential value-added market for compost. Compost Sci. & Util. 14(1):23-31.

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

Wright, R.D. 1984. The pour-through method: a quick and easy way to determine a medium's nutrient availability. Amer. Nurseryman 160(3):109-111.

Yeager, T.H., T. Bilderback, D. Fare, C. Gilliam, J. Lea-Cox, A. Niemiera, J. Ruter, K. Tilt, S. Warren, T. Whitwell, R. Wright. 2007. Best Management Practices: Guide for Producing Nursery Crops 2nd ed. The Southern Nursery Association. Atlanta, GA.

Yu, Z.Y., J.T. Akridge, M.N. Dana, and J. Lowenberg-DeBoer. 1990. An economical evaluation of horticultural alfalfa as a substitute for sphagnum peat moss. Agribusiness 6:443-462.

CHAPTER II

Spent Tea Grinds as a Substrate Component in Greenhouse Crop Production

Abstract

In the United States, the market for freshly brewed, ready-to-drink tea has grown exponentially in the last 20 years (Simarny, 2007). Along with generating more product, tea brewers have also produced more waste. Spent Tea Grinds (STG) are the finely ground waste product of the tea brewing process. STG's high water-holding capacity and organic nature make it a potential replacement for common substrate components such as pine bark (PB) and peat moss (PM). Two greenhouse studies were conducted to evaluate STG as a greenhouse substrate component. In the first study, *Lantana camara* 'New Gold', from 3.5-inch diameter containers, and *Nephrolepis exaltata* 'Bostoniensis', from 36-cell market flats, were placed into 6.5-inch diameter containers filled with various substrates, and grown on a raised greenhouse bench, for 10 weeks. Along with STG, a composted product was also evaluated. STG and PB were co-composted in an in-vessel composter for one week (1:1, v:v) to yield a product referred to as TBC (tea-bark-compost). Substrates containing STG or TBC were compared with a commercial greenhouse substrate (Fafard® 3B). Substrates containing 100% TBC and Fafard® 3B were evaluated with and without incorporation of a supplemental fertilizer. Substrate pH measurements were generally above a recommended range (5.8 – 6.8) for substrates

containing TBC throughout the study. Substrate pH was initially below the recommended range for the 100% STG and 50:50 PB:STG substrates in both lantana and fern. Substrate pH of 100% STG remained below the recommended range throughout the study in lantana. Substrate electrical conductivity (EC) was initially below a recommended range (1.0 – 2.6 mS/cm) for 100% TBC without supplemental fertilizer in lantana, and above the recommended range for 100% TBC and Fafard® 3B with supplemental fertilizer in fern. By the end of the study, only substrates without supplemental fertilizer had substrate EC values outside of the recommended range. No differences existed in growth index of boston ferns at 70 days after planting (DAP). Boston fern plants grown in 100% TBC with supplemental fertilizer (+F), 80:20 TBC:perlite (+F), and 50:50 PB:STG (+F) had the highest leaf chlorophyll contents at 26 DAP. At 70 DAP, boston ferns grown in 80:20 TBC:perlite (+F), 100% TBC without fertilizer (-F), 100% STG (+F), 50:50 PB:STG (+F) had the highest leaf chlorophyll contents. At 70 DAP, boston ferns grown in 100% TBC (+F), 80:20 TBC:perlite (+F), Fafard® 3B (-F), and 50:50 PB:STG (+F) had the highest shoot dry weights (SDW). Lantana grown in 100% TBC (+F), 80:20 TBC:perlite (+F), 50:50 PB:STG with fertilizer had the largest increase in growth index at 70 DAP. At 26 DAP, lantana grown in 80:20 TBC:perlite (+F) and 50:50 PB:STG (+F) had the highest leaf chlorophyll contents. At 70 DAP, lantana grown in 100% TBC (+F), 80:20 TBC:perlite (+F), and 50:50 PB:STG (+F) had the highest leaf chlorophyll contents. Lantana grown in 80:20 TBC:perlite (+F) and 50:50 PB:STG (+F) had the highest SDW. A subsequent greenhouse study was conducted to determine if pre-plant incorporated elemental sulfur could deter foliar chlorosis symptoms, observed in preliminary studies, of petunias grown in STG. *Petunia* x *hybrida* 'Dreams Mix' and *Begonia* x *semporflorens-cultorum* 'Harmony Mix' from 288-cell trays were planted into 3.5-inch diameter containers filled with various substrate blends were grown for 10 weeks in a greenhouse. Four substrate blends and two rates of agricultural grade elemental sulfur were tested. At 70 DAP, petunias grown in 70:20:10 PB:STG:Perlite, 70:20:10 PB:PM:Perlite, and 45:45:10 PB:PM:Perlite had the highest SDW and the highest visual quality ratings. No differences existed in leaf chlorophyll content of petunia at 70 DAP. At 70 DAP, begonias grown in substrates containing PM had the highest SDW and visual quality ratings. No differences in leaf chlorophyll content existed in begonia at 70 DAP.

Introduction

Pine bark (PB) and peat moss (PM) are major substrate components used in the greenhouse industry for production of ornamental plants. The steadily increasing costs of these components are of major concern to growers. Future availability of PB for horticulture production is also predictably low (Lu et al., 2006). In Europe, environmental concerns have encouraged the production and use of many PM alternatives (Robertson, 1993). In 1996, the U.S. imported 667,000 metric tons of PM which cost $173.91 per metric ton ($116 million total) (Morse, 1996). In 2006, PM imports had increased to 924,000 metric tons costing $241.34 per metric ton ($223 million total) (Jasinski, 2007). Since the majority of PM is imported from Canada (Yu et al., 1990), rising fuel costs have likely escalated this problem. These factors have led to a search for alternative substrate components. Composted green materials have proven to be beneficial substrate components in conjunction with PB (Spiers and Fietje, 2000). Many studies have shown that marketable plants can be grown in several types of substrates containing different components (Fain et al., 2008, Cole et al., 2005, Jackson et al., 2005, Sibley et al., 2005, Garcia-Gomez et al., 2002). Furthermore, Hernandez-Apaolaza et al., 2005 reported that waste materials can be reused in growing substrate to produce viable plants. Tea brewers are faced with disposal problems of their waste materials. These materials are most often dumped into landfills at the tea brewer's expense. However, composts of agroindustrial wastes, including some brewing waste products, have proven to be potential replacements for PM (Garcia-Gomez et al., 2002).

The majority of tea consumed worldwide is fresh brewed with leaves from *Camellia sinensis* (Harler, 1966). However, over the past twenty years market development for refrigerated, ready-to-use tea has grown exponentially (Simarny, 2007). Like many other rapidly developing industries, in the tea brewing business, most attention has focused on production and the bottom line with little regard for recapture of the byproducts. However, costly and inconvenient disposal of their byproduct has prompted tea brewers to search for a suitable avenue for its recapture or reuse. Finding an alternative use for this byproduct may alleviate unnecessary costs for the tea brewers and position them as more environmentally friendly.

Spent tea grinds (STG) is a term used to describe the byproduct of the tea-brewing process. STG contains finely ground tea leaves that have a high water holding capacity, with peat-like qualities, offering the potential to replace a portion of the PB or PM fractions of greenhouse substrates.

The objective of this research was to evaluate the potential uses of STG in greenhouse crop production. A series of studies were designed to assess the potential of STG as a substrate component for greenhouse production of a variety of crops.

Materials and Methods

Study 1

On 22 September 2006, seventy liners of 'New Gold' lantana (*Lantana camara* 'New Gold') from 0.38 L (3.5-inch diameter) containers and 70 liners of boston fern (*Nephrolepis exaltata* 'Bostoniensis'), from 36-cell market flats, were planted into 1.67 L (6.5-inch diameter; Dillen Products, Middlefield, OH) containers filled with various substrate blends. One plant was placed into each container. Containers were placed on a raised bench in a double layered polyethylene greenhouse. Along with STG, a composted product was also evaluated in this study. STG and PB were co-composted in an in-vessel composter (Model 616, 12 yd^3 capacity; B W Organics, Sulfur Springs, TX) for one week (1:1, v:v) to yield a product referred to as TBC (tea-bark-compost). Seven treatments were 100% TBC with supplemental fertilizer (+F), Fafard® 3B with supplemental fertilizer (+F), 80:20 TBC:perlite with supplemental fertilizer (+F), Fafard® 3B without supplemental fertilizer (-F), 100% TBC (-F), 100% STG (+F), and 50:50 STG:PB (+F). Standard horticultural grade perlite was used. For treatments containing supplemental fertilizer, 12.4 kg/m^3 (20.8 lbs/yd^3) of 12N-2.6P-4.9K (12-6-6 Nursery Special ™; 2-3 month release) was pre-plant incorporated along with 0.9 kg/m^3 (1.5 lbs/yd^3) Micromax® (The Scotts Company, Marysville, Ohio), which was added to all treatments. Growth indices of each species were measured at 1 day after planting (DAP) and 70 DAP. Leaf chlorophyll content was estimated using a SPAD-502 Chlorophyll Meter (Konica Minolta Sensing Inc., Osaka, Japan) at 26 DAP and 70 DAP. Three recently matured leaves were measured per plant. The Virginia Tech pour-thru extraction method was used to determine substrate pH and electrical conductivity (EC) of the treatments on a weekly basis (Wright, 1986). At the end of the study, tissue samples from both species were analyzed for nutrient content (Auburn University, Soil Testing Laboratory, Auburn, AL). At 70 DAP, all foliage was removed and oven-dried at 68 $^{\circ}$C (154 $^{\circ}$F) for 48 hours to determine shoot dry weight (SDW) values. This study was a completely randomized design (CRD) conducted at Paterson Greenhouse Complex in Auburn, AL. Each species was arranged as a separate experiment. Data was subjected to analysis of variance (ANOVA) in SAS and means were separated using Duncan's Multiple Range Test ($\alpha = 0.05$).

Study 2

On 28 January 2008, 80 petunias (*Petunia* x *hybrida* 'Dreams Mix') and 80 begonias (*Begonia* x *semporflorens-cultorum* 'Harmony Mix') from 288 cell plug trays, were planted into 0.4 L (3.5 in.) containers (Dillen Products, Middlefield, OH) filled with various substrate blends. Containers were placed on a raised bench in a double layered polyethylene greenhouse. Four different substrates were 70:20:10 PB:STG:perlite, 45:45:10 PB:STG:perlite, 70:20:10 PB:PM:perlite, and 45:45:10 PB:PM:perlite. All substrates were pre-plant incorporated with 0.9 kg/m^3 (1.5 lbs/yd^3) Micromax® (The Scotts Company, Marysville, Ohio), 1.19 kg/m^3 (2 lbs/yd^3) bifenthrin, and 3.0 kg/m^3 (5 lbs/yd^3) dolomitic limestone. Bifenthrin was added to control possible fungus gnat

(*Orphelia* spp.) populations. Two different rates of agricultural grade elemental sulfur (90% S; Tiger-Sul Products LLC, Atmore, AL) were also pre-plant incorporated, yielding a total of eight treatments. Four treatments contained 1.19 kg/m^3 (2 lbs/yd^3) sulfur and four treatments contained 1.79 kg/m^3 (3 lbs/yd^3) sulfur. Elemental sulfur was added to the substrates to manipulate pH and to change the chemical dynamic of the substrate.

All plants were hand watered as needed. Beginning at 1 week after planting (WAP), all plants were irrigated with a 150 parts per million (ppm) fertilizer solution (20-10-20; SDT Industries, Inc. Winnsboro, Louisiana). From 3 WAP to 10 WAP, a 300 ppm (20-10-20; SDT Industries, Inc. Winnsboro, Louisiana) solution was used to water plants as needed. Plants were watered with mineral water (without fertilizer) every fourth watering.

Substrate physical properties, including total porosity, air space, container capacity, and bulk density were determined using the NCSU Porometer (Fonteno et al. 1995). A commercial greenhouse substrate (Fafard® 3B) was analyzed for comparison. Particle size distribution (PSD) of substrates was determined by passing a 100-g air dried sample through a series of sieves with the following opening sizes: 12.5, 9.5, 6.35, 3.35, 2.36, 2.0, 1.4, 1.0, 0.5, 0.25, and 0.11 mm. Particles that passed the 0.11 mm sieve were collected in a pan. Sieves were shaken for 3 minutes with a Ro-Tap (Ro-Tap RX-29, W.S. Tyler, Mentor, OH) sieve shaker (278 oscillations/min; 159 taps/min).

At the end of the study, a visual rating scale was developed for overall plant quality. Each plant was assigned a numeric value between 1 and 5 based on the overall health and quality of the plant (1 = lowest quality; 5 = highest quality). Foliar chlorophyll content was estimated using a SPAD-502 Chlorophyll Meter (Konica Minolta Sensing Inc., Osaka, Japan). An average of the chlorophyll content of three recently matured leaves of each plant was recorded. Foliar samples were collected and analyzed for nutrient content (Auburn University, Soil Testing Laboratory, Auburn, AL). All foliage was removed and oven-dried at 68 $^{\circ}$C (154 $^{\circ}$F) for 48 hours to determine shoot dry weight (SDW) values. This study was a randomized complete block design (RCBD) conducted at the Paterson Greenhouse Complex in Auburn, AL. Each species was arranged as a separate experiment. For each species there were ten blocks containing eight plants each. Data was subjected to analysis of variance (ANOVA) in SAS and means were separated using Tukey's Studentized Range Test ($\alpha = 0.05$).

Results and Discussion

Study 1

pH and EC

Initial substrate pH was high for substrates containing TBC in lantana and boston fern (Table 1) (recommended range: 5.8-6.8; Cavins et al., 2000). At 63 DAP, substrate EC of 100% TBC (+F) and 100% TBC (-F) barely fell into the recommended range while substrate pH of 80:20 TBC:perite (+F) remained above the recommended range in lantana. All substrates containing TBC had pH values above the recommended range at 63 DAP in boston fern. High pH values for substrates containing composts have been previously reported. Wilson et al. (2001) reported pH values as high as 7.1 for substrates containing100% (by volume) composted biosolids and yard trimmings. Garcia-Gomez et al. (2002) reported substrate pH values between 7.54 and 8.05 for substrates containing

100% (by volume) composted brewing wastes (malt + yeast), lemon tree prunings, olive leaves, and the solid fraction of olive mill waste water. Hernandez-Apaolaza et al. (2005) reported substrate pH values as high as 7.6 for a PB-based substrate amended with only 30% (by volume) composted sewage sludge. 100% STG (+F) and 50:50 PB:STG (+F) substrates had low initial pH values in lantana and boston fern. At 63 DAP, substrate pH of 100% STG (+F) remained below the recommended range in lantana, but was within the recommended range in boston fern. Substrate pH of 50:50 PB:STG (+F) fell within the acceptable range in both lantana and fern at 63 DAP.

High soluble salt levels contained in composts have led to high substrate EC values in previous studies. Jackson et al. (2005) reported initial substrate EC measurements as high as 9.1 mS/cm for substrates containing 64% (by volume) cotton gin compost. Chong and Cline (1993) reported initial substrate EC measurements between 6.2 and 7.6 mS/cm for substrates containing only 30% (by volume) paper mill sludge, while Hernandez-Apaolaza et al. (2005) reported initial substrate EC measurements between 8.2 and 9.3 mS/cm for substrates containing only 30% (by volume) composted sewage sludge. Exceedingly high substrate EC values were not recorded during this study. Initial substrate EC measurements in lantana were all within an acceptable range with the exception of 100% TBC (-F), which was slightly below the recommended range (Table 1) (recommended range: 1.0-2.6 mS/cm; Cavins et al. 2000). All substrate EC values were acceptable in boston fern with the exception of 100% TBC (+F), which was above the recommended range, at 7 DAP. At 63 DAP, substrate EC values were below the recommended range for 100% TBC (-F) and Fafard® 3B (-F) in both lantana and fern. All other substrate EC values were within the acceptable range at 63 DAP in both species.

Boston Fern

Boston fern exhibited similar growth in all treatments (Table 2).

Leaf chlorophyll content at 26 DAP was highest in plants grown in 80:20 TBC:perlite (+F), 100% TBC (+F), and 50:50 STG:PB (+F), while plants grown in 100% TBC (-F) and 100% STG (+F) had the lowest leaf chlorophyll contents. At 70 DAP, leaf chlorophyll content of boston fern was highest in plants grown in 80:20 TBC:perlite (+F), 50:50 STG:PB (+F), 100% TBC (-F), and 100% STG (+F), while those grown in Fafard® 3B (-F) and Fafard® 3B (+F) had the lowest leaf chlorophyll contents.

Where different, shoot dry weights (SDW) for boston ferns grown in 50:50 STG:PB (+F) were highest at 70 DAP. Those grown in 100% TBC (+F), 80:20 TBC:perlite (+F), and Fafard® 3B (-F) had similar SDW.

Lantana

Lantana exhibited superior growth in 100% TBC (+F), 80:20 TBC:perlite (+F), and 50:50 STG:PB (+F) (Table 3). Plants grown in Fafard® 3B (-F) and 100% TBC (-F) had the lowest increase in growth index at 70 DAP.

At 26 DAP, leaf chlorophyll content was highest in lantana grown in 80:20 TBC:perlite (+F) and 50:50 STG:PB (+F). Plants grown in 100% TBC (-F) had the lowest leaf chlorophyll contents at 26 DAP. At 70 DAP, plants grown in 50:50 STG:PB (+F) and 80:20 TBC:perlite (+F) had the highest leaf chlorophyll contents. Lantana had the highest SDW when grown in 80:20 TBC:perlite (+F) and 50:50 STG:PB (+F). Plants grown in Fafard® 3B (+F), Fafard® 3B (-F), 100% TBC (-F), and 100% STG (+F) had the lowest SDW at 70 DAP (Figure 1).

Growth results from this study were consistent with previously conducted studies. Garcia-Gomez et al. (2002) reported that greenhouse-grown marigolds had the highest shoot fresh weights (SFW) when grown in substrates containing up to 75% (by volume) composts containing brewing wastes (malt + yeast), lemon tree prunings, olive leaves, and the solid fraction of olive mill wastewater when combined with sphagnum peat moss (PM) or a commercial greenhouse substrate. Klock (1997) reported that growth of petunia and dianthus was greatest in a substrate containing 60% (by volume) composted yard trimmings and biosolids. In a later study, Klock-Moore (1999) reported that shoot dry weight (SDW) and growth index (GI) of impatiens increased linearly as the percentage of composted biosolids contained in a PM, vermiculite, perlite substrate increased. Growth of impatiens was greatest in 100% compost. Wilson et al. (2001) reported that no differences in GI and leaf chlorophyll content (SPAD) existed between golden shrimp plants grown in PM-based substrates containing (by volume) 0, 25, 50, 75, and 100% composted biosolids and yard trimmings.

Foliar Analysis

According to Mills and Jones, (1996) sufficiency ranges for plant macronutrients based on foliar analyses of boston fern are as follows: nitrogen (2.1-3.0 %), phosphorus (0.25-0.7 %), and potassium (1.6-3.8 %). Foliar nitrogen contents of boston ferns were highest for those grown in 80:20 TBC:perlite (+F), 100% STG (+F), 100% TBC (-F), and 50:50 PB:STG (+F), and lowest for those grown in Fafard® 3B (+F) and Fafard® 3B (-F)

(Table 4). Foliar nitrogen contents of boston ferns grown in Fafard® 3B (+F) and Fafard® 3B (-F) were below the given sufficiency range, while those grown in 80:20 TBC:perlite (+F), 100% TBC (-F), 100% STG (+F), and 50:50 PB:STG (+F) were slightly above the given sufficiency range. Foliar phosphorus contents were highest for boston ferns grown in substrates containing TBC or STG and were lowest for those grown in Fafard® 3B (-F). Foliar phosphorus content was slightly above the recommended sufficiency range for boston ferns grown in all substrates containing TBC and 50:50 PB:STG (+F). Foliar potassium content was highest for boston ferns grown in substrates containing TBC and was lowest in those grown in Fafard® 3B (-F), 100% STG (+F), and 50:50 PB:STG (+F). Boston ferns grown in Fafard® 3B (-F) and 100% STG (+F) had foliar potassium contents that were slightly below the given sufficiency range. Foliar calcium and magnesium contents fell into the given sufficiency ranges for boston ferns grown in all treatments.

Sufficiency ranges for foliar micronutrient contents of boston fern are: iron [28-300 parts per million (ppm)], manganese (27-200 ppm), and zinc (33-65 ppm) (Mills and Jones, 1996). Foliar iron contents of boston ferns grown in all treatments fell into the given sufficiency range (Table 5). Foliar manganese contents of boston ferns grown in substrates containing STG were higher than those grown in any other substrate and were well above the given sufficiency range. Foliar zinc contents were highest in boston ferns grown in 50:50 PB:STG (+F) and were above the given sufficiency range in those grown in 100% STG (+F) and 50:50 PB:STG (+F). No foliar nutrient sufficiency ranges are given for lantana, however it was apparent that foliar manganese content of lantana was also exceedingly high when grown in substrates containing STG. According to Mengel and Kirkby (2001), excessive manganese can lead to iron deficiency. Furthermore, Lee et al. (1992) reported that foliar chlorophyll, as well as, foliar iron content of petunia decreased with increasing concentrations of manganese. While no iron deficiency symptoms were observed in this study, excessive manganese content of STG may have induced iron deficiency symptoms in annual crops grown in previous and subsequent studies (Appendix A; Tables A2 and A7).

A substrate containing 80% (by volume) TBC or 50% (by volume) STG can produce *Lantana camara* 'New Gold' of similar or greater size and quality to those grown in Fafard® 3B. A substrate containing 100% (by volume) TBC or 50% (by volume) STG can be used to produce *Nephrolepis exaltata* 'Bostoniensis' of similar size and quality to those grown in Fafard® 3B.

Study 2

Physical Properties

No universally accepted parameters exist for physical properties of greenhouse substrates. Poole et al. (1981) suggested the following: 5-20 % air space (AS), 20-60 % container capacity (CC), and 0.3-0.75 g/cm^3 bulk density (BD). Other suggested parameters were given by Jenkins and Jarrell (1989): 60-75 % total porosity (TP), 50-65 % CC, and 10-20% AS. Yeager et al. (2007) recommended the following physical property parameters for nursery substrates: 50-85 % TP, 10-30 % AS, 45-65 % CC, and 0.19-0.70 g/cm^3 BD.

45:45:10 PB:STG:Perlite and Fafard® 3B had the highest TP (Table 6). Since substrates containing 70:20:10 PB:STG:Perlite and 70:20:10 PB:PM:Perlite had the highest percentage of coarse (>3.35 mm) particles (Table 7), they possessed the lowest TP and CC, while having the highest AS (Table 6). 45:45:10 PB:STG:Perlite had the highest percentage of fine particles (<1.00 mm), the lowest percentages of both coarse (>3.35 mm) and medium textured particles (<3.35 mm >1.00 mm) (Table 7), the highest CC, along with Fafard® 3B (Table 6), and the lowest percent AS along with Fafard® 3B and 45:45:10 PB:PM:Perlite. As the percentage of STG contained in the substrate increased, TP and CC increased while AS decreased. Similarly, as the percentage of PM contained in the substrate increased, CC increased and AS decreased. However, particle size distribution was not affected as profoundly by PM as by STG. 45:45:10 PB:PM:Perlite had less fine particles than 45:45:10 PB:STG:Perlite. Furthermore, there was no difference between the percentage of fine particles contained in 70:20:10 PB:PM:Perlite versus 45:45:10 PB:PM:Perlite. Fafard® 3B had the lowest BD while substrates containing STG had the highest BD.

Petunia

Petunias grown in 70:20:10 PB:PM:Perlite, 70:20:10 PB:STG:Perlite, and 45:45:10 PB:PM:Perlite had the highest SDW, while those grown in 45:45:10 PB:STG:Perlite had the lowest SDW at 70 DAP (Table 8). Petunias grown in all substrates had similar leaf chlorophyll contents. Sulfur incorporation rate did not affect SDW or leaf chlorophyll content. Petunias grown in 70:20:10 PB:STG:Perlite, 70:20:10 PB:PM:Perlite, and 45:45:10 PB:PM:Perlite had the highest visual quality ratings, while those grown in 45:45:10 PB:STG:Perlite were similar to those grown in 45:45:10 PB:PM:Perlite (Figure 2). Petunias grown in treatments containing 2 lbs/yd^3 incorporated elemental sulfur had significantly higher quality ratings than plants grown in treatments containing 3lbs/yd^3 incorporated elemental sulfur.

Begonia

At 70 DAP, begonias grown in 70:20:10 PB:PM:Perlite and 45:45:10 PB:PM:Perlite had the highest SDW (Table 9). Begonias grown in 70:20:10 PB:STG:Perlite and 45:45:10 PB:STG:Perlite had the lowest SDW. Begonias grown in all substrates had similar leaf chlorophyll contents. Begonias grown in 70:20:10 PB:PM:Perlite and 45:45:10 PB:PM:Perlite had the highest quality ratings, while those grown in 45:45:10 PB:STG:Perlite had the lowest (Figure 3). Begonias grown in 70:20:10 PB:STG:Perlite were of similar visual quality as those grown in 70:20:10 PB:PM:Perlite. Rate of incorporation of sulfur was not significant for SDW, leaf chlorophyll content, or quality ratings.

Similar results were reported in previous studies. Evans (2004) reported that no differences in SDW and root dry weight (RDW) of vinca, coleus, and tomato existed when up to 30% (by volume) processed poultry feather fiber was added to PM-based or commercial substrates. Wilson et al. (2001) reported a linear decrease in SDW of golden shrimp plant when PM and coir-based substrates were amended with more than 50% (by volume) composted biosolids and yard clippings. In 2000, Spiers and Fietje reported that green waste compost could only replace 30% (by volume) of a traditional PB substrate before decreasing SDW of tomato.

Foliar Analysis

Mills and Jones (1996) suggest the following foliar micronutrient content sufficiency ranges for petunia: copper [3-19 parts per million (ppm)], iron (84-168 ppm), manganese (44-177 ppm), and zinc (33-85 ppm). Foliar copper contents of petunias grown in all treatments were within the suggested sufficiency range (Table 10). Foliar copper content of petunia was highest in 70:20:10 PB:STG:Perlite, 45:45:10 PB:STG:Perlite, and 45:45:10 PB:PM:Perlite, and was lowest in 70:20:10 PB:PM:Perlite. In previous studies evaluating STG for production of petunia, foliar chlorosis (Figure 3) was evident and attributed to high foliar manganese contents, which may have caused iron-deficiency symptoms (Appendix A; Tables A2 and A7). No differences in foliar iron, manganese, or zinc contents were observed while all values fell into the suggested sufficiency ranges. Sulfur incorporation rate was not significant. Petunias grown in STG showed no foliar chlorosis symptoms (Figure 4).

Up to 20% (by volume) STG can be used to replace PM in greenhouse production of *Petunia* x *hybrida* ‘Dreams Mix’. Incorporated elemental sulfur at 2 lbs/yd^3 lowered foliar manganese contents and alleviated foliar chlorosis symptoms previously observed in petunias grown in STG.

Literature Cited

Cavins, T.J., B.E. Whipker, W.C. Fonteno, B. Harden, I. McCall, and J.L. Gibson. 2000. Monitoring and managing pH and EC using the pourthru extraction method. N.C. State Univ. Coop. Ext. Hort. Info. Leaflet 590.

Cole, D.M., J.L. Sibley, E.K. Blythe, D.J. Eakes, and K.M. Tilt. 2005. Effect of cotton gin compost on substrate properties and growth of azalea under differing irrigation regimes in a greenhouse setting. HortTechnology 15:145-148.

Evans, M.R. 2004. Processed poultry feather fiber as an alternative to peat in greenhouse crops substrates. HortTechnology 14:176-179.

Fain, G.B., C.H. Gilliam, J.L. Sibley, C.R. Boyer, and A.L. Witcher. 2008. WholeTree substrate and fertilizer rate in production of greenhouse-grown petunia and marigold. HortScience 43:700-705.

Fonteno, W.C., C.T. Hardin, and J.P. Brewster. 1995. Procedures for determining physical properties of horticultural substrates using the NCSU Porometer. Horticultural Substrates Laboratory. North Carolina State University.

Garcia-Gomez A., M.P. Bernal, and A. Roig. 2002. Growth of ornamental plants in two composts prepared from agroindustrial wastes. Bio Tech. 83:81-87.

Harler, C.R. 1966. Tea growing. Oxford University Press.

Hernandez-Apaolaza, L., A.M. Gasco, J.M. Gasco, and F. Guerroro. 2005. Reuse of waste materials as growing media for ornamental plants. Bioresource Tech. 96:125-131.

Jackson, B.E., A.N. Wright, D.M. Cole, and J.L. Sibley. 2005. Cotton gin compost as a substrate component in container production of nursery crops. J. Environ. Hort. 23:118-122.

Jasinski, S.M. 2007. Peat - U.S. Geological Survey Minerals Yearbook. 7 Oct. 2007. http://minerals.usgs.gov/minerals/pubs/commodity/peat/myb1-2006-peat.pdf

Jenkins, J.R. and W.M. Jarrell. 1989. Predicting physical and chemical properties of container mixtures. HortScience 24:292-295.

Klock, K. A., 1997. Growth of dianthus and petunia in media amended with composted urban waste. J. Environ. Hort. 15:135-137.

Klock-Moore, K. 1999. Growth of impatiens ‘accent orange’ in two compost products. Compost Sci. & Util. 7:58-62.

Lee, C.W., C.H. Pak, J.M. Choi, and J.R. Self. 1992. Induced micronutrient toxicity in petunia hybrida. J. Plant Nutr. 15:327-339.

Lu, W., J.L. Sibley, C.H. Gilliam, J.S. Bannon, and Y. Zhang. 2006. Estimation of U.S. bark generation and implications for horticultural industries. J. Environ. Hort. 24:29-34.

Mengel, K. and Kirkby, E.A. 2001. Manganese. *In*: Principles of plant nutrition 5th ed. Kluwer Academic Publishers, Dordrecht, The Netherlands.

Mills, H.A., and J.B. Jones, Jr. 1996. Plant analysis handbook II: a practical sampling, preparation, analysis, and interpretation guide. Micromacro Publishing, Inc.

Morse, D.E. 1996. Peat – U.S. Geological Survey Minerals Information. http://minerals.usgs.gov/minerals/pubs/commodity/peat/510496.pdf

Poole, R.T., C.A. Conover, and J.N. Joiner. 1981. Soils and potting mixtures. *In*: J.N. Joiner (Ed.). Foliage plant production. Prentice Hall. Englewood Cliffs, NJ.

Robertson, A. 1993. Peat, horticulture, and environment. Biodiv. Conserv. 2:541-547.

Sibley, J.L., C.H. Gilliam, W.G. Foshee, III, A.N. Wright, and G.B. Fain. 2005. Development of nursery crop substrates from recycled materials and composted poultry litter. Proc. SNA Res. Conf. 50:127-130.

Spiers, T.M., and G. Fietje. 2000. Green waste compost as a component in soilless growing media. Compost Sci. & Util. 8: 19-23.

Tatum, D. H., and Owings, A. D., 1992. Ground tea leaves as a bedding plant medium amendment. Proc. SNA Res. Conf. 37:75-76.

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

Wilson, S.B., P.J. Stoffella, and D.A. Graetz. 2001. Evaluation of compost as an amendment to commercial mixes used for container-grown golden shrimp plant production. HortTechnology 11:31-35.

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

Yeager, T.H., T. Bilderback, D. Fare, C. Gilliam, J. Lea-Cox, A. Niemiera, J. Ruter, K. Tilt, S. Warren, T. Whitwell, R. Wright. 2007. Best management practices: guide for producing nursery crops 2nd ed. The Southern Nursery Association. Atlanta, GA.

Yu, Z.Y., J.T. Akridge, M.N. Dana, and J. Lowenberg-DeBoer. 1990. An economical evaluation of horticultural alfalfa as a substitute for sphagnum peat moss. Agribusiness 6:443-462.

Table 1. Substrate pH and EC measurements in *Lantana camara* 'New Gold' and *Nephrolepis exaltata* 'Bostoniensis'.

Treatment[Z]	pH				EC[Y]			
	Lantana		Fern		Lantana		Fern	
	7 DAP[X]	63 DAP	7 DAP	63 DAP	7 DAP	63 DAP	7 DAP	63 DAP
100% TBC w/ fertilizer	6.9a	6.8a	7.0a	6.9a	1.5abc	1.4bc	3.4a	2.4a
100% Fafard 3B w/ fertilizer	6.2b	6.0b	6.2b	6.2b	1.7ab	1.5b	2.7ab	2.1ab
80:20 TBC:Perlite w/ fertilizer	7.0a	7.0a	6.9a	7.0a	2.5a	2.0ab	2.5bc	2.3a
100% Fafard 3B no fertilizer	6.0b	5.8bc	6.1b	6.2b	1.5abc	0.6d	1.1de	0.6c
100%TBC no fertilizer	7.0a	6.8a	7.0a	7a	0.9bc	0.8cd	1.2de	0.7c
100% STG w/ fertilizer	4.6d	5.5c	4.9c	6.1b	2.5a	1.8b	1.8cd	1.6b
50:50 PB:STG w/ fertilizer	5.6c	5.9b	5.1c	6.3b	2.5a	2.4a	2.3bc	1.5b

[Z]Treatments were: STG = spent tea grinds; PB = pine bark; TBC = composted STG:PB (1:1, v:v).

[Y]EC = electrical conductivity measured in milliSiemens per centimeter.

[X]DAP = days after planting.

Table 2. Effects of various substrates on growth of *Nephrolepis exaltata* 'Bostoniensis'.

Treatment[Z]	Growth Index[Y]	SPAD[X]		Dry Weights (g)
	70 DAP[W]	26 DAP	70 DAP	70 DAP
100% TBC w/ fertilizer	22.5a[V]	31.9ab	31.9b	8.2ab
100% Fafard 3B w/ fertilizer	21.2a	28.7b	22.9c	6.0b
80:20 TBC:Perlite w/ fertilizer	22.2a	35.6a	40.7a	7.4ab
100% Fafard 3B no fertilizer	18.4a	27.6b	17.4c	6.8ab
100%TBC no fertilizer	18.4a	17.5c	35.0ab	5.6b
100% STG w/ fertilizer	18.5a	19.8c	35.8ab	5.1b
50:50 PB:STG w/ fertilizer	20.9a	33.5ab	41.0a	9.8a

[Z]Treatments were: STG = spent tea grinds; PB = pine bark; TBC = composted STG:PB (1:1, v:v).

[Y]Growth Index = (Height + Widest Width + Perpendicular Width) / 3.

[X]Leaf chlorophyll content was estimated using a SPAD-502 chlorophyll meter (Konica Minolta Sensing Inc., Osaka, Japan).

[W]DAP = days after planting.

[V]Values in column followed by different letters are significant according to Duncan's Multiple Range Test (α = 0.05).

Table 3. Effects of various substrates on growth of *Lantana camara* 'New Gold'.

Treatment[Z]	Growth Index[Y]	SPAD[X]		Dry Weights (g)
	70 DAP[W]	26 DAP	70 DAP	70 DAP
100% TBC w/ fertilizer	22.7a[V]	39.0bc	43.8abc	8.5b
100% Fafard 3B w/ fertilizer	12.7bc	36.3cd	30.6d	5.5c
80:20 TBC:Perlite w/ fertilizer	20.9a	42.6a	47.1ab	11.8a
100% Fafard 3B no fertilizer	6.6c	35.2de	25.8d	4.2c
100%TBC no fertilizer	6.3c	27.2f	41.1bc	3.1c
100% STG w/ fertilizer	14.3b	32.8e	39.7c	4.5c
50:50 PB:STG w/ fertilizer	25.5a	39.9ab	47.7a	9.5ab

[Z]Treatments were: STG = spent tea grinds; PB = pine bark; TBC = composted STG:PB (1:1, v:v).

[Y]Growth Index = (Height + Widest Width + Perpendicular Width) / 3.

[X]Leaf chlorophyll content was estimated using a SPAD-502 chlorophyll meter (Konica Minolta Sensing Inc., Osaka, Japan).

[W]DAP = days after planting.

[V]Values in column followed by different letters are significant according to Duncan's Multiple Range Test (α = 0.05).

Table 4. Foliar macronutrient content of *Lantana camara* 'New Gold' and *Nephrolepis exaltata* 'Bostoniensis'.

Treatment[Z]	Nitrogen (%)		Phosphorus (%)		Potassium (%)		Calcium (%)		Magnesium (%)	
	Lantana	Fern	Lantana	Fern	Lantana	Fern	Lantana	Fern	Lantana	Fern
	70 DAP[Y]									
100% TBC w/ fertilizer	2.8a[X]	2.8b	0.74ab	0.80a	1.49ab	2.01a	1.24ab	0.80ab	0.80a	0.88bc
100% Fafard 3B w/ fertilizer	1.1bc	1.2c	0.37cd	0.59b	1.07ab	1.63bc	1.45a	0.69abc	0.79a	0.93ab
80:20 TBC:Perlite w/ fertilizer	2.5ab	3.1ab	0.54bc	0.78a	1.54a	1.91ab	1.03bc	0.64bc	0.78a	0.86c
100% Fafard 3B no fertilizer	1.0c	0.7c	0.22d	0.28c	0.99b	1.48c	1.18abc	0.57c	0.76ab	0.93ab
100%TBC no fertilizer	2.8a	3.1ab	0.50bc	0.82a	1.46ab	2.02a	0.90c	0.67abc	0.69b	0.86c
100% STG w/ fertilizer	3.2a	3.6a	0.65ab	0.69ab	1.23ab	1.58c	1.14bc	0.79ab	0.76ab	0.92abc
50:50 PB:STG w/ fertilizer	3.6a	3.8a	0.88a	0.81a	1.25ab	1.6c	1.10bc	0.86a	0.8a	0.88abc

[Z]Treatments were PB = pine bark, TBC = spent tea grinds and bark composted; fertilizer is 3 lbs N/yd^3 (12-6-6); STG = spent tea grinds.

[Y]DAP = days after planting.

[X]Values in column followed by different letters are significant according to Duncan's Multiple Range Test (α = 0.05).

Table 5. Foliar micronutrient content of *Lantana camara* 'New Gold' and *Nephrolepis exaltata* 'Bostoniensis'.

Treatment[Z]	Iron[Y]		Manganese[Y]		Zinc[Y]	
	Lantana	Fern	Lantana	Fern	Lantana	Fern
	70 DAP[X]					
100% TBC w/ fertilizer	127.9a[W]	90.5abc	311.1c	154.0c	146.5a	60.2b
100% Fafard 3B w/ fertilizer	239.4a	64.6bc	350.0bc	117.4c	186.7a	65.0b
80:20 TBC:Perlite w/ fertilizer	143.4a	135.2a	262.8c	129.6c	155.3a	64.0b
100% Fafard 3B no fertilizer	161.9a	54.8c	185.9c	97.3c	173.8a	61.2b
100%TBC no fertilizer	184.7a	99.1abc	207.6c	168.6c	153.4a	63.8b
100% STG w/ fertilizer	198.0a	104.8abc	540.6b	293.4b	182.5a	66.1b
50:50 PB:STG w/ fertilizer	172.6a	122.8ab	917.0a	523.7a	198.9a	80.9a

[Z]Treatments were: STG = spent tea grinds; PB = pine bark; TBC = composted STG:PB (1:1, v:v); fertilizer was 3 lbs/yd^3 N (12-6-6).

[Y]Values given in parts per million.

[X]DAP = days after planting.

[W]Values in column followed by different letters are significant according to Duncan's Multiple Range Test (α = 0.05).

Table 6. Physical characteristics[Z] of five substrates.

Treatment[Y]	Total Porosity	Container Capacity	Air Space	Bulk Density
	% Pore Space	% Water	% Air	g/cm^3
100% Fafard 3B	80.8ab[X]	66.5a	14.3b	0.13d
70:20:10 PB:STG:Perlite	77.8c	56.7c	21.1a	0.18a
45:45:10 PB:STG:Perlite	81.1a	67.2a	13.9b	0.18a
70:20:10 PB:PM:Perlite	76.5c	54.7c	21.7a	0.17b
45:45:10 PB:PM:Perlite	78.7bc	61.9b	16.7b	0.15c

[Z]Physical characteristics were determined using the NC State Porometer.

[Y]Treatments were PB = pine bark ; STG = spent tea grinds ; PM = peat moss.

[X]Values in column followed by different letters are significant according to Tukey's Studentized Range Test ($\alpha = 0.05$).

Table 7. Particle size analysis of four substrates.

U.S. standard sieve no.	Sieve opening (mm)	Substrate[Z] 70:20:10 PB:STG:P	45:45:10 PB:STG:P	70:20:10 PB:PM:P	45:45:10 PB:PM:P
1/2	12.5	0.00a[YX]	0.00a	0.00a	0.00a
3/8	9.50	0.00a	0.00a	0.00a	0.00a
1/4	6.35	6.09a	2.55b	5.99a	3.49b
6	3.35	25.97a	14.10b	23.47a	22.17a
8	2.36	15.11a	9.45b	13.90a	14.18a
10	2.00	5.65a	3.67c	4.99b	5.12ab
14	1.40	13.53a	8.88c	10.95b	11.57b
18	1.00	13.19a	11.58b	8.92d	9.87c
35	0.50	15.21b	33.34a	15.76b	15.36b
60	0.25	3.54c	13.92a	8.93b	8.89b
140	0.11	0.78d	2.19c	4.17b	5.32a
270	0.05	0.00c	0.19c	1.53b	2.13a
pan	0.00	0.93a	0.13a	1.39a	1.89a
Texture[WX]					
Coarse		32.06a	16.63c	29.46ab	25.67b
Medium		47.48a	33.59c	38.76b	40.73b
Fine		20.46c	49.78a	31.78b	33.60b

[Z]Substrates were: PB = pine bark; STG = spent tea grinds; PM = peat moss; P = horticultural grade perlite.

[Y]Percent weight of samples collected on each screen.

[X]Values in column followed by different letters are significant according to Tukey's Studentized Range Test (α = 0.05).

[W]Coarse = > 3.35 mm; medium = > 1.00 mm - < 3.35 mm; fine = < 1.00 mm.

Table 8. Effects of substrate and incorporated sulfur on final growth of *Petunia* x *hybrida* 'Dreams Mix'.

Treatment	Shoot Dry Weight (g)	SPAD[Z]	Visual Quality Rating[Y]
Substrate[X]			
70:20:10 PB:STG:Perlite	4.514a[W]	43.20a	3.65a
70:20:10 PB:PM:Perlite	5.016a	43.43a	3.45a
45:45:10 PB:STG:Perlite	2.981b	43.48a	2.65b
45:45:10 PB:PM:Perlite	5.214a	41.66a	3.15ab
Incorporated Elemental Sulfur[V]			
2 lbs/yd^3	4.489a	43.81a	3.45a
3 lbs/yd^3	4.409a	42.04a	2.98b
Significance[U]			
Substrate	***	NS	**
Incorporated Elemental Sulfur	NS	NS	*
Substrate x Incorporated Elemental Sulfur	NS	NS	NS

[Z]Leaf chlorophyll content measured using a SPAD-502 Chlorophyll Meter (Konica Minolta Inc., Tokyo, Japan).

[Y]Quality Rating Scale was: 1 = lowest quality; 5 = highest quality.

[X]Substrates were: PB = pine bark; STG = spent tea grinds; PM = peat moss; Perlite = horticultural grade perlite.

[W]Values in column followed by different letters are significant according to Tukey's Studentized Range Test (α = 0.05).

[V]Agricultural Grade Elemental Sulfur (90% S).

[U]Significance denoted as: NS = not significant; * = significant at 0.05 level; ** = significant at 0.01 level; *** significant = at 0.001 level.

Table 9. Effects of substrate and incorporated sulfur on final growth of *Begonia* x *semperflorens-cultorum* 'Harmony Mix'.

Treatment	Shoot Dry Weight (g)	SPAD[Z]	Visual Quality Rating[Y]
Substrate[X]			
70:20:10 PB:STG:Perlite	1.969b[W]	44.32a	2.60bc
70:20:10 PB:PM:Perlite	2.384a	43.18a	3.10ab
45:45:10 PB:STG:Perlite	1.899b	44.57a	2.30c
45:45:10 PB:PM:Perlite	2.661a	45.37a	3.45a
Incorporated Elemental Sulfur[V]			
2 lbs/yd^3	2.271a	44.74a	2.90a
3 lbs/yd^3	2.185a	43.98a	2.83a
Significance[U]			
Substrate	***	NS	***
Incorporated Elemental Sulfur	NS	NS	NS
Substrate x Incorporated Elemental Sulfur	NS	NS	NS

[Z]Leaf chlorophyll content measured using a SPAD-502 Chlorophyll Meter (Konica Minolta Inc., Tokyo, Japan).

[Y]Quality Rating Scale was: 1 = lowest quality; 5 = highest quality.

[X]Substrates were: PB = pine bark; STG = spent tea grinds; PM = peat moss; Perlite = horticultural grade perlite.

[W]Values in column followed by different letters are significant according to Tukey's Studentized Range Test (α = 0.05).

[V]Agricultural Grade Elemental Sulfur (90% S).

[U]Significance denoted as: NS = not significant; * = significant at 0.05 level; ** = significant at 0.01 level; *** significant = at 0.001 level.

Table 10. Effect of substrate and incorporated elemental sulfur on selected foliar micronutrient contents of *Petunia* x *hybrida* 'Dreams Mix'.

Treatment	Micronutrient			
	Cu	Fe	Mn	Zn
	ppm[Z]			
Substrate[Y]				
70:20:10 PB:STG:Perlite	6.83a[X]	127.3a	146.5a	37.17a
70:20:10 PB:PM:Perlite	4.83b	156.3a	132.3a	35.67a
45:45:10 PB:STG:Perlite	7.17a	126.8a	166.3a	35.17a
45:45:10 PB:PM:Perlite	6.00a	143.2a	146.7a	31.50a
Incorporated Elemental Sulfur[W]				
2 lbs/yd^3	6.42a	140.9a	150.8a	36.42a
3 lbs/yd^3	6.00a	135.9a	145.1a	33.33a
Significance[V]				
Substrate	*	NS	NS	NS
Incorporated Elemental Sulfur	NS	NS	NS	NS
Substrate x Incorporated Elemental Sulfur	NS	NS	NS	NS

[Z]ppm = parts per million.

[Y]Substrates were: PB = pine bark; STG = spent tea grinds; PM = peat moss; Perlite = horticultural grade perlite.

[X]Values in column followed by different letters are significant according to Tukey's Studentized Range Test (α = 0.05).

[W]Agricultural Grade Elemental Sulfur (90% S).

[V]Significance denoted as: NS = not significant; * = significant at 0.05 level; ** = significant at 0.01 level; *** significant = at 0.001 level.

Figure 1. Comparison of *Lantana camara* 'New Gold' grown in various substrate blends. Substrates were: PB = pine bark; STG = spent tea grinds; TBC = PB:STG co-composted (1:1; v:v); Perlite = horticultural grade perlite.

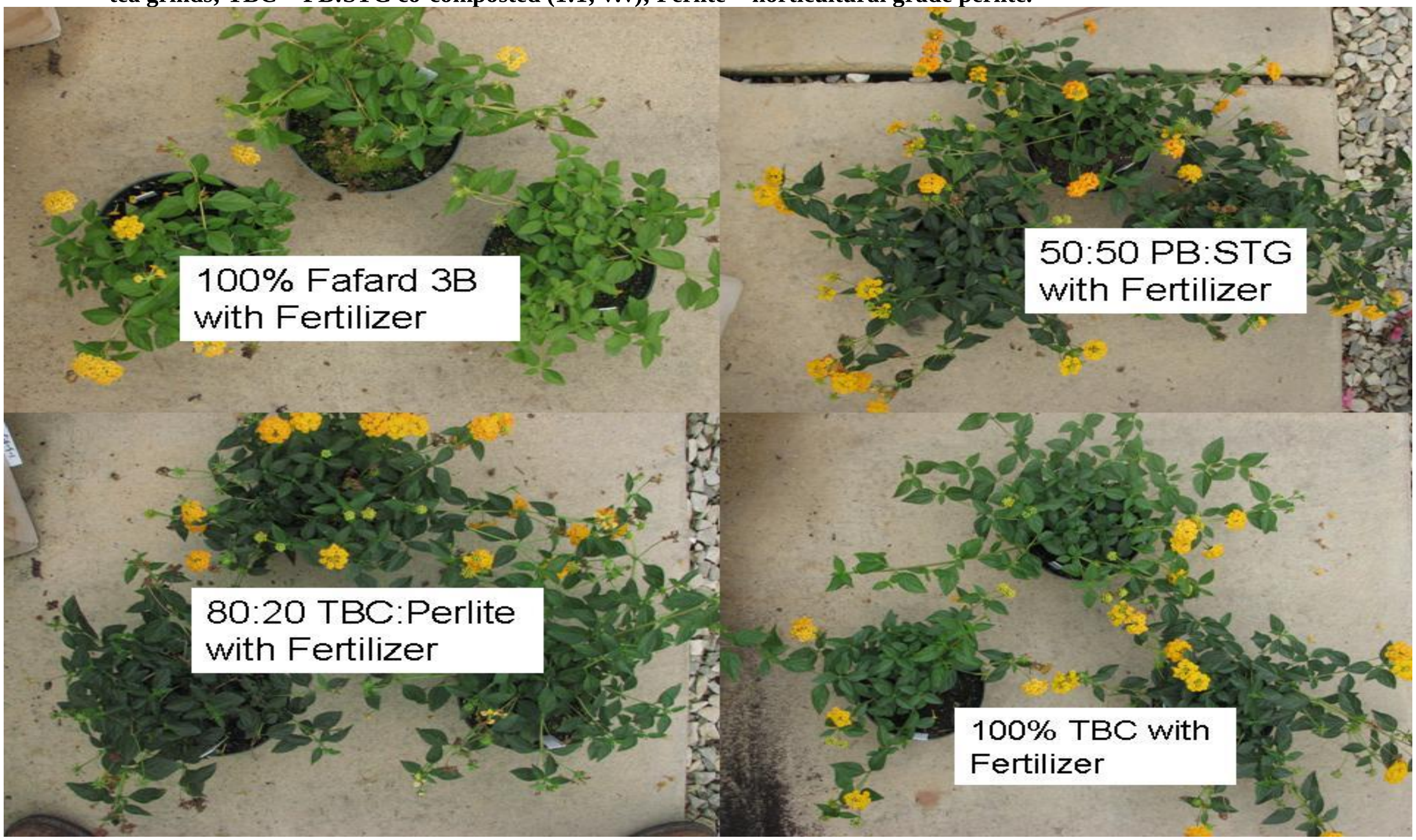


Figure 2. Comparison of Petunia x hybrida 'Dreams Mix' grown in substrates comprised of pine bark, spent tea grinds, and perlite.

Figure 3. Foliar chlorosis symptoms of Petunia x hybrida 'Dreams Pink' grown in a substrate containing pine bark, spent tea grinds, and perlite.

Figure 4. Effect of incorporated elemental sulfur on foliar chlorosis symptoms in Petunia x hybrida 'Dreams Mix' grown in a substrate containing pine bark, spent tea grinds, and perlite.

Chapter III

Spent Tea Grinds as a Substrate Component in Nursery Crop Production

Abstract

In the United States, the market for freshly brewed, ready-to-drink tea has grown exponentially in the last 20 years (Simarny, 2007). Along with generating more product, tea brewers have also produced more waste. Spent Tea Grinds (STG) are the finely ground waste product of the tea brewing process. STG's high water-holding capacity and organic nature make it a potential replacement for common substrate components such as pine bark (PB) and peat moss (PM). Two container production studies were conducted to evaluate STG as a substrate component in nursery crop production. In the first study, *Lagerstroemia indica* 'Tuscarora', *Loropetalum chinense* 'Chang's Ruby', *Nandina domestica* 'Fire Power', and *Rhododendron* x 'Micrantha Pink' were potted from trade gallon liners into 3-gallon containers filled with five substrates composed of PB and/or STG (100% PB, 75:25 PB:STG, 50:50 PB:STG, 25:75 PB:STG, and 100% STG). Plants were placed outside in full sun under overhead irrigation for 168 days. Substrate pH remained within an acceptable range throughout the study. Substrate electrical conductivity (EC) measurements were within an acceptable range at the beginning of the study, but fell below an acceptable range in substrates containing 50% or greater (by volume) STG by the end of the study. There were no differences in leaf

chlorophyll content of crapemyrtle from 60 days after planting (DAP) to 168 DAP. No difference in leaf chlorophyll content existed in loropetalum after 91 DAP. Leaf chlorophyll content of dwarf nandinas grown in100% STG were lowest from 60 DAP through the duration of the study. There were no differences in leaf chlorophyll content of azalea throughout the study. Crapemyrtles grown in the 100% STG substrate were the smallest, while plants grown in substrates containing 75% or less (by volume) STG were the largest at 168 DAP. Loropetalum grown in substrates containing 75% or more (by volume) STG had the lowest increase in growth index at 168 DAP, while those grown in substrates containing 50% or less STG were the largest. Dwarf nandinas and azaleas were the smallest when grown in 100% STG at 168 DAP and were largest when grown in substrates containing 75% or less (by volume) STG.

In the second study, calla lilies (*Zantadeschia* hybrids 'Elliotiana') and two hosta cultivars (*Hosta* hybrids 'T-Rex' and *H*. hybrids 'Wide Brim') were grown in eight-inch diameter pots filled with five substrates composed of PB and/or STG (100% PB, 75:25 PB:STG, 50:50 PB:STG, 25:75 PB:STG, and 100% STG). Plants were placed outside under overhead irrigation and 40% shade for 15 weeks. Calla lilies were planted as bulbs and hostas were planted as bare root liners. Hosta 'T-Rex' had the lowest shoot fresh weights (SFW) and shoot dry weights (SDW) when grown in the 100% STG substrate. Root quality ratings of 'T-Rex' hostas grown in the substrate containing 25% (by volume) STG were not different from those grown in 100% PB. 'Wide Brim' hosta grown in 100% STG had the lowest SFW and SDW. Root quality ratings of 'Wide Brim' hosta grown in 100% PB and 75:25 PB:STG were highest. Calla lilies grown in substrates containing 50% (by volume) STG or less had the highest SFW, SDW, and root quality ratings.

Introduction

Pine bark (PB) is the major substrate component used in the nursery industry for production of container-grown plants. Future availability of PB for horticulture production is predictably low (Lu et al., 2006). Another widely used substrate component is peat moss (PM). However, PM is typically the most expensive substrate component (Bugbee and Frink, 1989). These factors have led to a search for alternative substrate components. Composted green materials have proven to be beneficial substrate components in conjunction with PB (Spiers and Fietje, 2000). Many studies have shown that marketable plants can be grown in several types of substrates containing different components (Fain et al., 2008, Cole et al., 2005, Jackson et al., 2005, Sibley et al., 2005, Garcia-Gomez et al., 2002). Furthermore, Hernandez-Apaolaza et al., (2005) reported that waste materials can be reused in substrate blends to produce viable plants.

The majority of tea consumed worldwide is fresh brewed with leaves from *Camellia sinensis* (Harler, 1966). However, over the past twenty years market development for refrigerated, ready-to-use tea has grown exponentially. Tea brewers are faced with disposal problems of their waste materials. These materials are most often dumped into landfills at the tea brewer's expense. Composts of agroindustrial wastes, including some brewing waste products, have proven to be potential replacements for PM (Garcia-Gomez et al., 2002).

Like many other rapidly developing industries, in the tea brewing business, most attention has focused on production and the bottom line with little regard for recapture of the byproducts. However, costly and inconvenient disposal of their byproduct has prompted tea brewers to search for a suitable avenue for its recapture or reuse. Finding an alternative use for this byproduct may alleviate unnecessary costs for the tea brewers and position them as more environmentally friendly.

Spent tea grinds (STG) is a term used to describe the waste product of the tea-brewing process. STG contains finely ground tea leaves that have a high water holding capacity, with peat-like qualities, offering the potential to replace a portion of the PB fractions of container-production substrates.

The objective of this research was to evaluate the potential uses of STG in container-grown crop production. Studies were designed to assess the potential of STG as a substrate component for container production of a variety of crops.

Materials and Methods

Study 1

On 18 May 2007, crapemyrtles (*Lagerstroemia* x 'Tuscarora'), loropetalum (*Loropetalum chinense* 'Chang's Ruby'), dwarf nandinas (*Nandina* x 'Fire Power'), and azaleas (*Rhododendron* x 'Micrantha Pink'), were planted from trade gallon containers (3.2 L) into 3-gallon (10.6 L) containers filled with five substrates (100% PB, 75:25 PB:STG, 50:50 PB:STG, 25:75 PB:STG, and 100% STG by volume). All treatments were pre-plant incorporated with 9.9 kg/m^3 (16.7 lb/yd^3) of 18N-2.6P-9.9K (18-6-12 Polyon® NPK; 8-9 month release; Agrium Advanced Technologies, Sylacauga, AL), 0.9 kg/m^3 (1.5 lbs/yd^3) Micromax® (The Scotts Company, Marysville, OH), and 3.0 kg/m^3 (5 lbs/yd^3) dolomitic limestone. All plants were placed outside and were irrigated with 1 cm (0.4 inch) water daily. Substrate physical properties, including total porosity, air space, container capacity, and bulk density were determined using the NCSU Porometer (Fonteno et al. 1995). Particle size distribution (PSD) of substrates was determined by passing a 100-g air dried sample through a series of sieves with the following opening sizes: 12.5, 9.5, 6.35, 3.35, 2.36, 2.0, 1.4, 1.0, 0.5, 0.25, and 0.11 mm. Particles that passed the 0.11 mm sieve were collected in a pan. Sieves were shaken for 3 minutes with a Ro-Tap (Ro-Tap RX-29, W.S. Tyler, Mentor, OH) sieve shaker (278 oscillations/min; 159 taps/min). Substrate pH and EC were measured using the Virginia Tech pour-thru nutrient extraction method at 28, 60, 91, 126, and 168 DAP (Wright, 1986). Growth indices [(height + widest width + perpendicular width) / 3] were measured at 1 DAP and 168 DAP. Chlorophyll content was estimated using the SPAD-502 Chlorophyll Meter (Konica Minolta Sensing Inc., Osaka, Japan) at 28, 60, 91, 126, and 168 DAP. Substrate shrinkage was quantified by measuring substrate height in each container at 1 DAP and at 168 DAP. Plants were arranged by species in a randomized complete block with five single plant replications per treatment per block. Data was subjected to analysis of variance (ANOVA) in SAS and means were separated using Tukey's Studentized Range Test ($\alpha = 0.05$).

Study 2

On 25 May 2007, two hosta cultivars (*Hosta* hybrids 'T Rex' and *H.* hybrids 'Wide Brim') calla lilies (*Zantedeschia* hybrids 'Elliottiana') were planted into 3.1 L (eight-inch diameter; Dillen Products, Middlefield, OH) containers filled with five substrate blends. Hostas were planted as bare root liners and calla lilies were planted as bulbs. Five treatments were 100% PB, 75:25 PB:STG, 50:50 PB:STG, 25:75 PB:STG, and 100% STG. All treatments were pre-plant incorporated with 9.9 kg/m^3 (16.7 lb/yd^3)

of 18N-2.6P-9.9K (18-6-12 Polyon® NPK; 8-9 month release; Agrium Advanced Technologies, Sylacauga, AL), 0.9 kg/m^3 (1.5 lbs/yd^3) Micromax® (The Scotts Company, Marysville, OH), and 3.0 kg/m^3 (5 lbs/yd^3) dolomitic limestone. All plants were placed outside, under 40% shade, and were overhead irrigated with 1 cm (0.4 inch) clear water daily. Substrate shrinkage was quantified by measuring substrate height in each container at 1 day after planting (DAP) and 84 DAP. Upon conclusion of the study, all foliage was removed and weighed to determine shoot fresh weight values, then oven-dried at 68 $^{\circ}$C (154 $^{\circ}$F) for 48 hours prior to determination of shoot dry weight values. A visual rating scale was developed for root quality. Each plant's root system was assigned a numeric value from 1 to 5 (1 = lowest quality; 5 = highest quality) to describe overall root system quality. Plants were arranged by species in a completely randomized design (CRD) with 15 single plant replications. Data was subjected to analysis of variance (ANOVA) in SAS and means were separated using Tukey's Studentized Range Test (α = 0.05).

Results and Discussion

Study 1

Physical Properties

According to Yeager et al. (2007), a substrate used for nursery production should possess the following properties after irrigation and drainage (% volume basis): a total porosity of 50 to 80%, air space of 10 to 30%, water holding capacity of 45 to 65%, and a bulk density of 0.19 to 0.70 g/cm^3. Total porosity for all substrates fell into the recommended range of 50-80% (Table 1). Container capacity was below the recommended range (45-65%) for the substrate containing 100% PB (36.5%) and above the recommended range for the substrate containing 100% STG (68.7%). Inversely, air space was above the recommended range (10-30%) for the 100% PB substrate (36.9%) and low for the substrate containing 100% STG (9.5%). Substrate bulk densities were slightly below the recommended range (0.19 -0.70 g/cm^3) for substrates containing 50% or more STG. However, since these substrates possessed high container capacities, blow over from wind was not encountered.

100% PB and 75:25 PB:STG had the highest percentage of coarse (>3.35 mm) particles (Table 2). Since coarse particles increase air space of a substrate, the substrate containing 100% PB had the highest air space (36.9%) (Table 1). As the percentage of STG contained in the substrate increased, coarse particle percentages decreased (Table 2) leading to decreased air space in corresponding substrates (Table 1). 100% STG contained the lowest percentages of coarse (>3.35 mm) and medium textured (<3.35 mm >1.00 mm) particles and had the highest percentage of fine (<1.00 mm) textured particles (Table 2) corresponding to its high container capacity (68.8%) and low air space (9.6%) percentages (Table 1).

Substrate Shrinkage

Substrate shrinkage is caused by microbial decomposition of the substrate which leads to compaction of the root zone (Robbins, 2002). This compaction can lead to decreased root growth and possible marketability concerns. However, no standards exist for determining acceptable levels of substrate shrinkage. Substrate particle sizes greatly affect substrate container capacity (CC), total porosity (TP), and air space (AS) with a high percentage of fine particles (<0.5 mm) (Bilderback et al., 2005) often resulting in substrate shrinkage (Mathers et al., 2007). Substrate shrinkage is commonly encountered when composts are added to the substrate. Beeson (1996) reported that substrate shrinkage was significant when only 20% composted yard trimmings were added to a PB substrate. Substrate shrinkage was unacceptable when 40% compost or greater comprised the substrate. In this study, the proportion of STG contained in the substrate had a marked effect on shrinkage (Figure 1) which was likely a function of particle size distribution. Substrates containing 100% STG had the highest percentage of fine particles while substrates containing 50% and 75% STG by volume had percentages that were higher than substrates containing 25% or less STG (Table 2).

A linear relationship existed between substrate shrinkage and the ratio of STG:PB at 168 DAP (Figure 1). A Pearson correlation coefficient (r) of 0.945 existed between the ratio of STG:PB in the substrate and substrate shrinkage. Since this value is close to one, a strong linear relationship was identified. The correlation coefficient is positive, which illustrates a positive relationship between the STG:PB ratio and substrate shrinkage. As this ratio increased, substrate shrinkage increased.

pH and EC

Substrate pH measurements remained in an acceptable range of 5.0 to 6.0 (Yeager et al, 2007) for substrates containing 50% or less (by volume) STG throughout the study (Table 3). Substrate pH measurements were within an acceptable range for substrates containing 75% or more (by volume) at the beginning of the study, but rose slightly above this level by the end of the study. Substrate EC measurements were within an acceptable range of 0.5 to 1.0 milliSiemens/cm (Yeager et al., 2007) at the beginning of the study, but fell below an acceptable range in substrates containing 50% or greater (by volume) STG by the end of the study (Table 3). Exceedingly high substrate pH and electrical conductivity (EC) levels are often encountered when using waste materials as substrate components. Spiers and Fietje (2000) reported pH levels as high as 7.3 and EC levels above 2.0 mS/cm for a substrate containing 40% (by volume) green waste compost. Jarvis et al. (1996) reported pH levels between 7.7 and 8.9 for substrate components including green waste composts, composted wood chips, municipal waste compost, and rubber tire chips. Chong and Cline (1993) reported substrate pH values between 6.8 and 7.1 and substrate EC values between 4.1 and 7.6 mS/cm when the substrate consisted of 15% or more (by volume) paper mill sludge. Exceedingly high substrate pH and EC values were not encountered in this study.

Crapemyrtle

Initial leaf chlorophyll content was lowest in crapemyrtles grown in 100% STG (Table 4). However, by 60 DAP there were no differences in leaf chlorophyll content of crapemyrtle grown in any treatments for the duration of the study.

Growth indices of crapemyrtle were highest in plants grown in 50:50 PB:STG and were similar in 100% PB, 75:25 PB:STG, and 25:75 PB:STG at 168 days after planting (DAP) (Table 4; Figure 2)

Loropetalum

There were no differences in foliar chlorophyll content for loropetalum grown in any treatment at 28 DAP (Table 5). However, loropetalum grown in the treatment containing 100% STG had significantly lower leaf chlorophyll content than loropetalum grown in all other treatments at 60 DAP and was similar to those grown in 100% PB, 50:50 PB:STG, and 25:75 PB:STG at 91 DAP. At 126 DAP and 168 DAP, there were no differences in leaf chlorophyll content of loropetalum grown in any treatment.

Where different, loropetalum grown in 50:50 PB:STG were the largest (Table 5). All treatments containing 50% or more STG produced similar sized plants. Treatments containing 75% or greater STG produced plants that were smaller than those grown in 50:50 PB:STG (Figure 3).

Nandina

At 28 DAP no differences in foliar chlorophyll content of dwarf nandina were recorded (Table 6). However, at 60 DAP, nandinas grown in 100% STG had lower leaf chlorophyll contents than those grown in 100% PB. At 91 DAP and 168 DAP, dwarf nandinas grown in treatments containing 75% or less STG had similar leaf chlorophyll contents, while those grown in 100% STG were similar to those grown in 25:75 PB:STG. Where different, nandina grown in 100% PB and 50:50 PB:STG had the highest leaf chlorophyll contents at 168 DAP. Nandina grown in 100% STG had similar leaf chlorophyll contents to those grown in 75:25 PB:STG and 25:75 PB:STG.

Treatments containing 75% or less STG produced the largest plants (Table 6). Dwarf nandinas grown in the treatment containing 100% STG were similar in size to those grown in 25:75 PB:STG (Figure 4).

Azalea

Leaf chlorophyll content was similar for azaleas grown in all treatments throughout the entirety of the study (Table 7). Azaleas grown in 100% STG were smaller than plants grown in 50:50 PB:STG, but were similar in size to those grown in 100% PB, 75:25 PB:STG, and 25:75 PB:STG (Figure 5).

Plant growth results from this study are consistent with previous container production studies focused on PB substitutes. Jackson et al. (2005) reported similar or greater growth of dwarf nandina (*Nandina domestica* 'Fire Power') azalea (*Rhododendron indicum* 'Midnight Flare' and *R. indicum* 'Renee Mitchell'), and boxwood (*Buxus microphylla* 'Winter Gem') grown in substrates containing up to 56% (by volume) cotton gin compost compared to those grown in 6:1 PB:sand. Similarly, Beeson (1996) reported superior growth of azalea (*Rhododendron indicum* 'Duc du Rohan') and variegated pittosporum (*Pittosporum tobira* 'Variegata') in substrates containing 4:5:1 (v:v:v) composted yard waste:PB:sand. Craig and Cole (2000) reported similar growth of spirea (*Spirea japonica* 'Froebelii') grown in substrates containing up to 50% by volume recycled paper when combined with PB. As the percentage of recycled paper increased to 75% or greater (by volume), plant growth was decreased. Another study, conducted by Chong and Cline (1993), reported that up to 30% (by volume) raw paper mill sludge, when combined with PB, produced plants of similar size to those grown in 100% PB.

For all four species, plant growth in substrates containing up to 50% by volume STG was similar or greater that those grown in 100% PB. Leaf chlorophyll content was similar in all species grown in substrates containing up to 75% STG by volume. These results indicate that STG could be used to replace up to 50% by volume of a PB substrate for container production of crapemyrtle, loropetalum, dwarf nandina, and azalea.

Study 2

Substrate Shrinkage

A strong linear relationship between the ratio of STG:PB and substrate shrinkage existed (Pearson correlation coefficient (r) = 0.946). Substrate shrinkage increased linearly as the proportion of STG:PB increased (Figure 6).

'T-Rex' Hosta

'T-Rex' hostas grown in the treatment containing 100% STG had the lowest shoot fresh weights (SFW) and shoot dry weights (SDW) (Table 8). Plants grown in substrates containing 75% or less (by volume) STG were similar in size.

'T-Rex' hostas grown in treatments containing 100% PB and 75:25 PB:STG produced plants with the highest quality root systems. Plants grown in the 100% STG substrate had the lowest quality root systems. Overall root quality was acceptable for all substrates except 100% STG (Figure 7).

'Wide Brim' Hosta

'Wide Brim' hosta grown in the 100% STG substrate had the lowest SFW and SDW (Table 9). Substrates containing 75% or less (by volume) STG produced the largest plants.

'Wide Brim' hostas grown in 100% PB and 75:25 PB:STG had the highest quality root systems. Plants grown in the treatment containing 50:50 PB:STG had root systems that were similar to those grown in 75:25 PB:STG. Plants grown in 100% STG had root systems that were similar to those grown in 25:75 PB:STG.

Calla lily

Calla lilies grown in the substrates containing 50% or less (by volume) STG had the highest SFW and SDW (Table 10). Plants grown in 25:75 PB:STG had similar SFW and SDW to those grown in 50:50 PB:STG. Calla lilies grown in 100% STG had the lowest SFW, but had similar SDW to those grown in 25:75 PB:STG.

Root system quality was highest for plants grown in treatments containing 50% or less STG by volume. Plants grown in 25:75 PB:STG had similar root systems to those grown in 50:50 PB:STG. 100% STG produced plants with the lowest quality root systems.

Root growth is affected by aeration and compaction of the substrate (Pokorny, 1987). Since STG decreased air space of the substrate (Table 2), root growth was affected by the proportion of STG:PB in the substrates. *Hosta* 'T-Rex' and 'Wide Brim' had the greatest root growth when STG composed 25% or less of the substrate by volume (Tables 8, 9). Calla lilies had the greatest root growth in substrates containing 50% or less STG by volume (Table 10). These results are consistent with previously conducted studies. Craig and Cole (2000) reported a linear decrease in root dry weight of spirea (*Spiraea japonica* 'Froebelii') as the ratio of recycled paper:PB increased. Beeson (1996) reported that root growth of azalea (*Rhododendron indicum* 'Duc du Rohoan') and pittosporum (*Pittosporum tobira* 'Variegata') declined as the percentage of composted yard waste contained in a PB substrate increased.

Plant growth was not affected for any species when the substrate contained 50% or less STG by volume. Calla lilies had the lowest SDW when grown in substrates containing 75% or more STG by volume (Table 10). However, plant growth was only limited in hosta species when grown in 100% STG (Tables 8 and 9). Similarly, Jackson et al. (2005) reported that growth of boxwood (*Buxus microphylla* 'Winter Gem'), dwarf nandina (*Nandina domestica* 'Fire Power'), and azalea (*Rhododendron indicum* 'Midnight Flare' and *R. indicum* 'Renee Mitchell') was similar or greater in substrates containing up to 56% by volume cotton gin compost when compared with a traditional PB:sand substrate.

These results indicate that STG, in combination with PB, is a suitable substrate component when composing 50% or less (by volume) of the substrate for container production of hosta and calla lily.

Literature Cited

Beeson, R.C., Jr. 1996. Composted yard waste as a component of container substrates. J. Environ. Hort. 14:115-121.

Bilderback, T.E., S.L. Warren, J.S. Owen, Jr., and J.P. Albano. 2005. Healthy substrates need physicals too. HortTechnology 15:747-751.

Bugbee, G.J. and C.R. Frink. 1989. Composted waste as a peat substitute in peat-lite media. HortScience 24:625-627.

Chong, C., R.A. Cline. 1993. Response of four ornamental shrubs to container substrate amended with two sources of raw paper mill sludge. HortScience 28:807-809.

Cole, D.M., J.L. Sibley, E.K. Blythe, D.J. Eakes, and K.M. Tilt. 2005. Effect of cotton gin compost on substrate properties and growth of azalea under differing irrigation regimes in a greenhouse setting. HortTechnology 15:145-148.

Craig, P.B., J.C. Cole. 2000. Recycled paper as a growth substrate for container spirea production. HortScience 35:1253-1257.

Fain, G.B., C.H. Gilliam, J.L. Sibley, C.R. Boyer, and A.L. Witcher. 2008. WholeTree substrate and fertilizer rate in production of greenhouse-grown petunia and marigold. HortScience 43:700-705.

Fonteno, W.C., C.T. Hardin, and J.P. Brewster. 1995. Procedures for determining physical properties of horticultural substrates using the NCSU Porometer. Horticultural Substrates Laboratory. North Carolina State University.

Garcia-Gomez A., M.P. Bernal, and A. Roig. 2002. Growth of ornamental plants in two composts prepared from agroindustrial wastes. Bio Tech. 83:81-87.

Harler, C.R. 1966. Tea growing. Oxford University Press.

Hernandez-Apaolaza, L., A.M. Gasco, J.M. Gasco, and F. Guerroro. 2005. Reuse of waste materials as growing media for ornamental plants. Bioresource Tech. 96:125-131.

Jackson, B.E., A.N. Wright, D.M. Cole, and J.L. Sibley. 2005. Cotton gin compost as a substrate component in container production of nursery crops. J. Environ. Hort. 23:118-122.

Jarvis, B.R., J.B. Calkins, and B.T. Swanson. 1996. Compost and rubber tire chips as peat substitutes in nursery container media: effects on chemical and physical media properties. J. Environ. Hort. 14:122-129.

Lu, W., J.L. Sibley, C.H. Gilliam, J.S. Bannon, and Y. Zhang. 2006. Estimation of U.S. bark generation and implications for horticultural industries. J. Environ. Hort. 24:29-34.

Mathers, H.M., S.B. Lowe, C. Scagel, K.K. Struve, and L.T. Case. 2007. Abiotic factors influencing root growth of woody nursery plants in containers. HortTechnology 17:151-162.

Pokorny, F.A. 1987. Available water and root development within the micropores of pine bark particles. J. Environ. Hort. 5:89-92.

Robbins, J.A. 2002. Effect of media type on the growth of container-grown woody Ornamentals. Proc. SNA Res.Conf. 47:67-72.

Sibley, J.L., C.H. Gilliam, W.G. Foshee, III, A.N. Wright, and G.B. Fain. 2005. Development of nursery crop substrates from recycled materials and composted poultry litter. Proc. SNA Res. Conf. 50:127-130.

Simarny, J. P., 2007. The state of the U.S. tea industry. Tea Association of the U.S.A., Inc. http://www.teausa.com/general/002ga.cfm

Spiers, T.M., and G. Fietje. 2000. Green waste compost as a component in soilless growing media. Compost Sci. & Util. 8: 19-23.

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

Yeager, T.H., T. Bilderback, D. Fare, C. Gilliam, J. Lea-Cox, A. Niemiera, J. Ruter, K. Tilt, S. Warren, T. Whitwell, R. Wright. 2007. Best Management Practices: Guide for Producing Nursery Crops 2nd ed. The Southern Nursery Association. Atlanta, GA.

Table 1. Physical characteristics[Z] of five various substrate blends.

Treatment[Y]	Total Porosity	Container Capacity	Air Space	Bulk Density
	% Pore Space	% Water	% Air	g/cm^3
100% PB	73.5c[X]	36.5e	36.9a	0.19a
75:25 PB:STG	75.4bc	47.7d	27.6b	0.19a
50:50 PB:STG	77.1ab	58.3c	18.8c	0.18a
25:75 PB:STG	77.4ab	64.7b	12.8d	0.18a
100% STG	78.3a	68.8a	9.6e	0.18a

[Z]Physical Characteristics were determined using the NC State Porometer.

[Y]Treatments were PB = pine bark ; STG = spent tea grinds.

[X]Values in column followed by different letters are significant according to Tukey's Studentized Range Test (α = 0.05).

Table 2. Particle size analysis of five various substrate blends.

U.S. standard sieve no.	Sieve opening (mm)	Substrate[Z]				
		100% PB	75:25 PB:STG	50:50 PB:STG	25:75 PB:STG	100% STG
1/2	12.5	0.00a[YX]	0.00a	0.00a	0.34a	0.00a
3/8	9.50	0.00a	0.00a	0.00a	0.39a	0.00a
1/4	6.35	9.37a	5.19b	4.98bc	1.98cd	0.00d
6	3.35	23.92a	19.59ab	15.22bc	10.18c	0.00d
8	2.36	12.12a	11.1a	8.21b	6.97b	0.00c
10	2.00	4.59a	4.31ab	3.44ab	3.06b	0.00c
14	1.40	11.22a	10.49ab	8.13c	9.64b	0.00d
18	1.00	8.97c	9.30c	9.86bc	13.19b	21.93a
35	0.50	13.38c	17.88c	27.78b	34.11b	44.99a
60	0.25	7.68c	13.02bc	18.15b	17.34b	28.03a
140	0.11	4.4ab	6.01a	3.57ab	2.59b	4.39ab
270	0.05	1.99a	1.62ab	0.37ab	0.18b	0.50ab
pan	0.00	2.35a	1.46b	0.19c	0.16c	0.16c
Texture[XW]						
Coarse		33.28a	24.77ab	20.29bc	12.90c	0.00d
Medium		36.91a	35.24a	29.64ab	32.88ab	21.93c
Fine		29.80d	39.98cd	50.07bc	54.22b	78.07a

[Z]Substrates were PB = pine bark; STG = spent tea grinds;

[Y]Percent weight of samples collected on each screen.

[X]Values in column followed by different letters are significant according to Tukey's Studentized Range Test ($\alpha = 0.05$).

[W]Coarse = > 3.35 mm; medium = > 1.00 mm - < 3.35 mm; fine = < 1.00 mm.

Table 3. Substrate pH and EC measurements in *Loropetalum chinense* 'Chang's Ruby'.

Treatment[Y]	pH		EC (mS/cm)[Z]	
	28 DAP[X]	168 DAP	28 DAP	168 DAP
100% PB	5.93a[W]	5.32c	0.415b	0.525a
75:25 PB:STG	5.39a	5.64bc	0.452b	0.473a
50:50 PB:STG	5.53a	5.79abc	0.811ab	0.374b
25:75 PB:STG	5.17a	6.38a	1.22a	0.268c
100% STG	5.33a	6.25ab	1.00a	0.171d

[Z]mS/cm = milliSiemens per centimeter.

[Y]Treatments were PB = pine bark ; STG = spent tea grinds.

[X]DAP = days after planting.

[W]Values in columns followed by different letters are significant according to Tukey's Studentized Range Test α = 0.05.

Table 4. Effects of various substrates on growth of *Lagerstroemia indica* 'Tuscarora'.

Treatment[Z]	Leaf Chlorophyll Content[Y]				Growth Index[X]
	28 DAP[V]	60 DAP	91 DAP	126 DAP	168 DAP
100% PB	73.7a[W]	76.0a	79.9a	58.6a	56.9ab
75:25 PB:STG	77.7a	70.3a	79.9a	62.9a	54.1ab
50:50 PB:STG	73.5a	65.7a	80.8a	68.6a	62.0a
25:75 PB:STG	71.4a	65.3a	75.6a	66.8a	49.9ab
100% STG	62.4b	71.0a	70.7a	61.6a	40.8b

[Z]Treatments were: PB = pine bark; STG = spent tea grinds.

[Y]Leaf chlorophyll content was estimated using a SPAD-502 Chlorophyll Meter (Konica Minolta Sensing, Inc. Osaka, Japan).

[X]Growth index = (height + widest width + perpendicular width) / 3.

[V]DAP = days after planting.

[W]Values in column followed by different letters are significant according to Tukey's Studentized Range Test (α = 0.05).

Table 5. Effects of various substrates on growth of *Loropetalum chinense* 'Chang's Ruby'.

Treatment[Z]	Leaf Chlorophyll Content[Y]					Growth Index[X]
	28 DAP[V]	60 DAP	91 DAP	126 DAP	168 DAP	168 DAP
100% PB	44.7a[W]	56.4a	55.5ab	51.8a	47.4a	73.4ab
75:25 PB:STG	43.5a	57.2a	60.0a	50.9a	47.5a	73.9ab
50:50 PB:STG	42.3a	58.8a	53.1ab	53.2a	51.8a	79.3a
25:75 PB:STG	45.3a	50.3a	54.4ab	48.3a	47.8a	56.2b
100% STG	38.7a	36.6b	50.1b	43.8a	45.9a	56.6b

[Z]Treatments were: PB = pine bark; STG = spent tea grinds.

[Y]Leaf chlorophyll content was estimated using a SPAD-502 Chlorophyll Meter (Konica Minolta Sensing, Inc. Osaka, Japan).

[X]Growth index = (height + widest width + perpendicular width) / 3.

[V]DAP = days after planting.

[W]Values in column followed by different letters are significant according to Tukey's Studentized Range Test ($\alpha = 0.05$).

Table 6. Effects of various substrates on growth of *Nandina domestica* 'Fire Power'.

Treatment[Z]	Leaf Chlorophyll Content[Y]					Growth Index[X]
	28 DAP[V]	60 DAP	91 DAP	126 DAP	168 DAP	168 DAP
100% PB	32.3a[W]	44.2a	40.7a	40.5a	39.9a	25.6a
75:25 PB:STG	25.9a	38.0ab	42.9a	40.3a	37.8ab	29.7a
50:50 PB:STG	22.9a	36.3ab	44.2a	40.8a	41.3a	24.9a
25:75 PB:STG	28.7a	39.4ab	39.4ab	34.9ab	35.3ab	21.1ab
100% STG	24.2a	30.6b	33.4b	29.3b	29.9b	8.9b

[Z]Treatments were: PB = pine bark; STG = spent tea grinds.

[Y]Leaf chlorophyll content was estimated using a SPAD-502 Chlorophyll Meter (Konica Minolta Sensing, Inc. Osaka, Japan).

[X]Growth index = (height + widest width + perpendicular width) / 3.

[V]DAP = days after planting.

[W]Values in column followed by different letters are significant according to Tukey's Studentized Range Test ($\alpha = 0.05$).

Table 7. Effects of various substrates on growth of azalea (*Rhododendron* x 'Micrantha Pink').

Treatment[Z]	Leaf Chlorophyll Content[Y]					Growth Index[X]
	28 DAP[V]	60 DAP	91 DAP	126 DAP	168 DAP	168 DAP
100% PB	42.3a[W]	45.9a	48.8a	54.7a	51.8a	12.1ab
75:25 PB:STG	40.2a	47.3a	53.1a	53.8a	53.3a	11.9ab
50:50 PB:STG	39.2a	45.4a	50.4a	51.9a	49.2a	12.8a
25:75 PB:STG	36.8a	43.7a	50.3a	52.7a	53.6a	11.6ab
100% STG	35.0a	35.8a	46.9a	48.2a	51.3a	7.9b

[Z]Treatments were: PB = pine bark; STG = spent tea grinds.

[Y]Leaf chlorophyll content was estimated using a SPAD-502 Chlorophyll Meter (Konica Minolta Sensing, Inc. Osaka, Japan).

[X]Growth index = (height + widest width + perpendicular width) / 3.

[V]DAP = days after planting.

[W]Values in column followed by different letters are significant according to Tukey's Studentized Range Test ($\alpha = 0.05$).

Table 8. Effects of various substrates on growth of *Hosta* hybrids 'T-Rex'.

Treatment[Z]	Fresh Weight (g)	Dry Weight (g)	Root Rating[Y]
	105 DAP[X]		105 DAP
100% PB	87.9a[W]	17.3a	4.4a
75:25 PB:STG	100.6a	19.2a	4.4a
50:50 PB:STG	75.0a	14.8a	3.0b
25:75 PB:STG	103.4a	18.7a	2.8b
100% STG	35.8b	7.2b	1.0c

[Z]Treatments were: PB = pine bark ; STG = spent tea grinds.

[Y]Rating scale was: 1 = lowest quality ; 5 = highest quality.

[X]DAP = days after planting.

[W]Values in columns followed by different letters are significant according to Tukey's Studentized Range Test (α = 0.05).

Table 9. Effects of various substrates on growth of *Hosta* hybrids 'Wide Brim'.

Treatment[Z]	Fresh Weight (g)	Dry Weight (g)	Root Rating[Y]
	105 DAP[X]		105 DAP
100% PB	101.6a[W]	14.6a	4.4a
75:25 PB:STG	100.9a	13.8a	3.8ab
50:50 PB:STG	103.3a	13.9a	2.8bc
25:75 PB:STG	121.2a	15.2a	2.2cd
100% STG	76.1b	10.9b	1.2d

[Z]Treatments were: PB = pine bark ; STG = spent tea grinds.

[Y]Rating scale was: 1 = lowest quality ; 5 = highest quality.

[X]DAP = days after planting.

[W]Values in columns followed by different letters are significant according to Tukey's Studentized Range Test ($\alpha = 0.05$).

Table 10. Effects of various substrates on growth of calla lily (*Zantadeschia* hybrids 'Elliottiana').

Treatment[Z]	Fresh Weight (g)	Dry Weight (g)	Root Rating[Y]
	105 DAP[X]		105 DAP
100% PB	113.8a[W]	16.6a	4.2a
75:25 PB:STG	110.6ab	15.2ab	4.2a
50:50 PB:STG	106.6ab	13.7ab	3.4ab
25:75 PB:STG	91.9b	10.8bc	2.6b
100% STG	69.6c	7.1c	1.2c

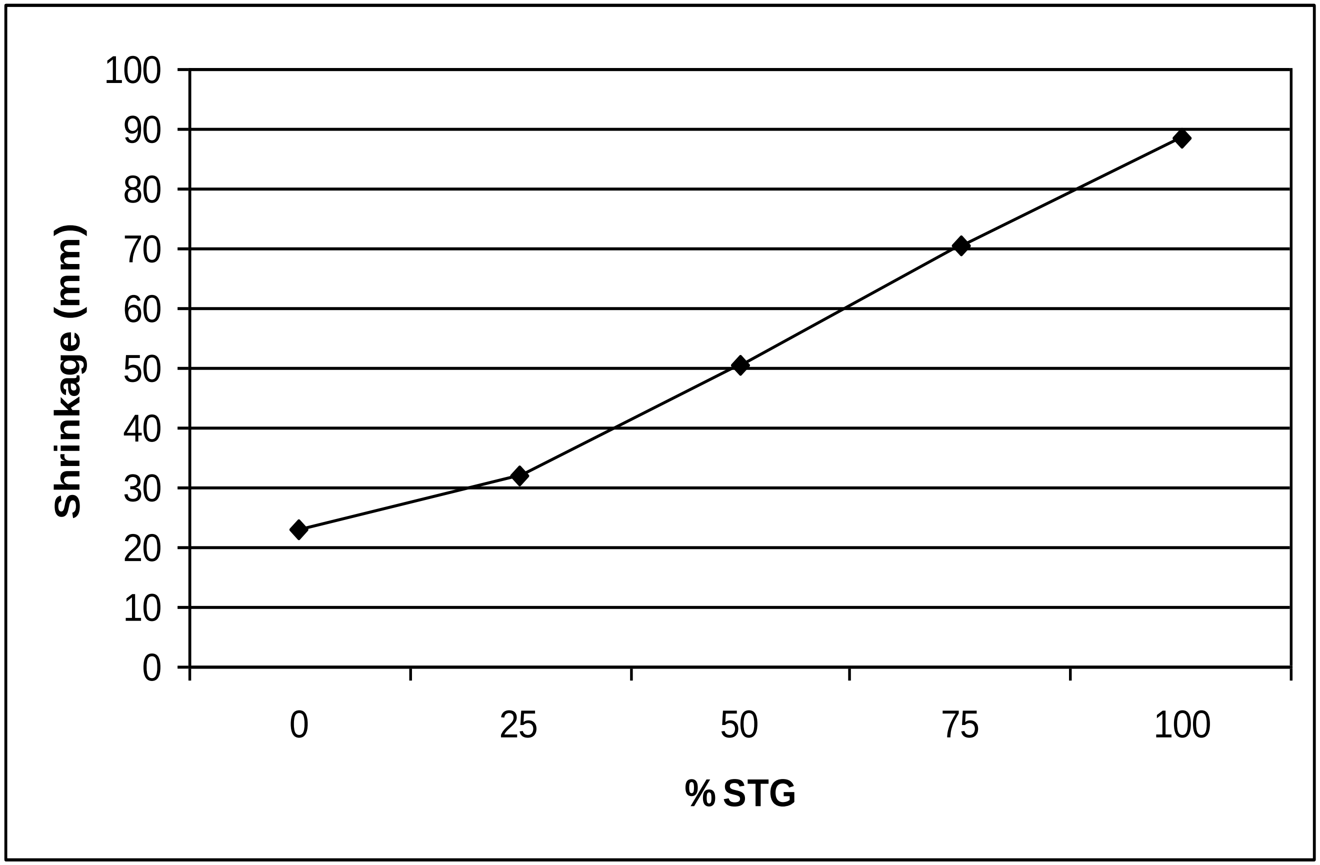
[Z]Treatments were: PB = pine bark ; STG = spent tea grinds.

[Y]Rating scale was: 1 = lowest quality ; 5 = highest quality.

[X]DAP = days after planting.

[W]Values in columns followed by different letters are significant according to Tukey's Studentized Range Test ($\alpha = 0.05$).

Figure 1. Effect of spent tea grinds (STG) on substrate shrinkage in container-grown 'Micrantha Pink' azalea.



Y = 18.92 + 0.68x
$R^2 = 0.894$

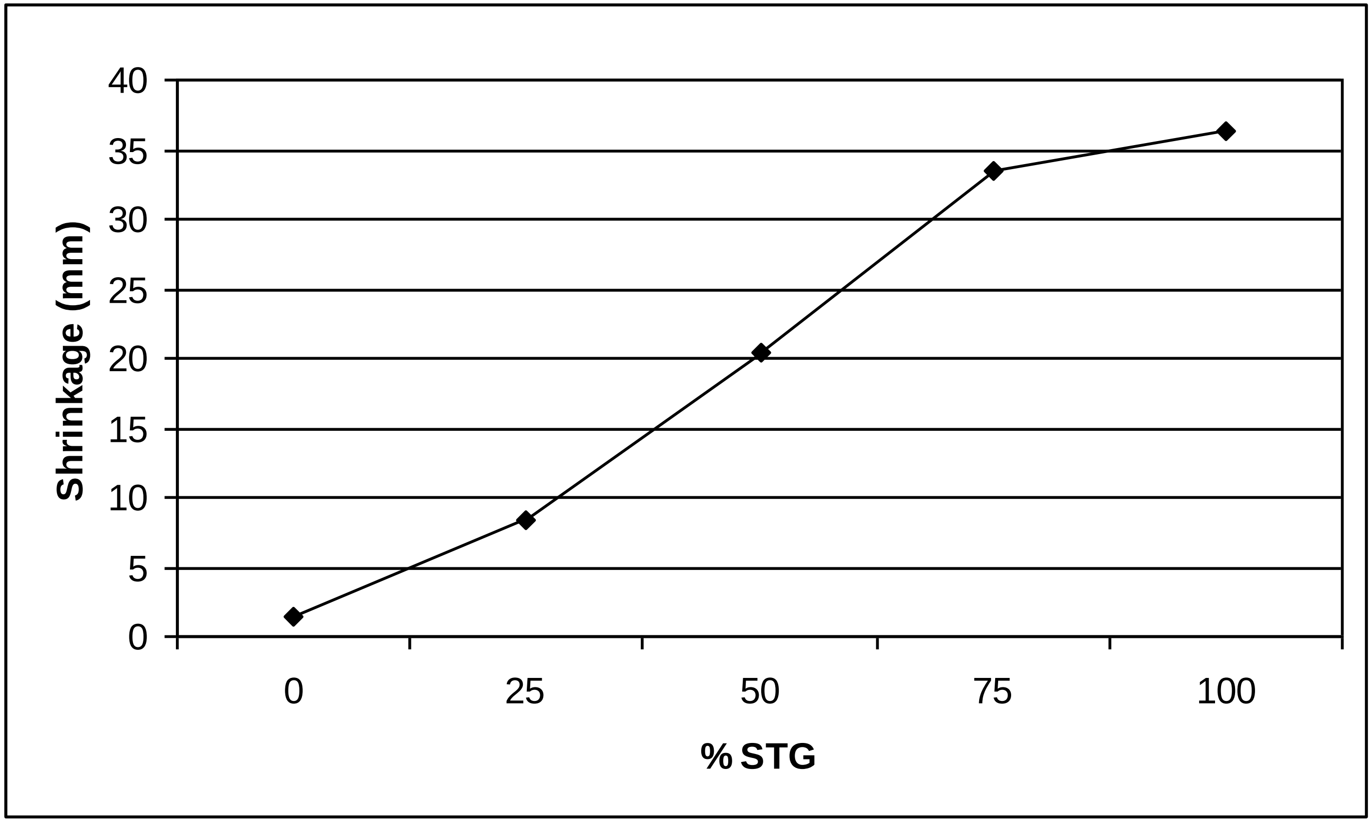
Figure 2. Comparison of *Lagerstroemia indica* 'Tuscarora' grown in various substrate blends.

Figure 3. Comparison of *Loropetalum chinense* 'Chang's Ruby' grown in various substrate blends.

Figure 4. Comparison of *Nandina domestica* 'Fire Power' grown in various substrate blends.

Figure 5. Comparison of *Rhododendron* x 'Micrantha Pink' grown in various substrate blends.

Figure 6. Effect of spent tea grinds (STG) on substrate shrinkage in container-grown 'Wide Brim' hosta.



$Y = 1.12 + 0.38x$
$R^2 = 0.895$

Figure 7. Root rating scale for *Hosta* hybrids 'T-Rex'.

Chapter IV

FINAL DISCUSSION

Pine bark (PB) and peat moss (PM) are major substrate components used in the greenhouse industry for production of ornamental plants. The steadily increasing costs of these components are of major concern to growers. Future availability of PB for horticulture production is also predictably low (Lu et al., 2006). In Europe, environmental concerns have encouraged the production and use of many PM alternatives (Robertson, 1993). In 1996, the U.S. imported 667,000 metric tons of PM which cost $173.91 per metric ton ($116 million total) (Morse, 1996). In 2006, PM imports had increased to 924,000 metric tons costing $241.34 per metric ton ($223 million total) (Jasinski, 2007). Since the majority of PM is imported from Canada (Yu et al., 1990), rising fuel costs have likely escalated the cost of imported peat. These factors have led to a search for alternative substrate components.

Very limited research had previously been conducted on the possibility of using spent tea grinds (STG) as a substrate component. Tatum and Owings (1992) conducted a study using "ground tea leaves" as a bedding plant medium amendment. Ground tea leaves were used alone and were mixed with perlite and vermiculite. Substrates containing ground tea leaves were tested against similar PM-based substrates and a commercial greenhouse substrate mix. The blend of ground tea leaves:perlite:vermiculite (1:1:1, v:v:v) produced the highest quality tomatoes along with the commercial greenhouse substrate. For all three species, when combined with perlite and vermiculite, ground tea leaves produced similar plants to those grown in PM-based substrates. These results indicated that ground tea leaves have potential as a greenhouse substrate component. However, no further known research was conducted.

We conducted several experiments to further test the efficacy of STG as a greenhouse substrate component. STG was used fresh and was composted with pine bark (PB) (1:1; v:v) to form a product referred to as TBC. Many species were shown to perform well in STG and TBC-containing substrates, most notably *Lantana camara*, *Nephrolepis exaltata* 'Bostoniensis', *Euphorbia pulcherrima*, *Saintpaulia* hybrids, *Antirrhinum majus*, *Viola* x *wittrockiana*, and *Petunia* x *hybrida*.

From the first greenhouse study we concluded that a substrate containing up to 80% (by volume) TBC or 50% (by volume) STG could produce *Lantana camara* 'New Gold' of similar or greater size and quality to those grown in Fafard® 3B. Also, a substrate containing up to 100% (by volume) TBC or 50% (by volume) STG could be used to produce *Nephrolepis exaltata* 'Bostoniensis' of similar size and quality to those grown in Fafard® 3B. Results from this study were consistent with previously conducted studies. Garcia-Gomez et al. (2002) reported that greenhouse-grown marigolds had the highest shoot fresh weight (SFW) when grown in substrates containing up to 75% (by volume) composts containing brewing wastes (malt + yeast), lemon tree prunings, olive leaves, and the solid fraction of olive mill wastewater when combined with sphagnum peat moss (PM) or a commercial greenhouse substrate. Klock (1997) reported that growth of petunia and dianthus was greatest in a substrate containing 60% (by volume) composted yard trimmings and biosolids. In a later study, Klock-Moore (1999) reported that shoot dry weight (SDW) and growth index (GI) of impatiens increased linearly as the percentage of composted biosolids contained in a PM, vermiculite, perlite substrate increased. Growth of impatiens was greatest in 100% compost. Wilson et al. (2001) reported that no differences in GI and leaf chlorophyll content (SPAD) existed between golden shrimp plants grown in PM-based substrates containing (by volume) 0, 25, 50, 75, and 100% composted biosolids and yard trimmings.

Our initial trials revealed that growing petunias in STG-containing substrates would be more challenging than other species. A chlorotic foliar response was evident when petunias were grown in STG and TBC. Upon review of substrate analysis data, it was determined that STG-containing substrates possessed excessive amounts of manganese. Excessive manganese levels can cause iron deficiency symptoms (Mengel and Kirkby, 2001) since manganese and iron compete at the cellular level (Mills and Jones, 1996). Foliar analyses also provided evidence that higher than normal manganese levels were present in petunias grown in STG-containing substrates. Therefore, we incorporated agricultural grade elemental sulfur (90% S) into two different STG-containing substrates and grew petunias for 10 weeks in a greenhouse. No foliar chlorosis symptoms existed in any petunia. Foliar analysis showed that foliar manganese content of petunias grown in STG amended with sulfur was within a normal range. However, growth of petunia was decreased when more than 20% (by volume) STG was contained in the substrate. Evans (2004) reported that no differences in SDW and root dry weight (RDW) of vinca, coleus, and tomato existed when up to 30% (by volume) processed poultry feather fiber was added to PM-based or commercial substrates. Wilson et al. (2001) reported a linear decrease in SDW of golden shrimp plant when PM and coir-based substrates were amended with more than 50% (by volume) composted biosolids and yard clippings. Spiers and Fietje (2000) reported that green waste compost could only replace 30% (by volume) of a traditional PB substrate before decreasing SDW of tomato.

Pine bark (PB) is the major substrate component used in outdoor nursery crop production. Alternative substrates are needed for this area since the future availability of PB for the horticulture industry is questionable (Lu et al., 2006). Therefore, another possible avenue for the reuse of STG that was explored was outdoor nursery crop production. Our focus was to reduce pine bark (PB) usage by supplementing a PB substrate with a proportion of STG.

In the first nursery crop production study, crapemyrtle, loropetalum, dwarf nandina, and azalea were grown in PB-based substrates containing 0, 25, 50, 75, and 100% (by volume) STG. For all four species plant growth in substrates containing up to 50% by volume STG was similar or greater that those grown in 100% PB. Leaf chlorophyll content was similar in all species grown in substrates containing up to 75% STG by volume. These results indicated that STG can be used to replace up to 50% by volume of a PB substrate for container production of crapemyrtle, loropetalum, dwarf nandina, and azalea. Plant growth results from this study were consistent with previous container production studies focused on PB substitutes. Jackson et al. (2005) reported similar or greater growth of dwarf nandina (*Nandina domestica* ‘Fire Power’) azalea

(*Rhododendron indicum* 'Midnight Flare' and *R. indicum* 'Renee Mitchell'), and boxwood (*Buxus microphylla* 'Winter Gem') grown in substrates containing up to 56% (by volume) cotton gin compost compared to those grown in 6:1 PB:sand. Similarly, Beeson (1996) reported superior growth of azalea (*Rhododendron indicum* 'Duc du Rohan') and variegated pittosporum (*Pittosporum tobira* 'Variegata') in substrates containing 4:5:1 (v:v:v) composted yard waste:PB:sand. Craig and Cole (2000) reported similar growth of spirea (*Spirea japonica* 'Froebelii') grown in substrates containing up to 50% by volume recycled paper when combined with PB. As the percentage of recycled paper increased to 75% or greater (by volume), plant growth was decreased. Another study, conducted by Chong and Cline (1993), reported that up to 30% (by volume) raw paper mill sludge, when combined with PB, produced plants of similar size to those grown in 100% PB.

In a subsequent container production study calla lilies and hosta were grown in PB-based substrates containing 0, 25, 50, 75, and 100% (by volume) STG. Plant growth was not affected for any species when the substrate contained 50% or less STG by volume. Calla lilies had the lowest shoot fresh weights (SFW) and shoot dry weights (SDW) when grown in substrates containing 75% or more STG by volume. However, plant growth was only limited in hosta species when grown in 100% STG. Similarly, Jackson et al. (2005) reported that growth of boxwood (*Buxus microphylla* 'Winter Gem'), dwarf nandina (*Nandina domestica* 'Fire Power'), and azalea (*Rhododendron indicum* 'Midnight Flare' and *R. indicum* 'Renee Mitchell') was similar or greater in substrates containing up to 56% by volume cotton gin compost when compared with a traditional PB:sand substrate. Our results indicated that STG, in combination with PB, is a suitable substrate component when composing 50% or less (by volume) of the substrate for container production of hosta and calla lily. Hopefully, by reducing the amount of PB used by 25 to 50% growers would be able to reduce production costs and alleviate some dependence on a limited resource.

Milo's Tea Company, Inc., (Bessemer, AL) generates about 35 tons of its byproduct (STG) weekly, which costs the company nearly $55,000 annually in disposal fees (personal communication, Milo's Tea Company, Inc.). Since the onset of this research project, a suitable avenue for the recapture and reuse of STG in the ornamental horticulture industry has been identified. By utilizing STG in some of its retail bagged substrates, The Scotts Company, Inc. will be able to increase profits by reducing the amount of other common and more expensive substrate components, such as PM and PB, used in their mixes. Furthermore, Milo's Tea Company, Inc. has been able to increase its profit margin by reducing its waste disposal costs. This new system has also produced an environmentally advantageous result by discontinuing the dumping of STG into landfills.

Literature Cited

Beeson, R.C., Jr. 1996. Composted yard waste as a component of container substrates. J. Environ. Hort. 14:115-121.

Chong, C., R.A. Cline. 1993. Response of four ornamental shrubs to container substrate amended with two sources of raw paper mill sludge. HortScience 28:807-809.

Craig, P.B., J.C. Cole. 2000. Recycled paper as a growth substrate for container spirea production. HortScience 35:1253-1257.

Evans, M.R. 2004. Processed poultry feather fiber as an alternative to peat in greenhouse crops substrates. HortTechnology 14:176-179.

Garcia-Gomez A., M.P. Bernal, and A. Roig. 2002. Growth of ornamental plants in two composts prepared from agroindustrial wastes. Bio Tech. 83:81-87.

Jackson, B.E., A.N. Wright, D.M. Cole, and J.L. Sibley. 2005. Cotton gin compost as a substrate component in container production of nursery crops. J. Environ. Hort. 23:118-122.

Jasinski, S.M. 2007. Peat - U.S. Geological Survey Minerals Yearbook. 7 Oct. 2007.

http://minerals.usgs.gov/minerals/pubs/commodity/peat/myb1-2006-peat.pdf

Klock, K. A., 1997. Growth of dianthus and petunia in media amended with composted urban waste. J. Environ. Hort. 15:135-137.

Klock-Moore, K. 1999. Growth of impatiens 'accent orange' in two compost products. Compost Sci. & Util. 7:58-62.

Lu, W., J.L. Sibley, C.H. Gilliam, J.S. Bannon, and Y. Zhang. 2006. Estimation of U.S. bark generation and implications for horticultural industries. J. Environ. Hort. 24:29-34.

Mengel, K. and Kirkby, E.A. 2001. Manganese. *In*: Principles of plant nutrition 5th ed. Kluwer Academic Publishers, Dordrecht, The Netherlands.

Mills, H.A., and J.B. Jones, Jr. 1996. Plant analysis handbook II: a practical sampling, preparation, analysis, and interpretation guide. Micromacro Publishing, Inc.

Morse, D.E. 1996. Peat – U.S. Geological Survey Minerals Information. http://minerals.usgs.gov/minerals/pubs/commodity/peat/510496.pdf

Robertson, A. 1993. Peat, horticulture, and environment. Biodiv. Conserv. 2:541-547.

Spiers, T.M., and G. Fietje. 2000. Green waste compost as a component in soilless growing media. Compost Sci. & Util. 8: 19-23.

Tatum, D. H., and Owings, A. D., 1992. Ground tea leaves as a bedding plant medium amendment. Proc. SNA Res. Conf. 37:75-76.

Wilson, S.B., P.J. Stoffella, and D.A. Graetz. 2001. Evaluation of compost as an amendment to commercial mixes used for container-grown golden shrimp plant production. HortTechnology 11:31-35.

Yu, Z.Y., J.T. Akridge, M.N. Dana, and J. Lowenberg-DeBoer. 1990. An economical evaluation of horticultural alfalfa as a substitute for sphagnum peat moss. Agribusiness 6:443-462.

Appendix A:

Evaluation of Spent Tea Grinds as a Potential Greenhouse Substrate Component

Abstract

In the United States, the market for freshly brewed, ready-to-drink tea has grown exponentially in the last 20 years. Along with generating more product, tea brewers have also produced more waste. Spent Tea Grinds (STG) are the finely ground waste product of the tea brewing process. STG's high water-holding capacity and organic nature make it a potential replacement for common substrate components such as pine bark (PB) and peat moss (PM). A series of greenhouse studies were conducted to evaluate STG as a greenhouse substrate component. In the first study *Petunia* x *hybrida* 'Dreams White' petunias were grown for eight weeks. This was a rapid screening trial conducted to determine whether or not petunias could be grown in substrates containing STG without supplemental fertilizer incorporated into the substrate or applied as a foliar feed. Results showed that STG:PB blends may have potential as greenhouse substrates. Subsequent studies were conducted to determine whether or not poinsettias could be grown in a substrates containing TBC or STG. In the first such study, *Euphorbia pulcherrima* 'Prestige Red' were grown in a substrate containing TBC for 10 weeks in a greenhouse. Visual observations indicated that 'Prestige Red' poinsettias could be grown in substrates containing TBC. In a subsequent study, 60 *Euphorbia pulcherrima* 'Prestige Red' and 60

E. pulcherrima 'Christmas Feeling' plants were placed into 6.5-inch diameter containers filled with various substrate blends and grown on a raised greenhouse bench for nine weeks. 'Prestige Red' poinsettias grown in 100% PB had the highest visual quality ratings at 63 DAP, while those grown in 100% PB and 75:25 PB:STG had the largest increase in growth index. 'Christmas Feeling' poinsettias grown in 100% PB and 75:25 PB:STG had the highest visual quality ratings, while those grown in 100% PB had the highest increase in growth index at 63 DAP.

A following study was conducted to evaluate differing levels of perlite blended with STG or TBC substrates for the production of greenhouse-grown pansies, petunias, and snapdragons. *Viola* x *wittrockiana* 'Matrix ™ Blue Deep Blotch', *Viola* x *wittrockiana* 'Matrix ™ Sunrise', *Petunia* x *hybrida* 'Dreams Pink', *Petunia* x *hybrida* 'Dreams White', and *Antirrhinum majus* 'Solstice Mix' were grown for 10 weeks in a greenhouse. Visual observations indicated that perlite added to STG and TBC substrates at 10% by volume produced similar plants to those grown in substrates containing 20% perlite by volume. A subsequent study was conducted to evaluate the use of bifenthrin to control fungus gnat populations in substrates containing TBC. African violets (*Saintpaulia* hybrids) were grown for eight weeks in a greenhouse. The efficacy of bifenthrin for controlling fungus gnat populations was determined by visual observations. Results suggest that fungus gnat larvae can be controlled by 2 lbs/yd^3 of incorporated insecticide (0.2% bifenthrin). Another greenhouse study was conducted to determine if supplemental liquid-soluble fertilizer could deter foliar chlorosis symptoms in petunia grown in STG and TBC containing substrates. *Petunia* x *hybrida* 'Bravo Blue' were grown in a greenhouse for 10 weeks. Visual observations indicated that liquid soluble fertilizer did not prevent foliar chlorosis in ‘Bravo Blue’ petunias grown in STG and TBC containing substrates.

Materials and Methods

Study 1

‘Dreams White’ petunias were grown in several different substrate blends containing various amounts of fresh STG and PB. Seven treatments were: 100% STG, 100% Fafard® 3B, 100% PB, 50:50 STG:PB, 50:50 STG:Fafard®, 75:25 STG:perlite, 50:50 STG:perlite. Upon conclusion of the study, tissue samples were analyzed for nutrient content (Auburn University, Soil Testing Laboratory, Auburn, AL). Visual analysis was conducted to determine which treatments had promise as a greenhouse substrate. The study was a completely randomized design (CRD), conducted at Paterson Greenhouse Complex in Auburn, AL.

Study 2

Based on successful results with previously grown crops, ‘Prestige Red’ poinsettias (*Euphorbia pulcherrima* ‘Prestige Red’) were grown in a substrate containing 80:20 TBC:perlite. The test substrate was pre-plant incorporated with 2.5 lbs/yd^3 N (12-6-6 Nursery Special™) fertilizer and 0.9 kg/m^3 (1.5 lbs/yd^3) Micromax® (The Scotts Company, Marysville, Ohio). This was a single treatment study conducted strictly to observe the response of ‘Prestige Red’ poinsettias to TBC as a growing media. Visual observations were made.

Study 3

On 28 September, 2007, 60 *Euphorbia pulcherrima* ‘Prestige Red’ and 60 *E. pulcherrima* ‘Christmas Feeling’ were planted from OASIS® *Wedge*® (Smithers-Oasis North America , Kent, OH) cubes into 60, 1.67 L (6.5-inch diameter; Dillen Products, Middlefield, OH) containers filled with various substrate blends. One plant was placed into each container. Containers were placed on a raised bench in a double layered polyethylene greenhouse. Five treatments were 100% PB, 75:25 PB:STG, 50:50 PB:STG, 25:75 PB:STG, and 100% STG. All treatments were pre-plant incorporated with 14.9 kg/m^3 (25 lbs/yd^3) 12N-2.6P-4.9K (12-6-6 Nursery Special™; 2-3 month release) 0.9 kg/m^3 (1.5 lbs/yd^3) Micromax® (The Scotts Company, Marysville, Ohio), and 3.0 kg/m^3 (5 lbs/yd^3) dolomitic limestone. Growth indices [(height + width + perpendicular width) / 3] were recorded at 1 day after planting (DAP) and 63 DAP. A visual rating scale was developed for overall plant quality. Each plant was assigned a numeric value between 1 and 5 based on the overall health and quality of the plant (1=lowest quality; 5=highest quality). This study was a randomized complete block design (RCBD). Each cultivar was arranged as a separate experiment. Twelve blocks contained five plants each. Data was subjected to analysis of variance (ANOVA) in SAS. Means were separated using Tukey’s Studentized Range Test ($\alpha = 0.05$).

Study 4

In an effort to more carefully manage costs for using STG or TBC while still increasing air apace and water drainage, a study was conducted to evaluate differing amounts of perlite. Two cultivars of pansies (*Viola* x *wittrockiana* ‘Matrix™ Blue Deep Blotch’ and *Viola* x *wittrockiana* ‘Matrix™ Sunrise’), two cultivars of petunias (*Petunia* x *hybrida* ‘Dreams Pink’ and *Petunia* x *hybrida* ‘Dreams White’), and snapdragons (*Antirrhinum majus* ‘Solstice Mix’) from 288-cell plug flats, were planted into 36-cell market flats containing eight various substrate blends. The eight treatments were 100% Fafard® 3B with supplemental fertilizer (+F), 100% Fafard® 3B without supplemental fertilizer (-F), 80:20 TBC:Perlite (+F), 80:20 TBC:Perlite (-F), 90:10 TBC:Perlite (+F), 90:10 TBC:Perlite (-F), 40:40:20 STG:PB:Perlite (+F), and 45:45:10 STG:PB:Perlite (+F). For treatments containing supplemental fertilizer, 1.5 lbs/yd^3 of 12-6-6 Nursery Special™ fertilizer was pre-plant incorporated along with 0.9 kg/m^3 (1.5 lbs/yd^3) Micromax® (The Scotts Company, Marysville, Ohio), which was added to all treatments. Standard horticultural grade perlite was used. Substrate pH, EC, and soluble salt content (SS) for all treatments was determined using the saturated paste extraction method (Warncke, 1986) (Auburn University, Soil Testing Laboratory, Auburn, AL). Tissue samples from each cultivar and species were analyzed for nutrient content (Auburn University, Soil Testing Laboratory, Auburn, AL). Visual observations were made to determine what proportion of perlite should be used in combination with STG for greenhouse production. Each species was arranged as a separate experiment

Study 5

In all previous studies, one of the recurring problems was a heavy infestation of fungus gnats (*Orfelia* spp.). Typically, growers pre-plant incorporate an insecticide containing bifenthrin (0.2%) or a similar active ingredient to control gnats, fireants, and other insects. In fact, this or a similar insecticide is a required ingredient for growing any plant to be shipped out of the Southeast due to fireant quarantines. However, since plants grown in research projects are never shipped, we do not normally comply with FIFRA laws and therefore we failed to include insecticide in our initial studies. However, we quickly saw the need to address this concern, not to be in compliance with FIFRA laws, but to eliminate unwanted insect pests. Therefore, based on successful results with lantana, Boston ferns, many bedding plants, and poinsettias, several cultivars of African Violets (*Saintpaulia* hybrids) were grown in a substrate containing 80:20 TBC:perlite, where we had only two treatments which were 80:20 TBC:perlite with pre-plant incorporated bifenthrin (0.2%) and 80:20 TBC:perlite without any bifenthrin added. Both treatments were pre-plant incorporated with 2.5 lbs/yd^3 12-6-6 Nursery Special™ fertilizer and 0.9 kg/m^3 (1.5 lbs/yd^3) Micromax® (The Scotts Company, Marysville, Ohio). Perlite was incorporated at 20% by volume since Study 4 was not yet complete. This experiment was a completely randomized design (CRD), conducted at the Paterson Greenhouse Complex in Auburn, AL. At 56 days after planting (DAP), the two treatments were de-randomized into two blocks. Yellow sticky cards were placed one inch above the foliage at even intervals within each block. The sticky cards were visually assessed for the presence or absence of fungus gnats. The root system of each plant was examined for the presence or absence of fungus gnat larvae.

Study 6

While previous studies indicated strong possibilities for using STG or TBC for production of some greenhouse crops, more attention was needed to alleviate foliar chlorosis symptoms encountered while growing petunias in substrates containing STG and TBC. A study was conducted to determine if supplementing the pre-plant incorporated fertilizer in the substrate with foliar liquid feed fertilizer would overcome some of the recurring foliar chlorosis symptoms in petunia observed in previous studies.

'Bravo Blue' petunias (*Petunia* x *hybrida* 'Bravo Blue') were planted from 288-cell plug flats into 36-cell market flats containing seven various substrate blends. The seven treatments were 100% Fafard® 3B without supplemental fertilizer (-F), 90:10 TBC:perlite with supplemental fertilizer (+F), 90:10 TBC:perlite (-F), 60:30:10 TBC:PB:perlite (+F), 60:30:10 TBC:PB:perlite (-F), 60:30:10 TBC:STG:perlite (+F), and 60:30:10 TBC:STG:perlite (-F). For treatments containing supplemental fertilizer, 1 lb/yd^3 N from 12-6-6 Nursery Special™ fertilizer was pre-plant incorporated along with 0.9 kg/m^3 (1.5 lbs/yd^3) Micromax® (The Scotts Company, Marysville, Ohio), and 3.0 kg/m^3 (5 lbs/yd^3) dolomitic limestome, which were added to all treatments. All treatments were also pre-plant incorporated with 1.19 kg/m^3 (2 lbs/yd^3) bifenthrin (0.2%) to control possible fungus gnat (*Orphelia* spp.) populations. Standard horticultural grade perlite was used. All treatments were irrigated with a 150 ppm solution of 20-20-20 (SDT Industries, Inc. Winnsboro, Louisiana) water soluble fertilizer in 3 day intervals. Treatments were irrigated with clear tap water containing no supplemental fertilizer every fourth day. Visual assessments of foliage color, root structure, and general plant size were made throughout the duration of the study. The purposes of this study were to mimic a liquid fertilizer program that might be practiced by a greenhouse grower, and to find a suitable "starter charge" that may be comparable to the starter charge in Fafard® 3B.

Results and Discussion

Study 1

Results indicated that STG can be a viable substrate component. However, the lack of fertilizer was evident in all treatments except for Fafard® 3B which is pre-incorporated with a starter charge of fertilizer that normally lasts about 3-4 weeks in a greenhouse crop. Visual observations indicated that plants grown in 100% STG were smaller and weaker plants than plants grown in treatments containing some proportion of STG with PB. Treatments of 100% Fafard® 3B and 100% PB produced superior plants. However, treatments containing STG did have satisfactory plant growth overall.

Foliar chlorosis was evident in all treatments containing STG. Foliar manganese content was exceedingly high in petunias grown in 50:50 STG:PB (Table A2). A typical range for foliar manganese content in petunias is 44 – 177 parts per million (ppm) (Mills, H.A., and J.B. Jones, Jr. 1996. Plant analysis handbook II: a practical sampling, preparation, analysis, and interpretation guide. Micromacro Publishing, Inc.). Petunias grown in 50:50 STG:PB had average foliar manganese contents of over 500 ppm. While this treatment did provide adequate plant growth, a foliar disorder was evident.

The results from this study suggested that the reduced air space and high water holding capacity of blends with STG may have led to decreased plant growth. Further studies were conducted to address these issues. Some conclusions from this study were that perlite should be added to STG:PB blends to increase air space and water drainage. It was also determined that PB and STG (1:1; v:v) could be co-composted resulting in a substrate referred to as TBC. Substrate blends containing proportions of fresh STG and TBC were then subsequently evaluated.

Study 2

Visual observations during and at the conclusion of this study suggest that poinsettias (*Euphorbia pulcherrima* 'Prestige Red') can be grown in a substrate containing 80:20 TBC:perlite. No observations suggested nutrient deficiencies or growth retardation. However, as in Study 3, which was conducted at the same time as Study 4, the presence of fungus gnats (*Orfelia* spp.) was observed. Fungus gnats are not generally harmful to plants. Their larvae, however, can harm plants by feeding on the plant's root system if they are in large enough populations. Since fungus gnats prefer substrates that are moist and high in organic matter, substrates containing STG or TBC are good candidates for fungus gnat contamination. The main concern with fungus gnat populations is that they are nuisances to the consumer, especially when present indoors. Since poinsettia is used as an indoor plant in the United States, a suitable control method is needed.

Study 3

Prestige Red poinsettias grown in the treatment containing 100% PB exhibited superior quality (Table A3). Treatments containing containing 50:50 PB:STG, 25:75 PB:STG, and 100% STG produced the lowest quality 'Prestige Red' poinsettias. The treatment containing 100% PB produced the highest quality 'Christmas Feeling' poinsettias, while plants grown in 75:25 PB:STG were similar. The treatment of 100% STG produced the lowest quality 'Christmas Feeling' poinsettias. The treatment containing 100% PB produced the largest 'Prestige Red' poinsettias, while the treatment of 75:25 PB:STG produced similar plants. 'Prestige Red' poinsettias grown in 100% STG were the smallest plants. The largest 'Christmas Feeling' poinsettias were produced in the treatment containing 100% PB. Treatments of 75:25 PB:STG, 50:50 PB:STG, and 25:75 PB:STG produced similar plants while the treatment of 100% STG yielded the smallest plants.

Marketable 'Prestige Red' and 'Christmas Feeling' poinsettias can be grown in PB substrates containing up to 25% by volume STG. Ancillary observations of fungus gnat populations in all treatments containing STG further suggest that pre-plant incorporation of an insecticide may be necessary for greenhouse crops. Current agricultural laws do not require fire ant or gnat insecticide incorporation for non-woody greenhouse crops. However, the high moisture level of substrates containing STG may warrant precautionary inclusion of such an insecticide.

Study 4

Results indicate that pansies (*Viola* x *wittrockiana* 'Matrix™ Blue Deep Blotch' and *Viola* x *wittrockiana* 'Matrix™ Sunrise') , petunias (*Petunia* x *hybrida* 'Dreams Pink' and *Petunia* x *hybrida* 'Dreams White'), and snapdragons (*Antirrhinum majus* 'Solstice Mix') can be grown in substrates containing TBC and STG. Substrate pH measurements for treatments containing STG fell slightly below the recommended range for actively growing plants (Table A4). Substrate EC for all treatments except for 100% Fafard® 3B fell within the acceptable range for actively growing plants (0.5-2.5 mS/cm).

All substrates containing TBC had exceedingly high $N0_3$-N contents which mostly likely accounts for high pH values measured for TBC-containing substrates in this and other conducted studies (Table A5).

Substrates containing STG had the highest micronutrient contents (Table A6). Manganese content was also much higher in STG-containing substrates than any other substrate.

Foliar samples of petunias grown in STG-containing substrates had the highest micronutrient contents (Table A7). Foliar manganese contents in ‘Dreams Pink’ petunia grown in STG-containing substrates were exceedingly high.

A heavy population of fungus gnats (*Orphelia* spp.) was observed through the duration of this study. Foliar chlorosis was evident in petunias and snapdragons grown in treatments containing STG and TBC. However, no differences in growth or development of the three species were observed when the percentage of perlite was decreased from 20 percent down to 10 percent.

Study 5

Results indicated that African violets (*Saintpaulia* hybrids) can be grown in a substrate containing 80:20 TBC:perlite. Fungus gnats were still present in treatments containing bifenthrin and treatments without bifenthrin on the surface of the substrate. However, pre-plant incorporated granular bifenthrin only controls fungus gnat larvae. The presence of adults does not confirm the presence of larvae. What we found was that even though gnats continued to swarm both treated and un-treated TBC, the treatment containing bifenthrin successfully eliminated fungus gnat larvae. The observed presence of adult fungus gnats in both treatments could have been the result of the close proximity of the different treatments to each other.

Study 6

As we had seen in previous studies with petunias, visual observations indicated that petunias (*Petunia* x *hybrida* 'Bravo Blue') can be grown in substrates containing TBC and STG in the proper proportions. However, a chlorotic response was still observed in all treatments at some point in this study (even in the Fafard® 3B treatments). However, in treatments containing TBC and STG, the chlorosis was more severe and lasted through the duration of the study. Poor root growth was observed in all treatments except those containing 100% Fafard® 3B (+F) and 60:30:10 TBC:PB:perlite (+F).

STG and TBC have potential as substrate components. However, further research should be conducted to determine to what extent STG and TBC can be utilized as greenhouse substrate components.

Table A1. Chemical analysis[Z] of pine bark and spent tea grinds.

Macronutrient (%)	STG[Y]	PB
Carbon	15.5	35.2
Nitrogen	1.03	0.11
Phosphorus	0.057	0.012
Potassium	0.11	0.06
Calcium	0.25	0.16
Magnesium	0.05	0.04
Sulfur	0.07	0.02
Micronutrient (ppm)[X]		
Iron	0.68	0.17
Manganese	3.82	0.10
Zinc	0.16	0.59
Aluminum	0.46	0.20
Sodium	0.51	0.62
Boron	7	7
Copper	7	2
Chemical Properties		
pH	5.49	3.95
EC (mS/cm)[W]	1	0.29

[Z]Analysis performed using the saturation extraction method.

[Y]STG = spent tea grinds ; PB = pine bark.

[X]ppm = parts per million.

[W]mS/cm = milliSiemens per centimeter.

Table A2. Selected foliar nutrient content of *Petunia* x *hybrida* 'Dreams White'.

Treatment[Z]	N	P	K	Al	Cu	Fe	Mn
	%			ppm			
100% Fafard 3B	2.31ab[Y]	0.42c	2.27de	312.4a	12.97bc	200.2b	116.1e
100% STG	1.69c	0.41c	2.43cd	221.9b	32.2a	610.3a	203.6cd
50:50 Fafard 3B:STG	2.27ab	0.51ab	2.58bc	188.9b	3.0c	143.2bcd	431.7b
100% PB	2.31ab	0.45bc	2.24e	148.1b	6.17bc	145.9bc	211.5c
50:50 PB:STG	1.94bc	0.41c	2.47c	164.7b	14.77bc	161.6b	511.4a
50:50 STG:Perlite	2.57a	0.58a	2.77a	311.8a	9.73bc	91.5cd	161.8de
75:25 STG:Perlite	2.62a	0.55a	2.72ab	162.8b	17.77b	74.4d	154.5e

[Z]Treatments were: STG = spent tea grinds ; PB = pine bark: Perlite = standard horticultural grade perlite.

[Y]Values in column followed by different letters are significant according to Tukey's Studentized Range Test (α = 0.05).

Table A3. Effect of various substrates on growth of Euphorbia pulcherrima 'Prestige Red' and E. pulcherimma 'Christmas Feeling'.

Treatment[Z]	Prestige Red'		Christmas Feeling'	
	Visual Quality Rating[Y]	Growth Index[X]	Visual Quality Rating	Growth Index
	63 DAP[V]			
100% PB	4.4a[W]	29.0a	4.5a	33.5a
75:25 PB:STG	2.6b	27.6ab	3.8ab	30.1b
50:50 PB:STG	1.8c	23.4c	3.2bc	28.4b
25:75 PB:STG	1.7c	24.3bc	2.5c	27.4b
100% STG	1.7c	21.2c	1.7d	22.2c

[Z]Treatments were: PB = pine bark; STG = spent tea grinds.

[Y]Rating scale = 1 (lowest quality) to 5 (highest quality).

[X]Growth index = (height + widest width + perpendicular width) / 3.

[V]DAP = days after planting.

[W]Values in column followed by different letters are significant according to Tukey's Studentized Range Test (α = 0.05).

Table A4. Chemical properties of various substrates.

Treatments[Z]	EC[Y]	pH
	mS/cm[X]	log (1/[H+])
100% Fafard 3B w/ fertilizer	0.64bc[W]	5.75ab
100% Fafard 3B w/o fertilizer	0.33c	6.35a
80:20 TBC:perlite w/ fertilizer	1.72abc	6.07ab
80:20 TBC:perlite w/o fertilizer	2.05abc	5.90ab
90:10 TBC:perlite w/ fertilizer	2.13ab	5.94ab
90:10 TBC:perlite w/o fertilizer	2.50a	5.98ab
40:40:20 STG:PB:perlite w/ fertilizer	1.65abc	5.32b
45:45:10 STG:PB:perlite w/o fertilizer	1.15abc	5.41b

[Z]Treatments were: STG = spent tea grinds; PB = pine bark; TBC = composted STG:PB (1:1, v:v).

[Y]EC = electrical conductivity.

[X]mS/cm = milliSiemens per centimeter.

[W]Values in columns followed by different letters are significant according to Tukey's Stundentized Range Test (α = 0.05).

Table A5. Selected macronutrient contents[Z] of various substrates.

Treatment[Y]	$N0_3$-N	K	P	Ca	Mg
	ppm[X]				
100% Fafard 3B w/ fertilizer	1.7b[W]	38.2b	20.4b	91.3ab	54.5ab
100% Fafard 3B w/o fertilizer	1.4b	46.9b	11.7b	28.2b	28.4b
80:20 TBC:perlite w/ fertilizer	93.6ab	254.9ab	66.7a	220.8a	97.0a
80:20 TBC:perlite w/o fertilizer	230.2ab	472.6ab	61.1a	153.2ab	77.8ab
90:10 TBC:perlite w/ fertilizer	172.8ab	346.4ab	69.9a	247.8a	109.6a
90:10 TBC:perlite w/o fertilizer	308.3a	639.3a	68.6a	172.8ab	84.9ab
40:40:20 STG:PB:perlite w/ fertilizer	35.1ab	106.2b	47.1ab	218.6a	96.4a
45:45:10 STG:PB:perlite w/o fertilizer	4.2b	72.3b	33.6ab	166.9ab	79.9ab

[Z]Values determined by Saturation Extraction Method (Auburn University, Soil Testing Laboratory, Auburn, AL).

[Y]Treatments were: STG = spent tea grinds; PB = pine bark; TBC = composted STG:PB (1:1, v:v).

[X]ppm = parts per million.

[W]Values in column followed by different letters are significant according to Tukey's Studentized Range Test ($\alpha = 0.05$).

Table A6. Selected micronutrient contents[Z] of various substrates.

Treatment[Y]	Al	B	Cu	Fe	Mn
	ppm[X]				
100% Fafard 3B w/ fertilizer	0.7bc[W]	0.33cd	0.33ab	0.70b	0.50c
100% Fafard 3B w/o fertilizer	0.65bc	0.08d	0.12b	0.22b	0.10c
80:20 TBC:perlite w/ fertilizer	0.36c	0.92ab	0.22ab	0.28b	0.56c
80:20 TBC:perlite w/o fertilizer	0.51c	0.49bcd	0.14b	0.19b	0.84c
90:10 TBC:perlite w/ fertilizer	0.44c	0.96a	0.24ab	0.26b	1.49c
90:10 TBC:perlite w/o fertilizer	0.3c	0.57abc	0.15b	0.10b	0.90c
40:40:20 STG:PB:perlite w/ fertilizer	2.65ab	0.90ab	0.30ab	0.70b	13.4a
45:45:10 STG:PB:perlite w/o fertilizer	3.00a	0.85ab	0.55a	1.85a	8.95b

[Z]Values determined by Saturation Extraction Method (Auburn University, Soil Testing Laboratory, Auburn, AL).

[Y]Treatments were: STG = spent tea grinds; PB = pine bark; TBC = composted STG:PB (1:1, v:v).

[X]ppm = parts per million.

[W]Values in column followed by different letters are significant according to Tukey's Studentized Range Test (α = 0.05).

Table A7. Selected foliar micronutrient contents of *Petunia* x *hybrida* 'Dreams Pink' grown in various substrates.

Treatment[Z]	Al	Cu	Fe	Mn	Zn
	ppm[Y]				
100% Fafard 3B w/ fertilizer	81.2a[X]	24.7bc	265.7a	295.7b	143.8abc
100% Fafard 3B w/o fertilizer	205.4a	17.4bc	182.3a	121.9c	89.5c
80:20 TBC:perlite w/ fertilizer	92.0a	35.3bc	115.7a	201.4bc	114.5abc
80:20 TBC:perlite w/o fertilizer	154.3a	14.1c	148.4a	209.6bc	73.1c
90:10 TBC:perlite w/ fertilizer	132.0a	20.8bc	129.4a	255.2bc	103.3bc
90:10 TBC:perlite w/o fertilizer	161.6a	33.7bc	161.4a	237.0bc	74.4c
40:40:20 STG:PB:perlite w/ fertilizer	180.1a	46.8ab	210.3a	784.5a	170.7ab
45:45:10 STG:PB:perlite w/o fertilizer	159.7a	70.6a	156.0a	837.7a	184.4a

[Z]Treatments were: STG = spent tea grinds; PB = pine bark; TBC = composted STG:PB (1:1, v:v).

[Y]ppm = parts per million.

[X]Values in column followed by different letters are significant according to Tukey's Studentized Range Test (α = 0.05).