




Strategies for Carbon Sequestration and Reducing Greenhouse Gas Emissions from Nursery Production Systems







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Progress Report

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Executive Summary

Over the past three decades, climate change and its potential impacts on the global environment have received significant attention from the scientific community. Increased atmospheric carbon dioxide (CO_2) concentration, along with other trace gases [i.e., methane (CH_4) and nitrous oxide (N_2O)] are widely believed to be the driving factors behind global warming. Much of the work on reducing greenhouse gas (GHG) emissions and carbon (C) sequestration has been conducted in row crop and forest systems; however, virtually no work has focused on contributions from sectors of the specialty crop industry such as ornamental horticulture. Ornamental horticulture impacts rural, suburban, and urban landscapes. While this industry may have some negative impacts (e.g., CO_2 and trace gas efflux), it also has potential to reduce GHG emissions and increase C sequestration. Priorities for this project are to determine baseline GHG emissions from common nursery production systems while also developing strategies to reduce these emissions and sequester C by altering management practices.

Currently two experiments are being conducted to determine the impact of the ornamental horticulture industry on GHG emissions and on C sequestration. One study focuses on the effect of nursery container size to begin indentifying components of the industry that may impact GHG emissions. In this study, dwarf yaupon hollies are being grown in four commonly used container sizes using standard potting media. Greenhouse gas emissions are being sampled *in situ* using the static, closed chamber method according to USDA's Greenhouse Gas Reduction Through Agricultural Carbon Enhancement network (GRACEnet) protocols. Greenhouse gas emissions (CO_2, CH_4, N_2O) are being assessed weekly and analyzed using gas chromatography. Data are currently being analyzed and processed.

The second study focuses on determining techniques for increasing potential C storage in urban and suburban landscapes. This is being accomplished by evaluating different plant species and potting media and determining how these factors affect C sequestration in the landscape. The Horticulture Department at Auburn University has ongoing research to develop alternative substrates for horticulture production. This study utilizes three growth substrates: 1) Pinebark (industry standard); 2) Clean Chip Residual; and 3) Whole Tree. Twelve commonly grown woody ornamentals were grown in these differing substrates and then outplanted to the field in December, 2008. Of these twelve species, three tree species (oak, magnolia, and crape myrtle) were first selected to monitor soil C efflux and soil C content. Initial soil samples were collected in summer 2009 for determination of soil C and N on all twelve species. An Automated Carbon Efflux System (ACES) was installed adjacent to the three tree species within this study to continuously monitor C lost through soil respiration. Periodic soil samples are being taken to monitor changes in soil C, providing information on both inputs (biomass) and outputs (respiration). Preliminary results from soil C analysis and ACES system efflux data indicate that potting media and species do have significant effects on C sequestration in the landscape. In November, 2010, the three tree species were destructively harvested to determine biomass of both aboveground and root portions of the plant. These data are currently being analyzed to further investigate the role of species and media on C sequestration in the landscape. In addition, the ACES system was installed next to three additional species following the destructive harvest of the trees to determine soil C efflux from additional container ornamental species. To date, this research has resulted in two recent peer reviewed journal articles, three conference proceedings articles, and 12 presentations at regional and national scientific meetings.

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Introduction

Over the past three decades, an issue which has received significant attention from the scientific community is climate change and the possible impacts on the global environment. Increased atmospheric carbon dioxide (CO_2) concentration, along with other trace gases [i.e., methane (CH_4) and nitrous oxide (N_2O)] are widely believed to be the driving factors behind global warming. Much of the work on reducing greenhouse gas (GHG) emissions and carbon (C) sequestration has been conducted in row crop and forest systems; however, virtually no work has focused on contributions from sectors of the specialty crop industry such as ornamental horticulture. Ornamental horticulture is an industry which impacts rural, suburban, and urban landscapes (Fig. 1 and 2). While this industry may have some negative impacts on the global environment (e.g., CO_2 and trace gas efflux), it also has potential to reduce GHG emissions and increase C sequestration. Priorities for this project are to determine baseline CO_2 and trace gas emissions from common nursery production systems and sequentially develop strategies to reduce these emissions and sequester C by altering management practices.

Fig. 1. Container production in Mobile, AL.

Fig. 2. Commercial loropetalum production.

In the first year, a study was initiated which focuses on the effect of nursery container size on GHG emissions to begin indentifying components of the industry that may impact these emissions. If a direct relationship between the volume of potting media and GHG emissions can be established, future measurements in differing management schemes could be scaled to determine industry-wide impacts. In this study, dwarf yaupon holly (*Ilex vomitoria* 'Nana') was grown in four common container sizes using standard potting media (i.e., pinebark). Greenhouse gas emissions are being sampled *in situ* using the static closed chamber method according to USDA's Greenhouse Gas Reduction through Agricultural Carbon Enhancement network (GRACEnet) protocols (Appendix 1). Greenhouse gas emissions (CO_2, CH_4, N_2O) are being assessed weekly and analyzed using gas chromatography. In addition to the work described above, a nursery survey of the thirteen largest container producers in Alabama was conducted in spring, 2009. This survey was used to develop an estimate of the media used in Alabama container production each year to determine the amount of C potentially stored belowground annually from the planting of ornamental species in the landscape.

An additional study in the first year focuses on determining techniques for increasing potential C storage which can be implemented within the nursery and landscape industries. The

Horticulture Department at Auburn University has ongoing research to develop alternative substrates for horticulture production. This study utilizes three growth substrates: 1) Pinebark (industry standard); 2) Clean Chip Residual; and 3) Whole Tree. Plants were grown in these differing substrates and then outplanted to the field in December, 2008. Initial soil samples were collected in summer, 2009 for determination of soil C and N content. An Automated Carbon Efflux System (ACES) was installed adjacent to three plant species within this study to continuously monitor C lost through soil respiration. Biomass was and will continue to be assessed to determine the amount of C in plant material. Also, soil samples will continue to be taken to monitor changes in soil C, providing information on both inputs (biomass) and outputs (respiration) which will allow determination of C sequestration potential in these potting media/plant species systems. Once baseline estimates of GHG emissions and C sequestration potential are established, further work will be conducted to evaluate additional production inputs during the second year of the project.

Objectives for the second year include evaluating nursery fertilizer practices and developing Best Management Practices to provide guidelines for growers which will help reduce GHG emissions from fertilization practices. Methods of fertilization will be evaluated. The three predominate methods growers use to fertilize container grown plant material include: 1) topdressing (placing fertilizer on media surface of the pot); 2) dibble (placing a hole in the container media and placing the fertilizer in the hole); and 3) incorporation (fertilizer is mixed with media prior to potting). Gas sampling will be conducted as described above to determine which method is most effective at reducing GHG emissions.

This project is unique in the fact that no previous data exist showing the impact horticulture production systems have on global GHG emissions. This document is a progress report on the activities conducted between May, 2009 and February, 2011.

This project requires a multi-disciplinary team with expertise in different areas to achieve the goals set forth. Principle Investigators working on this project include:

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Students

S. Christopher Marble, a doctorate level graduate student in the Department of Horticulture at Auburn University, joined the project in January, 2010. Mr. Marble's research is being conducted under the supervision of Drs. Prior, Gilliam, Runion, Torbert, and Fain.

Six undergraduate students have assisted in this research as hourly employees of Auburn University (Department of Biosystems Engineering) housed at the USDA-ARS National Soil Dynamics Laboratory in Auburn, AL.

Activities to Secure Additional Resources

Preliminary research and results have been used to attempt to secure additional funding. As of January, 2011, five grant proposals have been written and submitted in this attempt. Three of these grants were not funded, one submission is currently under review, and another is currently being revised for a 2011 submission. The funding sources and the current status of these grants are as follows:

Gilliam, C., Torbert, A., Prior S., Fain G., and Marble C. 2009. Carbon Sequestration and Greenhouse Gas Emission Reduction from Nursery Production Systems. Alabama Agricultural Experiment Station. $50,000. 2010-2011 (Not Funded).

Gilliam, C., Torbert, A., Prior, S., and Fain G. Carbon Sequestration and Greenhouse Gas Emission Reduction from Nursery Production Systems. 2009. USDA Agriculture and Food Research Initiative (AFRI) Competitive Grants Program. $304,423. 2010-2012 (Not Funded)

Fain, G., Gilliam, C., Sibley, J., Gallagher, T., Wehtje, G., Altland, J., Rinehart, T., Albano, J., Owen J., Leavengood, S., Seavert, C., Sullivan, D., Blythe, E., Jackson, B., Bilderback, T., Fonteno, B., Boyer, C., Cogger, C., and Hummel, R. 2010. Development of Cost Effective, Renewable and Regional Substrates for Production of Containerized Specialty Crops. USDA-NIFA Specialty Crops Research Initiative. $4,183,871. 2011-2015 (Not Funded). *Currently being rewritten for 2011 submission.

Gilliam, C.H., Fain, G.B., and Sibley, J.L. 2010. Carbon Sequestration and Greenhouse Gas Emission Reduction in Horticultural Production Practices. Alabama Agricultural Experiment Station. $371,200. 2011-2015 (Not Funded).

Gilliam, C.H., Prior, S.A., and Gallagher, T.V. 2010. Carbon Sequestration and Greenhouse Gas Emission Reduction in Horticulture. Auburn University Intramural Grants Program (AU-IGP). $50,000. 2011-2012 (Pending).

Project Description

Greenhouse gas emissions to the atmosphere are among the documented anthropogenic factors driving climate change. It is known that land management practices may be altered to reduce GHG emissions and/or to sequester C in soil. However, there is a need to obtain baseline data on GHG emissions and C sequestration from ornamental horticulture production facilities. This information will provide the basis for the development of management practices to reduce GHG emissions and increase C sequestration while also balancing production goals and profitability.

It is believed that the ornamental horticulture industry has potential to reduce GHG emissions and increase C sequestration. Priorities for the project described here are to determine baseline carbon and trace gas emissions from common nursery production systems and sequentially develop strategies to reduce these emissions and sequester C by altering management practices.

Objectives:

1. Determine the carbon sequestration potential within nursery systems

2. Develop strategies to increase carbon sequestration above current levels

3. Measure greenhouse gas emissions from nursery production systems

4. Develop practices to reduce greenhouse gas emissions from nursery production systems

Approach:

Determining Greenhouse Gas Emissions from Container-grown Ornamentals

Initially, this research will focus on measuring GHG emissions from nursery production systems and will attempt to identify components of the industry with the most potential to impact these emissions. The initial project, being conducted at Auburn University's Paterson

Greenhouse Complex adjacent the the USDA-ARS National Soil Dynamics Laboratory (Fig. 1), is focusing on nursery pot size as a main treatment factor. This will not only establish a general baseline for a variety of different production systems, but will also potentially establish the relative importance of container size on greenhouse gas fluxes. For example, if a direct relationship between potting media volume and gas emissions can be established, then future measurements in different management schemes could potentially be scaled to determine industry level impacts in different potting systems.

Fig. 3. USDA-ARS National Soil Dynamics Laboratory (on left) and Auburn University's Paterson Greenhouse Complex (on right).

In this study, four pot sizes commonly used in the nursery industry (i.e., trade gallon, 1 gallon, 2 gallon and 3 gallon) are being examined (Fig. 4 and 5). For each pot size, seven replications contain plants [*Ilex vomitoria* 'Nana' (dwarf yaupon holly)] and 3 replications contain only pinebark potting media and serve as the control. Potting media and production systems follow Auburn University standard production practices. Greenhouse gas emissions are being measured weekly from these pots. In addition, other sampling times associated with production practices will be included. For example, sampling associated with watering (before and after) will be made to measure the potential temporal impact which may occur during these normal management practices. Future studies will also include additional plant species and also evaluate multiple potting media (i.e., WholeTree, Clean Chip Residual, etc.).

Trace gases emitted from potting systems are being sampled *in situ* using the static closed chamber method (Hutchinson and Mosier 1981; Hutchinson and Livingston 1993). Custom-made gas flux chambers have been designed and constructed as an initial component of this study (Fig. 6). The design is based on the construction criteria of the GRACEnet protocol (Parkin and Kaspar 2006; Baker et al. 2003) to accommodate nursery potting systems (rather than field plot studies).

A structural base consisting of polyvinyl chloride (PVC) cylinders (25.4 cm inside diameter by 38.4 cm tall) is sealed at the bottom. During gas measurement, the entire plant-pot system is placed inside the base cylinder and a vented flux chamber (25.4 cm diameter x 11.4 cm height) is placed on top of the base cylinder. The top flux chambers are constructed of PVC, covered with reflective tape, and have a center sampling port. Gas samples for CO_2, CH_4, and N_2O are taken at

0, 15, 30, and 45 min intervals following chamber closure, allowing gas flux rate to be calculated from the change in concentration over the 45 min interval. At each time interval, gas samples (10 mL) are collected with polypropylene syringes (Fig. 7 and 8) and injected into evacuated glass vials (6 mL) fitted with butyl rubber stoppers as described by Parkin and Kaspar (2006).

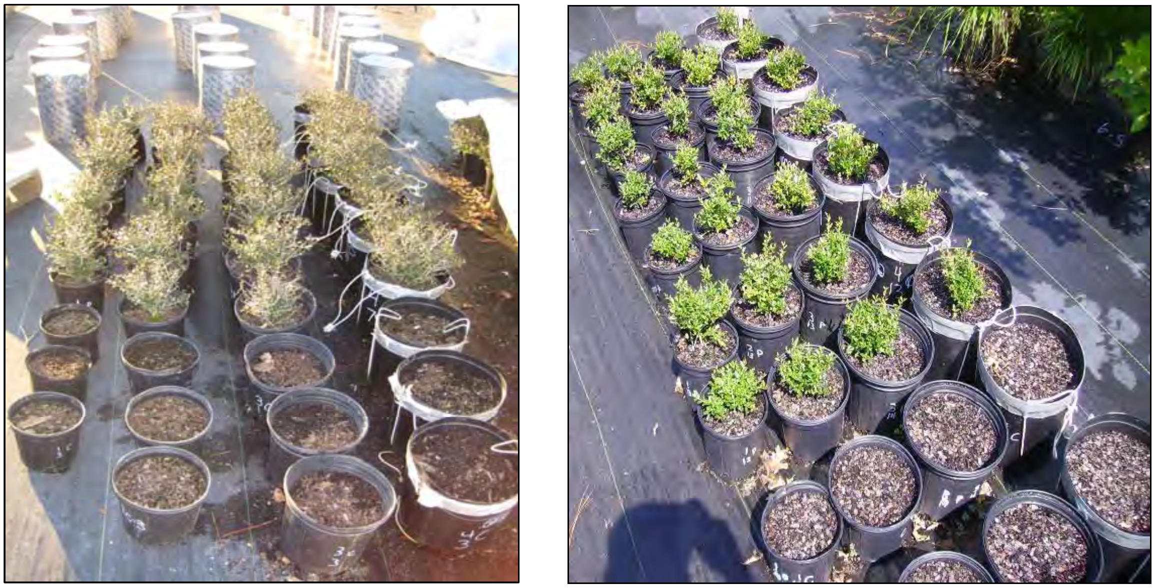

Fig. 4. (From L to R) Trade, one, two, and three gallon pots used in the study.

Fig. 5. Custom made gas flux chambers

Fig. 6. Gas flux chamber and four vials used during gas collection.

Fig. 7. Gas samples being drawn for analysis with Gas Chromatograph.

The overpressure facilitates the subsequent removal of the gas sample for analysis. Gas samples are analyzed by a gas chromatograph (Shimadzu GC-2014, Columbia, MD) equipped with three detectors: thermal conductivity detector for CO_2, electrical conductivity detector for N_2O, and flame ionization detector for CH_4.

Fig. 8. Shimadzu Gas Chromatograph (GC-2014).

Gas concentrations are determined by comparison to a standard curve using standards obtained from Air Liquide America Specialty Gases, LLC (Plumsteadville, PA). Gas flux rates are determined using linear or curvilinear equations as appropriate (Parkin and Kaspar 2006).

Effects of Species and Potting Media on Carbon Sequestration Potential in the Landscape

A study was also implemented focused on determining potential C storage techniques that can be implemented in the nursery and landscape industries. Measurement of potential C (Fig. 10) sequestration is accomplished by making soil and gas sampling measurements in an existing alternative substrate study. The Department of Horticulture at Auburn University has an ongoing effort to develop alternative substrates for horticultural production. One ongoing study has utilized standard planting procedures to examine plant establishment and growth of common horticultural plant species that were initially grown in alternative substrates prior to planting into the landscape. Within this study, the substrates used were Pinebark (industry standard), Clean Chip Residual, and Whole Tree.

Fig. 9. Alternative substrates study at Auburn field site.

Fig. 10. Pinebark, Clean Chip Residual, and Whole Tree substrate (left to right, respectively).

Plant species used in this study include: Japanese Holly (Ilex crenata ‘Soft Touch’); Juniper (*Juniperus horizontalis* 'Blue Rug'); Lantana (*Lantana camara* 'Lucky Gold Yellow Improved'); Gardenia (*Gardenia jasminoides* 'August Beauty'); Indian hawthorn (*Rhaphiolepis indica*); dwarf nandina (*Nandina domestica* 'Dwarf firepower'); Reeves spirea (*Spiraea cantoniensis*); knockout rose (*Rosa* 'Knockout'); cleyera (*Ternstroemia gymnanthera*); loropetalum (*Loropetalum chinensis*); crape myrtle (*Lagerstroemia* x ‘Acoma’); Magnolia (*Magnolia grandiflora*); and Shumard Oak (*Quercus shumardii*).

Both C inputs and outputs are being measured in the study. Plant biomass increases (as measured by plant growth) are being monitored to assess the C sequestration potential in the plant. Also, soil samples are being taken to monitor changes in soil C as impacted by the addition of potting substrate and plant rooting as compared to a no-plant control. As a measure of management impacts, soil C changes over time will also be measured. Soil samples are being collected and analyzed as described by Prior (2004) in Spring and Fall to measure any increases (or decreases) in soil C levels.

In addition, in a selected subset of treatments, soil respiration is being continuously monitored to assess CO_2 emissions to the atmosphere as affected by alternative substrate management. Monitoring is accomplished with the use of an Automated Carbon Efflux System (ACES; Fig. 11). This unique system, developed by the USDA Forest Service (Southern Research Station Laboratory, Research Triangle Park, NC; U.S. patent # 6,692,970), not only allows for continuous measurement of CO_2 flux (24 hours a day, 7 days a week), but does so under open atmospheric conditions (Butnor et al. 2003; Fang and Moncrieff 1996).

Fig. 11. Automated Carbon Efflux System (ACES) and ACES sampling chambers.

This system was installed to measure the 3 substrate treatments x 3 plant species and the no-plant control in 3 replications. Within these areas, changes in soil moisture and soil temperature are also being measured. In the first year, the ACES system was used to collect soil respiration data on the three tree species listed above (oak, magnolia, and crape myrtle; Fig. 12). Soil respiration was monitored on these species from the Summer of 2009 until the winter of 2010. At the conclusion of this study, all three species were destructively harvested. Aboveground plant biomass was separated into component parts (stems, leaves, reproductive tissues), dried, weighed, and are currently being processed to determine C content. Roots were also collected, dried, weighed, and are currently being processed to determine C content. Following the destructive harvest of the three tree species, ACES equipment were re-installed in order to begin collecting soil respiration data on three additional species (Indian hawthorn, cleyera, and loropetalum).


Fig. 12. Aces system installed adjacent to crape myrtle to monitor soil C efflux.

Data collected from these studies will provide both baseline data for C sequestration potential and examine potential management strategies in the horticulture industry to increase this potential. Results from these studies will also provide baseline data for GHG emissions from some commonly used nursery production systems and help identify management schemes that may be important for further investigation.

Results and Progress to Date

- Weekly gas samples (CO_2, CH_4, and N_2O) have been collected in the container portion of the trial from April 2010 through December 2010 and are being analyzed weekly using the gas chromatograph. Data from this study are currently being processed. Delays were encountered in this portion of the project due to problems encountered with the septa used in gas collection vials. It was determined that manufacturer error caused this problem with the septa and supplies are now being ordered from a different company.

- Growth data (height and groundline diameter) were taken periodically on all three species during this study, as well as growth index [(plant height + canopy width1 + canopy width2)/3]. Growth data indicate that, within each species, plants had similar growth regardless of potting media used during production (Fig. 13).

- All plants were destructively harvested (Fig. 14), measured, dried, and ground. This plant tissue will be further analyzed in order to get carbon content for each type of plant tissue. Dry weights are currently being analyzed.

- Soil respiration data using the ACES system was collected on the three tree species (oak, magnolia, crape myrtle) from July 2009 through November 2010.

- Preliminary results from the ACES study show that CO_2 efflux was higher in crape myrtle than magnolia (9.4%), possibly due to a larger root system or faster growth rate of crape myrtle. This would indicate that the growth characteristics of southern magnolia could possibly be more beneficial as far as reducing GHG emissions is concerned; however, biomass and plant tissue carbon data will be needed before firm conclusions can be reached.

- Results from the efflux data on the oak species was delayed due to a temporary malfunction of the ACES system. These data are currently being analyzed.

- Crape myrtle had higher CO_2 efflux than magnolia in each potting medium. WholeTree (WT) had the lowest efflux of the three media. This could possibly be due to WT having a higher wood content than pinebark (PB) or clean chip residual (CCR), causing it to break down slower. In crape myrtle, WT had lower efflux than both PB and CCR; in magnolia it was also lower than PB but was similar to CCR. PB was higher than CCR in magnolia, but in crape myrtle PB was lower than CCR (Fig. 15).

- Carbon concentrations of the media were determined to be 49.2, 47.8, and 46.9%, for PB, WT, and CCR respectively. Soil analysis indicated that soil C in the top soil depth (0 - 15 cm) was higher for PB compared to WT, CCR, and native soil for all three species (Fig. 16). Soil C for the other two media did not differ in any species. Although soil C was much lower at the 15 - 30 cm depth, the same treatment pattern was observed in crape myrtle and magnolia; however, there were no differences in soil C for the oaks at this depth. No soil C differences were observed among media or the native soil in any species at the lower two depths (i.e., 30 - 45 and 45- 60 cm). Additional soil samples were collected in November 2010 and are currently being processed in order to determine changes in soil C over time.

- Data from these soil samples show that soil C ranged from 9 - 25% compared to about 2% found in the native soil. These data clearly show that planting containerized ornamentals into the landscape instantly transfers a large amount of C belowground; however, uncertainty remains regarding how long this C will be sequestered. Future studies are needed to determine the residence time of this C in the soil when planted into the landscape and to fully understand the role of the ornamental horticulture industry on C sequestration.

- A nursery survey was conducted to begin quantifying the amount of C used in container media in order to estimate the amount of C being placed underground (from planting containerized ornamental crops) from Alabama nurseries each year. Thirteen of the largest Alabama nurseries, representing approximately 50% of the total state container-grown plant production, were polled at regional scientific meetings, on-farm visits, and through the Alabama Agricultural Extension Service. Growers were asked how many container-grown plants they produced each year, what size containers were used (e.g., #1, #3, #5, etc.), and the primary potting media used (e.g., pine bark, pine bark + sand, pine bark + peat) as well as fertilization products and methods used, and how the nurseries irrigated their crops.

- Results from the survey indicated that approximately 72,000 m^3 of pinebark are used to produce container grown nursery crops in Alabama each year. Given that the survey represented approximately half of the state's production, this estimate could be doubled (140,000 - 150,000 m^3). Given that pinebark has a very high C concentration (49.2% in our analysis; with a density of 0.24 g cm^{-3}), this represents a significant amount of C (16,500 – 17,700 Mg C, or 18,150 - 19,470 U.S. tons) potentially placed belowground annually.

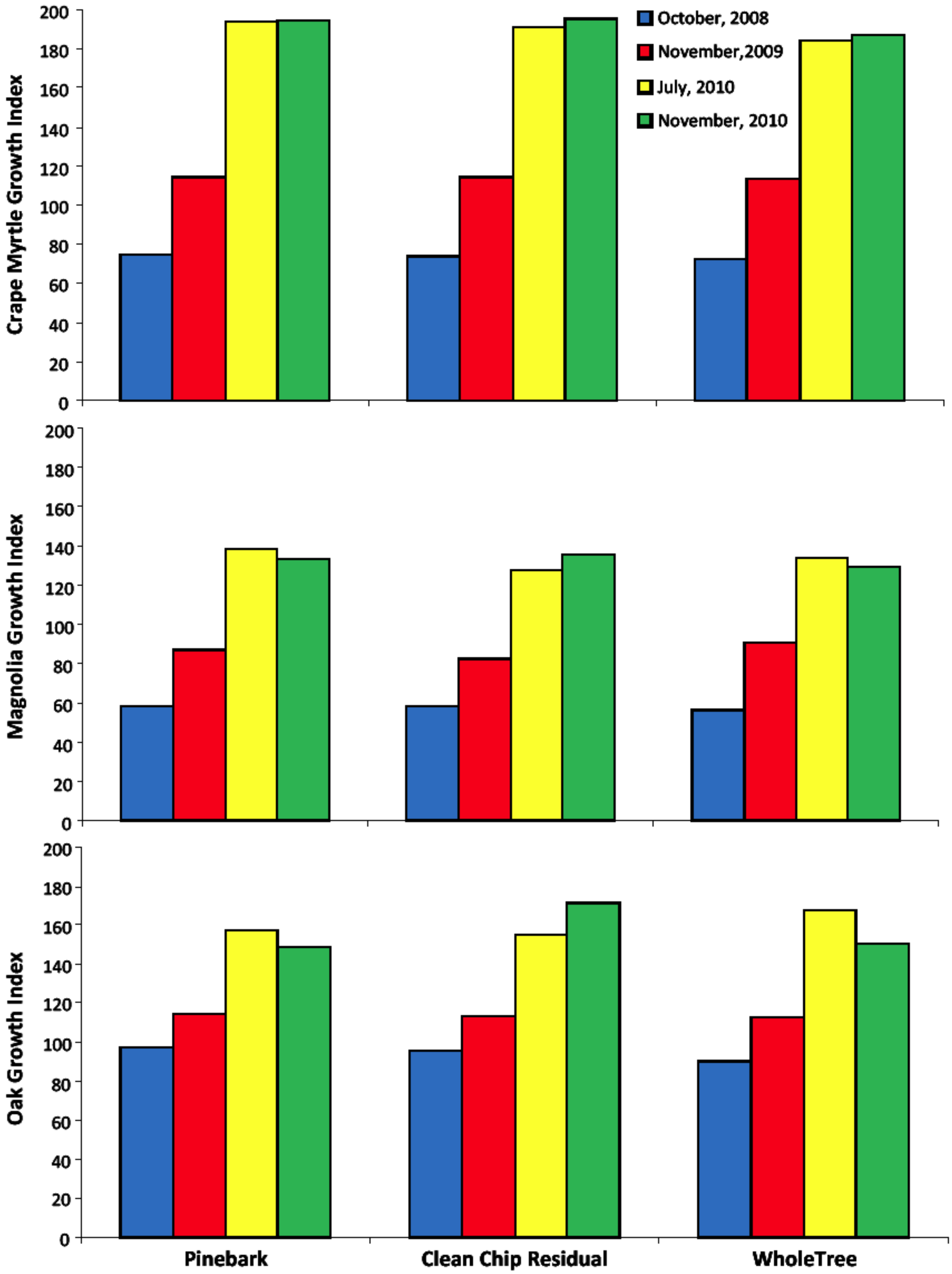

Fig. 13. Growth index [(plant height + canopy width1 + canopy width2)/3] for crape myrtle, magnolia, and oak (top to bottom, respectively) in the three growth substrates taken at various sampling periods over the course of the study.

Fig. 14. Crape myrtle (top), magnolia (middle), and oak (bottom) roots from Pinebark, Clean Chip Residual, and WholeTree substrates (from left to right, respectively) following destructive harvest.

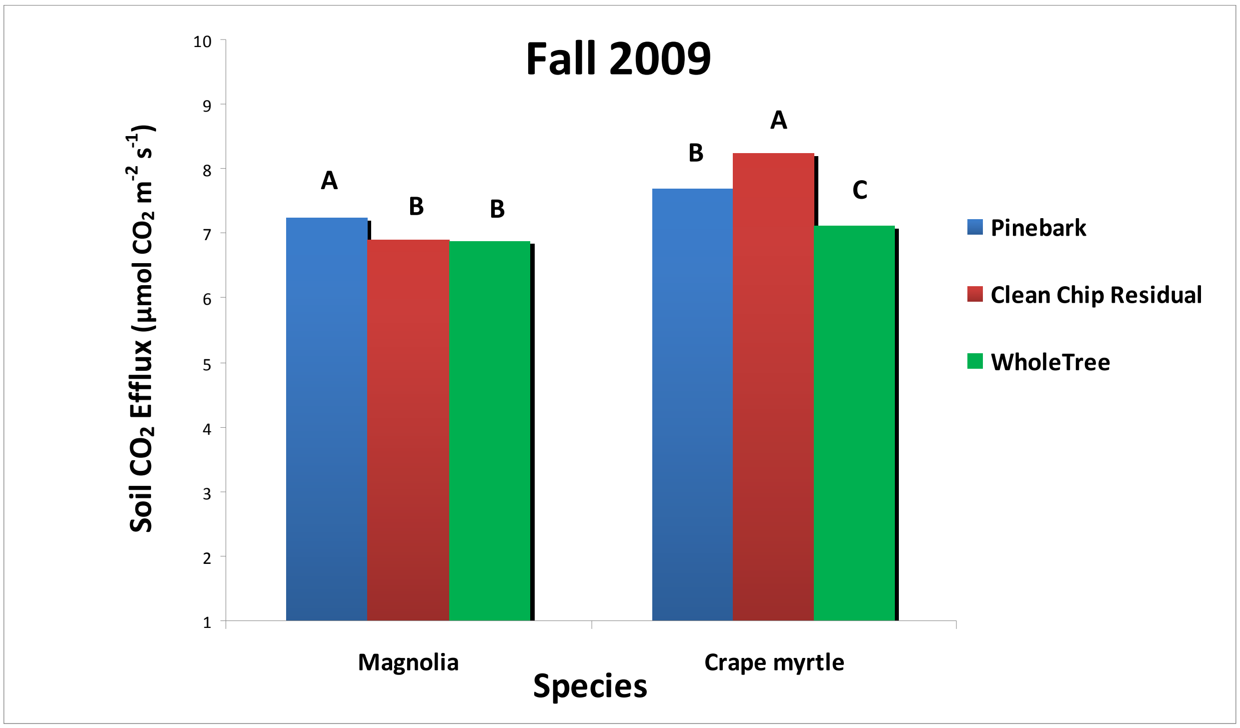

Fig. 15. Soil CO_2 efflux in Fall 2009 for magnolia and crape myrtle grown in three substrates. Bars with different letters are significantly different.

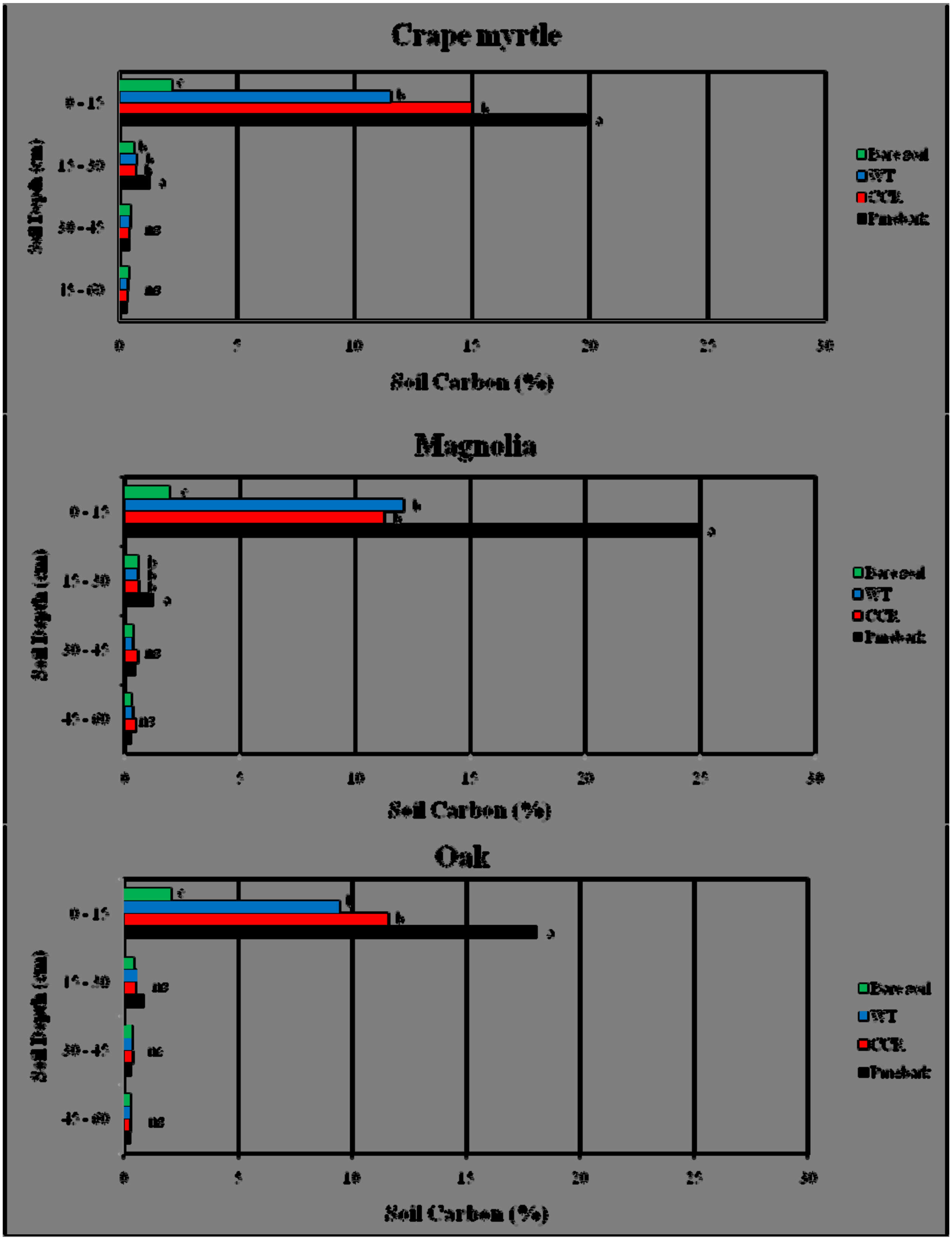

Fig. 16. Soil carbon levels in crape myrtle, magnolia, and oak (top to bottom, respectively). Bars with different letters are significantly different.

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Prior, S.A., Runion, G.B., Torbert, H.A., and Erbach, D.C. 2004. A hydraulic coring system for soil root studies. Agron. J. 96 (4):1202-1205.

Refereed Scientific Publications Produced as of February, 2011 (see Appendix 2 for full text):

Marble, S.C., Prior, S.A., Runion, G.B., Torbert, H.A., Gilliam, C.H., and Fain, G.B. 2011. The importance of determining carbon sequestration and greenhouse gas mitigation potential in ornamental horticulture. HortScience 46(2):240-244.

Prior, S.A., Runion, G.B., Marble, S.C., Rogers, H.H., Gilliam, C.H., and Torbert, H.A. 2011. A review of elevated atmospheric CO_2 effects on plant growth and water relations: Implications for horticulture. HortScience 46(2):158-162.

Scientific Proceedings Publications Produced as of February, 2011 (see Appendix 2 for full text)

Marble, S.C., Prior, S.A., Runion, G.B., Torbert, H.A., Gilliam, C.H., and Fain, G.B. 2010. Effects of outplanting horticultural species on soil CO_2 efflux. Proc. Southern Nurs. Assn. Res. Conf. 55:69-72.

Marble, S.C., Prior, S.A., Runion, G.B., Torbert, H.A., Gilliam, C.H., and Fain, G.B. 2010. Effects of media and species on soil CO_2 efflux in the landscape. Proc. Int. Plant Prop. Soc. xx:xxx (In Press).

Marble, S.C., Prior, S.A., Runion, G.B., Torbert, H.A., Gilliam, C.H., Fain, G.B., Sibley, J.L., and Knight, P.R. 2011. Soil carbon levels as affected by growth media and plant species. Proc. Southern Nurs. Assn. Res. Conf. xx:xxx-xxx (In Press).

Oral and Poster Presentations Given (Presenter in bold):

Marble, S.C., Prior, S.A., Runion, G.B., Torbert, H.A., Gilliam, C.H., Fain, G.B., Sibley, J.L., and Knight, P.R. 2011. Soil carbon levels as affected by growth media and plant species. Gulf States Horticultural Expo, Mobile, AL, Jan. 19-20. Oral Presentation.

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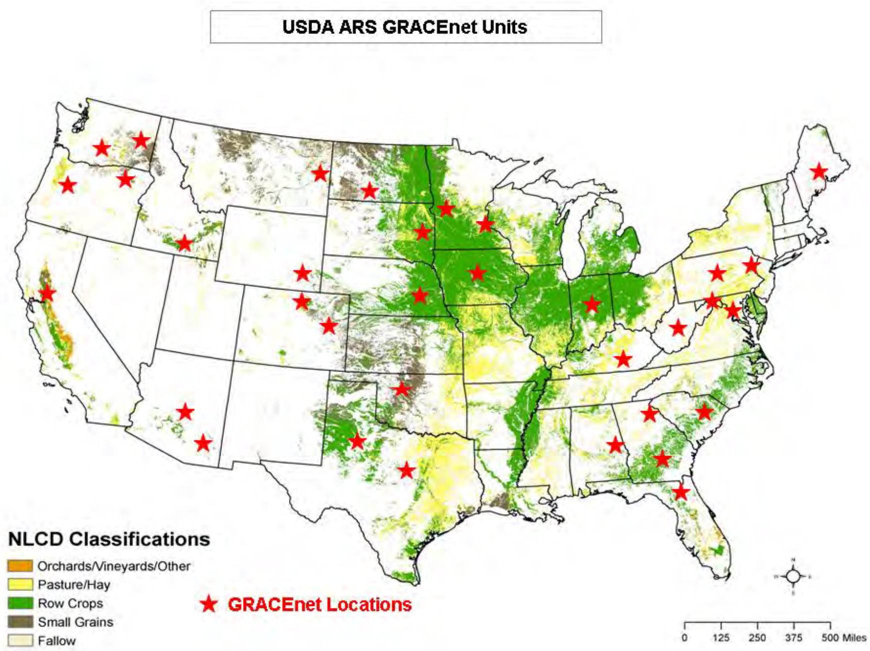
APPENDIX 1

GRACEnet

The ARS Greenhouse gas Reduction through Agricultural Carbon Enhancement network (GRACEnet) is a coordinated project across 34 ARS locations. GRACEnet is being conducted to provide information on the soil carbon (C) status and green house gas (GHG) emissions of current agricultural practices, and to develop new management practices to reduce net GHG emission and increase soil C sequestration.



Specific objectives include:

- Evaluate soil carbon status and its change in existing typical and alternative agricultural systems
- Determine the net GHG emissions (CO_2, CH_4 and N_2O) of existing and alternative agricultural systems
- Determine the environmental effects (affecting water, air and soil quality) of new agricultural systems developed to reduce GHG emission and increase soil C storage

GRACEnet has a core project plan with an ARS lead scientist who is assisted by a steering committee of other ARS scientists. Individual scientists produce project plans that contribute to the core GRACEnet project plan. As with all ARS research projects, the core project and the individual scientist project plans are peer-reviewed by non-ARS scientists under the supervision of the ARS Office of Scientific Quality Review (OSQR).

GRACEnet includes a common set of experiment scenarios:

- Business as usual (current management practices)
- Management practices designed to maximize C sequestration rate
- Management practices designed to minimize net GHG emission including N_2O and CH_4 emissions
- Management practices designed to maximize environmental benefits such as conservation and ecosystem services

Other elements of GRACEnet include:

- Common sampling guidelines
- Instrumentation development
- CQUESTR carbon sequestration and GHG simulation model development

Products from the research are strongly emphasized and include:

- A national GHG flux and C storage database
- Summary & synthesis papers for action agencies and policy makers
- Regional & national guidelines for management practices
- Development and evaluation of computer models that can be used for research and/or provide the basis for the development of decision support systems

Several GRACEnet manuscripts have had significant impact on the development of practices designed to increase C sequestration. The information in these documents has been accessed and used by groups seeking to participate in C credit trading. GRACEnet investigators also produce the U.S. Agriculture and Forestry Greenhouse Gas Inventory that can be accessed via: http://www.usda.gov/oce/climate_change/gg_inventory.htm

Future GRACEnet activities will seek to increase emphasis on N_2O emissions resulting from fertilizer applications, increase efforts on specialty crops (vegetables, fruits, nuts, horticulture, etc.), and focus more on the development of decision support and mitigation options

Cropping and rangeland systems have been the major focus of this research. The success of GRACEnet has fostered the organization of a GRACEnet Animal Systems project to focus on animal feeding operations, including confined and pasture systems.

The success of GRACEnet has also garnered attention from international researchers and their governments. Consequently, GRACEnet has been proposed as a cornerstone for the development of a global research collaboration effort under the Global Research Alliance: http://www.globalresearchalliance.org/

Further information, including the GRACEnet project plan and guidelines for the measurement protocols can be accessed via: http://www.ars.usda.gov/research/programs/programs.htm?np_code=212&docid=21223

APPENDIX 2

FULL TEXT OF MANUSCRIPTS

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The Importance of Determining Carbon Sequestration and Greenhouse Gas Mitigation Potential in Ornamental Horticulture

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***Abstract*. Over the past three decades, one issue that has received significant attention from the scientific community is climate change and the possible impacts on the global environment. Increased atmospheric carbon dioxide (CO_2) concentration along with other trace gases [i.e., methane (CH_4) and nitrous oxide (N_2O)] are widely believed to be the driving factors behind global warming. Much of the work on reducing greenhouse gas emissions and carbon (C) sequestration has been conducted in row crop and forest systems; however, virtually no work has focused on contributions from sectors of the specialty crop industry such as ornamental horticulture. Ornamental horticulture is an industry that impacts rural, suburban, and urban landscapes. Although this industry may have some negative impacts on the global environment (e.g., CO_2 and trace gas efflux), it also has potential to reduce greenhouse gas emissions and increase C sequestration. The work described here outlines the causes and environmental impacts of climate change, the role of agriculture in reducing emissions and sequestering C, and potential areas in ornamental horticulture container-grown plant production in which practices could be altered to increase C sequestration and mitigate greenhouse gas emissions.**

There is widespread belief among the scientific community that anthropogenic driven climate change is occurring and that it poses a serious global threat. Atmospheric concentrations of the three most important long lived greenhouse gases (GHG) have increased dramatically over the past 255 years (IPCC, 2007). Carbon dioxide, CH_4, and N_2O concentrations in the atmosphere have increased by ≈35%, 155%, and 18%, respectively, since 1750 (Dlugokencky et al., 2005; Keeling and Whorf, 2005; Prinn et al., 2000). Increases in GHG are widely believed to be the main factor causing global warming (Florides and Christodoulides, 2008). Fossil fuel combustion along with land use changes such as deforestation, biomass burning, soil cultivation, and drainage of wetlands have increased C emissions ≈80% from 1970 to 2004 (IPCC, 2007).

It is known that atmospheric GHG concentrations are increasing and that the earth's surface has warmed (IPCC, 2007). Temperature data recorded over the past ≈120 years show that the 10 warmest years occurred in the 1980s and 1990s (Douglas, 2004). Accumulation of GHG since the late 19th century may have led to the observed 0.6 °C (1.08 °F) increase in the average global surface temperature with a current warming rate of 0.17 °C (0.31 °F) occurring every 10 years (Lal, 2004). This observed increase in global average temperatures is in excess of the critical rate of 0.1 °C (0.18 °F)/decade; beyond this critical rate, ecosystems may have difficulty adjusting to the rise in temperature (Lal, 2004). Increasing global temperatures could negatively impact biological systems. Increasing global temperatures may also cause higher sea levels (disrupting marine and freshwater ecosystems); increase heat related illnesses; change precipitation patterns; and increase the spread of infectious disease vectors, insect pests, and invasive weed species (Douglas, 2004; IPCC, 2001). Agriculture could be one industry hit hardest by temperature change. Shifts in temperatures and precipitation patterns could benefit some cropping systems while hindering others. Some agricultural production systems may be sensitive to even small shifts in global temperature, requiring adaptation of management of available resources for sustained and successful economic development (Watson et al., 1998). Major technological advancements have been made in the agriculture industry in the last few decades such as improved pest control, development of genetically modified crops, and improved breeding techniques, which have produced the highest crop yields to date. However, modern agriculture may have difficulty meeting food demands of an expanding world population (U.S. Census Bureau, 2008). Even small reductions in yield of major food sources (e.g., corn, rice, wheat) could have devastating impacts, particularly in impoverished areas (Pimentel et al., 1996). Currently, researchers in almost every industry are developing strategies to reduce GHG emissions and the negative impacts of increased global temperature.

Greenhouse Gas Emissions from Agricultural Production

The agriculture industry in the United States is one of the largest contributors to GHG emissions behind energy production (Johnson et al., 2007). Carbon dioxide, CH_4, and N_2O are the three most important GHG as a result of their increasing atmospheric concentrations and the fact that these increases are mainly the result of human activities. Emissions from agriculture collectively account for an estimated one fifth of the annual increase in global GHG emissions. When land use changes involving clearing of land, biomass burning, and soil degradation are included, the overall radiative forcing from agriculture production is one third of the manmade greenhouse effect (Cole et al., 1997).

Increased CO_2 concentrations since the industrial revolution are mainly the result of emissions from the combustion of fossil fuels, gas flaring, and cement production (IPCC, 2007). Agriculture production and biomass burning also contribute to CO_2 emissions as does land use changes such as deforestation (Houghton, 2003). Deforestation globally released an estimated 136 billion tons of C or 33% of total emissions between 1850 and 1998, which exceeds any other anthropogenic activity besides energy production (Watson et al., 2000).

Agriculture is also considered a major contributor of CH_4 and N_2O and is estimated to produce ≈50% and 70%, respectively, of the total manmade emissions (Cole et al., 1997). The primary agricultural sources of CH_4 are enteric fermentation in ruminant animals, flooded rice fields, and biomass burning (Cole et al., 1997; Johnson et al., 1993; USDA, 2008); other major anthropogenic sources include landfills and natural gas emissions (Mathez, 2009). Managed livestock waste can also release CH_4 and N_2O through the biological breakdown of organic compounds such as

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those found in manure (USDA, 2008). Although N_2O forms naturally in soils and oceans through microbial processes, it is also a byproduct of agriculture and fossil fuel combustion (Mathez, 2009). The radiative forcing of N_2O is increasing from the large scale production and application of inorganic nitrogen (N) fertilizers, resulting in 80% of the total N_2O emissions in the United States (Mosier et al., 2003).

Many scientists believe that emissions from agriculture must be reduced to slow climate change. Opportunities for reducing GHG emissions in agriculture have been the focus of much research (Cole et al., 1997; Kroeze and Mosier, 2000; Lal et al., 1998; Lin et al., 1994; Paustian et al., 2000; Smith et al., 1998). However, it is widely believed that emissions reduction alone will not be sufficient to curtail the negative impacts on the environment; long term capture and storage (sequestration) of C are necessary. Carbon sequestration in plants is commonly referred to as terrestrial C sequestration, a process in which photosynthesis removes CO_2 from the atmosphere and stores it in plant biomass. Carbon is transferred to the substrate (growing media or soil) through plant litter, roots, and exudates and some is stored (Getter et al., 2009). Carbon transfer from plant biomass into soil organic matter is a key sequestration pathway and is a significant research area in agriculture. To date, most of the work on reducing GHG emissions and C sequestration has been conducted in row crop and forest systems with virtually no work on contributions (either positively or negatively) from specialty crop industries such as ornamental horticulture.

Carbon Sequestration Potential in Ornamental Horticulture Systems

Ornamental horticulture is an industry that impacts the landscape of rural, suburban, and urban environments. The economic impact of the "green industry" (nursery, greenhouse, and sod) is $148 billion annually in the United States (Hall et al., 2005) and was $2.8 billion in Alabama alone in 2008 (AAES, 2009). In the United States, it is one of the fastest growing businesses, expanding even during recessionary periods; it generates 1.9 million jobs, $64.3 billion in labor income, and $6.9 billion in indirect business taxes (Hall et al., 2005). In 2006, there were 7300 producers in the top 17 states, occupying approximately one half million acres (USDA, 2007). In addition, non agricultural land (e.g., urban and suburban) in the United States comprises 150 million areas (Lubowski et al., 2006), a significant proportion of which is (or could be) planted with ornamental trees and shrubs. Although the ornamental horticulture industry may be small relative to other sectors of agriculture (e.g., corn), it is one of the fastest growing sectors in agriculture and its potential impacts on climate change (either positively or negatively) have been virtually ignored.

There is need for the ornamental horticulture industry as well as other sectors of agriculture to examine how current production practices can be altered to reduce GHG emissions and sequester C. This will not only improve the environment, but these measures could soon be required by law. In Apr. 2007, the U.S. Supreme Court concluded that GHG meet the definition of air pollutants as stated in the 1970 Clean Air Act Extension; the U.S. Environmental Protection Agency (EPA) gained authority to regulate GHG emitted from new motor vehicles (mobile sources). This decision could become significant because the EPA may decide to strictly regulate and enforce limits on other (including industrial) sources of GHG emissions (EPA, 2008). There is also speculation that legislation limiting CO_2 and other GHG emissions could occur in the near future. All sectors of agriculture need to examine alternative management practices that comply with possible new legislation while reducing GHG emissions and sequestering C without decreasing productivity or profits.

The ornamental horticulture industry has the potential to benefit financially from reducing GHG emissions and its C footprint by altering management practices. Currently, there is interest in numerous agricultural sectors to earn new income from emerging C trading markets as well as new government incentives for reducing GHG emissions. The EPA has begun partnerships and programs to promote opportunities to conserve fossil fuels, improve energy efficiency, recover CH_4, and sequester C; these include tax incentives for some industries. Beginning in 2003, the U.S. Department of Agriculture (USDA) began providing targeted incentives to encourage wider use of land management practices that remove C from the atmosphere or reduce GHG emissions. In 2006, the federal government proposed energy tax incentives to promote GHG emission reductions totaling $524 million in fiscal year 2006 and $3.6 billion over 5 years. These included tax credits for the purchase of hybrid cars and use of solar heating systems, energy from landfill gas, and electricity produced from wind and biomass (EPA, 2008).

All sectors of the agricultural community could potentially profit by incorporating these "green" technologies into their production systems. Organizations such as the National Farmer's Union (NFU) have implemented new programs [in conjunction with the Chicago Climate Exchange's (CCE) Carbon Credit Program] in which farmers may be paid to reduce C emissions or to provide C credits to industries wanting to offset their C footprint (CCE, 2009; NFU, 2009). Other similar programs such as the Regional Greenhouse Initiative (a cooperative effort among 10 northeastern U.S. states) allows utility companies to apply offsets (i.e., farmers turning cropland into permanent pasture, planting of trees, burning of CH_4 in landfills, etc.) toward their compliance target of a 10% emission reduction between 2009 and 2018 (Schmidt, 2009). In 2008, Missouri farmers adopting no till could receive a C credit of 0.5 to 1.3 t/ha/year and cropland converted to grassland received C credits of 2.2 t/ha/year. In 2007, C contracts were selling for $4.40 per tonne, whereas in 2008, the price was $6.60 per tonne. However, should GHG become regulated, the price of C credits is likely to increase, translating to more income for farmers participating in these programs. In Europe, where GHG emissions are limited, C is valued at over $33 per tonne (Massey, 2008). For ornamental horticulture to reduce GHG emissions and benefit from such emerging programs, baseline estimates of GHG emissions and C sequestration from current production practices must be established.

The intent of this article is to explore GHG mitigation and sequestration possibilities in ornamental horticulture production. We focus on three aspects: 1) media used in container grown plant production; 2) fertilization practices; and 3) the ability of ornamental species to sequester C after being planted into the landscape.

Media for Container-grown Plant Production

Changes in row crop management such as minimizing soil disturbance (i.e., no tillage) and increasing plant residues (including use of cover crops) have been shown to enhance the C sequestration potential in agronomic systems (Lal, 2007; Smith et al., 1998). Opportunities also exist to enhance C sequestration in ornamental container grown plant production systems. Containerized nursery crops are a major sector of the ornamental horticulture industry in which plants are grown in a predominantly pine bark based medium. Pine bark is composed largely of organic C, having a C concentration greater than 60% compared with ≈3% C found in field soils (Simmons and Derr, 2007). When containerized ornamentals are planted into the landscape, a large amount of C is transferred belowground (sequestered). Uncertainty remains regarding how long this C will remain sequestered. If net primary plant biomass production exceeds the degradation rate of this transferred material, the microecosystems created by such outplantings would be net C sinks, at least in the short term (Getter et al., 2009). It is necessary to determine the number of container grown plants (as well as their container sizes) produced annually to estimate the amount of C being sequestered. This would generate critical data for the horticulture industry. Although much is known concerning the annual economic impact of the container grown plant industry, little data exist on the numbers and sizes of containers used in production systems regionally or nationally.

A nursery survey was conducted to begin quantifying the amount of C used in container media. Thirteen Alabama nurseries, representing ≈50% of the total state container grown plant production, were polled at regional scientific meetings, on farm visits, and through the Alabama Agricultural Extension Service. Growers were asked how many container grown plants they produced each year, what size containers were used (e.g., #1, #3, #5, etc.), and the primary potting media used (e.g., pine bark, pine bark + sand, pine bark +

peat) (Table 1). All growers polled used pine bark as their primary growth medium (Table 2). Although pine bark + other accounted for almost 42% of the media used (Table 2), the amendments were usually sand or peat in very small volumes (less than 10%). The survey indicated that ≈72,000 m^3 of pine bark was used to produce container grown nursery crops; given that the survey represented only half of the state's production, this estimate could be doubled (140,000 to 150,000 m^3). Because pine bark has a very high C concentration (49.2% in our analysis; with a density of 0.24 $g \cdot cm^{-3}$), this represents a significant amount of C (16,500 to 17,700 Mg C) potentially placed belowground.

Although the C sequestration potential of pine bark based media is needed, recent evidence suggests that future availability of pine bark could be limited (Lu et al., 2006) and researchers are beginning to search for alternatives. New alternative growing media such as WholeTree (WT) and clean chip residual (CCR) have been shown to be suitable replacements for pine bark based growing media (Boyer et al., 2008, 2009; Fain et al., 2008). Our analyses found these media have high wood content (≈90% for WT, ≈40% for CCR) and have C concentrations similar to pine bark (C was 47.8%, 46.9%, and 49.2% for WT, CCR, and pine bark, respectively). Future research is needed to determine the C storage potential of these various growth media along with decomposition studies to determine the longevity of this C storage. This information will be crucial in determining potential benefits to producers in terms of future "C cap and trade" issues.

Another issue in C sequestration will involve who gets credit for the container media (and other products such as bark and straw mulches) used in the ornamental horticulture industry because these products are produced primarily from forestry operations. In this regard, we are speaking more to which industry will get credit, in "C footprint" terms, than to who should receive any "C cap and trade" payments. We believe this will depend on several factors. First, had these materials (i.e., container media and mulches) not been used by the ornamental industry, what would their fate have been? If the material was left on site, the forestry operation should receive the credit. However, if the material was burned as a fuel source at forest products mills or burned on forest harvest sites, this would result in no C sequestration; thus, placing it into landscape settings would result in significant increases in C sequestration related to horticultural activities. A second consideration involves simple economics. If forest products companies are selling these materials to the horticultural producers, they have already made a financial gain and should not receive any C credit. It is then the horticultural and landscape industries, in addition to home owners, which are placing this purchased C in or on the ground and are "sequestering" it and the credit should belong to them. Which industry receives credit for this C will likely result in substantial debate.

Fertilization Practices

Fertilization is another aspect of ornamental container grown plant production that could be altered to reduce GHG emissions. Nitrogen fertilizer applications currently account for almost 80% of total agricultural N_2O emissions (Millar et al., 2010). Production of N fertilizers is an energy intensive process resulting in emission of GHG. In row cropping systems, research has shown that fertilizer rate, placement, and timing application with plant demand all have a major influence on N_2O emissions (Cole et al., 1997; Millar et al., 2010; Smith et al., 2007). Although this will likely be the case in nursery container grown plant production, no research exists to support this contention.

As part of the survey discussed previously, growers were asked to describe their fertilization methods (e.g., topdress, incorporate, dibble). Topdressing refers to placement of the fertilizer on the top of the media surface after planting; incorporation refers to incorporating the fertilizer in the potting media before planting; and dibbling refers to placing the fertilizer in a small hole formed in the potting media. Survey results show that almost all Alabama growers of containerized plants prefer to dibble or incorporate fertilizer at potting and then topdress later in the season as needed; this is consistent with the best management practices (BMPs) described by Yeager et al. (2007) (Table 2). Although the BMP Guide is an excellent tool to follow for cost effective production of healthy container grown nursery crops, none of the BMPs consider GHG emissions; it is possible that current BMPs could be altered to reduce GHG emissions. Nitrogen placement in agriculture (e.g., banding versus broadcast) has been shown to reduce surface N loss and increase plant N use (Paustian and Babcock, 2004). Nitrogen placement can also affect N movement and use in ornamental container grown plant production (Fain and Knight, 2006; Keever and Cobb, 1990; Warren et al., 2001). For example, dibbling fertilizer close to the liner root ball might reduce N leaching and increase plant N use, thereby reducing the amount of fertilizer used compared with methods such as incorporation. In addition, topdressing the plants only at peak growing times for each species could increase N use efficiency and reduce fertilizer use. The effect of altered N fertilization practices on growth, N use efficiency, N leaching, and N_2O emissions requires investigation to fine tune future BMPs for productivity, profitability, and environmental stewardship.

Other factors in fertilization practices could impact N losses (leaching and N_2O emissions). For example, if a higher fertilizer formulation is used (20N 10P 10K versus 8N 8P 8K), one might expect increased N_2O emissions; however, if application rates are reduced, N_2O emissions might not be changed. On the other hand, high analysis fertilizers are less energy intensive to produce, package,

Table 1. Estimation of container-grown plant production in Alabama by size of container sold annually by top producers in the state.

	Trade gal.	Size of container[z] #1	#3	#5	#7	#10	#15	#20	#25	Other[y]
Number sold	3,450,000	2,137,385	3,472,023	180,000	119,818	16,518	10,000	40,000	3,000	1,304,000
Size of container (L)	2.80	3.8	11.4	18.9	26.5	37.9	56.8	75.7	94.6	2.8
Total volume by size (m^3)	9,660	8,122	39,581	3,402	3,175	626	568	3,028	284	3,651
Total volume per year (m^3)										72,097

[z]Nursery growers were asked how many plants they sold annually in #1 (2.8 L or 1 gallon), #3 (11.4 L or 3 gallon), #5 (18.9 L or 5 gallon) containers, etc. Thirteen of the top container-grown plant production nurseries were polled in person at regional industry meetings and during on-farm visits. All of the nurseries polled participated in the survey.

[y]Other plants that range from smaller than trade gallon to larger that #25. A conservative size 2.8 L was used to estimate total volume of media used in these containers.

Table 2. Fertilization methods, potting media, and growth rate of plants produced in Alabama container-grown plant nurseries.

Potting media[z]		Fertilization method		Growth rate of plants sold[y]		
100% PB	PB + other	Incorporate then topdress	Dibble then topdress	Slow	Medium	Fast
58.3%	41.7%	83.3%	16.7%	23.6%	56.6%	19.8%

[z]PB + other indicates media in which PB was amended with other materials (sand, peat, wood shavings, etc.), usually at very small volumes (less than 10%).

[y]Nursery growers asked what percentage of their crops were slow- (less than 0.30 m per year), medium- (0.30 to 0.91 m per year), or fast-growing (greater than 0.91 m per year). Thirteen of the top container-grown plant production nurseries were polled in person at regional industry meetings and during on-farm visits. All of the nurseries polled participated in the survey.

ship, and apply (Gellings and Parmenter, 2008). In addition, most growers use high analysis, slow release or encapsulated fertilizers, which could affect N losses. Use of these types of fertilizers will affect GHG during production as well as application; however, research is needed to determine the best option for opti mizing growth and minimizing N_2O emissions from fertilizers in the horticulture industry both during production and after outplanting. Another interacting factor that could impact N losses is the frequency and amount of irri gation. Excessive irrigation could increase both N leaching and N_2O emissions. The effects of irrigation on N losses in container grown plant production systems require investiga tion to develop BMPs not only for reducing N_2O emissions, but also for water conserva tion, an issue becoming critical in a changing climate.

Carbon Sequestration Potential of Ornamental Plants in the Landscape

Another potential C sink in ornamental plant production is the ability of plants to store C in biomass. Previous research has shown that urban forests have a significant potential for removing CO_2 from the atmosphere and se questering C in standing biomass (Nowak, 1993). Rowntree and Nowak (1991) estimated that urban forests in the United States sequester ≈712 million tonnes of C. In addition to storing C, urban trees cool ambient air and provide shade, which reduces energy costs (Rowntree and Nowak, 1991). Simpson and McPherson (1998) reported that in Sacramento County, CA, a utilities sponsored tree planting program resulted in an estimated annual savings of $24 per mature tree. As energy prices rise and trees grow, they will become even more valuable. In addition, green roof systems have been shown to reduce energy costs as well as successfully sequester C (Getter et al., 2009).

Aside from trees, no research has addressed the potential benefits of shrubs, perennials, and other ornamental nursery species to the envi ronment, including C storage. Most ornamental shrubs require little or no management inputs and often accumulate biomass quickly, making them a potential major C sink. In our survey, producers categorized their crops by those that were fast (greater than 0.91 m per year), medium (0.30 to 0.91 m per year), or slow growing (less than 0.31 m per year). Fast , medium , and slow growing species made up 19.8%, 56.6%, and 23.6%, respectively, of container grown nursery crops (Table 2). Most of the trees described in the studies would be considered fast or medium growers and would accumulate more biomass (more C storage potential) than shrubs. However, most land scapes have more shrubs than trees. It is pos sible that, in any given landscape, the total C accumulated in shrubs could be greater than that in trees.

To determine the C "footprint" or C budget of the ornamental horticulture industry, C "costs" or C losses must also be considered. The C costs associated with both production and application of pesticides, fertilizers, irriga tions, etc., must be taken into consideration. These figures are likely to be relatively low for the ornamental horticulture industry because much work (i.e., weed control, application of other pesticides, fertilization) is done by hand as opposed to agriculture where most of this work is conducted with machines. Carbon losses (from decomposition of mulches, trim mings, media substrates, etc., along with those associated with plant respiration) must also be considered. For example, in studies of managed turfgrass systems, it was found that, although irrigation and fertilization enhance productivity and C storage, soil GHG emis sions in these systems can increase. It was suggested that managed turf systems are not often considered C sinks given the amount of fossil fuel needed to mow, fertilize, and apply pesticides to these systems (Townsend Small and Czimczik, 2010). At present, it is not known if the ornamental horticulture industry will represent a net source or sink for C.

Production and outplanting of ornamental nursery crops could still prove to be a significant C sink given the quantity of C accumulated in biomass and that added to soil as growth media. At present, however, this is unknown as is how the C sequestration ability of the ornamental horticulture industry compares with that of other systems (e.g., row crops and forests). Nonetheless, the ornamental horticulture in dustry provides the average U.S. homeowner an ability to participate in reducing their C footprint by landscaping their yards while increasing property values in the process.

Conclusions

There remains much uncertainty regarding the best practices for lowering GHG emissions and increasing C storage in the ornamental horticulture industry; this is an area deserving investigation. Changes in production practices that have been shown to reduce GHG emis sions and increase C storage in other agricul ture fields could possibly be applicable to nursery container grown production. As data become available, the role of the ornamental horticulture industry on climate change (both positive and negative) will begin to be eluci dated. Industry leaders and growers can then begin to fine tune BMPs to maximize pro ductivity and profitability while minimizing GHG emissions. Research is needed to pro vide the industry with the necessary tools for adapting to future legislation that could cap GHG emissions and provide growers oppor tunities in the emerging C trading and offsets market. Continued investigation is also needed to discover profitable and environmentally sustainable ways to grow plants. In addition, determining C sequestration potential of vari ous landscape species when planted into urban and suburban landscapes could provide home owners a means of directly contributing to mitigation of climate change.

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Soil Carbon as Affected by Horticultural Species and Growth Media

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Significance to Industry: Increasing atmospheric concentrations of greenhouse gases (GHG) are widely believed to be a main contributing factor to climate change. United States agriculture is one of the largest contributors of GHG emissions, trailing only energy production, which leads scientists to believe that emissions from agriculture must be reduced to slow climate change. However, emission reductions alone may not sufficiently curtail negative environmental impacts and, therefore, long-term capture and storage of carbon (C) will be necessary. To date, most research on GHG emissions and C sequestration has focused on row crop and forest systems with virtually no work on ornamental horticulture. Farmers in other agricultural sectors are now earning additional income in the emerging C trading market for reducing C emissions and pledging to alter management practices which will provide C offsets by increasing C sequestration. The ornamental horticulture industry also has the potential to sequester C through transplanting container-grown ornamentals into urban and suburban landscapes which sequester C in biomass and soils. In addition, transplant growth media can be an additional C sink that has not been accounted for in previous research. Our data shows that when ornamental species are planted in the landscape, the addition of media from container-grown plant production increased soil carbon levels 4 to 12 times higher than soil C levels observed in native soils. If future legislation requires caps to be placed on agricultural emissions, the horticulture industry will need to demonstrate possible benefits it has on the atmospheric environment. The objective of this research is to determine the effects of growth media on soil carbon levels from commonly grown horticultural species planted into the landscape.

Nature of Work: While still debatable, there is widespread belief in the scientific community that anthropogenic-driven climate change poses serious threats to the global environment. Atmospheric concentrations of the three most important, long-lived greenhouse gases [i.e., carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O)] have increased over the past 255 years (IPPC, 2007).

In the United States, agriculture is the second largest contributors to GHG emissions behind energy production (Johnson et al., 2007). Emissions from agriculture collectively account for an estimated one-fifth of the annual increase in global GHG emissions. When land use changes involving clearing of land, biomass burning, and soil degradation are included, the overall radiative forcing from agriculture production is one third of the man-made greenhouse effect (Cole et al., 1997). Many scientists believe that emissions from agriculture must be reduced to slow climate change; however, emission reductions in agriculture alone may not curtail the negative impacts of agriculture on the environment. Therefore, long term capture and storage of these gases will also be necessary. Carbon from atmospheric CO_2 can be stored for long periods in biomass and soils (USDA, 2008). Carbon sequestration in agriculture has been a heavily researched topic, particularly in the last 15 to 20 years. Conservation tillage or “no-till” farming has been shown to reduce fossil fuel use, increase soil C storage (Reicosky et al, 1999), and improve soil characteristics (Lal, 2007). Further, improved forestry management practices such density control and nutrient management have been shown to increase C storage in biomass and soil (USDA, 2008).

Due to the large land area they cover in the U.S., most work on C sequestration has focused on row crop (280 million acreas) and forest (740 million acres) systems (Smith et al., 2001; EPA, 2009). However, non-agricultural land (e.g., urban and suburban) in the U.S. comprise 150 million areas (Lubowski et al., 2006). A significant proportion of this land is (or could be) planted with ornamental trees and shrubs. If C sequestration in agriculture is necessary to mitigate climate change, it is important to examine the contributions from all sectors of agriculture, including specialty crop industries such as ornamental horticulture.

Ornamental horticulture is an industry which impacts the landscape of rural, suburban, and urban environments through production and planting of ornamental horticulture species. Hall (et al., 2005) showed the economic impact of the green industry (including nursery, greenhouse, and sod) to be $148 billion in the U.S. In 2006, there were 7,300 nursery producers in the top 17 states, encompassing one-half million production acres (USDA, 2007). Ornamental horticulture is one of the fastest growing sectors in agriculture; however, its potential impacts on climate change (either positively or negatively) have been virtually ignored in previous research. While this industry may have some negative impacts on the environment (e.g. CO_2 and trace gas efflux), it also has potential to reduce GHG emissions and increase C sequestration. Previous research has shown the potential of urban trees have for sequestering CO_2 as well as other pollutants (Nowak, 1993). In a study by Rowntree and Nowak (1991) it was estimated that total urban forest C storage in the U.S. was approximately 800 million tons. In addition to storing CO_2, urban trees have also been shown to cool ambient air and provide shade which allows residents to minimize annual energy costs (Rowntree and Nowak, 1991). While ornamental plants have been shown to take up CO_2 and accumulate C in biomass, a large amount of C is also transferred belowground in the form of various growth media (e.g., pine bark, or new alternative substrates such as WholeTree or Clean Chip Residual). However, little is known concerning the impact of these growth media on belowground C sequestration. The objective of this research is to determine the effects of growth media on soil carbon levels from commonly grown horticultural species planted into the landscape.

Materials and Methods:

In order to explore the effects of growth media on soil C sequestration, three commonly grown nursery crops, crape myrtle (*Lagerstroemia* x ‘Acoma’), southern magnolia (*Magnolia grandiflora*) and Shumard Oak

(*Quercus shumardii*) were evaluated. These three species were transplanted from 7.6 cm (3 in), 10.2 cm (4 in), or 2.7 L (trade gallon) liners, respectively, into 11.6 L (3 gal) containers on 25 March 2008. Plants were potted using one of three growth media; Pine Bark (PB), Whole Tree (WT), or Clean Chip Residual (CCR). Each growth medium was mixed with sand (6:1, v:v) and 8.3 $kg \cdot m^{-3}$ (14 lbs/yd^3) 18-6-12 Polyon control-release fertilizer, 3.0 $kg \cdot m^{-3}$ (5 lb/yd^3) lime, and 0.9 $kg \cdot m^{-3}$ (1.5 lb/yd^3) Micromax were added. Whole Tree (Fain et al., 2006) and CCR (Boyer et al., 2008), are by-products of the forestry industry which are currently being investigated as alternative media sources due to decreasing PB supplies (Lu et al., 2006). Plants were grown in the 11.6 L (3 gal) containers for an entire growing season and then outplanted to the field on 11 December 2008. Outplanted species were arranged as a randomized complete block design with three replicate blocks. Belowground soil C was assessed in Summer, 2009. Two soil cores [3.8 cm (1.5 in) diameter x 60 cm (23.6 in) depth] were collected from each treatment within all blocks according to methods described by Prior et al. (2004). In addition, samples of native soil (no plant or growth media) were collected within each block for comparison. All cores were divided into 15 cm (5.9 in) depth segments, sieved (2 mm), and oven dried at 55˚ C (131˚ F). Ground subsamples of soil (0.15 mm sieve) were analyzed for C on a LECO TruSpec CN analyzer (LECO Corp., Saint Joseph, MI). Data were analyzed using the Proc GLM procedure of SAS (SAS version 9.1).

Results and Discussion: Soil analysis indicated that soil C in the top depth of soil (0 - 15 cm) was higher for PB compared to WT, CCR and the native soil for all three species (Figures 1-3). Soil C for the other two media did not differ in any species. Although soil C was much lower at the 15 - 30 cm depth, the same treatment pattern was observed in crape myrtle and magnolia; however, there were no differences in soil C for the oaks at this depth. No soil C differences were observed among media or the native soil in any species at the lower two depths (i.e. 30 - 45 and 45- 60 cm). These initial soil C data indicate that the media were contained in the upper 15 cm of the soil profile with a possibility that some of the PB was incorporated slightly below that depth in the crape myrtles and magnolias. It has been shown that changes in agricultural management practices that minimize soil disturbance and increase surface crop residues, such as conservation tillage ("no-till") can enhance soil C sequestration potential (Smith et al, 1998; Lal, 2007), however this soil C increase may only be realized many years after adoption of these practices (Six et al., 2004). Data from this study show that soil C ranged from 9 - 25% compared to about 2% found in the native soil. These data clearly show that planting containerized ornamentals into the landscape transfer a large amount of C belowground instantly; however, uncertainty remains regarding how long this C will remain sequestered. Future studies are needed to determine the residence time of this C in the soil when planted into the landscape and to fully understand the role of the ornamental horticulture industry on C sequestration. These data will prepare the horticulture industry for possible future legislation as well as provide homeowners a means of directly contributing to the mitigation of climate change via soil C sequestration while improving the aesthetic value of their homes.

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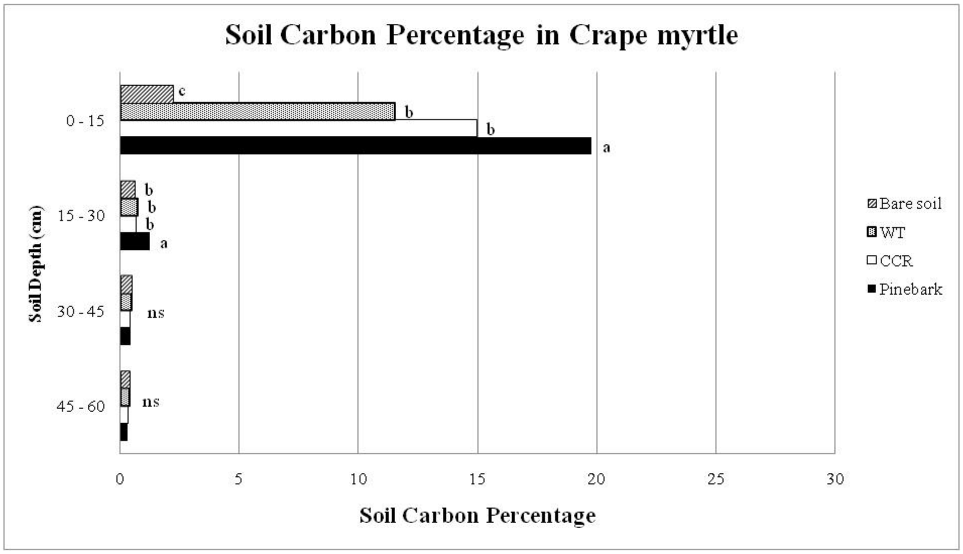

Figure 1. Media effects on soil carbon percentage in crape myrtle. Bars with the same letter are not significantly different according to the Least Significant Differences Test (alpha = 0.05). ns = not significant according to the Least Significant Differences Test. PB = Pine Bark, WT = WholeTree, CCR = Clean Chip Residual.

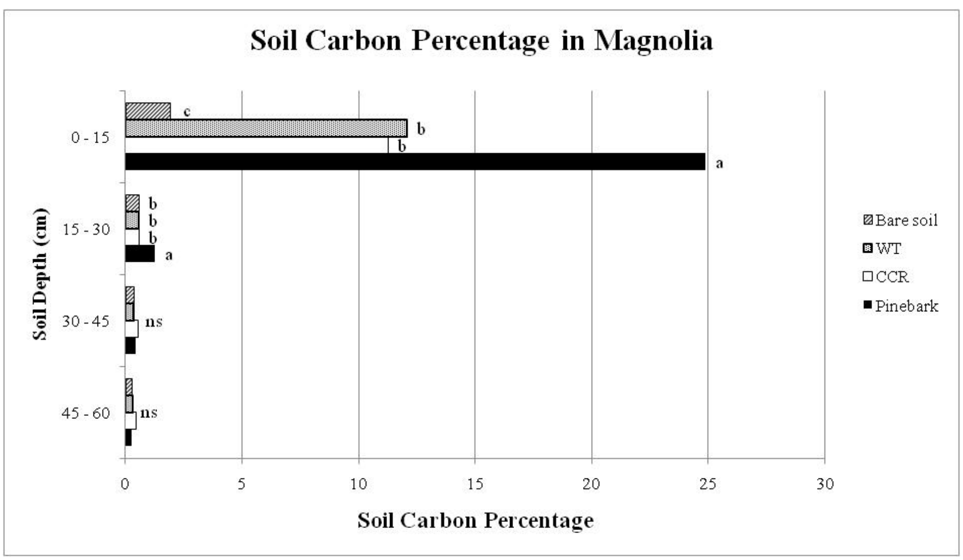

Figure 2. Media effects on soil carbon percentage in magnolia. Bars with the same letter are not significantly different according to the Least Significant Differences Test (alpha = 0.05). ns = not significant according to the Least Significant Differences Test. PB = Pine Bark, WT = WholeTree, CCR = Clean Chip Residual.

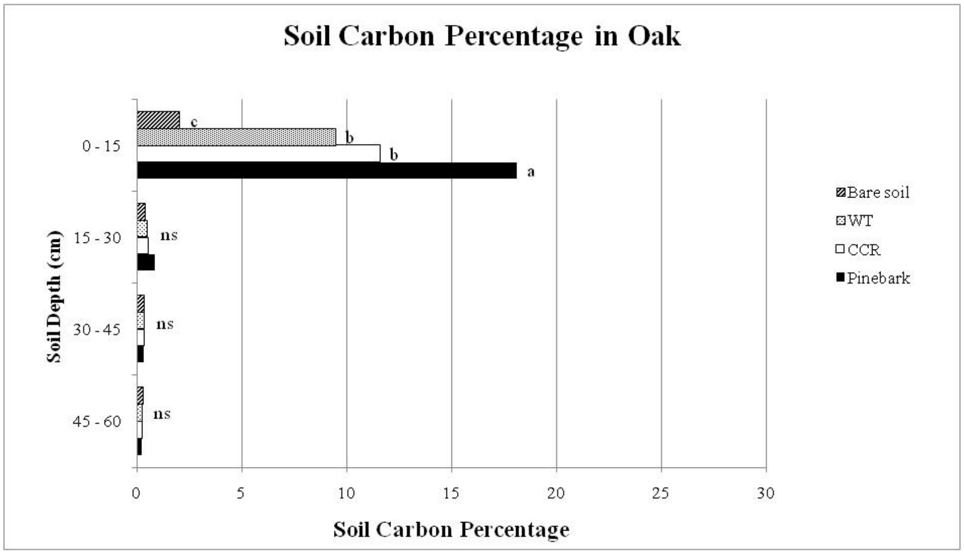

Figure 3. Media effects on soil carbon percentage in oak. Bars with the same letter are not significantly different according to the Least Significant Differences Test (alpha = 0.05). ns = not significant according to the Least Significant Differences Test. PB = Pine Bark, WT = WholeTree, CCR = Clean Chip Residual.

A Review of Elevated Atmospheric CO_2 Effects on Plant Growth and Water Relations: Implications for Horticulture

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Additional index words. carbon dioxide, global change, photosynthesis, trace gases, transpiration, water use efficiency

***Abstract*. Empirical records provide incontestable evidence for the global rise in carbon dioxide (CO_2) concentration in the earth's atmosphere. Plant growth can be stimulated by elevation of CO_2; photosynthesis increases and economic yield is often enhanced. The application of more CO_2 can increase plant water use efficiency and result in less water use. After reviewing the available CO_2 literature, we offer a series of priority targets for future research, including: 1) a need to breed or screen varieties and species of horticultural plants for increased drought tolerance; 2) determining the amount of carbon sequestered in soil from horticulture production practices for improved soil water-holding capacity and to aid in mitigating projected global climate change; 3) determining the contribution of the horticulture industry to these projected changes through flux of CO_2 and other trace gases (i.e., nitrous oxide from fertilizer application and methane under anaerobic conditions) to the atmosphere; and 4) determining how CO_2-induced changes in plant growth and water relations will impact the complex interactions with pests (weeds, insects, and diseases). Such data are required to develop best management strategies for the horticulture industry to adapt to future environmental conditions.**

The level of CO_2 in the atmosphere is rising at an unprecedented rate, has increased from ≈280 ppm at the beginning of the industrial revolution (≈1750) to ≈380 ppm today, and is expected to double preindustrial levels some time during this century (Keeling and Whorf, 2001; Neftel et al., 1985). This global rise can be primarily attributed to fossil fuel burning and land use change associated with industrial and/or population expansion (Houghton et al., 1990). This rise, along with other trace gases, is widely thought to be a primary factor driving global climate change (IPCC, 2007). Aside from the debate on anthropogenic driven climate change, vegetation will be directly impacted and research has shown that plants respond positively to elevated CO_2 (Amthor, 1995). Most of this research has focused on agricultural and forest species with limited work on specialty crops associated with horticulture. Horticulture is a diverse industry (encompassing many small businesses) that impacts the landscape of both rural and urban environments and has an economic impact of $148 billion annually in the United States (Hall et al., 2005). We will attempt to discuss the effects of the rise in atmospheric CO_2 concentration on plant growth and water relations with a focus toward implications for horticultural production systems with suggestions for future research areas.

PLANT GROWTH

Carbon dioxide links the atmosphere to the biosphere and is an essential substrate for photosynthesis. Elevated CO_2 stimulates photosynthesis leading to increased carbon (C) uptake and assimilation, thereby increasing plant growth. However, as a result of differences in CO_2 use during photosynthesis, plants with a C_3 photosynthetic pathway often exhibit greater growth response relative to those with a C_4 pathway (Amthor, 1995; Amthor and Loomis, 1996; Bowes, 1993; Poorter, 1993; Rogers et al., 1997). The CO_2 concentrating mechanism used by C_4 species limits the response to CO_2 enrichment (Amthor and Loomis, 1996). For C_3 plants, positive responses are mainly attributed to competitive inhibition of photorespiration by CO_2 and the internal CO_2 concentrations of C_3 leaves (at current CO_2 levels) being less than the Michaelis Menton constant of ribulose bisphosphate carboxylase/oxygenase (Amthor and Loomis, 1996). Although increased photosynthesis under elevated CO_2 enhances growth for most plants, summaries have consistently shown that this increase varies for plants with a C_3 (33% to 40% increase) versus a C_4 (10% to 15% increase) photosynthetic pathway (Kimball, 1983; Prior et al., 2003).

Given that most horticulture species have a C_3 pathway, it is expected that they will show similar responses to elevated CO_2. Early work (Cummings and Jones, 1918) demonstrated that both vegetable and flower crops benefited from above ambient concentrations of CO_2; both cyclamens and nasturtiums showed increased dry weight and greater flower yield when exposed to elevated CO_2. Since this early work, others have shown that ornamental species respond positively to elevated levels of CO_2 (Davis and Potter, 1983; Gislerød and Nelson, 1989; Mattson and Widmer, 1971; Mortensen, 1987, 1991; Mortensen and Gislerød, 1989; Mortensen and Moe, 1992; Mortensen and Ulsaker, 1985). In fact, increasing the concentration of CO_2 in glasshouses is an economically efficient

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method of enhancing growth of ornamental and vegetable crops (Mastalerz, 1977; Mortensen, 1987).

In addition to stimulating photosynthesis and aboveground growth, elevated CO_2 can alter C partitioning/allocation. Increased C supply from elevated atmospheric CO_2 can preferentially induce the distribution of photosynthate belowground (Ceulemans and Mousseau, 1994; Lekkerkerk et al., 1990; Prior et al., 1997; Rogers et al., 1994). In many cases, the largest proportion of the extra biomass produced under elevated CO_2 is found below ground (Rogers et al., 1994; Wittwer, 1995), often resulting in increased root to shoot ratio (Rogers et al., 1996). This is not surprising in that plants tend to allocate photosynthate to tissues needed to acquire the most limiting resource (Chapin et al., 1987); when CO_2 is elevated, the most limiting resource becomes water or nutrients.

Although less studied than aboveground response, plants often show increased rooting under CO_2 enrichment (Chaudhuri et al., 1986, 1990; Del Castillo et al., 1989; Rogers et al., 1992). In addition to this early work with plants in containers, increased rooting has also been observed in the field using both open top field chambers (OTC) and free air CO_2 enrichment systems (FACE). Elevated CO_2 increased dry weight of root systems for both soybean (44%) and sorghum (38%) growing in OTC (Prior et al., 2003). Prior et al. (1994) also found increases in cotton fine roots (dry weight and length) under FACE and that these plants had proportion ately more of their roots allocated away from the row center. Furthermore, Prior et al. (1995) reported that these FACE cotton plants had larger taproots and increases in the number and size of lateral roots. The development of more robust root systems in CO_2 enriched en vironments may allow for greater carbohydrate storage and infers greater exploration of the soil for resources such as water and nutrients to meet plant growth needs during periods of peak demand such as boll development and filling.

In addition to increases in rooting, coloni zation of roots with mycorrhizae (the symbi otic association of plant roots with fungi) has been shown to increase under elevated CO_2 (Norby et al., 1987; O'Neill et al., 1987; Runion et al., 1997). Mycorrhizae increase nutrient uptake by their host plants (Abbott and Robson, 1984), provide additional water to plants through hyphal proliferation in soil (Luxmoore, 1981), and protect roots from path ogenic microorganisms (Marx, 1973).

Because horticultural plants are generally grown in containers without resource limita tions (i.e., water and nutrients), increased root growth or mycorrhizal colonization may not become critical for survival and growth until after outplanting into the landscape. However, as a result of limited rooting space, growth in containers has been shown to dampen the re sponse to CO_2 enrichment (Arp, 1991). For plants to use a higher level of atmospheric CO_2, they must have a means of storing the additional carbohydrates produced. We have shown that plants with a tuberous or woody root system tend to respond to CO_2 enrichment to a greater degree than plants with smaller or more fibrous root systems (Rogers et al., 1994; Runion et al., 2010). The limited rooting volume experienced by plants growing in containers may help ex plain the fact that increased growth of horticul tural species under elevated CO_2 is sometimes slightly lower than that generally observed for other C_3 plants, falling in the range of 15% to 25% (Mortensen, 1991, 1994). Nonetheless, the increased biomass production under high CO_2 should be advantageous for horticultural plants in that they should attain a marketable size more rapidly.

PLANT WATER RELATIONS

In addition to the effects of CO_2 on photo synthesis and C allocation mentioned, elevated CO_2 can impact growth through improved plant water relations (Rogers and Dahlman, 1993). In fact, most plants (both C_3 and C_4 species) exhibit improved plant water re lations. Elevated CO_2 slows transpiration by inducing the partial closure of leaf stomatal guard cells (Jones and Mansfield, 1970). Studies in growth chambers and glasshouses have shown that elevated CO_2 reduces tran spiration for both C_3 (Allen et al., 1994; Jones et al., 1984, 1985; Pallas, 1965; Prior et al., 1991; Valle et al., 1985) and C_4 (Chaudhuri et al., 1986; Pallas, 1965; Van Bavel, 1974) plants. Dugas et al. (1997), using stem flow gauges under actual field conditions, also showed that whole plant transpiration was reduced under elevated CO_2 for both a soybean (C_3) and a sorghum (C_4) crop.

This reduction in transpiration, coupled with increased photosynthesis, can contribute to increased water use efficiency (WUE the ratio of carbon fixed to water transpired), which has often been reported (Baker et al., 1990; Morison, 1985; Sionit et al., 1984). In fact, Kimball and Idso (1983) cited 46 obser vations that cumulatively showed that tran spiration would be lowered by an average of 34%, which, coupled with an economic yield enhancement of 33% (over 500 observations), suggested a doubling of WUE for a doubling of CO_2 level. From a physiological standpoint, increased WUE may represent one of the most significant plant responses to elevated CO_2 (Rogers et al., 1994).

Plants with a C_4 photosynthetic pathway show a smaller response to elevated CO_2 than plants with a C_3 pathway. However, both C_3 and C_4 plants show reduced transpiration under elevated CO_2. Therefore, WUE should be primarily controlled by transpiration in C_4 plants, whereas both are important in C_3 plants. This was demonstrated by Acock and Allen (1985) using data from Valle et al. (1985) and Wong (1980). In a more recent long term field study, similar calculations showed contribu tions of 74% and 26% (for photosynthesis and transpiration, respectively) in soybean com pared with respective contributions of 42% and 58% in sorghum (Prior et al., 2010a). Although photosynthesis still dominated WUE increase in C_3 soybean, relative contributions of the two processes were more similar for C_4 sorghum than that reported by Acock and Allen (1985).

Given the fact that elevated CO_2 can reduce transpiration, it has been suggested that this might partially ameliorate the effects of drought (Bazzaz, 1990) and allow plants to maintain increased photosynthesis. This has frequently been observed (Acock and Allen, 1985; Gifford, 1979; Goudriaan and Bijlsma, 1987; Nijs et al., 1989; Rogers et al., 1984; Sionit et al., 1981; Wong, 1980); however, it should be noted that much of this work was conducted in growth chambers and glasshouses using plants growing in containers. Working with container grown soybean in field OTC, Prior et al. (1991) reported that, at elevated levels of CO_2, xylem pressure potential of water stressed plants was equivalent to that of adequately watered plants, indicating ame lioration of drought stress.

It has been suggested that in more natural environments, although instantaneous WUE is increased, whole plant water use may be differentially affected as a result of increased plant size. Allen (1994) reported that larger plant size [higher leaf area index (LAI)] counterbalanced the reduction in water use, offsetting enhanced WUE. Jones et al. (1985) showed that, although elevated CO_2 increased WUE for plants with both a high and a low LAI, this increase was greater for plants with a lower LAI. Working with longleaf pine grow ing in large (45 L) containers, we found that nitrogen (N) availability was also an important factor affecting the interaction of WUE and plant water stress (Runion et al., 1999). Long leaf pine seedlings grown with adequate N grew larger under elevated CO_2, resulting in increased whole plant water use and increased water stress despite increased WUE. Seed lings grown with limited N did not exhibit a growth response to elevated CO_2, so the in creased WUE resulted in decreased whole plant water use and reduced stress.

In addition to improved plant water re lations, elevated CO_2 can also affect water movement through the landscape. Water in filtration can be increased and sediment loss through runoff can be decreased in high CO_2 environments (Prior et al., 2010b). These im provements can result from increased plant rooting (as noted previously) and from changes in soil physical properties. Elevated CO_2 can increase soil C, aggregate stability, and hy draulic conductivity and decrease soil bulk density (Prior et al., 2004). These improve ments in soil/water relations will be particu larly important for horticultural plants in the landscape.

Water is also a crucial resource in many horticultural production facilities and its con servation is becoming an increasingly im portant issue. The fact that elevated CO_2 can increase plant WUE (Rogers et al., 1994) may indicate that plants could be watered less frequently as CO_2 levels continue to rise. However, because these plants are generally grown with optimal nutrients, elevated CO_2 may increase plant size to a point where water ing frequency will need to be maintained at current levels or even increased. This interaction of elevated CO_2 and resource availability will also be of critical importance for horticultural species after outplanting to the landscape where periodic droughts could be relatively frequent. The landscape's response may not be adequately reflected by studies of small numbers of plants grown in containers; obviously, more work is needed within this important industry to maximize plant growth, health, and efficient use of resources.

PRIORITY TARGETS FOR FUTURE RESEARCH

Although much is known regarding the effects of elevated CO_2 on plants, horticultural species have received much less attention than agronomic and forest species. Although it is likely that most horticultural species will benefit (through increased growth) from rising CO_2, research to support this contention is lacking. Horticulture comprises diverse species in terms of growth forms (e.g., annuals, perennials, trees, shrubs, forbs, grasses, vegetables, floriculture crops, C_3, C_4) and the conditions in which they are grown (e.g., container versus in ground, indoor versus outdoor). Knowledge of how these diverse plant types will respond to elevated CO_2 under current growing conditions would be valuable in terms of adapting management strategies to future environmental conditions. For example, although container grown plants are known to respond positively to elevated CO_2 in terms of increased growth, it is also known that root restriction can dampen this CO_2 response; therefore, it is important to determine optimal container sizes for producing marketable plants on timely schedules.

As noted previously, positive growth responses to elevated CO_2 result not only from increased uptake and assimilation of CO_2, but also from decreased transpiration, which improves plant water relations and WUE. Water conservation is a critical issue for crop production, particularly in certain regions of the United States. Within the horticulture industry, adjustments to watering frequency may become a crucial management decision. Knowledge of the effects of rising CO_2 on whole plant water use will aid managers in optimizing irrigation schedules and amounts.

In addition to understanding the effects of rising CO_2 on water use of currently grown horticultural species, it is important for the industry to breed or screen for varieties and species with higher degrees of drought tolerance. It will also be important that these efforts be conducted at current and future levels of atmospheric CO_2 to select plants that show large responses to elevated levels of CO_2. One predicted outcome of global climate change is alterations in precipitation patterns with more extreme weather events, including droughts (IPCC, 2007). It is crucial to the industry that plants survive after outplanting in residential and commercial landscape environments.

One means of improving survivability is through use of mulch to conserve soil water. In an agronomic setting, cover crops used in no tillage management systems can act as mulch (Balkcom et al., 2007). We have shown that these cover crops increase soil C (Prior et al., 2005) and aid in the improvement of soil physical properties (Prior et al., 2004), which also improves soil water relations (Prior et al., 2010b). Mulch (commonly pine bark, pine straw, or wood chips in the southeastern United States) contains high concentrations of plant organic C and, when used in landscape settings, can contribute to soil C sequestration. However, the extent of this contribution is not currently known, locally, regionally, or nationally. Furthermore, depending on the fate of these materials (e.g., left on site, burned on site, or used as a fuel source at forest products mills), the potential net increase in soil C from using these materials in landscape settings is also largely unknown.

In addition to mulch, the horticulture industry adds to soil C content through burial of container media at the time of outplanting. In container grown plant production of nursery crops, plants are grown in a predominantly pine bark based substrate. Pine bark is composed almost entirely of organic C, having a C content greater than 60% (Simmons and Derr, 2007). When these plants are outplanted to the landscape, this represents a very large amount of C possibly being sequestered in soil. Carbon can also be sequestered in plant biomass through positive growth responses to rising CO_2. However, to date, little is known concerning the C sequestration potential of the horticulture industry as a whole; this is critical to assess its potential contribution to mitigating potential climate change.

The C sequestration potential of the horticulture industry will be affected by the C:N ratio of inputs from biomass, mulch, and container media. The C:N ratio of these inputs can be high, suggesting slow decomposition and, therefore, slow release of CO_2 back to the atmosphere, aiding mitigation of global climate change. At present, the amount of C added to soil through outplanting container grown horticultural plants is largely unknown. There is also little knowledge of the residence time of these materials in soil and of the rate of soil CO_2 flux back to the atmosphere. This knowledge will be crucial to determining the C sequestration potential of the horticulture industry and its contribution to potential global climate change through flux of CO_2 from soil to air.

There is also little information on the flux of other trace gases (nitrous oxide and methane) in these systems. Horticulture production facilities often use large amounts of water in irrigation as well as large amounts of fertilizers; this combination of resources could result in substantial fluxes of other gases. Like with CO_2 flux, this information is critical to determining the industry's potential contribution to climate change. It is also necessary to develop best management strategies that minimize trace gas flux, maximize resource use efficiency, and optimize growth and economic gain.

Another largely unknown but important consideration of rising CO_2 will be management of pests (weeds, insects, and diseases) in these systems. Weeds often show greater growth responses to elevated CO_2 than do crop plants, which may be the result of weeds having greater genetic diversity and physiological plasticity than managed plants (Ziska and Runion, 2007). How rising CO_2 will impact weed management strategies in horticultural systems is unknown. The interactions of plants with both insects and diseases are complex and vary according to the host pest system of interest; however, these interactions have received very little attention (Ziska and Runion, 2007). More knowledge in this area is required to develop best management strategies to deal with these potentially serious threats to productivity and profitability not only in horticulture, but for agriculture and forestry as well.

CONCLUSIONS

In general, elevated CO_2 increases plant growth (both above and belowground) and improves plant water relations (reduces transpiration and increases WUE). It is likely these benefits will also occur for horticultural plants, but data to support this are lacking relative to crop and forest species. In addition to basic research on the response of diverse horticultural species to future levels of atmospheric CO_2, it may become crucial to breed or screen varieties and species of horticultural plants for increased drought tolerance as a result of predicted changes in precipitation patterns. It is also important to determine the amount of C sequestered in soil from horticulture production practices not only for improvement of soil water holding capacity, but also to aid in mitigation of projected global climate change. Furthermore, determining the contribution of the horticulture industry to these projected changes through flux of CO_2 and other trace gases (through irrigation and fertilization) is of critical importance. How CO_2 induced changes in plant growth and water relations will impact the complex interactions with pests (weeds, insects, and diseases) is a deficient area of research not only for horticulture, but for plants in general. All this information is needed to develop best management strategies for the horticulture industry to successfully adapt to future environmental change.

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Effects of Media and Species on soil CO_2 efflux in the landscape

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ABSTRACT

Increasing concentrations of greenhouse gases (GHG) including carbon dioxide, methane, and nitrous oxide are widely believed to be the main contributing factors leading to global climate change. The horticulture industry has the potential to improve GHG conditions through sequestering carbon (C) in urban landscapes. In order to determine effects of growth media on soil CO_2 efflux, a study was conducted in which two common landscape species were grown in containers using three different growing media: 1) Pine Bark, 2) Clean Chip Residual, or 3) Whole Tree; after one growing season they were outplanted into the field. Initial soil samples were collected for C content determinations. Automated Carbon Efflux Systems (ACES) were installed adjacent to three plants of each species in each media for continuously monitoring (24 hr d^{-1}) of C lost via soil respiration and to determine media C sequestration potential. Increased soil C was primarily noted in the upper soil depth (0 - 15 cm), where PB was higher than the other media; a similar pattern was observed for the 15 – 30 cm depth although C values were much lower. Crape myrtle had higher soil CO_2 efflux than magnolia possibly due to crape myrtle having a larger root system or faster growth rate. All media had different soil CO_2 efflux values in crape myrtle (CCR was highest and WT lowest), while for magnolia PB was higher than the other media. Across both species, WT had lower efflux than PB and CCR possibly due to its higher wood content causing it to break down slower. Placing containerized plants into the landscape transfers a large amount of C belowground, suggesting that opportunities exist for the horticulture industry and homeowners to contribute positively to mitigating climate change via soil C sequestration. However, further investigation is needed to fully understand the impact of various growing media and ornamental species on soil CO_2 emissions and the residence time of this C in soil when planted into urban and suburban landscapes.

INTRODUCTION

Concentrations of the three most important long-lived greenhouse gases (GHG) in the atmosphere have increased dramatically over the past 255 years. Carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O) concentrations in the atmosphere have increased by approximately 35% (Keeling and Whorf 2005), 155% (Dlugokencky et al. 2005), and 18%

(Prinn et al. 2000), respectively, since 1750. Annual C emissions have increased approximately 80% from 1970 to 2004 (IPPC, 2007). Fossil fuel combustion along with land use changes such as deforestation, biomass burning, soil cultivation, and drainage of wetlands are the main contributors to increased C emissions. Increased concentration of atmospheric CO_2 and other GHG is widely accepted as the main factor causing global warming (Florides and Christodoulides 2008). While it has not been proven that GHG are causing global climate change, data has been presented which indicates the earth's surface temperature in increasing which could lead to possible negative environmental impacts (Lal, 2004; IPCC, 2007).

The agriculture industry in the United States is one of the highest contributors to GHG emissions behind only energy production (Johnson et al., 2007). CO_2, CH_4, and N_2O are the three most important GHG because of their atmospheric concentrations and because elevated levels of these gases are primarily due to human activity. Emissions of CO_2, CH_4, and N_2O from agriculture collectively account for an estimated one-fifth of the annual increase in GHG emissions. When land use changes involving clearing of land, biomass burning, and soil degradation are included, the overall impact from agriculture is one third of the total man-made greenhouse effect (Cole et al., 1997).

Opportunities to reduce GHG in agriculture have been the focus of much research (Hogan et al., 1993; Sommer and Hutchings, 1995; Cole et al., 1997; Kroeze et al., 1999); however, it is widely believed long term capture and storage of these gases is necessary to mitigate climate change. Unlike many other industries, agriculture has the potential or offset emissions by altering production practices which have the capacity to increase C uptake and storage in biomass and soils, referred to as carbon sequestration (USDA, 2008). Research has shown that row cropping systems utilizing conservation or "no-till" farming practices can reduce fossil fuel consumption while increasing C storage in soil (Reicosky et al., 1999). Changes in forestry management practices such as nutrient management, density control, and use of genetically improved species has been shown to increase C uptake and storage in biomass and soils (USDA, 2008).

Horticulture is a large-scale industry which impacts the landscape of rural (production facilities) and urban environments. The economic impact of the "green industry" (nursery, greenhouse, and sod) is $148 billion annually (Hall et al., 2005) and was $2.8 billion in Alabama alone in 2008 (AAES, 2009). Nationally, the green industry generates 1.9 million jobs, $64.3 billion in labor income, and $6.9 billion in indirect business taxes (Hall et al., 2005). While horticulture is one of the fastest growing sectors in agriculture, its potential impacts on climate change (either positively or negatively) have been virtually ignored. Farmers and ranchers in other agricultural sectors are now earning additional income in the emerging carbon trading market in which farmers may be paid to reduce their C emissions or sign contracts pledging to alter production practices which provide C offsets (i.e., C credits) to other industries which want to reduce their C footprint (CCE, 2009; NFU, 2009). In order for the horticulture industry to reduce GHG emissions and benefit from these new emerging programs, baseline estimates of C emissions and the ability of growers/landscapers to sequester C using current production practices must be established. The objective of this research is to develop baseline data to determine the ability of the nursery and landscape industry to mitigate climate change by sequestering C with the planting of ornamental trees and shrubs in the landscape.

MATERIALS AND METHODS

In order to determine the potential that the nursery and landscape industry has for C storage and to begin to understand the effects of growth media on soil CO_2 efflux, two commonly grown nursery crops including crape myrtle (*Lagerstroemia* x 'Acoma') and southern magnolia (*Magnolia grandiflora*) were transplanted from 7.6 cm (3 in) and 10.2 cm (4 in) liners, respectively, into 11.6 L (3 gal) containers on March 25, 2008. Plants were potted using one of three growing media; Pine Bark (PB), Whole Tree (WT), or Clean Chip Residual (CCR). Each substrate was mixed with sand (6:1, v:v) and 8.3 kg·m^{-3} (14 lbs/yd^3) 18-6-12 Polyon control-release fertilizer, 3.0 kg·m^{-3}(5 lb/yd^3) lime, and 0.9 kg m^{-3} (1.5 lb/yd^3) Micromax were added. Whole Tree (Fain et al., 2006) and CCR (Boyer et al., 2008), are by-products of the forestry industry which are currently being investigated as alternative media sources due to decreasing PB supplies (Lu et al., 2006). Plants were grown in the 11.6 L (3 gal) containers for an entire growing season and then outplanted to the field in December, 2008. To monitor soil CO_2 efflux, Automated Carbon Efflux Systems (ACES, USDA Forest Service, Southern Research Station Laboratory, Research Triangle Park, NC; US patent #6,692,970) were installed adjacent to the two plant species previously mentioned to continuously monitor (24 hr d^{-1}) C lost via soil respiration. Three replicate sampling chambers were placed on each potting media/species combination. Belowground soil C was also assessed in Summer, 2009, prior to placement of ACES. Two soil cores [3.8 cm (1.5 in) diameter x 60 cm (23.6 in) depth] were collected from each treatment within all blocks according to methods described by Prior et al. (2004). Cores were divided into 15 cm (5.9 in) depth segments, sieved (2 mm), and oven dried at 55˚ C (131˚ F). Ground subsamples of soil (0.15 mm sieve) were analyzed for C on a LECO TruSpec CN analyzer (LECO Corp., Saint Joseph, MI). The experiment was designed as a randomized complete block design. Soil CO_2 efflux data were analyzed using the Proc Mixed procedure and percent soil C was analyzed using the Proc GLM procedure of SAS (SAS version 9.1).

RESULTS AND DISCUSSION

Soil analysis at the beginning of the study period indicated that soil C in the top depth of soil (0 - 15 cm) was higher for PB compared to WT and CCR for both plant species (Fig. 1 and 2). Soil C for the other two media did not differ in either species. Although soil C was much lower at the 15 – 30 cm depth, the same treatment pattern was observed for both species. No soil C differences were observed among media in either species at the lower two depths (i.e., 30 - 45 and

45 - 60 cm). These initial soil C data indicate that the media were contained in the upper 15 cm of the soil profile with a possibility that some of the pine bark was incorporated slightly below that depth.

Crape myrtle had higher soil CO_2 efflux than magnolia when compared across all media; this was generally true when considering each media separately (Table 1). This higher efflux may be due to crape myrtle having a larger root system or faster growth rate than magnolia. In crape myrtle, all three media had significantly different soil CO_2 efflux values; CCR was highest and WT lowest. In magnolia, PB was higher than the other media, which did not differ. Across both species, WT had lower efflux than PB or CCR which were similar. Given that all three media had similar C content at potting (49.2, 47.8, and 46.9% for PB, WT, and CCR, respectively), the lower efflux for WT may be due to its higher wood content (~90% for WT vs. ~40% for CCR) causing it to break down slower. Further, Boyer et al. (2008) reported that PB and CCR had equivalent microbial respiration suggesting that these materials decompose at similar rates which is supported by our findings.

It is interesting to note that, for magnolia, the soil CO_2 efflux data mirrored the initial soil C data; that is, PB had higher soil C values and higher efflux values than the other two media, which did not differ. This was not the case for crape myrtle where soil C followed the same pattern as magnolia but where efflux was highest for CCR, followed by PB, then by WT with each being significantly different. The reason for this is not know but may involve interactions of media and root growth; this will be investigated at study termination.

It has been shown that changes in agricultural management practices which minimize soil disturbance (i.e., no-tillage) and increase surface crop residues (including use of cover crops) can enhance soil C sequestration potential (Smith et al., 1998; Lal, 2007), however this may be true only in the long term (Six et al., 2004). In the present study, soil C ranged from 11 – 25% in the upper soil profile of the planting area compared with about 3% found in field soils (Simmons and Derr, 2007). These data clearly show that planting containerized ornamentals into the landscape transfers a large amount of C belowground instantly, suggesting that opportunities exist for the horticulture industry to contribute positively to soil C sequestration. However, uncertainty remains regarding how long this C will remain sequestered. Further investigation is needed to fully understand the impact of various growing media and ornamental species on soil CO_2 emissions and the residence time of this C in soil when planted into urban and suburban landscapes. These data will not only prepare the horticultural industry for possible future legislation, they also provide homeowners a means of directly contributing to the mitigation of climate change via soil C sequestration.

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Table 1. Effects of species and growth media on soil CO_2 efflux[a]. Means with associated separation statistics are shown.

Species effects on soil CO_2 efflux across all media		
Species[b]	**Soil Flux**	**P-value**
CM	7.68	<0.001
MG	7.01	
	% Difference	
MG vs CM	9.6	
Media effects on soil CO_2 efflux across both species		
Media[c]	**Soil Flux**	**P-value**
PB	7.46	<0.001
WT	7.01	
CCR	7.57	
	% Difference	**P-value**
PB vs WT	-6.0	<0.001
PB vs CCR	1.5	0.265
WT vs CCR	8.0	<0.001
Media effects on soil CO_2 efflux within Crape Myrtle		
Media	**Soil Flux**	
PB	7.68	
WT	7.12	
CCR	8.24	
	% Difference	**P-value**
PB vs WT	-7.3	<0.001
PB vs CCR	7.3	<0.001
WT vs CCR	15.7	<0.001
Media effects on soil CO_2 efflux within Magnolia		
Media	**Soil Flux**	
PB	7.24	
WT	6.89	
CCR	6.90	
	% Difference	**P-value**
PB vs WT	-4.8	0.016
PB vs CCR	-4.7	0.018
WT vs CCR	0.1	0.977
Species effects on soil CO_2 efflux within media		
	% Difference	**P-value**
MG vs CM in PB	6.1	0.002
MG vs CM in WT	3.3	0.099
MG vs CM in CCR	19.4	<0.001

[a]Efflux in $\mu mol\ CO_2\ m^{-2}\ s^{-1}$; [b]CM=Crape Myrtle, MG=Magnolia
[c]PB=Pine Bark, CCR=Clean Chip Residual, WT=Whole Tree

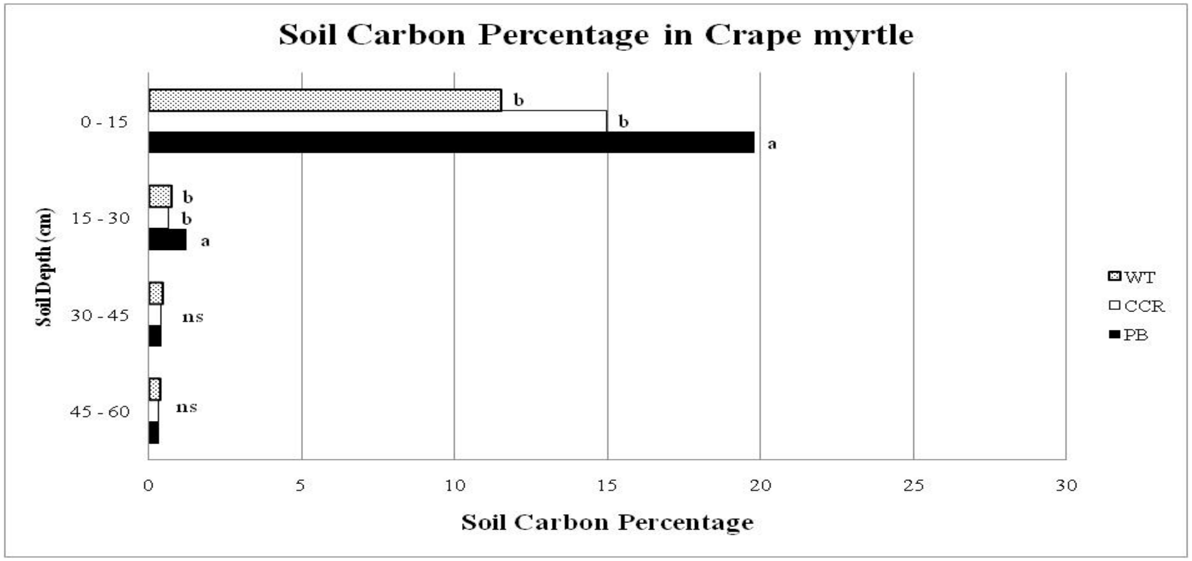

Figure 1. Media effects on soil carbon percentage in crape myrtle. Bars with the same letter are not significantly different according to the Least Significant Differences Test (alpha = 0.05). ns = not significant according to the Least Significant Differences Test. PB = Pine Bark, WT = WholeTree, CCR = Clean Chip Residual.

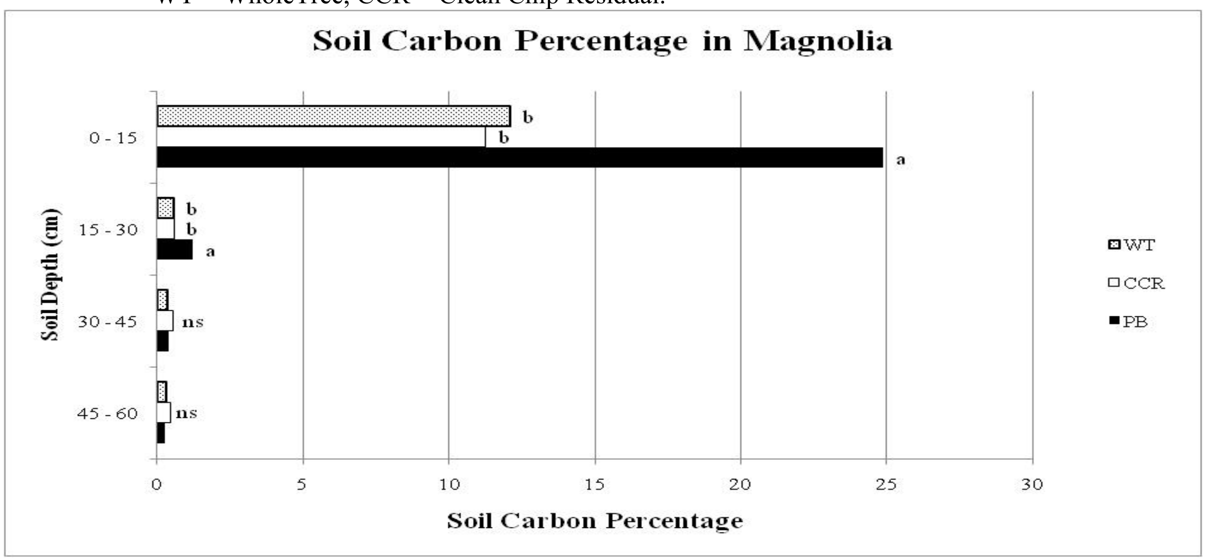

Figure 2. Media effects on soil carbon percentage in magnolia. Bars with the same letter are not significantly different according to the Least Significant Differences Test (alpha = 0.05). ns = not significant according to the Least Significant Differences Test. PB = Pine Bark, WT = WholeTree, CCR = Clean Chip Residual.

Effects of Outplanting Horticultural Species on Soil CO_2 Efflux

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Significance to Industry: Increased atmospheric carbon dioxide (CO_2) concentration is widely thought to be the main driving factor behind global climate change. Much of the work on reducing greenhouse gas (GHG) emissions and methods of carbon (C) sequestration has been conducted in row crop and forest systems; however, virtually no work has focused on contributions from sectors of the specialty crop industry such as horticulture. As with all industries, horticulture has the potential to negatively impact the global atmosphere, but it also has tremendous potential to improve atmospheric GHG conditions through the sequestering of C in urban landscapes. The objective of this on-going research is to determine the positive and negative effects of growth media on soil CO_2 efflux from commonly grown horticultural species planted in the landscape.

Nature of Work: Global warming and the possible impacts it may have on the global environment is one of the most researched topics of the last several decades. Annual CO_2 emissions have increased approximately 80% since the start of the industrial revolution (6). This increase in atmospheric CO_2 and other long-lived GHG [i.e., methane (CH_4) and nitrous oxide (N_2O)] are widely thought to be the main causes leading to predicted increase in global temperature. While it is difficult to prove that GHG are the only cause of global climate change, there are indications that the earth's surface is warming which may result in negative environmental impacts (6, 7).

While agriculture is a major contributor to GHG emissions, it also has great potential to offset emissions by altering production and management practices. These practices have the capacity to increase C uptake and storage in biomass, wood products, and soils (i.e., carbon sequestration) (12). For example, row cropping systems utilizing no-till practices can reduce fossil fuel use while promoting C storage in soil (11). Improved forest management practices such as density control, nutrient management, and genetic improvement benefit forest production and C accumulation in biomass and soil; wood products also serve as long term C storage pools (12).

Horticulture is a multi-billion dollar industry, with an economic impact of $2.8 billion in Alabama alone (5). However no research to date has focused on this industry's impact on global change. There is great interest among ranchers and farmers in other agriculture sectors to earn new income in the emerging carbon trading market. Organizations such as the National Farmer's Union have implemented new programs (in conjunction with the Chicago Climate Exchange's Carbon Credit Program) in which farmers may be paid to reduce their C emissions or sign contracts pledging to alter production practices which provide C offsets (i.e., C credits) to other industries which want to reduce their C footprint (3, 10). In order for the horticulture industry to reduce GHG emissions and benefit from such new emerging programs, baseline estimates of C emissions and the ability of growers/landscapers to sequester C using current production practices must be established. The focus of this research is to determine how three different container growth media impact CO_2 emissions once planted into the landscape.

In order to determine the potential that the nursery and landscape industry has for C storage and to begin to understand the effects of growth media on soil CO_2 efflux, two commonly grown nursery crops [crape myrtle (*Lagerstroemia* x 'Acoma') and magnolia (*Magnolia grandiflora*)] were transplanted from 3 in. and 4 in. liners, respectively, into 3 gallon containers on March 25, 2008. Plants were potted using one of three growing media; pinebark (PB), WholeTree (WT), or clean chip residual (CCR). Each substrate was mixed with sand (6:1, v:v) and 14 lbs Polyon (18-6-12), 5 lbs dolomitic lime, and 1.5 lbs Micromax (incorporated on a cubic yard basis). WholeTree (4) and CCR (1), which are by-products of the forestry industry, are being investigated as alternative potting media due to decreasing PB supplies (9). Plants were grown in the 3 gallon containers for an entire growing season and then outplanted to the field in December, 2008. Soil samples were collected in Summer, 2009 (data not shown) for determination of soil C and nitrogen. At this time, Automated Carbon Efflux Systems (ACES, USDA Forest Service, Southern Research Station Laboratory, Research Triangle Park, NC; US patent #6,692,970) were installed adjacent to the two plant species previously mentioned to continuously monitor (24 hr d^{-1}) C lost via soil respiration. Three replicate sampling chambers were placed on each potting media/species combination. In addition, three chambers were placed in non-plant (bare soil) areas. The experiment was designed as a randomized complete block and data were analyzed using the PROC MIXED procedure of SAS (8).

Results and Discussion: When comparing CO_2 efflux between species, crape myrtle had higher soil CO_2 efflux than magnolia (Table 1), possibly due to a larger root system or faster growth rate of crape myrtle (Table 1). Overall, PB and CCR had similar soil CO_2 efflux values; in crape myrtle PB had lower efflux than CCR, while in magnolia this relationship was reversed. However, WT had significantly lower soil CO_2 efflux than either PB or CCR (Table 1). Boyer et al. (2) reported that PB and CCR had similar microbial respiration suggesting that these materials decompose at similar rates. WholeTree has a higher percentage of wood than either PB or CCR which may cause it to break down slower, resulting in lower soil CO_2 efflux. With crape myrtle, all three media had significantly different soil CO_2 efflux values; there was no effect of media for magnolia (Table 1). These results indicate that C storage potential may increase with utilization of WT as a growing media for container crops. Additional data such as plant biomass increase and changes in soil C levels over time will also be needed to fully understand the impact of these growing media on soil CO_2 emission.

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Table 1. Effects of species and growth media on soil CO_2 efflux[a]. Means with associated separation statistics are shown.

Species effects on soil CO_2 efflux across all media		
Species[b]	**Soil Flux**	**P-value**
CM	7.67	<0.001
MG	7.01	
	% Difference	
MG vs CM	9.4	
Media effects on soil CO_2 efflux across both species		
Media[c]	**Soil Flux**	**P-value**
PB	7.46	<0.001
WT	7.00	
CCR	7.57	
	% Difference	**P-value**
PB vs WT	-6.2	<0.001
PB vs CCR	1.6	0.0265
WT vs CCR	8.1	<0.001
Media effects on soil CO_2 efflux within Crape Myrtle		
Media	**Soil Flux**	
PB	7.68	
WT	7.12	
CCR	8.24	
	% Difference	**P-value**
PB vs WT	-7.3	<0.001
PB vs CCR	7.3	<0.001
WT vs CCR	15.8	<0.001
Media effects on soil CO_2 efflux within Magnolia		
Media	**Soil Flux**	
PB	7.24	
WT	6.89	
CCR	6.90	
	% Difference	**P-value**
PB vs CCR	-4.8	0.0163
WT vs PB	-4.7	0.0176
WT vs CCR	-0.1	0.9766
Species effects on soil CO_2 efflux within media		
	% Difference	**P-value**
MG vs CM in PB	6.0	0.0017
MG vs CM in WT	3.3	0.0988
MG vs CM in CCR	19.4	<0.001

[a]Efflux in μmol CO_2 m^{-2} s^{-1}; [b]CM=Crape Myrtle, MG=Magnolia
[c]PB=Pine Bark, CCR=Clean Chip Residual, WT=Whole Tree