Carbon Sequestration and Greenhouse Gas Emission Reduction from Horticultural Production Practices

by

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Abstract

Over the past three decades, one 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 emissions (GHG) 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 a large scale industry which impacts rural, suburban, and urban landscapes. While this industry may have negative impacts on the global environment (e.g., CO_2 and trace gas efflux), it also has the potential to reduce greenhouse gas emissions and increase C sequestration by altering current production practices. The objective of this research was to develop baseline estimates of trace gas emission levels from current horticultural production practices and then examine ways in which these production practices can be altered to decrease emissions and increase C sequestration. To develop baseline estimates of trace gas emissions from container plant production, efflux patterns of CO_2, CH_4, and N_2O associated with four different nursery container sizes [3.0 L (trade gal; TG), 3.8 L (#1; 1 gal), 7.6 L (#2; 2 gal), and 11.4 L (#3; 3 gal) were determined using dwarf yaupon holly (*Ilex vomitoria* 'Nana' L.) grown under common production practices for one year. Weekly measurements indicated that CO_2 and N_2O fluxes were highest in the largest containers (#3). There was a significant positive relationship between container size and CO_2 efflux. Nitrous oxide efflux followed a similar pattern, except there were no differences between the two smallest container sizes. Methane flux was consistently low and had no significant effect on total trace gas emissions. Results from this study begin to address uncertainties regarding the environmental impact of the horticulture industry on climate change while providing baseline data of trace gas emissions from container production systems needed to develop future mitigation strategies. In a second study, efflux patterns of CO_2, CH_4, and N_2O associated with three different fertilization methods (dibble, incorporated, or topdressed) commonly used in nursery container production were determined. Results indicated that CO_2 fluxes were slightly lower when fertilizer was dibbled compared to the other two methods. Nitrous oxide fluxes were consistently highest when fertilizer was incorporated. Methane flux was generally low with few differences among treatments. Results from this study begin to provide data which can be used to implement mitigation strategies in container plant production which will help growers adapt to possible emission regulations and benefit from future GHG mitigation or offset programs.

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CHAPTER I

Introduction and Literature Review

There is widespread belief among the scientific community that climate change brought upon by human activity is occurring, and that it poses a serious global threat. While it is still uncertain that man-made emissions are causing an increase in global temperatures, it is known that concentrations of the three most important long-lived greenhouse gases (GHG) in the atmosphere have increased dramatically over the past 255 years (IPCC, 2007). Carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O) concentrations in the atmosphere have increased by approximately 35%, 155%, and 18%, respectively, since 1750 (Dlugokencky et al., 2005; Keeling and Whorf, 2005; Prinn et al., 2000) and high concentrations of these gases are widely accepted as the main factor that causes 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 carbon (C) emissions approximately 80% from 1970 to 2004 (IPCC, 2007).

Environmental Impact of Rising Greenhouse Gas Concentrations

Increased atmospheric CO_2 can cause both positive and negative environmental changes. It is well established that elevated CO_2 increases growth and yield of most plant species (Kimball, 1983), and this increase is attributed to increased rates of photosynthesis and water use efficiency (Amthor, 1995; Rogers and Dahlman, 1993). The increase in photosynthesis resulting from increased CO_2 results from two properties of Ribulose-1,5-bisphosphate carboxylase oxygenase (RuBisCO). Rubisco is an enzyme involved in the Calvin cycle. Rubisco catalyzes the first step of C fixation, a process in which atoms of CO_2 are made available to plants or other organisms as energy in forms such as sucrose. Increases in plant photosynthesis due to higher CO_2 concentrations results from the Michaelis constant (Km) of the enzyme for CO_2 being close to the current atmospheric CO_2 concentration. Due to the Km of the CO_2 enzyme being close to current CO_2 concentrations, elevated CO_2 increases the speed of carboxylation. Carbon dioxide also competitively inhibits the oxygenation reaction, which produces glycolate leading to photorespiration. By inhibiting the oxygenation reaction, the efficiency of net C CO_2 uptake is increased by decreasing photorespiratory CO_2 loss and diverting ATP and NADPH (generated by light reactions) away from photorespiratory metabolism to photosynthetic assimilation. Because net photosynthesis is increased, the rate of photosynthesis is increased regardless of other environmental factors that could slow photosynthesis down (light, water stress, etc.), resulting in a faster growing, more efficient plant (Long et al., 2004). While plants may benefit from increased atmospheric CO_2 levels, these increased atmospheric levels of CO_2 along with other GHG are often cited for many negative environmental impacts resulting from global warming.

While it is difficult to prove that GHGs are the only cause of global climate change, it is known that the earth’s surface is warming, and atmospheric GHG concentrations are increasing (IPPC, 2007). The ten warmest years in history (past 150 years since data has been accurately recorded) occurred in the 1980’s and 1990’s (Douglas, 2004). Since the late 19th century, the accumulation of all GHGs is believed to have led to the observed increase in the average global surface temperature of 0.6° C, with a current warming rate of 0.17° C occurring every ten years (Lal, 2004). This observed increase in global average temperatures is in excess of the critical rate of 0.1°C/decade. Beyond this critical rate, ecosystems may have difficulty adjusting to the rising temperatures (Lal, 2004). Countless environmental and biological systems could be negatively impacted by increasing global temperatures.

The increase in mean global temperatures is related to rising sea levels. Melting icecaps and glaciers are projected to raise sea levels 15 cm to 1 m by the end of the 21st century (Douglas, 2004). In 2002, one arctic ice shelf was observed as being 2.2°C warmer and lost 325,000 ha in surface area in a 35 day period (Douglas, 2004). Higher sea levels disrupt countless marine and fresh water ecosystems due to changes in ice cover, salinity, oxygen levels, increased water temperature, and circulation (IPCC, 2007). Salt water merging with fresh water devastates drinking and irrigation water supplies, and higher sea levels result in the loss of mangroves and wetlands. Fish and other aquatic life may be negatively impacted by such change and could result in the loss of some species. Low lying island nations are also considered to be at risk for completely disappearing (Douglas, 2004).

Rising sea levels are not the only concern related to climate change. Some human illnesses are being related to climate change. Mortality rates from heat related illness have increased in relation to warmer temperatures and it is hypothesized that the spread of infectious disease vectors and increased allergic pollen levels are due to warmer temperatures (IPPC, 2007). For example, warmer temperatures increase the breeding range for mosquitoes and other insects that vector malaria and dengue fever (Douglas, 2004). The occurrence of tornadoes and hurricanes is believed to increase in a warmer environment as well. Drought and flooding cycles are also a concern. Warmer temperatures cause accelerated evaporation of rain and irrigation. Warmer atmospheric conditions also make it difficult for water molecules to stick together to form rain drops, reducing annual precipitations. However, when sufficient raindrops are finally formed, extra water vapor in clouds will cause increased rainfall and flooding, resulting in erosion (Douglas, 2004; IPCC, 2007).

Agriculture could be one industry severely impacted by increased temperatures. Increased temperatures and precipitation could benefit some cropping systems, while hindering others. Many environmental systems may be sensitive to even small shifts in global temperature and would not be able to adapt with the needed resources on a sustained basis for successful economic development (Watson et al., 1998). In order to mitigate or sequester (capture and store) GHG, it is important to first understand where these gases come from and why they are suspected of causing increased global temperatures.

The Greenhouse Effect

The temperature of the earth's surface depends on a balance of incoming radiation from the sun (solar radiation) and outgoing radiation from the surface of the earth (terrestrial radiation). A small amount of the heat energy emitted from the planet's surface passes through the atmosphere back into space. The majority of this energy is absorbed by molecules of CO_2, water vapor, CH_4, N_2O, chlorofluocarbons (CFCs), and ozone, collectively known as greenhouse gases (GHG). The trapped radiation contributes to the energy radiated back down to warm the Earth's surface and the lower atmosphere, which is commonly referred to as the greenhouse effect (Long, 2004). The ability of these molecules to absorb radiation is based upon how loosely their atoms are held together. Carbon dioxide consists of one C atom with an oxygen atom covalently bonded to each side. When its atoms are bonded tightly together, the CO_2 molecule can absorb infrared radiation and the molecule starts to vibrate. Eventually, the vibrating molecule will emit the radiation again, which will then be absorbed by another GHG molecule.

This absorption – emission – absorption cycle keeps heat near the surface of the Earth, or in excess, may cause increased temperatures on the Earth (Anonymous, 2010). The absorbance potential of these molecules also depends on how much they absorb specific wavelengths and the location of these spectral absorption bands relative to the spectral distribution of incident energy. For example, CO_2 strongly absorbs energy having a wavelength of 15 microns, which is also the maximum intensity of infrared radiation, meaning CO_2 can strongly absorb infrared radiation from the sun (Mathez, 2009). Methane and N_2O are also molecules composed of more than two component atoms bound loosely enough together to be able to vibrate and strongly absorb heat.

The major components of the atmosphere (N_2 and O_2) are two atom molecules and are bound too tightly to vibrate and therefore do not absorb heat or contribute to the greenhouse effect (Nelson, 2003). Methane, N_2O, ozone, and CFCs absorb radiation much more efficiently than CO_2, but are also present at much lower concentrations. Typically GHG levels are present as dimensionless numbers representing parts per billion multiplied by a scaling factor known as global warming potential (GWP) which allows their relative efficiency of producing global temperature increase to be compared (Nelson, 2003). For CO_2, this scaling factor is 1. The factors for CH_4 and N_2O are 21 and 310, respectively. While water vapor contributes to the greenhouse effect, it does not have a GWP. Ozone has a much higher GWP than does CO_2; however, this is tropospheric ozone, which is unlike naturally forming ozone of the stratosphere. Tropospheric ozone is a pollutant from reactions involving hydrocarbons, carbon monoxide, and N_2O. Other gases such as sulfur hydroxide which has a GWP of 23,900 (Nelson, 2003) are much more potent than CO_2, NH_4, or N_2O. Without GHGs, the average temperature on Earth would be about 33° C degrees colder and would be unable to support life. Conversely, higher levels of GHGs appear to lead to rising surface temperatures (Long, 2004).

Greenhouse Gas Emissions from Agricultural Production

The agriculture industry in the United States is one of the highest contributors to GHG emissions, behind only energy production (Johnson et al., 2007). Carbon dioxide, CH_4, and N_2O are the three most important GHGs because of their atmospheric concentrations and because elevated levels of these gases are mostly caused by human activities. 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 and biomass burning and soil degradation are included, the overall radiative forcing from agriculture production, or influence that a factor has as a potential climate change mechanism, is one third of the man-made greenhouse effect (Cole et al., 1997).

Carbon dioxide is emitted primarily through land use changes and the burning of fossil fuel in production, and the causes of increased CO_2 concentrations since the industrial revolution are mainly due to CO_2 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 well as land use changes such as deforestation (Houghton, 2003). Deforestation globally released an estimated 136 billion tons of C or 33% of total C emissions between 1850 and 1998, which exceeded any other anthropogenic activity besides energy production (Watson et al., 2000).

Methane, the second most important GHG, and N_2O are considered the major contributors to agricultural impacts and are estimated to produce about 50 and 70%, respectively, of the total man-made emissions of these gases (Cole et al., 1997). The major sources of CH_4 emissions from human activities include agriculture, landfills, and natural gas emissions (Mathez, 2009). The primary sources of CH_4 emissions in agriculture are enteric fermentation in ruminant animals, flooded rice fields, and biomass burning (Johnson et al., 1993; Cole et al., 1997; USDA, 2008). In addition, managed livestock waste can release CH_4 through the biological breakdown of organic compounds and nitrous oxide (N_2O) through nitrification and denitrification of N contained in manure (USDA, 2008).

Nitrous oxide is also a major GHG. Nitrous oxide forms naturally in soils and the ocean and is also a by-product of agriculture and fossil fuel combustion (Mathez, 2004). Nitrous oxide is produced naturally in soil through microbial processes and the radiative forcing is increased exponentially from the production and large scale application of N fertilizers in agriculture. Past and current atmospheric N_2O increases are directly attributed to increased N-fixation in synthetic fertilizer and legume crops (Mosier et al., 2003), resulting in 80% of the total N_2O emissions in the United States.

Sequestration Potential in Agriculture

Many scientists believe that emissions from agriculture must be reduced in order to slow climate change; however, it is widely believed that emission reductions in agriculture alone will not be enough to curtail the negative impacts of agriculture on the environment, but that long term capture and storage of these gases, or sequestration, is necessary. These gases, primarily CO_2, can be stored for long periods of time in biomass, wood products, soils, and forests (USDA, 2008) and the process of C sequestration in agriculture has been a heavily researched topic, particularly in the last 10 to 15 years.

Sequestration of C from plant biomass into soil organic matter (SOM) is a key sequestration pathway and is the most researched area of sequestration in agriculture. Soil C sequestration is viewed as a win-win strategy in that it restores degraded soils, enhances biomass or crop production, purifies surface and ground waters, as well as providing the environmental benefits of reducing atmospheric CO_2 concentrations by storing C in the soil profile (Reicosky et al., 1999). Croplands often emit CO_2 as a result of conventional tillage practices and other soil disturbances in which soil organic matter that would otherwise be protected by vegetative cover are exposed through conventional tillage practices and become susceptible to decomposition. Frequent tillage breaks down soil macroaggregates, enhances the exposure of C to microbial activity, and increases soil temperatures and speeds decomposition, thus increasing the rate in which C is lost from the soil from respiration (Lal et al., 1998). Conservation tillage (no-till), has been the focus of much research. No till is farming in which the amount of tillage is reduced and crops are grown with minimal cultivation. Most of the plant residues are left on top of the soil rather than being plowed or disked into the soil (Arshad et al., 1990). Smith (et al., 1998) estimated that 100% conversion to no till agriculture in Europe could mitigate all fossil fuel C emission from agriculture in Europe. No-till provides environmental benefits but has also been shown to provide other benefits. Lal (2007) reported that soils with high C levels also had improved soil quality, increase soil productivity, and reduced risk of erosion.

Mitigation strategies for CH_4 and N_2O have also been investigated. The greatest opportunity for reducing CH_4 emissions in agriculture from ruminants is through feed supplementation of cattle and buffalo in Africa, Asia, and Latin America (Leng, 1991; Lin et al., 1994). Hogan (1993) reported CH_4 lost from anaerobic digestion of livestock manure can be recovered and used as an energy source using manure management and treatment practices adapted for CH_4 collection. Cole et al. (1997) estimated that with current technology, CH_4 emissions from manures can be reduced from 25 to 80%. Increased efficiency of N fertilization has been shown to directly reduce emissions of N_2O, ammonia, and NO (Kroeze et al., 1999).

Kroeze and Mosier (2000) estimated that improved crop N-use efficiency could decrease soil derived N_2O emissions from agriculture by 35% globally.

The Role of the Horticulture Industry in Climate Change Research

Much of the work on reducing greenhouse gas emissions and on C sequestration has been conducted in row crop or forest systems; however, virtually no research has focused on contribution from sectors of the specialty crop industry such as horticulture. Horticulture production is a large scale industry which has a tremendous impact on the landscape of both the rural (production facilities) and urban environments. Horticulture is a multi-billion dollar industry; the economic impact of the nursery, greenhouse, and sod industry was $2.8 billion in Alabama in 2008 (AAES, 2009). Nationally, the green industry (nursery, greenhouse, and sod production) has an economic impact of $148 billion and is not only one of the nation’s fastest growing businesses, but continues to expand even during recessionary periods (Hall et al., 2005). Additionally, 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 largest and fastest growing sectors in agriculture, the impact of this industry on climate change, either positively or negatively, has been virtually ignored. There is need for the horticulture industry, as well as other sectors of agriculture to determine ways in which current production practices can be altered in order to mitigate or potentially sequester GHGs, not only to improve the environment, but also because these measures could soon be required by law. In April 2007, the US Supreme Court concluded that GHGs satisfies the definition of an air pollutant as stated in the Clean Air Act (CAA) which was passed in the 1970’s. Therefore, the EPA has authority under the CAA to regulate GHGs that are emitted from new motor vehicles (mobile sources). This decision is significant since the EPA now can decide to strictly regulate and enforce limits on other sources of GHG emissions. This may include establishing and permitting requirements for stationary (industrial) sources of air pollutants (EPA, 2008). Government officials are also in the process of passing legislation limiting CO_2 and other GHG emissions in the near future. All sectors of agriculture need to examine ways to reduce and or sequester GHG emissions in ways that do not drastically alter current production practices or decrease profit margins.

The horticulture industry has the potential to not only reduce emissions and reduce its C footprint, but also provide possible financial advantages for changes in production management. There is now great interest among ranchers and farmers in other agriculture sectors to earn new income in the emerging C trading market and new government incentives to try and reduce GHG emissions. The US EPA has begun partnerships and programs to promote opportunities to conserve fossil fuels, improve energy efficiency, recover CH_4, and sequester C, including tax incentives for some industries. Beginning in 2003, the USDA began providing targeted incentives to encourage wider use of land management practices that remove C from the atmosphere or reduce emissions of greenhouse gases. 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 including tax credits for the purchase of hybrid cars, utilizing solar heating systems, using energy from landfill gas, and using electricity produced from wind and biomass (EPA, 2009). All sectors of the agricultural community could potentially profit by incorporating these “green” technologies into their production systems. Organizations such as the National Farmers Union (2009) 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 (CCE, 2009; NFU, 2009). Other similar programs such as the Regional Greenhouse Initiative, a cooperative effort among 10 Northeastern 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).

Farmers and ranchers can receive payments for their offset projects provided they meet four certain criteria: 1) They have to be additional (they must come from activities that would not happen in the absence of offset incentive, 2) They have to be quantifiable (must be able to measurably reduce emissions, 3) they have to be permanent, and 4) they have to be real and subject to verification by a third-party inspector (Schmidt, 2009). In 2008, Missouri farmers adopting no-till could receive a credit of 0.4 to 1.3 tonnes C/ha. For cropland that was converted to grassland they could receive a 1 ton C/acre (2.2 tonnes/ha) credit. In 2008 C contracts were selling for $6.60/tonne, and in 2007 the price was $4.40/tonne. However, should GHG become regulated, the price of C credits are likely to rise meaning more money for farmers that adopt these changes. In Europe where GHG emissions are limited, C is valued at over $33/tonne (Massey, 2008). 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.

In order to determine GHG emissions and means of reducing emissions in the green industry, common, industry wide production practices must be evaluated for GHG mitigation and emission potential. Once practices that contribute to a large portion of GHG emissions from the Horticulture industry are established, a Best Management Practices (BMP) guide can be developed which provides growers and landscapers a reference on how to alter production practices in order to lower GHG emissions, with the goal of also increasing efficiency and profit margins.

Current Horticulture Production Practices

1. Media

Ornamental horticulture commodities are primarily grown either in containers or in the field. Container production of nursery crops began in the 1950's and since then the acreage has continued to increase. Growing plants in containers is a unique production system compared to growing plants in field soil in that container plants are grown in soilless substrates (media) that contain a limited amount of water, retain small amounts of nutrients, and confine the roots in a limited volume (Yeager et al., 2007). Field production is also a large sector of the horticulture industry but is far less intensive than container production because container production requires more properly timed applications and inputs such as irrigation, fertilization, and pest control in order to grow healthy, salable plants as efficiently as possible (Yeager et al., 2007).

Container plants are predominately grown in pine bark (PB) in the southeastern U.S. because it has been found to be inexpensive (historically), readily available, largely inert, pathogen free, and have physical and chemical properties favorable for plant growth (Airhart et al., 1978; Lunt and Kohl, 1956). While PB once provided an effective, inexpensive growing media for container producers, future availability and increasing costs associated with PB has become a concern in recent years. Reduced forestry production in the United States paired with the increased use of PB as a fuel source is reducing the availability of PB (Lu et al., 2006). Along with the growing concern over future availability of PB, increased shipping costs over the past decade has led to the exploration for alternatives to PB such as WholeTree (WT) and Clean Chip Residual (CCR) (Boyer et al., 2008; Fain et al., 2008b).

WholeTree consists of entire pine trees (*Pinus taeda* L.) that are harvested from pine plantations at the thinning stage, chipped whole and later hammermilled through specific screen sizes based upon crop specification (Fain et al., 2007). WholeTree (~90% wood fiber) is made up of wood, bark, limbs, needles, and cones. Studies suggest WT can be used successfully in production of greenhouse crops (Fain et al., 2007; Fain et al., 2008a).

Clean chip residual is a result of new tree harvesting practices that use mobile field equipment to harvest pine trees in the field. This equipment is used in the field and processes trees into ‘clean chips’ for pulp mills, leaving behind a residual material composed of about 50% wood, 40% bark, and 10% needles (Boyer et al., 2008). Clean chip residual is either sold as boiler fuel or spread back across the harvested area and accounts for about 25% of the total biomass harvested. With millions of acres in the southeast United States in forestry production, CCR has the potential to provide an economical and sustainable substrate alternative for the nursery industry (Boyer et al., 2009). When determining GHG emissions or sequestration potential from nursery production practices, the impact of these two substrates, WT and CCR, as well as other viable PB alternatives should be determined as well. If PB supplies continue to decrease, growers may be forced to begin using these two substrates in container production in the near future.

2. Irrigation

When using soilless potting media, irrigation is a very important aspect of plant production. While irrigation does depend on nursery size, location, and the crops to be grown, most growers irrigate as much as one to two times per day during the growing season using overhead irrigation. Overhead irrigation is now considered the most economically feasible watering method for relatively small containers (Yeager et al., 2007). However, research is needed in order to determine the best method of irrigation that provides the plant water needed for optimal growth without overwatering the container which leads to increased fertilizer and pesticide leaching (Yeager et al., 2007). An example of a production change which might lead to less leaching of nutrients would be changing from one to two watering cycles a day to several shorter cycles a day which may decrease leaching, reduce N fertilizer use, and lead to reduced N_2O emissions via improved N use efficiency (Fain et al., 1999).

3. Fertilization

Fertilization is another important aspect of container production. Use of control-released fertilizers (CRF) is the recommended and most used method of container fertilization (Yeager et al., 2007). However, countless CRF products are available with different longevities (lasting 3-4 months, 8 to 9 months, 10 to 12 months, etc) nutrient ratios (varying N-P-K ratios), and nutrient release mechanisms (different coatings). Application methods also vary: some growers prefer to incorporate the fertilizer (or mix) in the media at potting, while some prefer to dibble (drill a small hole in the media surface and fill with fertilizer) and others believe that top-dressing (applying fertilizer to the top of the container surface after potting) the plant is best method. Nutrient efficiency and consequently GHG emissions likely differ greatly between fertilizer formulation and application methods. Emissions must be determined from different fertilization products and methods in order to estimate GHG emissions from horticultural systems.

Emission Reductions and Sequestration Potential in Horticulture

After baseline estimates of GHG emissions are determined from these major production practices, changes in current practices can be explored to determine if GHG emission reductions are feasible and economical. If small changes such as changing from fertilizer incorporation to dibble fertilization or possibly use of WT to supplement PB in potting media are determined to reduce GHGs, these new production changes could greatly reduce the C footprint of the industry as well as provide new financial opportunities for growers through new offset markets. While there are many possible GHG reduction strategies in production of container plants that need to be explored, these plants also have great potential to sequester C once planted in the landscape.

Previous research has shown the role of urban forests and the potential these 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 United States 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). Simpson and McPherson (1998) reported that in Sacramento County, CA a utilities-sponsored tree planting program resulted in an annual savings of an estimated $24 per mature tree. These trees become more valuable as energy prices rise. While the role of trees on C storage have been addressed in some research, no research has identified the positive impact that common nursery shrubs, perennials, and other plantings have on the environment

It is established that trees and other plants in the landscape will grow and store C in their biomass. However, another important aspect of horticulture is that these plants can be first grown in a substrate composed of primarily PB; or in the case of new alternatives, wood, that has an extremely high percentage of C. When these plants are planted in the landscape, C in the potting media is stored underground and will remain stored, or sequestered, for an indefinite period of time, similar to no-till farming practices. The difference between horticulture and no-till farming is that with no-till, it may take much longer to store the amount of C using no-till practices that would be stored instantaneously when planting a container-grown ornamental; however, these ornamentals planted in the landscape will take up far less acreage. In one long-term cropping study, the impact of no till management on C sequestration and GWP was only significant at the end of 20 years (Six et al., 2004). If C sequestration and GWP is determined to be significant from the planting of landscape trees, shrubs, and other ornamentals, the horticulture industry could reap the benefits of increased sales as well as provide environmental benefits. This would also provide every homeowner the potential to improve their property aesthetically, while helping to mitigate climate change.

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CHAPTER II

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

Abstract

Over the past 3 decades, climate change and the possible impacts on the global environment is one issue which has 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 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. 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 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.

Introduction

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 (CO_2), methane (CH_4), and nitrous oxide (N_2O) concentrations in the atmosphere have increased by approximately 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 approximately 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 approximately 120 years show that the ten warmest years occurred in the 1980's and 1990's (Douglas, 2004). Accumulation of GHG since the late 19th century may have led to the observed 0.6° C increase in the average global surface temperature with a current warming rate of 0.17° C occurring every ten years (Lal, 2004). This observed increase in global average temperatures is in excess of the critical rate of 0.1°C/decade; above 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, 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 (US Census Bureau, 2008). Even small reductions in yield of major food sources (e.g., corn, rice, and 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

Agriculture 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 due to their increasing atmospheric concentrations and the fact that these increases are mainly due to 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 man-made greenhouse effect (Cole et al., 1997).

Increased CO_2 concentrations since the industrial revolution are mainly due to 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 about 50% and 70%, respectively, of the total man-made 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 those found in manure (USDA, 2008). While N_2O forms naturally in soils and oceans through microbial processes, it is also a by-product 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 US (Mosier et al., 2003).

Many scientists believe that emissions from agriculture must be reduced in order 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 is 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) via 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 which 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 U.S. (Hall et al., 2005) and was $2.8 billion in Alabama alone in 2008 (AAES, 2009). In the U.S., 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 7,300 producers in the top 17 states, occupying approximately 200,000 hectares (USDA, 2007). In addition, non-agricultural land (e.g., urban and suburban) in the U.S. comprises 61 million hectares (Lubowski et al., 2006), a significant proportion of which is (or could be) planted with ornamental trees and shrubs. While 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 April 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 since 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 utilization 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 Farmers Union have implemented new programs (in conjunction with the Chicago Climate Exchange’s 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 $t \cdot ha^{-1}\ yr^{-1}$ and cropland converted to grassland received C credits of 2.2 $t \cdot ha^{-1}\ yr^{-1}$. In 2007, C contracts were selling for $4.40 per tonne, while in 2008 the price was $6.60 per tonne. However, should GHG become regulated, the price of C credits are 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). In order 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 paper is to explore GHG mitigation and sequestration possibilities in ornamental horticulture production. We will 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 predominately pine bark-based medium. Pine bark is composed largely of organic C, having a C concentration greater than 60% compared with about 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 micro-ecosystems created by such out-plantings 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 in order to estimate the amount of C being sequestered. This would generate critical data for the horticulture industry. While 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 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) (Table 1). All growers polled used pine bark as their primary growth medium (Table 2). While pine bark + other accounted for almost 42% of the media used (Table 2), the amendments were usually sand or very small volumes of peat (<10%). The survey indicated that about 72,000 m^3 of pine bark were used to produce container-grown nursery crops; given that the survey represented only half of the state's production, this estimate could be doubled (140,000-150,000 m^3). Since pine bark 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 tonnes C) potentially placed belowground.

While 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; Boyer et al., 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 since 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 homeowners, which are placing this purchased C in or on the ground and are “sequestering” it, and therefore the C 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 which 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). While 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 prior to planting; and dibbling refers to placing the fertilizer in a small hole formed in the potting media after planting. 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). While 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 vs. 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 to 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-4.4P-8.3K vs. 8N-3.5P-6.6K), increased N_2O emissions could occur. 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, 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 optimizing 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 irrigation. 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 investigation to develop BMPs not only for reducing N_2O emissions but also for water conservation, an issue becoming critical in a changing climate.

C 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 sequestering C in standing biomass (Nowak, 1993). Rowntree and Nowak (1991) estimated that urban forests in the U.S. sequester approximately 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 environment 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 (> 0.9 m per year), medium (0.3-0.9 m per year), or slow growing (<0.3 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 above would be considered fast or medium growers and would accumulate more biomass (more C storage potential) than shrubs. However, most landscapes have more shrubs than trees. It is possible that, in any given landscape, the total C accumulated in shrubs could be greater than that in trees.

In order 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, irrigations, etc., must be taken into consideration. These figures are likely to be relatively low for the ornamental horticulture industry as 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, trimmings, media substrates, etc., along with those associated with plant respiration) must be also be considered. For example, in studies of managed turfgrass systems it was reported that, while irrigation and fertilization enhance productivity and C storage, soil GHG emissions 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 industry provides the average U.S. homeowner an ability to participate in reducing their C footprint by landscaping their yards and increase their 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 emissions and increase C storage in other agriculture 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 elucidated. Industry leaders and growers can then begin to fine-tune BMPs to maximize productivity and profitability while minimizing GHG emissions. Research is needed to provide the industry with the necessary tools for adapting to future legislation that could cap GHG emissions and provide growers opportunities 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 various landscape species when planted into urban and suburban landscapes could provide homeowners a means of directly contributing to mitigation of climate change.

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

	Size of container[z]									
	Trade gal.	**#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 than #25. A conservative container size of 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	Incoporate 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 (<10%).

[y] Nursery growers asked what percentage of their crops were slow (<0.30 m per year), medium (0.30-0.91 m per year) or fast growing (> 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.

CHAPTER III

Determining Trace Gas Efflux from Container Production of Woody Nursery Crops

Abstract

Agriculture is a large contributor of greenhouse gas (GHG) emissions and much of the work on reducing GHG emissions has focused on row crops and pastures, as well as forestry and animal production systems; however, little emphasis has been placed on specialty crop industries such as horticulture. Our objective was to determine emission (efflux) patterns of CO_2, CH_4, and N_2O associated with four different nursery container sizes [3.0 L (trade gal; TG), 3.8 L (#1; 1 gal), 7.6 L (#2; 2 gal), and 11.4 L (#3; 3 gal) using dwarf yaupon holly (*Ilex vomitoria* 'Nana' L.) grown under common production practices for one year. Weekly measurements indicated that carbon dioxide (CO_2) and nitrous oxide (N_2O) effluxes were highest in the largest containers (#3). There was a significant positive relationship between container size and CO_2 efflux. Nitrous oxide efflux followed a similar pattern, except there were no differences between the two smallest container sizes. In general, CO_2 and N_2O effluxes increased with increasing temperature. Methane efflux was consistently low and had no significant effect on total trace gas efflux. Results from this study begin to address uncertainties regarding the environmental impact of the horticulture industry on climate change while providing baseline data of trace gas emissions from container production systems needed to develop future mitigation strategies.

Introduction

High concentrations of GHG are thought to be a main factor causing global warming (Dlugokencky et al., 2005; Florides and Christodoulides, 2008). Atmospheric concentrations of CO_2, CH_4, and N_2O have increased by approximately 35%, 155%, and 18%, respectively, since 1750 (Dlugokencky et al., 2005; IPCC, 2007; Keeling and Whorf, 2005; Prinn et al., 2000). Agriculture in the U.S. is a large contributor to GHG emissions, second only to energy production (Johnson et al., 2007). 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 radiative forcing from agriculture production is one third of the man-made greenhouse effect (Cole et al., 1997). Therefore, concerns for global climate change necessitate development of mitigation strategies to reduce trace gas emissions from agriculture.

Mitigation of trace gas emissions by altering agriculture production practices has been widely researched (Cole et al., 1997; Kroeze and Mosier, 2000; Lal et al., 1998; Lal, 2004; Lin et al., 1994; Paustian et al., 2000; Smith et al., 2007). Adoption of no-till agriculture (Smith et al., 1998), feed supplementation in ruminant animals (Cole et al., 1997; Lin et al., 1994), and increased efficiency of N fertilization (Kroeze and Mosier, 2000; Kroeze et al., 1999) have been shown to successfully reduce emissions of CO_2, CH_4, and N_2O, respectively.

Much of the work on reducing GHG emissions from agriculture has been conducted in row crops, forests, and animal production systems; however, virtually no research has focused on contributions from specialty crop industries such as horticulture. Horticulture is a multi-billion dollar industry which impacts the landscape of rural, suburban, and urban environments. In 2006, there were 7,300 nursery crop producers in the top 17 states, occupying approximately one-half million acres (USDA, 2007). Although horticulture production occupies much less acreage than most agronomic crops, horticulture is one of the fastest growing sectors in agriculture (Hall et al., 2005), and the impact of this industry on climate change (either positively or negatively) has not been thoroughly investigated.

Reduction of GHG from horticultural production not only provides environmental benefits, but could provide new sources of revenue for producers. Farmers in other agricultural sectors are now earning financial incentives in the emerging carbon (C) trading market and through government incentives to reduce GHG emissions (CCE, 2009; EPA, 2008; NFU, 2009; Schmidt, 2009).

Changing production practices to mitigate GHG emissions might not only provide new financial opportunities for agricultural producers, but may become required by law. Congress has been slow or hesitant to pass any major climate change bills. As a result, the U.S. Environmental Protection Agency is now beginning to regulate CO_2 and other GHG emissions, and in some cases even those from agriculture (Moore and Bruggen, 2011) which could dramatically impact production (Blanford and Josling, 2009).

Greenhouse Gas Reduction through Agricultural Carbon Enhancement network (GRACEnet) is a program initiated by the Agricultural Research Service of the USDA to identify and develop strategies that will enhance soil C sequestration, reduce GHG emissions, and provide a scientific basis for possible C credit and trading programs (Jawson et al., 2005). One of the goals of GRACEnet is to begin to establish baseline estimates of net GHG emissions from existing agricultural systems in order to explore ways to reduce these emissions. GRACEnet’s primary objectives focus on determining emissions from row crop and animal production systems. For horticulture producers to benefit from the same C trading or offset programs, baseline trace gas emissions (CO_2, N_2O, and CH_4) from current production practices must be established in order to develop strategies to reduce these emissions.

Determining GHG efflux from differing container sizes will establish both a baseline for common nursery container production practices and the relative importance of container size on these emissions. The objective of this research was to determine efflux patterns of CO_2, CH_4, and N_2O associated with different nursery container sizes under common production practices. If a direct relationship between potting media volume and trace gas efflux can be established, scaling up to industry-wide emissions levels can be accomplished using estimates of the number and size of plants produced in container nurseries (Marble et al., 2011).

Materials and Methods

This experiment was conducted at the Paterson Greenhouse Complex, Auburn University, AL. On April 1, 2010, *Ilex vomitoria* 'Nana' (dwarf yaupon holly) liners (2.5 cm) were transplanted into four different nursery container sizes: 3 L (trade gal; TG), 3.8 L (#1; 1 gal), 7.6 L (#2; 2 gal), and 11.4 L (#3; 3 gal). Containers were filled with a pinebark:sand (6:1 v:v) media (TG, #1, #2, and #3 were filled with media to a volume of 2.05, 3.15, 5.15, and 10.10 L, respectively). Media had been previously amended with 8.3 $kg \cdot m^{-3}$ of 17N-2.2P-4.2K (17-5-11) Polyon® control-release fertilizer (10-12 month), 3.0 $kg \cdot m^{-3}$ of ground dolomitic limestone, and 0.9 $kg \cdot m^{-3}$ of Micromax® micronutrient. The study used seven replicates for each container size which contained plants; there were no differences in plant size at study initiation. Three additional replications per container size contained only media and served as controls. After potting, all containers with plants were placed in full sun on a nursery container pad in a randomized complete block design and received daily overhead irrigation (1.3 cm) via impact sprinklers. Media only containers were placed directly adjacent to containers with plants on the full sun nursery container pad in a similar manner and received irrigation as described above. At the time of study initiation, an additional ten dwarf yaupon holly plants, similar in size to those used during the gas sampling portion of the study, were selected and used to determine approximate initial plant biomass. Plant growth index [(plant height + width1 + width2)/3] was measured, shoots were cut at the media surface, media was removed from roots, and shoots and roots were dried for approximately 72 hours at 55˚C in a forced-air oven and weighed. Roots and shoots were then ground separately to pass through a 0.2 mm mesh sieve. Concentrations of C and N were determined using a LECO 600-CHN analyzer (St. Joseph, MI).

Trace gases emitted from the containers were sampled *in situ* weekly for 1 year (April 1, 2010 to March 31, 2011) using the static closed chamber method (Hutchinson and Mosier, 1981; Hutchinson and Livingston, 1993). Custom-made gas efflux chambers were designed and constructed based upon criteria described in the GRACEnet protocol (Baker et al., 2003; Parkin and Kaspar, 2006) to accommodate nursery containers. A structural base consisting of polyvinyl chloride (PVC) cylinders (25.4 cm inside diameter by 38.4 cm tall) was sealed at the bottom. During gas measurements, the entire plant-pot system was placed inside the base cylinder and a vented efflux chamber (25.4 cm diameter x 11.4 cm height) was placed on top of the base cylinder. The top efflux chambers were constructed of PVC, covered with reflective tape, and contained a center sampling port. Gas samples for CO_2, CH_4, and N_2O were taken at 0, 15, 30, and 45 min intervals following chamber closure. At each time interval, gas samples (10 mL) were collected with polypropylene syringes and injected into evacuated glass vials (6 mL) fitted with butyl rubber stoppers as described by Parkin and Kaspar (2006). Corresponding air temperature data were collected for each sampling period using Hobo Portable Temperature Data Loggers (Model H08-032-08 with Solar Shield, Onset Computer Corp., Bourne, MA; Fig. 1).

Gas samples were analyzed using 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. Gas concentrations were determined by comparison with standard curves developed using gas standards obtained from Air Liquide America Specialty Gases LLC (Plumsteadville, PA). Gas effluxes were calculated from the rate of change in concentration of trace gas (CO_2, N_2O, or CH_4) in the chamber headspace during the time intervals while chambers were closed (0, 15, 30, and 45 minutes) as described by Parkin and Venterea (2010). Calculations in this study were used to express data as mg CO_2-C, µg CH_4-C, and µg N_2O-N emitted per day for each container size. Estimates of cumulative efflux were calculated from gas efflux at each sampling date integrated over time using a basic numerical integration technique (i.e., trapezoidal rule).

Upon study completion (March 31, 2011), all plants used during the gas sampling portion of the study were also measured (growth index), weighed, dried, ground, and analyzed as described above to determine C accumulation in plant biomass grown in each container size over the course of the study. Trace gas data was analyzed on each sampling date (data not shown), across all dates, and cumulatively. All trace gas and growth data were analyzed using the Proc Mixed procedure in SAS (SAS® Institute version 9.1, Cary, NC). Means were separated using Fishers Least Significance Difference Test in the Proc Mixed procedure. In all cases, differences were considered significant at $p \leq 0.05$. Linear correlations between temperature and CO_2 efflux were calculated using the Proc Corr procedure in SAS and were considered significant at $p \leq 0.05$.

Results

Weekly trace gas emissions indicated a significant positive relationship between container size (with plants) and CO_2 efflux, with efflux increasing as container size increased (Fig. 2). On 30 of the 50 sampling dates, #3 containers had higher efflux than any other container size (data not shown). This pattern was also observed when cumulative CO_2 efflux was calculated over the course of one year (Table 1). Additionally, on 13 sampling dates (with plants), #2 containers had higher efflux than #1 or TG containers (data not shown). Heterotrophic respiration from decomposition of larger quantities of growth media likely resulted in greater CO_2 loss and thus higher efflux rates from these containers. Efflux from media-only containers showed that the pinebark media accounted for an estimated 30%, 34%, 41% and 47% of yearly cumulative efflux from the TG, #1, #2, and #3 containers, respectively. Similarly to patterns observed in containers with plants (Fig. 2; Table 1), emissions from media only containers indicated a significant positive relationship between container size and CO_2 efflux, with efflux increasing as container size increased (Fig. 3; Table 1). Higher levels of plant respiration from the larger plants in the #3 containers (Table 2) resulted in greater CO_2 loss, especially during the growing season (Fig. 2). In addition to effects of container size, there was a positive linear correlation between CO_2 efflux and temperature ($p \leq 0.0001$, $R^2=0.29$). Carbon dioxide efflux was consistently highest during late spring and summer months when larger differences in efflux among container sizes were observed (Fig. 2 and 3). Carbon dioxide efflux has been shown to be highly dependent upon temperature and water content (Fang and Moncrieff, 2001); while water content was not monitored in this study, container moisture levels were uniform due to daily controlled irrigation.

Mean N_2O efflux (with plants), averaged over the course of the study, was highest in #3 containers, followed by #2 containers, with no difference among the other two container sizes (Fig. 4). Yearly cumulative N_2O efflux also showed that most N_2O was lost in #3 containers (Table 1). Over the course of the study, #3 containers had higher N_2O efflux than all other containers on 32 of the 50 sampling dates (data not shown). Because fertilizer was incorporated into the media prior to planting on a volume basis, larger containers had more fertilizer than smaller containers, likely causing a higher N_2O efflux. Further, all plants were similar in size at the beginning of the study and less fertilizer could be utilized by the plant in the larger containers, resulting in higher losses via N_2O efflux. This is further illustrated by observing N_2O efflux from media only containers (Fig. 5). As expected, N_2O efflux was higher in media only containers (Fig. 5; Table 1) than efflux observed in containers with plants (Fig. 4; Table 1), but followed the same general trends. Wagner-Riddle et al. (1994) showed that N_2O emissions will be reduced in agricultural soils when farmers avoid fallowing, and a new crop is planted as soon as possible after plowing to increase plant N use; this concept seems to be applicable to container plant production.

Nitrous oxide emissions increased dramatically in May, 2010 and remained high through July of the same year before leveling off in late summer (Figs. 4 and 5). This is likely because the release rate of the controlled-release fertilizer used in this study is highly dependent upon soil temperature, which may have caused higher N_2O effluxes during warmer months. However, no increases in N_2O efflux was observed in 2011 (Figs. 4 and 5) as most of the fertilizer (10-12 month formulation) was likely utilized or leached as soluble nitrate.

Methane efflux was consistently low in all containers for the duration of study (data not shown). Yearly cumulative CH_4 efflux showed no differences regardless of container size, with or without plants (Table 1). It is likely these values were close to or below the detection limits of the gas chromatograph. Previous work has shown that CH_4 efflux in non-saturated soils are generally small (Robertson et al., 2000) and so it is not surprising, given the media was well drained, the anaerobic conditions needed for CH_4 are not common in well-managed container production systems. Based on results from this study, CH_4 efflux does not appear to have a significant effect on total trace gas emissions from container-grown nursery crops.

Discussion

Our results showed that both CO_2 and N_2O efflux were greatest in the largest containers, while CH_4 efflux was low regardless of container size. While CO_2 and N_2O efflux was higher in larger containers, smaller containers would likely have higher emissions on a per acre basis. For example on a 0.4 ha production bed, #3 gallon containers spaced 15 cm apart (about 26,000 plants) would have approximately half (50 kg) of the cumulative CO_2-C efflux (Table 1) of TG containers (96 kg of CO_2-C efflux) spaced 5 cm apart (about 98,000 plants) over the span of 1 year. Therefore, while trace gas emissions increased with increasing container size, a larger number of smaller containers will likely have higher efflux than a lower number of larger containers in a given area of production space. Further, data indicate that trace gas emissions from container nursery production may be higher (for a given area of production) than from soils in row crop production systems (Collins et al., 2008). However, nursery production acreage is much smaller than that used for agronomic crops. For example, approximately 90 million acres of corn were harvested in the U.S. in 2007, compared with approximately 0.5 million acres of nursery stock (NASS, 2009). Thus, the nursery industry is likely producing only a fraction of total GHG emissions produced from agronomic production.

It is important to note that our container trace gas efflux data do not necessarily reflect net emissions as they do not account for C sequestered in growing biomass. Foliar analysis (Table 2) showed that 18.6, 32.3, 35.3, and 42.4 g C were contained within holly biomass (roots and shoots) grown in TG, #1, #2, and #3, respectively. Further, container nursery systems may contribute to C sequestration by placing large amounts of C-rich growing media belowground when plants are transplanted into the landscape (Marble et al., 2010). Average dry weight of pinebark in media only containers was 769.5, 1160.1, 1810.2, and 3315.7 g in the TG, #1, #2, and #3, respectively. Using a C percentage of 49.2% (previously determined using analysis methods described above) for the pinebark media used in this study, estimated C stored underground following landscape transplanting would be approximately 378.6, 570.8, 890.6, and 1631.3 g for the TG, #1, #2, and #3 containers, respectively. Subtracting cumulative CO_2-C efflux (Table 1) from the total C stored in biomass and media (i.e., following landscape outplanting) would result in a net C gain (in biomass and media) of 396.3, 601.6, 924.3, and 1671.8 g from the TG, #1, #2, and #3 containers, respectively. However, the longevity of this C storage is still unknown. The life span and growth rate of nursery crops will vary greatly depending on species and environment, and no long term studies have investigated the longevity of the pinebark media after being placed underground in the landscape. While our data suggest a net C gain from nursery container production, this storage may only be realized in the short term as longevity of this storage potential requires further investigation.

While high N_2O levels were observed at times, it is likely only a fraction of total N was lost via N_2O. Cumulative N_2O efflux from containers with plants (Table 1) indicates that approximately 0.6, 0.9, 2.0, and 5.4 mg of N were lost via N_2O over the course of the study in the TG, #1, #2, and #3 containers, respectfully. Considering the amount of N applied at potting (approximately 3, 5, 7, and 14 g N in the TG, #1, #2, and #3 containers, respectfully) most N was either used by the plant or more likely lost via leaching. Although not measured in this study, it appears that N leaching is likely more of an environmental concern in container production than N_2O emissions.

Data presented here indicate that container production of a typical woody nursery crop using common production practices would likely be a net C sink while in production and after being planted into the landscape. The benefits of this sink will be dependent on the longevity of the media and the rate of plant biomass accumulation over time. Further investigation is needed to determine the impact of different production variables (e.g., growing media, fertilization and irrigation practices, and other plant species) on trace gas emissions. While uncertainty remains regarding the overall impact of the nursery industry on climate change, results from this study begin to determine the overall environmental impact of the container nursery industry and provide baseline data of trace gas emissions from container-nursery production systems needed to evaluate future mitigation strategies.

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Table 1. Cumulative CO$_2$, CH$_4$, and N$_2$O gas efflux over 1 year from container production of woody nursery crops.

		Efflux (plants and media)[z]		
Container size	**Volume (L)[y]**	**CO$_2$-C (mg)**	**N$_2$O-N (µg)**	**CH$_4$ (µg)**
Trade gal. (TG)	2.05	983.35 d A[x]	593.54 c B	-39.35 a A
1 gal. (#1)	3.15	1191.00 c A	866.91 bc B	1.57 a A
2 gal. (#2)	5.15	1516.88 b A	1991.41 b B	-15.06 a A
3 gal. (#3)	10.10	1910.69 a A	5461.76 a B	27.65 a A
		Efflux (media only)[w]		
Container size	**Volume (L)**	**CO$_2$-C (mg)**	**N$_2$O-N (µg)**	**CH$_4$ (µg)**
Trade gal. (TG)	2.05	297.62 d B	2929.97 c A	-23.42 a A
1 gal. (#1)	3.15	407.89 c B	3098.34 c A	-24.68 a A
2 gal. (#2)	5.15	615.09 b B	5972.01 b A	-25.62 a A
3 gal. (#3)	10.10	888.39 a B	11712.00 a A	11.78 a A

[z] Containers measured with plants and media contained dwarf yaupon hollies (*Ilex vomitoria* 'Nana') in each container size listed (n=7).Containers were filled with a pinebark:sand (6:1 v:v) media previously amended with Polyon 17-5-11 (8.3 kg m^{-3}), dolomitic limestone (3.0 kg m^{-3}), and Micromax (0.9 kg m^{-3}). Cumulative efflux for 1 year (April 1, 2010 to March 31, 2011) was calculated a basic numerical integration technique (i.e., trapezoidal rule).

[y] Container volumes show the amount of substrate [pinebark: sand (6:1 v:v)] contained in each container size.

[x] Means were separated using Fishers Least Significance Difference Test in the Proc Mixed procedure ($p \leq 0.05$). Lower case letters show mean separation within each container size; containers with plants and media and media only containers were analyzed separately. Upper case letters show mean separation comparing efflux of containers with plants and media to media only containers.

[w] Media only containers were filled with pinebark:sand media described above (n=3).

Table 2. Biomass and carbon and nitrogen content of dwarf yaupon holly shoots and roots[z].

		Shoots			Roots			Total
Container size	**Volume (L)[y]**	Dry wt. (g)	C %	N %	Dry wt. (g)	C %	N %	Dry wt. (g)
Trade gal. (TG)	2.05	22.5 c	50.6 a	2.0 ab	14.7 c	49.2 a	1.9 c	37.2 c
1 gal. (#1)	3.15	42.6 b	50.4 ab	1.9 b	22.1 b	49.2 a	1.8 c	64.7 b
2 gal. (#2)	5.15	47.7 b	50.2 b	2.2 a	23.0 b	49.3 a	2.2 b	70.7 ab
3 gal. (#3)	10.10	55.3 a	50.2 b	2.2 a	30.3 a	49.0 a	2.4 a	85.6 a

[z] Holly shoots show the carbon and nitrogen content of all above ground plant material (leaves, stems, branches). Holly roots show the carbon and nitrogen content of belowground plant material (roots only). Total = sum shoots and roots

[y] Container volumes show the amount of substrate [pinebark: sand (6:1 v:v)] contained in each container size.

[x] Means were separated using Fishers Least Significance Difference Test in the Proc Mixed procedure ($p \leq 0.05$).

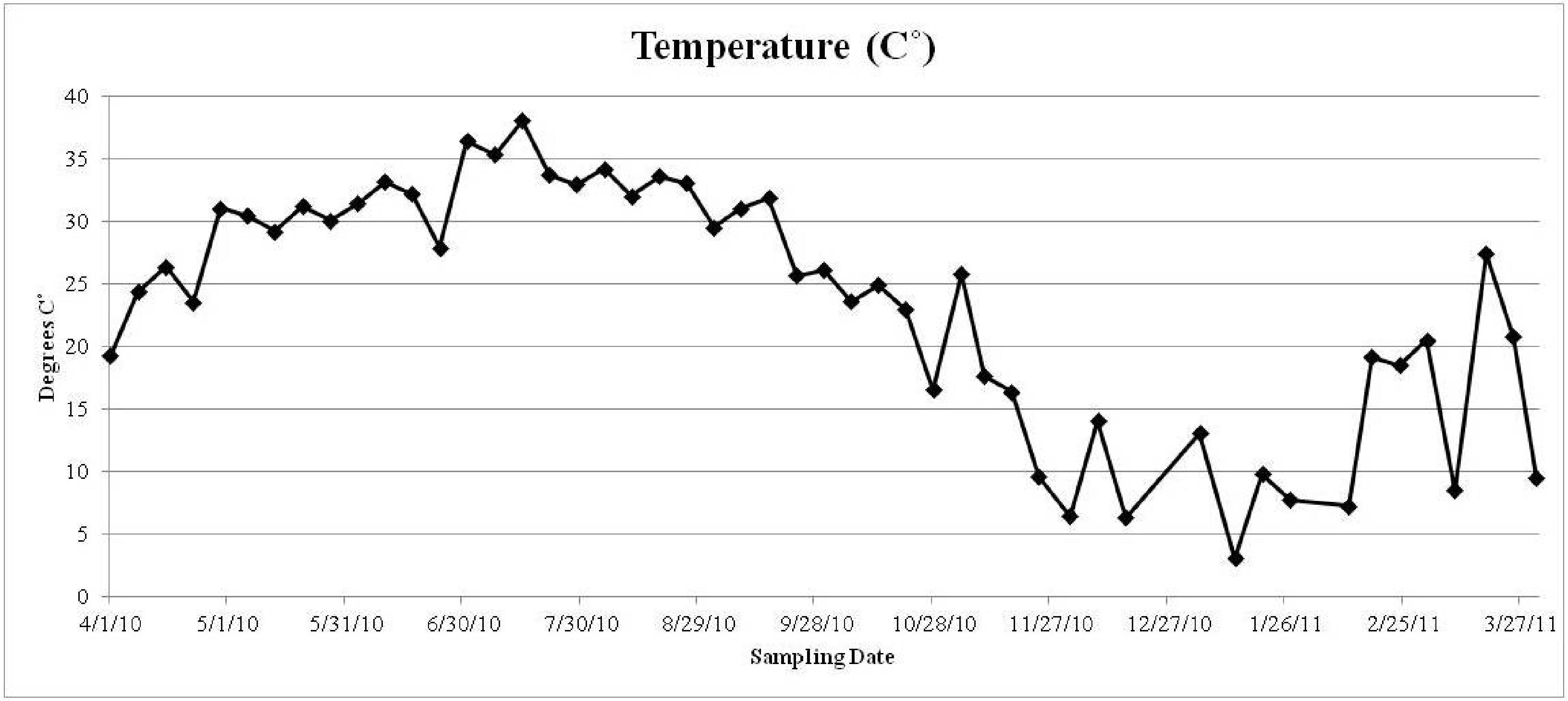

Fig. 1. Temperature during gas sampling.

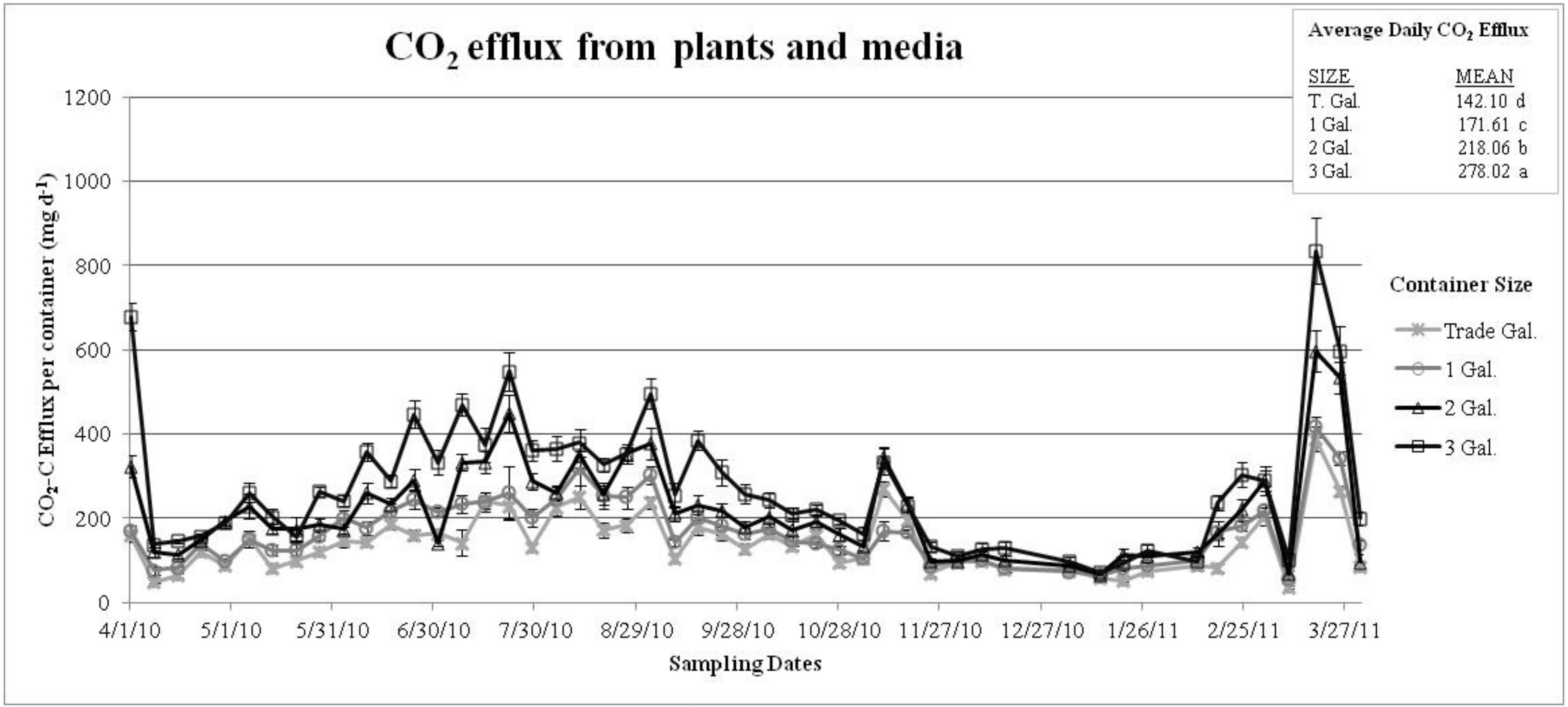

Fig. 2. Mean and standard error of CO_2-C efflux (mg d^{-1}) for dwarf yaupon holly grown in four container sizes over one year (April 1, 2010 - March 31, 2011). The insert shows average daily efflux (means followed by the same letter are not significantly different from each other, $p \leq 0.05$).

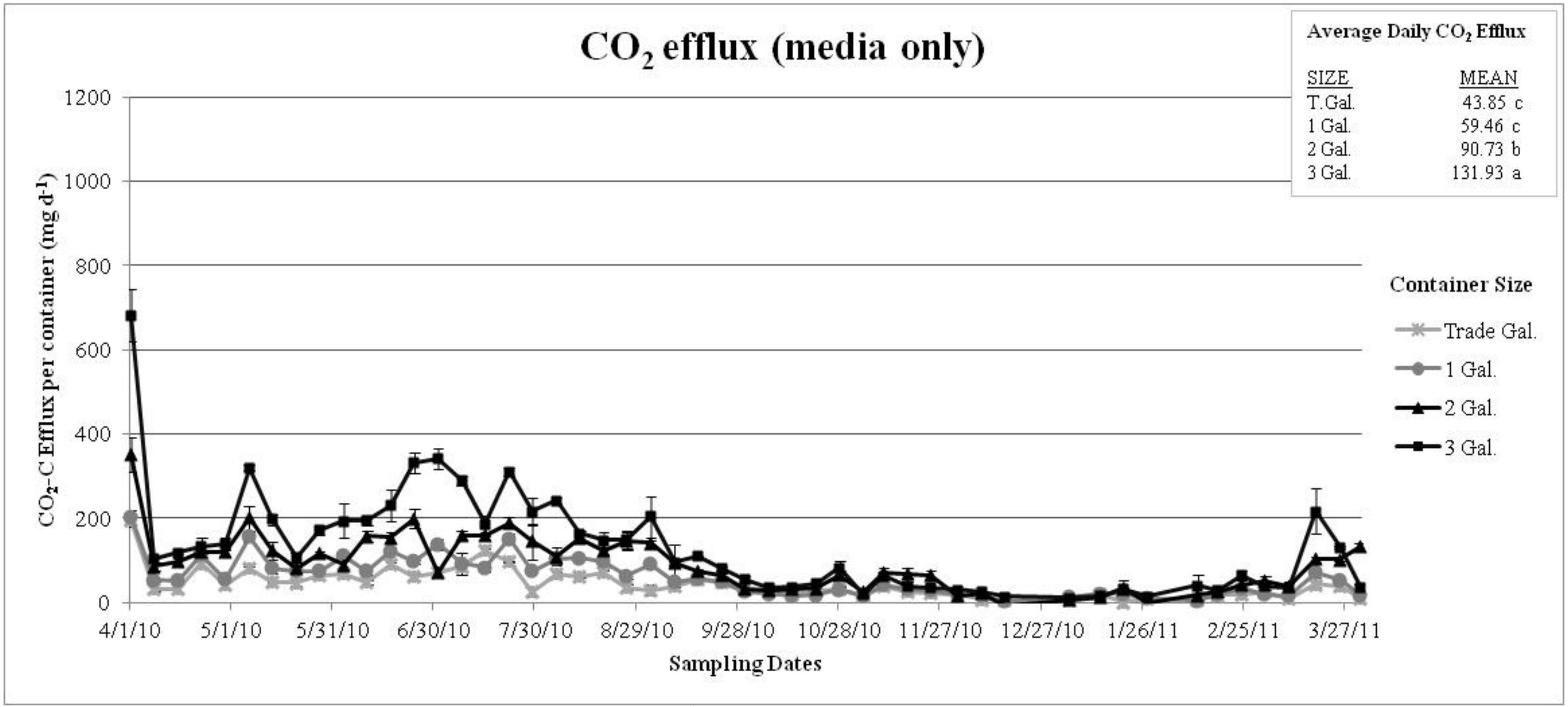

Fig. 3. Mean and standard error of CO$_2$-C efflux (mg d^{-1}) from four container sizes (media only) over one year (April 1, 2010 - March 31, 2011). The insert shows average daily efflux (means followed by the same letter are not significantly different from each other, $p \leq 0.05$).

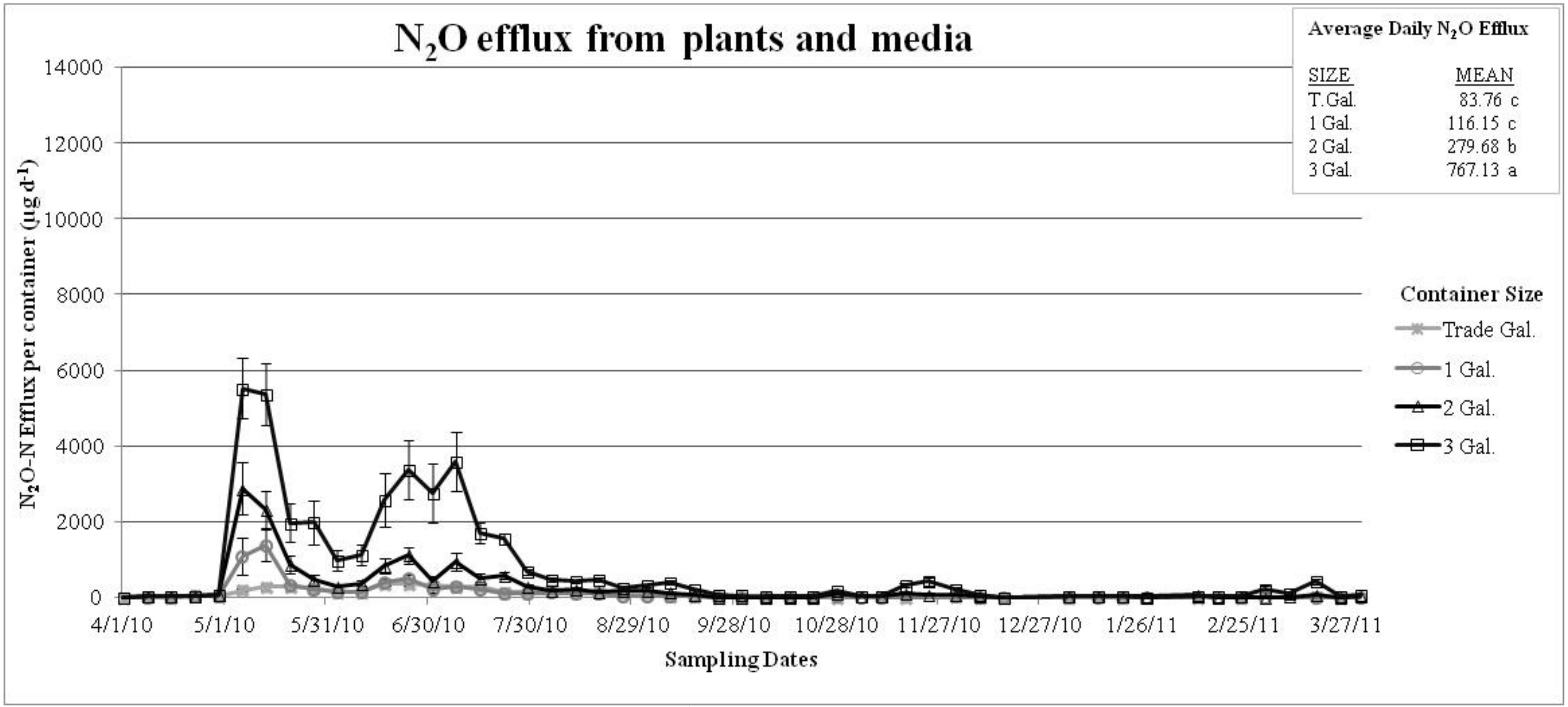

Fig. 4. Mean and standard error of N$_2$O-N efflux (µg d^{-1}) for dwarf yaupon holly grown in four container sizes over one year (April 1, 2010 - March 31, 2011). The insert shows average daily efflux (means followed by the same letter are not significantly different from each other, $p \leq 0.05$).

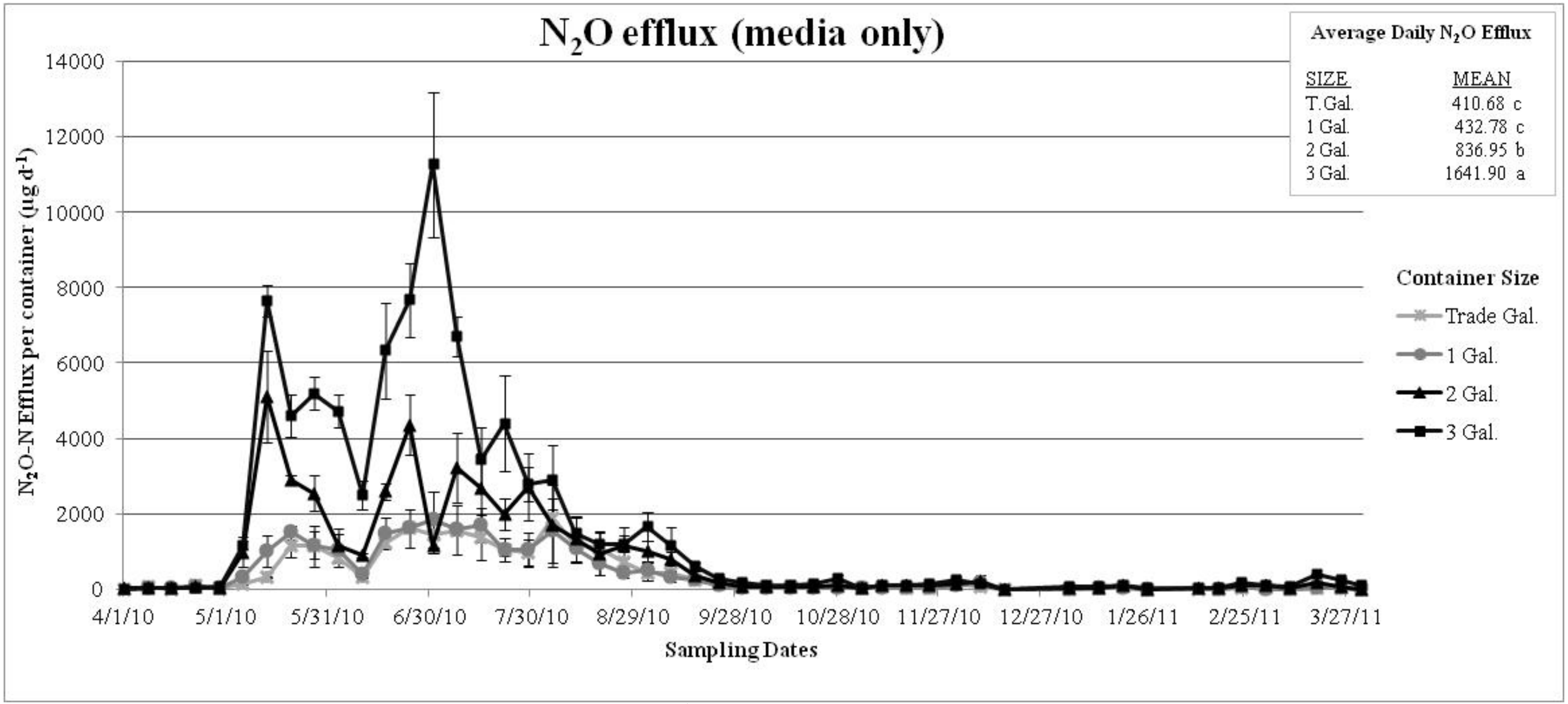

Fig. 5. Mean and standard error of N_2O-N efflux ($\mu g\ d^{-1}$) from four container sizes (media only) over one year (April 1, 2010 - March 31, 2011). The insert shows average daily efflux (means followed by the same letter are not significantly different from different from each other, $p \leq 0.05$).

CHAPTER IV

Effects of Fertilizer Placement on Trace Gas Emissions from Nursery Container Production

Abstract

Increased trace gas emissions (or efflux) of carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O) are widely believed to be a primary cause of global warming. Agriculture is a large contributor to these emissions; however, its role in climate change is unique in that it can act as a source of trace gas emissions or it can act as a major sink. Furthermore, agriculture can significantly reduce emissions through changes in production management practices. Much of the research on agriculture's role in mitigation of greenhouse gas (GHG) emissions has been conducted in row crops and pastures, as well as forestry and animal production systems with little focus on contributions from specialty crop industries such as horticulture. Our objective was to determine efflux patterns of CO_2, CH_4, and N_2O associated with three different fertilization methods (dibble, incorporated, and topdressed) commonly used in nursery container production. Weekly measurements indicated that CO_2 efflux was slightly lower when fertilizer was dibbled compared to the other two methods. Nitrous oxide fluxes were consistently highest when fertilizer was incorporated. Methane flux was generally low with few differences among treatments. Results from this study begin to provide data which can be used to implement mitigation strategies in container plant production which will help growers adapt to possible emission regulations and benefit from future GHG mitigation or offset programs.

Introduction

Over the past several decades global warming has received increased attention from the scientific community including possible impacts of increased temperature on the global environment. Anthropogenically enhanced climate change is still highly debatable. However, emissions of the three most important long-lived greenhouse gases (GHG) [carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O)] are known to have substantially increased in the past quarter-century (Dlugokencky et al., 2005; Keeling and Whorf, 2005; Prinn et al., 2000). Experts in almost every industry are searching for ways to reduce GHG emissions and lessen their respective carbon (C) footprint.

One area of particular interest in GHG mitigation research is agricultural production. Agriculture occupies 37% of the earth's land surface producing ~20% of total GHG emissions (Cole et al., 1997; Smith et al., 2008). High levels of CO_2 are emitted from agricultural production primarily through land use changes (deforestation), fossil fuel use, biomass burning, and soil disturbance accounting for 33% of total C emissions between 1850 and 1998, exceeding all other anthropogenic activities besides energy production (Houghton, 2003; IPCC, 2007; Johnson et al., 2007; Watson et al., 2000). Agricultural production is the largest contributor of anthropogenic CH_4 and N_2O emissions accounting for 52% and 84%, respectively, of annual anthropogenic global emissions (Smith et al., 2008). The major sources of CH_4 production from agriculture include enteric fermentation in ruminant animals, flooded rice fields, biomass burning, and manure management and storage (Cole et al., 1997; Johnson et al., 1993; USDA, 2008). Nitrous oxide emissions are a direct result of increased use of synthetic fertilizers and production of legumes, resulting in 80% of the total N_2O emissions in the United States (Mosier et al., 2003).

Agriculture production is unique compared with other industries in that it can act as a GHG source, but can also act as a sink for GHG through changes in production management. Increased C storage through conservation or “no-till” has been shown to maintain or increase soil C levels and reduce fossil fuel use (Paustian et al., 1997; Reicosky et al., 1999; Smith et al., 1998). Methane emissions have been shown to be greatly reduced by adding feed supplementation to the diets of ruminant animals and by proper manure handling (Cole et al., 1997; Leng, 1991; Lin et al., 1994; Safley et al., 1992). Nitrous oxide emissions can be reduced by improving nitrogen (N) use efficiency (Kroeze et al., 1999; Kroeze and Mosier, 2000). Proper N fertilization timing (Weier et al., 1993) and placement (Oenema et al., 2001; Youngdahl et al., 1986) have also been shown to successfully reduce total N loss.

Several best management practices have been developed for reducing emissions of CO_2 (Paustian et al., 2000), CH_4 (Mosier et al., 1998), and N_2O (Snyder et al., 2007) from agricultural production. Other programs such as Greenhouse Gas Reduction through Agricultural Carbon Enhancement network (GRACEnet) have also been initiated by USDA-ARS to focus on reducing GHG emissions by altering current agricultural production practices. Past research has focused predominately on agronomic, forestry, and animal production systems, with little attention given to specialty industries such as horticulture. The green industry (nursery, greenhouse, and sod production) is one of the fastest growing sectors in agriculture (Hall et al., 2005); however, almost no research has focused on the impacts of this industry on GHG emissions.

Providing best management options for reducing GHG would not only reduce the environmental impact of the industry, but could benefit growers financially. There are now government and industry programs which provide tax incentives and payments to encourage farmers to reduce emissions and provide C offsets by altering current production practices (CCE, 2009; EPA, 2009; NFU, 2009; Schmidt, 2009). There is also speculation that agricultural GHG emissions could be "capped" or taxed in the future (Adams, 2009; Blanford and Josling, 2009; Moore and Bruggen, 2011). There is a need to develop mitigation strategies for nursery production practices to help growers adapt to possible future legislation and benefit from C trading or offset programs.

One method of GHG mitigation which has been previously investigated is fertilizer placement in agricultural soils (Breitenbeck and Bremner, 1986; CAST, 2004; Engel et al., 2009; Hosen et al., 2000; Liu et al., 2006; Millar et al., 2010; Mosier et al., 1996; Prasertsak et al., 2002; Stefanson, 1976). Placement of fertilizers into the soil and near the zone of active root uptake may reduce N loss from leaching and increase plant N use efficiency, which would reduce the amount of N that could be lost via N_2O emissions (CAST, 2004). Concentrated N placement of urea fertilizer in agricultural soils using a band or nest placement has been shown to increase N_2O production when compared to a broadcasted application, due in part to higher soil N accumulations (Engel et al., 2009). Breitenbeck and Bremner (1986) reported that following injection of anhydrous ammonia fertilizer, N_2O production increased with injection depth, while in contrast, Stefanson (1976) and Hosen (et al., 2000) reported that emission rate of N_2O did not change with depth of fertilizer application.

Although less studied, fertilizer placement could also affect CO_2 and CH_4 emissions by impacting plant growth. In agricultural soils, CO_2 is primarily produced from oxidation of soil organic materials by heterotrophic microorganisms and the respiration of plant roots while CH_4 is produced under anaerobic conditions by microbial decomposition of organic materials (Yamulki and Jarvis, 2002). Fertilizer placement has been shown to affect shoot and root growth of container-grown nursery crops (Altland et al., 2004) which could indirectly impact net GHG emissions as increased crop growth will sequester more C in growing biomass. In a study by Liu et al. (2006), deep N placement (10-15 cm) resulted in lower N_2O emissions compared with shallow N placement (0-5 cm), although CO_2 and CH_4 emissions were not affected by N placement depth.

Due to lack of a general conclusion regarding the affect of N placement on GHG emissions, Mosier et al. (1996) concluded that the diverse combinations of physical and biological factors which control gas fluxes is likely the cause of the conflicting results seen in previously published literature. Smith et al. (1997) also concluded that emission rates from different placements will likely vary from one system to another because of complex interactions of soil, crop, and environmental factors which must be taken into account. The same could be said for fertilizer type or formulation, which has also yielded conflicting results depending upon the production system being evaluated (Snyder et al., 2009). While fertilization placement has been shown to effect emission rates, individual production systems will likely have varying results and different mitigation strategies may need to be developed for different production systems. Previous work has focused on agronomic crops; however, it is important to also understand how fertilizer placement will affect emissions in specialty crop industries such as horticulture. Therefore, the objective of this study was to determine the effects of fertilizer placement on CO_2, CH_4, and N_2O emissions from container production of a woody nursery crop.

Materials and Methods

This experiment was initiated at the Paterson Greenhouse Complex, Auburn University, AL. On May 17, 2011, *Azalea× hybrid* ‘Gumpo White’ (white gumpo azaleas) that were ~15 cm in height with a 10 cm canopy width were transplanted from 72 cell-pack liners (2.5 cm) into 3.8 L containers; enough transplants were obtained to ensure there were no differences in plant size among treatments at study initiation. Containers were filled with a pinebark:sand (6:1 v:v) media which had been previously amended with 3.0 $kg \cdot m^{-3}$ of ground dolomitic limestone and 0.9 $kg \cdot m^{-3}$ of Micromax® micronutrient (The Scotts Company, LLC, Marysville, OH). Polyon® (Harrell's LLC, Lakeland, FL) 17N-2.2P-4.2K (17-5-11) control-release fertilizer (10-12 month) was applied at potting at a rate of 25 g per container using the three different methods described by Altland et al. (2004): dibble; incorporation; and topdressing. Dibbled fertilizer was placed immediately beneath the root ball of azalea transplants (8 cm below the container media surface). Incorporated fertilizer was premixed into the pinebark media just prior to potting. Topdressed fertilizer was placed on the container surface immediately after potting. An additional treatment received only incorporated lime and Micromax® amendments with no other fertilization. The study used seven replicates for each fertilizer placement treatment with plants and three additional replications per treatment with media only. After potting, all containers with plants were placed in a retractable roof shade structure in a randomized complete block design and received daily overhead irrigation (1.3 cm). Media only containers were placed adjacent to containers with plants in the retractable roof shade structure in a similar manner. At the time of study initiation, an additional ten gumpo azaleas, similar in size to those used in the study, were used to determine initial plant biomass. Plant growth index [(plant height + width1 + width2)/3] was measured at the beginning of the study (19 May 2011) at three months after planting (18 Aug. 2011) and at study conclusion (30 Nov. 2011). At the conclusion of the study shoots were cut at the media surface, media was removed from roots, and shoots and roots were dried for approximately 72 hours at 55˚C in a forced-air oven before weighing. Roots and shoots were then ground separately to pass through a 0.2-mm mesh sieve. Concentrations of C and N were determined using a LECO 600-CHN analyzer (LECO Corp., St. Joseph, MI).

Trace gases emitted from the containers were sampled *in situ* weekly for 6 months (May 17 to November 17) using the static closed chamber method (Hutchinson and Livingston, 1993; Hutchinson and Mosier, 1981). Custom-made gas flux chambers were designed and constructed based upon criteria described in the GRACEnet protocol (Baker et al., 2003; Parkin and Kaspar, 2006) to accommodate nursery containers rather than field plot studies. A structural base consisting of polyvinyl chloride (PVC) cylinders (25.4 cm inside diameter by 38.4 cm tall) was sealed at the bottom. During gas measurements, the entire plant-pot system was placed inside the base cylinder and a vented flux chamber (25.4 cm diameter by 11.4 cm height) was placed on top of the base cylinder. Top flux chambers were constructed with PVC, covered with reflective tape, and contained a center sampling port. Gas samples were taken at 0, 15, 30, and 45 min intervals following chamber closure. At each time interval, gas samples (10 mL) were collected with polypropylene syringes and injected into evacuated glass vials (6 mL) fitted with butyl rubber stoppers as described by Parkin and Kaspar (2006). Corresponding air temperature data were collected for each sampling period using Hobo Portable Temperature Data Loggers (Model H08-032-08 with Solar Shield, Onset Computer Corp., Bourne, MA). Although container media moisture levels were not measured during this study, gas samples were collected in the morning prior to any irrigation event (with the exception of uncontrollable weather events) allowing container moisture levels to equilibrate prior to sampling.

Gas samples were analyzed using 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. Gas concentrations were determined by comparison with standard curves developed using gas standards obtained from Air Liquide America Specialty Gases LLC (Plumsteadville, PA). Gas fluxes were calculated from the rate of change in concentration of trace gas (CO_2, N_2O, or CH_4) in the chamber headspace during the time intervals while chambers were closed (0, 15, 30, and 45 minutes) as described by Parkin and Venterea (2010). Calculations in this study were used to express data as mg CO_2-C, µg CH_4-C, and µg N_2O-N trace gas per day. Estimates of cumulative efflux were calculated from gas efflux at each sampling date integrated over time using a basic numerical integration technique (i.e., trapezoidal rule; Yeh, 1991).

Upon study completion, all plants were measured and destructively harvested as described above for determination of C accumulation in plant biomass. Trace gas data were analyzed on each individual sampling date (data not shown), across all dates, and cumulatively. All trace gas and growth data were analyzed using the Proc Mixed procedure in SAS (SAS® Institute version 9.1, Cary, NC). Means were separated using Fishers Least Significance Difference Test in the Proc Mixed procedure. In all cases, differences were considered significant at $p \leq 0.05$.

Results

Average daily trace gas efflux from containers with plants indicated that CO_2-C efflux was lower in the dibble treatment (160.16 mg CO_2-C d^{-1}) when compared to incorporated or topdressed treatments (193.59 and 192.58 mg CO_2-C d^{-1}, respectively); all fertilized treatments had higher values than the non-fertilized containers (Fig. 1)**.** The incorporated treatment had higher CO_2-C efflux than any other treatment on 10 of the 29 sampling dates, while the topdressed treatment was highest on 6 dates (data not shown). Efflux from the dibble treatment was lower than incorporated or topdressed on 9 dates and had similar values to the non-fertilized treatment on four dates (data not shown); this pattern was also observed for cumulative CO_2-C losses (Table 1). Average daily efflux from media-only containers showed dibble and incorporated treatments had lower CO_2-C efflux (86.73 and 87.84 mg CO_2-C d^{-1}, respectively) than the topdressed treatment (118.96 mg CO_2-C d^{-1}) (Fig. 2); this pattern was also seen for cumulative efflux (Table 2).

Average N_2O efflux (with plants) was highest in the incorporated treatment (489.02 µ N_2O-N d^{-1}), with no differences observed between dibble and topdressed treatments (156.82 and 148.96 µg N_2O-N d^{-1}, respectively; Fig 3); all placement treatments had significantly higher N_2O-N efflux than the non-fertilized containers. Cumulative N_2O efflux also illustrated that more N_2O-N was lost from the incorporated treatment (Table 1). On 15 of the 29 dates, the incorporated treatment had a higher N_2O-N efflux than any other treatment (data not shown). Efflux from the media only containers followed similar trends (Fig. 4; Table 2) except that a much higher efflux was observed when no plants were present.

Methane efflux patterns were inconsistent (both with and without plants) but remained relatively low in all treatments for most of the study with no differences observed in daily averages among treatments (Figs. 5 and 6). Cumulative CH_4 efflux (with plants) showed the lowest value in the dibble treatment and the highest value in the non-fertilized treatment, with other treatments showing no significant difference (Table 1). No differences were observed in cumulative CH_4 efflux among media-only containers (Table 2). On many sampling dates, it is likely CH_4 efflux values were close to or below the detection limits of the gas chromatograph.

Gumpo azalea root and shoot dry weights did not differ among fertilizer placements at termination of the study; all were higher than the non-fertilized treatment (Table 3). Shoot C followed this same pattern. However, root C was lowest in the topdress treatment and highest in the non-fertilized treatment. Shoot N was higher in all treatments compared with the non-fertilized treatment and was higher in the incorporated treatment than the other placements; root N followed this same pattern.

Discussion

Lower CO_2-C efflux in the media only non-fertilized treatment must be due to lower heterotrophic respiration, likely attributable to N limitation in the microbial populations. Lower efflux in the non-fertilized treatment (with plants) was likely due to a combination of lower heterotrophic respiration and lower autotrophic respiration due to smaller plant size. Higher CO_2-C efflux for the topdressed treatment (media only) compared with the other treatments may be due to stimulation of the microbial populations near the media surface where the topdressed fertilizer was placed. Lower efflux for the dibble treatment (with plants) compared with the other placements may be due to patterns of root growth impacting autotrophic respiration. Altland et al. (2004) has shown that dibble placement of fertilizer can slightly reduce root growth of container grown crops. Further, growth index taken about half-way through the study (data not shown) indicated plants receiving dibble treatment were slightly smaller. Other studies using nursery crops have reported variable growth responses to fertilizer placement. Meadows and Fuller (1983) showed that dibble application of a controlled release fertilizer resulted in better growth of four azalea cultivars and two holly cultivars than when fertilizers were incorporated. Meadows and Fuller (1984) showed different results in a later study in which surface application or topdressing resulted in better growth of three azalea cultivars than dibble application. Cobb and Holt (1984) also showed that topdressing with a sulfur coated urea fertilizer increased growth of woody nursery crops when compared to dibbling or incorporating fertilizers. Our results demonstrate that plant growth was similar among all fertilization treatments at the conclusion of the study, but dibble fertilizer placement reduced CO_2-C losses in azalea container production.

Nitrous oxide emissions were generally higher in media only containers. When no plants were present to utilize N before it is emitted as N_2O, a much higher N_2O efflux can be expected (Wagner-Riddle et al., 1994). Nitrous oxide emissions were consistently higher when fertilizer was incorporated. There are two possible explanations as to why efflux from the incorporation treatment was much higher than that observed from dibble or topdressed treatments. As fertilizer was placed closer to roots in the dibble treatment, the plant was likely able to utilize the fertilizer more efficiently, especially at earlier dates when plant roots were small and localized which has been shown to reduce N_2O emissions (CAST, 2004). However, dibble placement did not appear to increase plant growth or N concentration when compared to other fertilization placements. Secondly, the controlled release fertilizer used has a release rate that is highly dependent upon temperature and moisture. The incorporation treatment had much greater contact with media (and subsequently moisture) than the topdressed treatment, and likely had a faster release rate. A faster release rate from the incorporated treatment also likely caused the higher N in azalea shoots and roots; however, this higher N did not result in plant growth differences (Table 3). In fact, all fertilized plants had N concentrations within the recommended sufficiency range (Mills and Jones, 1996). Previous investigations examining the effects of fertilizer placement on GHG emissions from agriculture have shown inconsistent results (Millar et al., 2010). For example, Liu et al. (2006) showed deep (10 - 15 cm) N placement resulted in a reduction of up to 70% in N_2O loss when compared to a shallow placement (5 cm), while Drury et al. (2008) showed N_2O

efflux increased 26% with deep injection (10 cm) compared with a shallow (2 cm) injection. Based on our results (using a controlled-release product), it is appears that incorporating fertilizer significantly increased N_2O efflux compared with the other two methods.

While CH_4 was produced at times in this study, efflux was generally low and differences among treatments were only observed when plants were included. Previous work has shown that CH_4 efflux from dry or well drained soils are generally small compared with saturated soils (Bharati et al., 2001; Robertson et al., 2000). Because the media used in this study was well drained, the anaerobic conditions needed for methane production were likely infrequent. Methane is generally thought to contribute significantly to the atmospheric pool from agriculture via enteric fermentation in ruminant animals, rice production, and manure handling (Cole et al., 1997). Based on results from this study, CH_4 efflux does not appear to have a significant effect on total trace gas emissions from container-grown nursery crops.

Results from this study indicate that dibbling fertilizer may reduce total trace gas emissions (CO_2, CH_4, and N_2O collectively) from container-production systems. When plants were included (as in a nursery production setting) dibbling reduced CO_2 emissions compared with incorporation and topdressed treatments while plant growth was statistically similar at the conclusion of the study. Dibbling and topdressing also significantly reduced N_2O emissions (68 and 70%, respectively) compared to the incorporated treatment. While dibbling also resulted in lower CH_4 emissions than topdressed treatments, the fact that CH_4 efflux was low in all treatments, indicate that CH_4 is not a trace gas of concern from container production systems regardless of the fertilization method employed. Further work is needed to determine the impact of different production variables on trace gas emissions from container plant production. However, results from this study begin to provide evidence of mitigation strategies which can be implemented in container plant production to help growers benefit from carbon offset programs, adapt to future legislation, and improve the environmental impact from container plant production without negatively affecting crop growth.

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Table 1. Cumulative CO_2 CH_4, and N_2O efflux over 6 months from container-grown woody nursery crops[z] using three different fertilization placements.

Fertilizer placement[y]	**Cumulative Efflux**		
	CO_2-C (mg)	**N_2O-N (µg)**	**CH_4 (µg)**
Dibble	651.80 b	602.62 b	-3.82 c
Incorporate	785.93 a	1883.84 a	21.70 bc
Topdress	781.45 a	572.27 b	56.16 ab
Non-fertilized	325.19 c	21.09 c	76.42 a

[z] Containers measured contained white gumpo azaleas (*Azalea* × *hybrida* 'gumpo') potted into a pinebark: sand (6:1 v:v) media. Cumulative efflux for 6 months (May 17-Nov. 17, 2011) was calculated using the trapezoid rule (n=7).

[y] The same fertilizer rate (25 g of product (Polyon® 17-5-11 per 3 L container) was used for all placement treatments with the exception of non-fertilized pots which received no Polyon® fertilizer. Media in all treatments was amended with dolomitic limestone (3.0 kg m^{-3}), and Micromax® (0.9 kg m^{-3}).

[x] Means were separated using Fishers Least Significance Difference Test in the Proc Mixed procedure ($p \leq 0.05$).

Table 2. Cumulative CO_2 CH_4, and N_2O efflux over 6 months from containers media only during container-grown plant production using three different fertilization placements.

	Cumulative Efflux		
Fertilizer Placement[y]	**CO_2-C (mg)**	**N_2O-N (µg)**	**CH_4 (µg)**
Dibble	370.85 b	629.25 b	25.62 a
Incorporate	384.67 b	2434.83 a	15.94 a
Topdress	501.19 a	789.74 b	84.28 a
Non-fertilized	266.49 c	14.45 c	36.52 a

[z] Container media used was a pinebark:sand (6:1 v:v) media that had been previously amended with dolomitic limestone (3.0 kg m^{-3}), and Micromax® (0.9 kg m^{-3}). Cumulative efflux for 6 months (April 17-Nov. 17, 2011) was calculated using the trapezoid rule (n=3).

[y] The same fertilizer rate (25 g of product (Polyon® 17-5-11 per 3 L container) was used for all placement treatments with the exception of non-fertilized pots which received no Polyon® fertilizer.

[x] Means were separated using Fishers Least Significance Difference Test in the Proc Mixed procedure ($p \leq 0.05$).

Table 3. Biomass, carbon, and nitrogen content of white gumpo azalea shoots and roots[z] following container production using three different fertilization placements.

	Shoots			Roots			Total
Fertilizer Placement[y]	Dry wt. (g)	C %	N %	Dry wt. (g)	C %	N %	Dry wt. (g)
Dibble	21.5 a	45.4 b	1.6 b	10.1 a	46.4 ab	0.9 b	31.6 a
Incorporated	27.1 a	45.3 b	1.7 a	11.6 a	47.2 ab	1.2 a	38.7 a
Topdressed	24.6 a	45.4 b	1.6 b	11.0 a	46.0 b	1.1 b	35.6 a
Non-fertilized	0.9 b	46.7 a	0.3 c	1.2 b	47.5 a	0.3 c	2.1 b

[z] Azalea shoots show the carbon and nitrogen content of all above ground plant material (leaves, stems, branches). Azalea roots show the carbon and nitrogen content of belowground plant material (roots only). Total = sum of shoots + roots.

[y] The same fertilizer rate (25 g of product (Polyon® 17-5-11 per 3 L container) was used for all placement treatments with the exception of non-fertilized pots which received no Polyon® fertilizer. Media in all treatments was amended with dolomitic limestone (3.0 kg m^{-3}), and Micromax® (0.9 kg m^{-3}).

[y] Means were separated using Fishers Least Significance Difference Test in the Proc Mixed procedure ($p \leq 0.05$).

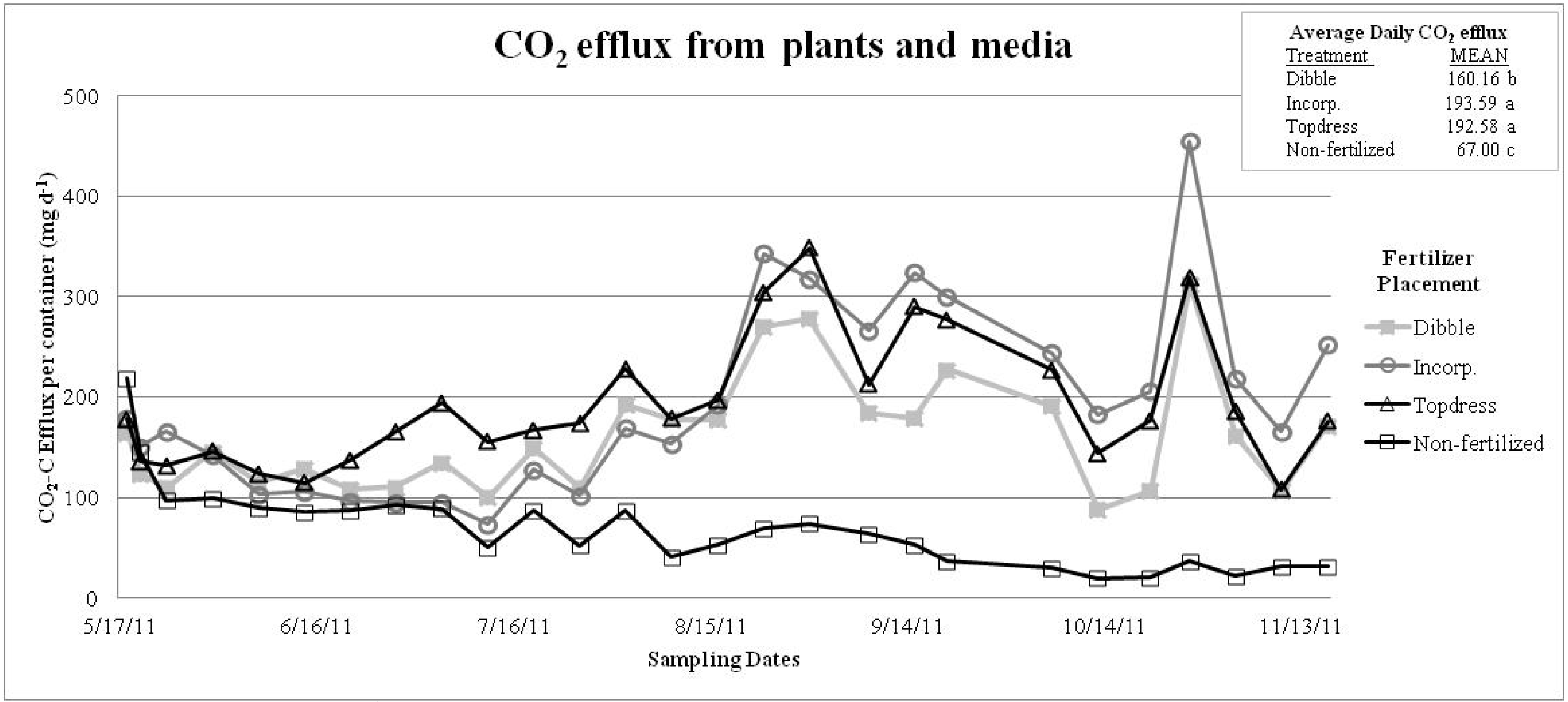


Figure 1. CO$_2$-C efflux (mg d^{-1}) for gumpo azaleas grown with three different fertilizer placements for 6 months (May 17 - November 17, 2011). The insert shows average daily efflux (means followed by the same letter are not significantly different from each other, $p \leq 0.05$).

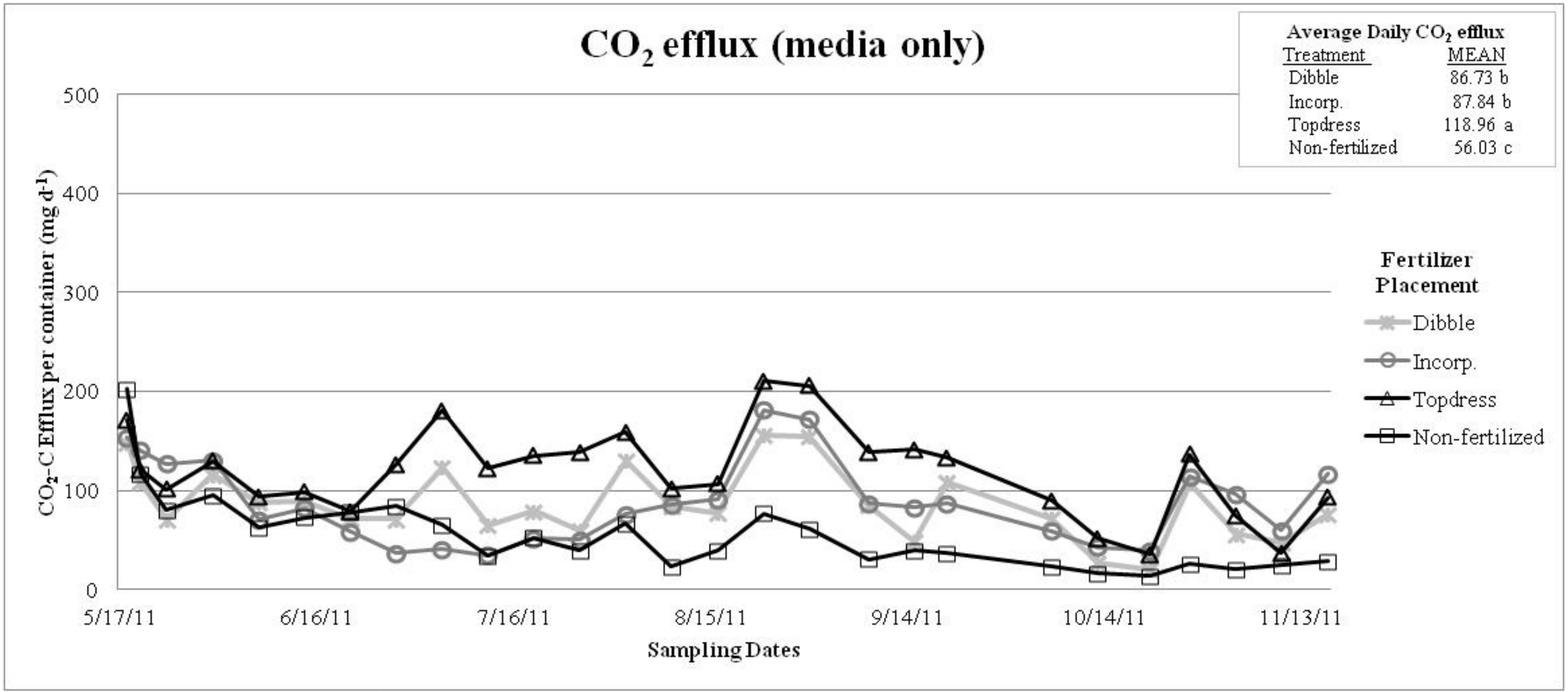


Figure 2. CO$_2$-C efflux (mg d^{-1}) from container media with three different fertilizer placements for 6 months (May 17 November 17, 2011). The insert shows average daily efflux (means followed by the same letter are not significantly different from each other, $p \leq 0.05$).

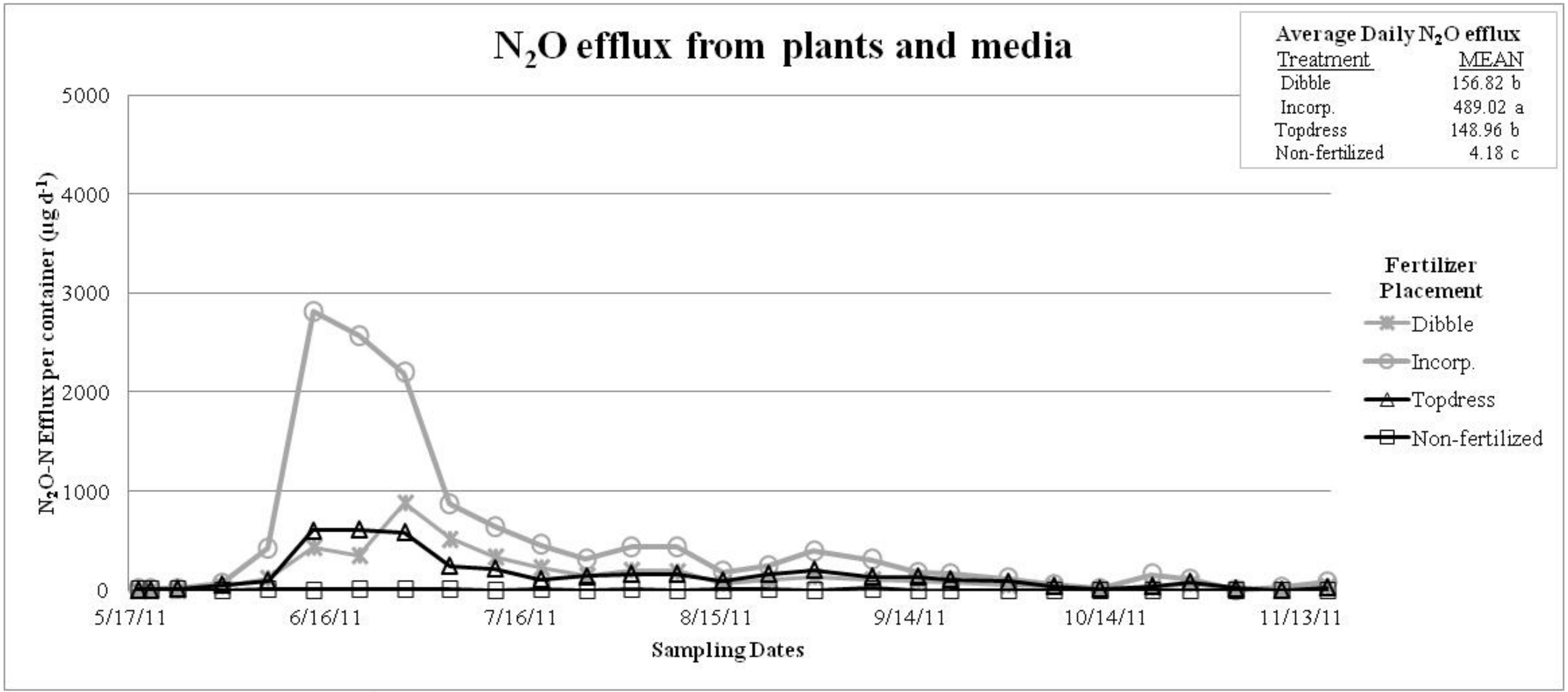


Figure 3. N$_2$O-N efflux (µg d^{-1}) for gumpo azaleas grown with three different fertilizer placements for 6 months (May 17 - November 17, 2011). The insert shows average daily efflux (means followed by the same letter are not significantly different from each other, $p \leq 0.05$).

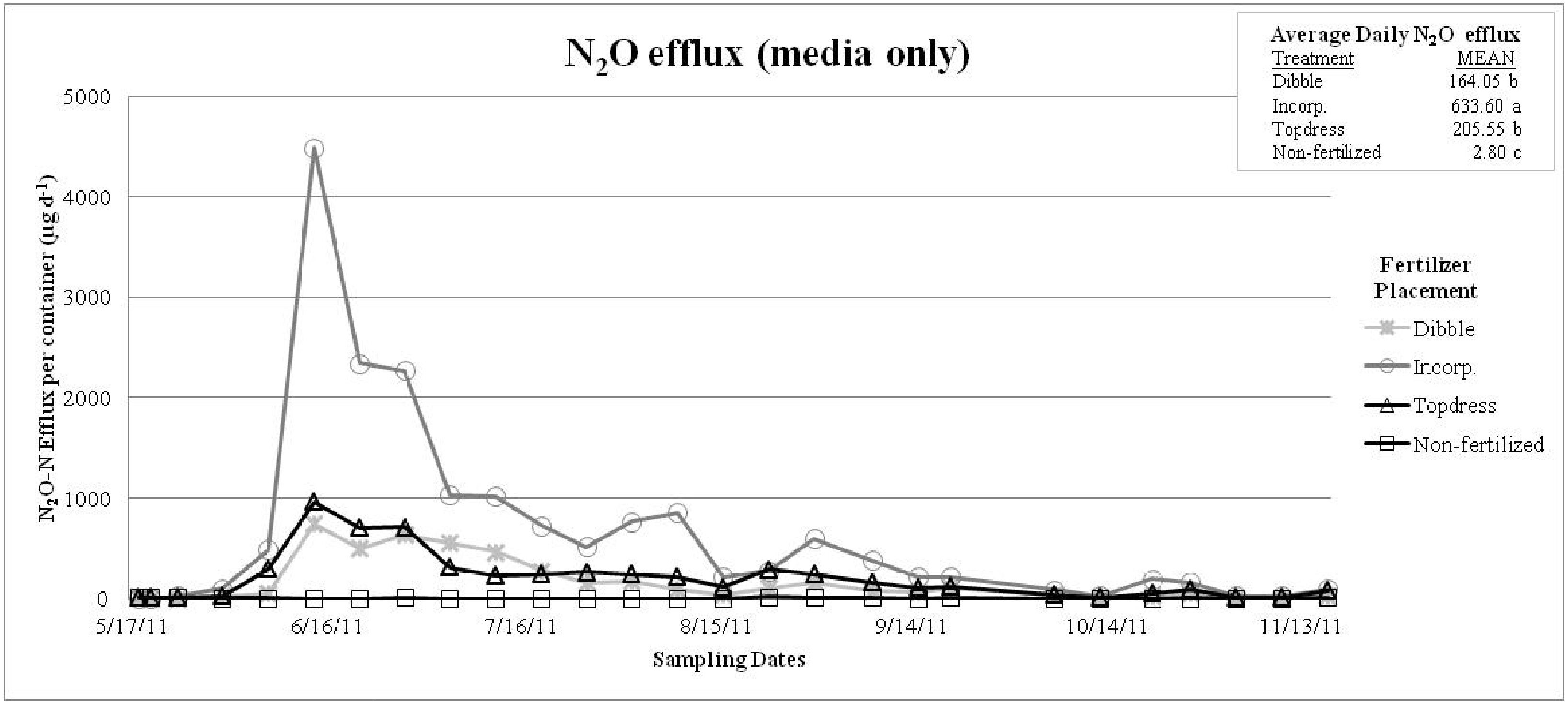
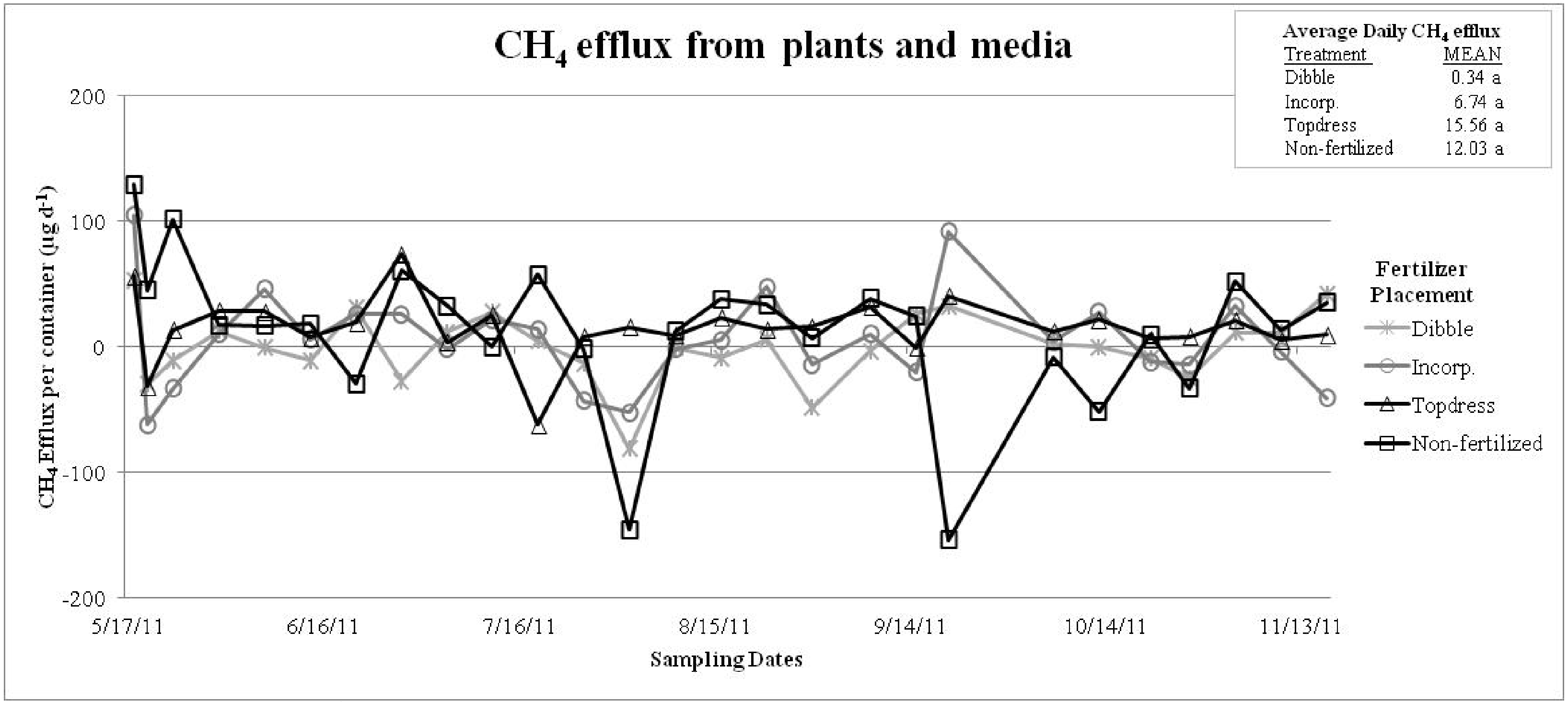


Figure 4. N_2O-N efflux (µg d^{-1}) from container media with three different fertilizer placements for 6 months (May 17 - November 17, 2011). The insert shows average daily efflux (means followed by the same letter are not significantly different from each other, $p \leq 0.05$).



Average Daily CH$_4$ efflux

Treatment	MEAN
Dibble	0.34 a
Incorp.	6.74 a
Topdress	15.56 a
Non-fertilized	12.03 a

Figure 5. CH$_4$ efflux (µg d^{-1}) from container media with three different fertilizer placements for 6 months (May 17 - November 17, 2011). The insert shows average daily efflux (means followed by the same letter are not significantly different from each other, $p \leq 0.05$).

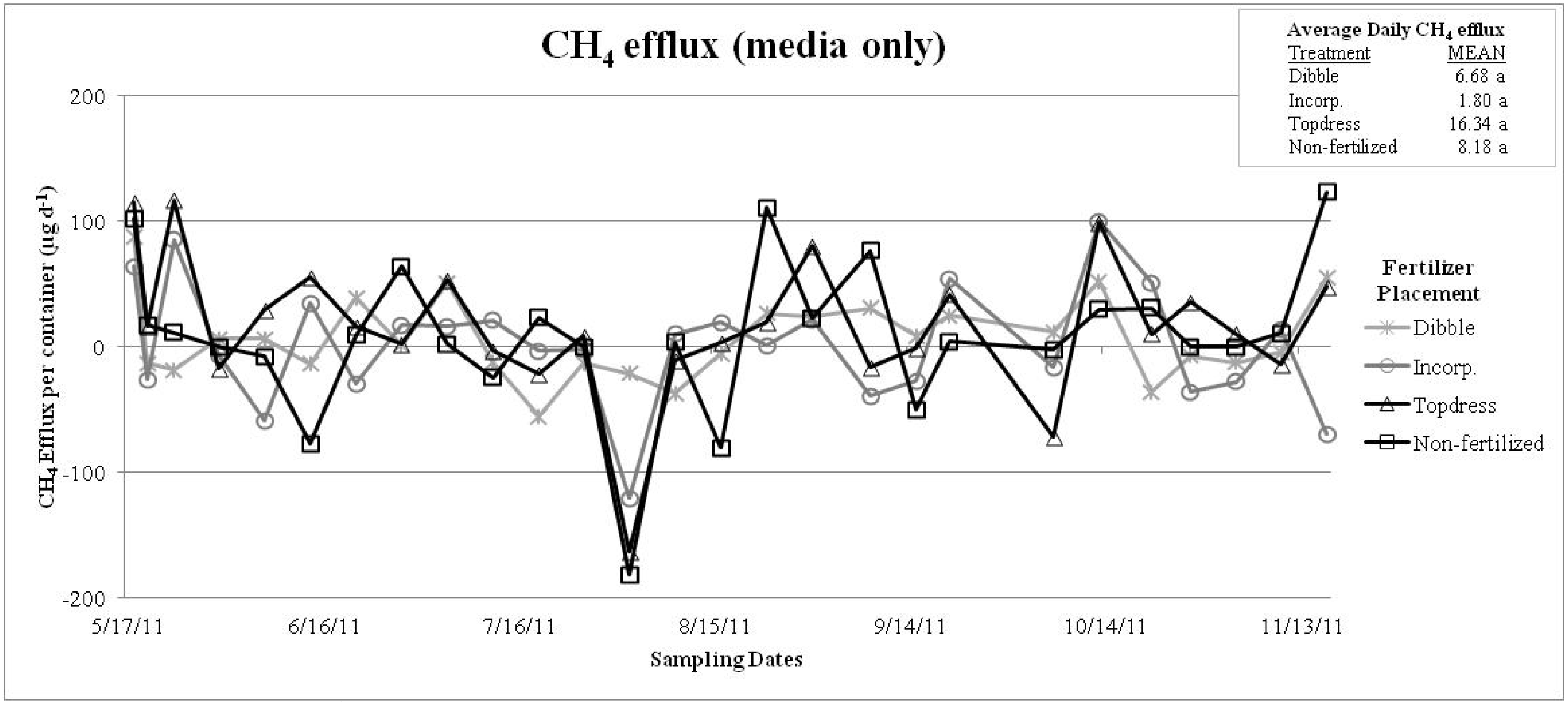


Figure 6. CH_4 efflux (µg d^{-1}) for gumpo azaleas grown with three different fertilizer placements for 6 months (May 17 - November 17, 2011). The insert shows average daily efflux (means followed by the same letter are not significantly different from each other, $p \leq 0.05$).

CHAPTER V

Final Discussion

Although athropogenically caused climate change is still highly debated, it is known that atmospheric concentrations of the three most important long-lived GHGs (CO_2, CH_4, and N_2O) are continuing to increase. Many scientists now believe that climate change is occurring and poses a serious global threat. While agriculture is a large contributor to these emissions, its role in climate change is unique compared with other industries in that it can act as a source of trace gas emissions or it can act as a major sink through changes in production management practices.

For over three decades, scientists in other agricultural sectors (e.g. row crop production, forestry, animal production) have been researching methods in which current production practices can be altered to mitigate GHG emissions and increase carbon (C) sequestration potential in their respective fields. While no mandatory C taxes or "caps" are currently in place in the United States, many are speculating that emissions levels could soon be monitored and limited, which could have a significant impact on agricultural production. Therefore, there is a need for all agricultural sectors to examine alternative management practices that comply with possible new legislation while reducing GHG emissions and sequestering C without decreasing productivity or profits.

There is also potential for horticulture producers to benefit financially from reducing GHG emissions and their C footprint by altering management practices. Agricultural producers in other sectors are now beginning to earn new income in the emerging C trading markets, as well as receive government incentives for reducing GHG emissions. These financial benefits are only possible because of earlier work in which scientists determined the impacts of these sectors (row crops, forestry, animal production, etc.) on climate change. If new regulations are put into place in the future, producers in these areas would have an advantage over specialty crop growers (e.g. nursery producers) as little work has focused on determining the impact of those crops on climate change.

In order 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. In chapter 2, we outlined the causes and environmental impact of climate change, the role of agriculture in reducing emissions and sequestering C, and potential areas in ornamental horticulture in which practices could be altered to increase C sequestration and mitigate GHG emissions. We also conducted a nursery survey of thirteen of the top container producers in Alabama to begin quantifying the amount of C used in container media. The purpose of this survey was to develop an estimate of the number and size of container-grown plants produced each year. Survey results showed that about 72,000 m^{-3} of pinebark is used annually in Alabama to produce container-grown nursery crops. Given that the study represented about half of the state's production, this estimate could conservatively be doubled (140,000 to 150,000 m^{-3}). Pinebark has a high C% (49.2% in our analysis with a bulk density of 0.24 g cm^{-3}). If all or most of these crops were transplanted into the landscape, this would represent a significant amount of C (16,500 to 17,700 Mg C) potentially placed belowground each year. If other states developed similar estimates, then future emission estimates could be scaled to determine industry wide emission and C storage levels, giving a more thorough analysis of horticulture's environmental impact.

In chapter 3, efflux patterns of CO_2, CH_4, and N_2O associated with different nursery container sizes [3.0 L (TG; trade gallon), 3.8 L (#1; 1 gal.), 7.6 L (#2; 2 gal.) and 11.4 L (#3; 3 gal.) under common production practices were determined. Dwarf yaupon hollies (*Ilex vomitoria* 'Nana') were potted into the one of the four container sizes using standard potting amendments and sampled weekly for trace gas emissions. Results indicated that carbon dioxide (CO_2) and nitrous oxide (N_2O) fluxes were highest in the largest containers (#3). There was a significant positive relationship between container size and CO_2 efflux. Nitrous oxide efflux followed a similar pattern, except there were no differences between the two smallest container sizes. In general, CO_2 and N_2O fluxes increased with increasing temperature. Methane flux was consistently low and had no significant effect on total trace gas emissions.

While CO_2 and N_2O losses were higher in the larger containers, smaller containers would likely have higher trace gas emissions on a per acre basis. For example, on a 0.4 ha production bed, #3 containers spaced 15 cm apart (about 26,000 plants) would have half (50 kg CO_2-C) of the cumulative CO_2-C efflux of a TG containers (96 kg CO_2-C) spaced 5 cm apart (98,000 plants). It is also important to note that our container trace gas flux data did not reflect net emissions as they did not account for C stored in growing biomass, or contained in potting media which is placed belowground during transplanting. Subtracting cumulative CO_2-C efflux (total CO_2-C emitted over the course of the study) from C stored in biomass and media results in a net C gain of 396.1, 601.6, 924.3, and 1671.8 g from TG, #1, #2, and #3 containers, respectively.

Our conclusion in chapter 3 was that container production of a typical woody nursery crop using common production practices would likely be a net C sink while in production and after being planted into the landscape. Data from this study also begin to elucidate the overall environmental impact of the container nursery industry and provide baseline data of trace gas emissions from container-nursery production systems which are needed to determine the impact of different production variables (e.g. growing media, fertilization, irrigation, species) on future mitigation strategies.

Mitigation strategies were explored in chapter four as our objective was to determine efflux patterns of CO_2, CH_4, and N_2O associated with three different fertilization methods (dibble, incorporated, or topdressed) commonly used in nursery container production. Measurements were taken over the course of six months (May 2011 through November 2011) on white gumpo azaleas (*Azalea* × *hybrid* ‘Gumpo White’) potted into #1 containers using one of the three fertilizer methods discussed above.

Over the course of the study, CO_2 fluxes were slightly lower when fertilizer was dibbled compared to topdressed or incorporated treatments. Nitrous oxide fluxes were consistently highest when fertilizer was incorporated, with few differences observed in the other two placements. Methane flux was generally low with few differences among treatments.

Chapter 4 results indicate dibbling fertilizer may reduce total trace gas emissions (CO_2, CH_4, and N_2O collectively) from container production systems. Dibbling reduced CO_2 emissions compared with incorporated and topdressed treatments, whereas plant growth was similar in all fertilizer treatments at the conclusion of the study. Dibbling and topdressing also significantly reduced N_2O emissions (68% and 70%, respectively) compared with the incorporated treatment. Although dibbling also resulted in lower CH_4 emissions than topdressed treatments, the fact that CH_4 efflux was low in all treatments indicates that CH_4 is not a trace gas of concern from container production systems regardless of the fertilization method used. Results from this study begin to provide data which can be used to implement mitigation strategies in container plant production which will help growers adapt to possible emission regulations and benefit from future GHG mitigation or offset programs.

Results from these studies show baseline estimates of GHG emissions from common horticultural production practices and begin to address ways in which to lower emissions below current levels. While the number and size of container grown plants produced each year in Alabama was estimated in chapter 1, currently, to our knowledge, no data exits on number and size of container-grown plants produced each year in other states. However, if other states developed similar estimates on the number and size of container-grown plants produced each year, efflux data developed in this project could be scaled to determine estimates of industry-wide emissions. As horticultural production occupies a fraction of the area of agronomic production, it is likely that the negative environmental impact of the horticultural industry will be minimal when compared to other agricultural sectors. We reported that most container production systems would likely results in a net C gain while the plants were in production, and further C gains would be realized as the media is placed belowground and the plant accumulates biomass. As most ornamental crops in landscape settings are relatively permanent with a long life span and require few additional inputs (irrigation, fertilizer, pesticides, etc.), environmental benefits from the industry likely far outweigh any negative impacts.

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 further investigation. As data become available, the role of the ornamental horticulture industry on climate change (both positive and negative) will begin to become more clearer. Industry leaders and growers can then begin to fine-tune BMPs to maximize productivity and profitability while minimizing GHG emissions. Research is needed to provide the industry with the necessary tools for adapting to future legislation that could cap GHG emissions and provide growers opportunities in the emerging C trading and offsets market. Continued investigation is also needed to determine profitable and environmentally sustainable ways to grow plants. Numerous changes in production practices have been shown to reduce GHG emissions and increase C storage in other agricultural sectors; however, researchers have been investigating mitigation strategies in these areas for decades. Successful mitigation strategies from agronomic or forestry crops could possibly be applicable to nursery container-grown production, but ornamental production poses many unique challenges in regard to climate change mitigation. In a typical nursery setting, dozens if not hundreds of different species occupy a small area of production space, and many of these crops have specific and often different growth requirements (nutrition, irrigation, chemical inputs, etc.). Although challenges exist, there are also opportunities to alter countless production variables on a wide variety of crops which will help growers adapt to possible future regulations while still remaining productive and profitable. Additionally, determining C sequestration potential of ornamental crops grown for use in landscapes will provide every homeowner a means of directly contributing to mitigation of climate change while improving property aesthetics and value.