Determining Trace Gas Efflux from Container Production of Woody Nursery Crops[1]

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Abstract

Agriculture is a large contributor of trace gas emissions and much of the work on reducing greenhouse gas (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 efflux patterns of CO_2, CH_4, and N_2O associated with four different nursery container sizes [3.0 liter (trade gal; TG), 3.8 liter (#1; 1 gal), 7.6 liter (#2; 2 gal), and 11.4 liter (#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) 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. 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.

Index words: climate change, greenhouse gas emissions, container production.

Species used in this study: dwarf yaupon holly (*Ilex vomitoria* 'Nana' L.).

Significance to the Nursery Industry

Agriculture production is a large contributor to greenhouse gas (GHG) emissions. Due to climate change concerns, scientists have investigated ways to reduce GHG emissions through altering agricultural practices. Past work has concentrated on row crops, forests, and animal production systems, with little attention given to specialty sectors such as container nurseries. In order to reduce emissions from the container nursery industry, baseline emission levels from common production practices must first be established. This study investigated efflux of carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O) from a woody nursery crop (dwarf yaupon holly) grown in four different container sizes for one year. Results showed that CO_2 and N_2O emissions generally increased as container size increased, while CH_4 emissions were minimal throughout the study in all container sizes evaluated. These results begin to provide baseline data needed to determine the environmental impact of the container nursery industry on climate change.

Introduction

High concentrations of GHG are thought to be a main factor causing global warming (6, 9); atmospheric concentrations of CO_2, CH_4, and N_2O have increased by approximately 35, 155, and 18%, respectively, since 1750 (6, 13, 16, 30). Agriculture in the United States is a large contributor to GHG emissions, second only to energy production (15). 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 (4). 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 (4, 17, 19, 21, 29, 33). Adoption of no-till agriculture (34), feed supplementation in ruminant animals (4, 21), and increased efficiency of N fertilization (17, 18) 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 (35). Although horticulture production occupies much less acreage than most agronomic crops, horticulture is one of the fastest growing sectors in agriculture (10), and the

[1]Recieved for publication February 23, 2012. In revised form April 7, 2012. Financial support for this research was provided by the USDA-ARS Floriculture Nursery Research Initiative and **The Horticulture Research Institute, 1200 G Street NW, Suite 800, Washington DC 20005.**

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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 (3, 7, 25, 32).

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 (24) which could dramatically impact production (2).

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 (14). 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 flux 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 (22).

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 (1 in)] were transplanted into four different nursery container sizes: 3 liter (trade gal; TG), 3.8 liter (#1; 1 gal), 7.6 liter (#2; 2 gal), and 11.4 liter (#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 10.1 liters, respectively) which had been previously amended with 8.3 $kg \cdot m^{-3}$ (14 $lbs \cdot yd^{-3}$) of 17N-2.2P-4.2K (17-5-11) Polyon® control-release fertilizer (10–12 month), 3.0 $kg \cdot m^{-3}$ (5 $lb \cdot yd^{-3}$) of ground dolomitic limestone, and 0.9 $kg \cdot m^{-3}$ (1.5 $lb \cdot yd^{-3}$) 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 (0.5 in)] 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 soil line, soil was removed from roots, and shoots and roots were dried for approximately 72 hours at 55C (130F) in a forced-air oven and weighed. Roots and shoots were then ground separately to pass through a 0.2 mm (0.08 in) 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 (11, 12). Custom-made gas flux chambers were designed and constructed based upon criteria described in the GRACEnet protocol (1, 28) to accommodate nursery containers. A structural base consisting of polyvinyl chloride (PVC) cylinders [25.4 cm (10 in) inside diameter by 38.4 cm (15.1 in) 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 (10 in) diameter × 11.4 cm (4.5 in) height] was placed on top of the base cylinder. The top flux 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 (0.6 in^{-3})] were collected with polypropylene syringes and injected into evacuated glass vials [6 mL (0.4 in^{-3})] fitted with butyl rubber stoppers as described by Parkin and Kaspar (28). 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 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 min) as described by Parkin and Venterea (27). 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 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

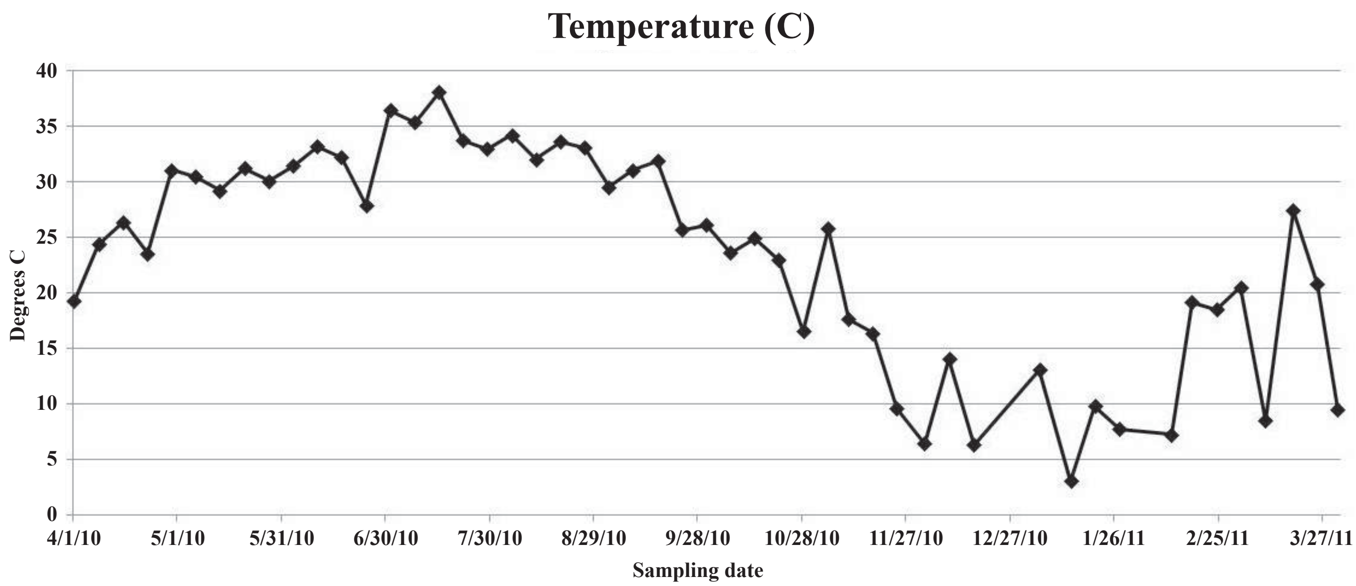

Fig. 1. **Temperature (degrees C) during trace gas sampling.**

procedure in SAS (SAS® Institute version 9.1, Cary, NC). Means were separated using Fisher's 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 and Discussion

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 flux 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 flux 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,

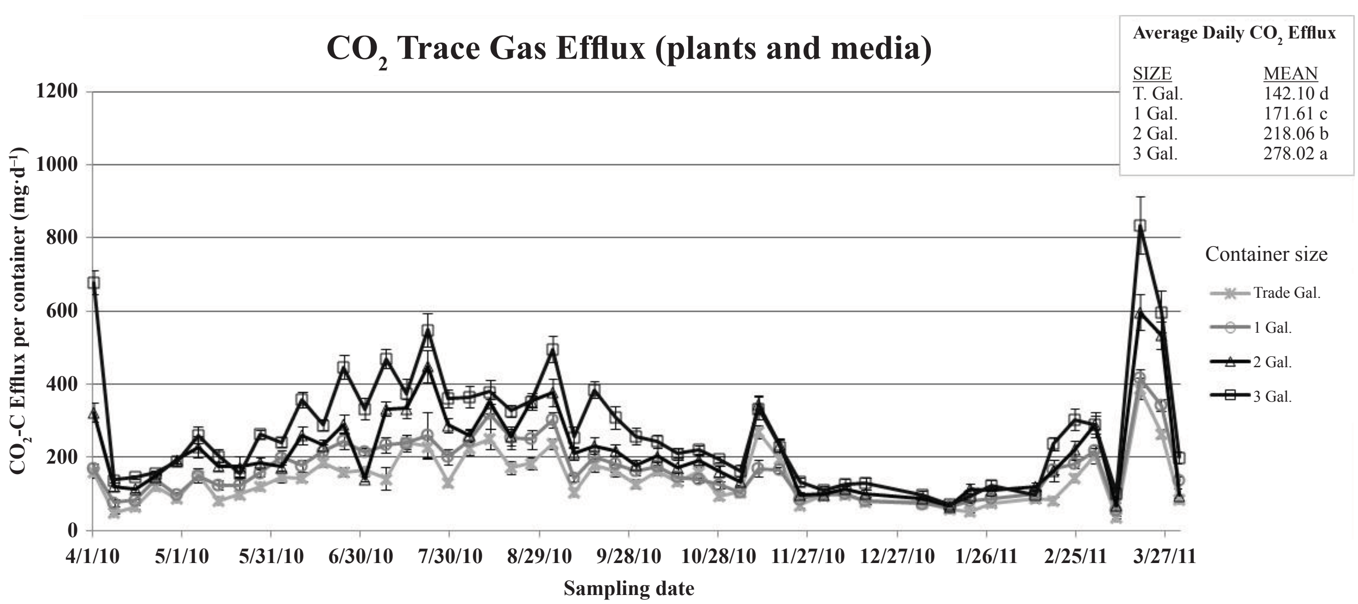

Fig. 2. **CO_2-C efflux ($mg \cdot d^{-1}$) for dwarf yaupon holly grown in four container sizes over one year (April 1, 2010–March 31, 2011). Means and standard errors are shown. The insert shows average daily efflux (means followed by the same letter are not significantly different from each other,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

Table 1. Cumulative trace gas (CO_2 CH_4, and N_2O) efflux from container production of woody nursery crops.

		Efflux (plants and media)[z]		
Container size	Volume (L)[y]	CO_2-C (mg)	N_2O-N (µg)	CH_4 (µg)
Trade gal	2.05	983.35dA[x]	593.54cB	–39.35aA
1 gal	3.15	1191.00cA	866.91bcB	1.57aA
2 gal	5.15	1516.88bA	1991.41bB	–15.06aA
3 gal	10.10	1910.69aA	5461.76aB	27.65aA
		Efflux (media only)[w]		
Container size	**Volume (L)**	**CO_2-C (mg)**	**N_2O-N (µg)**	**CH_4 (µg)**
Trade gal	2.05	297.62dB	2929.97cA	–23.42aA
1 gal	3.15	407.89cB	3098.34cA	–24.68aA
2 gal	5.15	615.09bB	5972.01bA	–25.62aA
3 gal	10.10	888.39aB	11712.00aA	11.78aA

[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} (14 lbs·yd^{-3})], dolomitic limestone [3.0 kg·m^{-3} (5.0 lbs·yd^{-3})], and Micromax [0.9 kg·m^{-3} (1.5 lbs·yd^{-3})]. All amendments were incorporated prior to potting. Cumulative efflux 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 Fisher's 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 being analyzed separately. Upper case letters show mean comparisons between each container size with plants and media to each container size with media only.

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

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 ($p = < 0.0001$, $R^2 = 0.29$). Carbon dioxide efflux was consistently highest during late spring and summer months when larger differences in efflux among container sizes were observed (Figs. 2 and 3). Carbon dioxide efflux has been shown to be highly dependent upon temperature and water content (8); 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

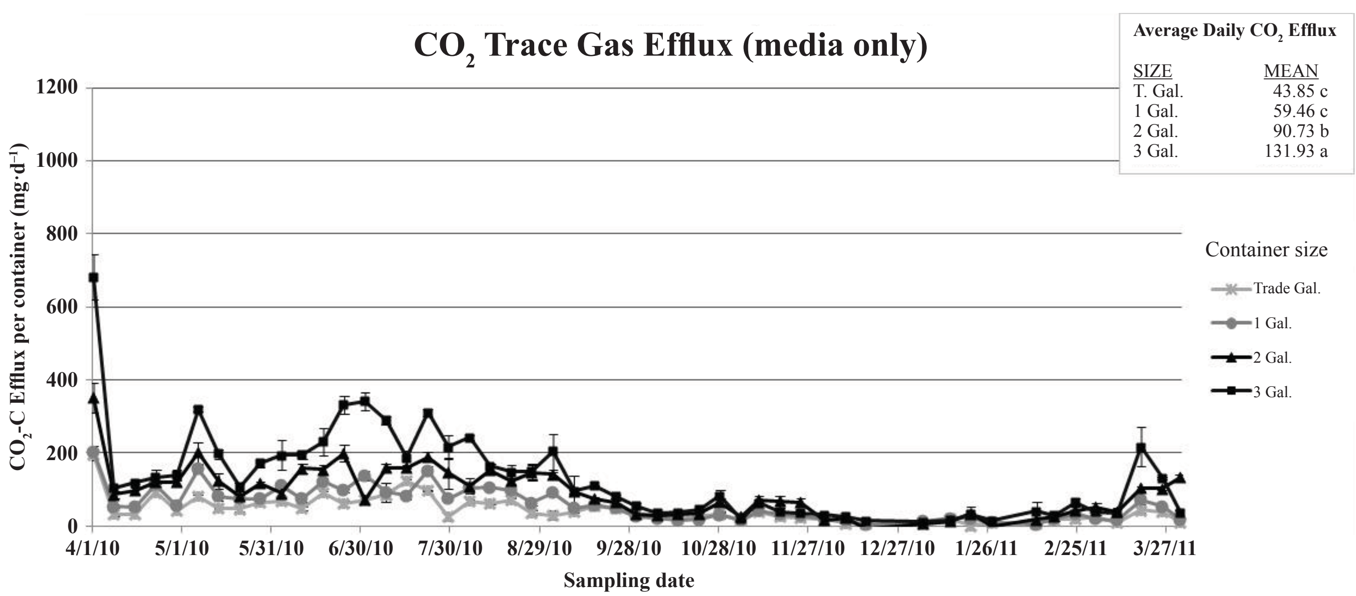

Fig. 3. **CO_2-C efflux (mg·d^{-1}) from four container sizes (media only) over one year (April 1, 2010–March 31, 2011). Means and standard errors are shown. The insert shows average daily efflux (means followed by the same letter are not significantly different from each other, $p \leq 0.05$).**

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

		Shoots			Roots		
Container size	Volume (L)[y]	Dry wt. (g)	Carbon %	Nitrogen %	Dry wt. (g)	Carbon %	Nitrogen %
Trade gal	2.05	22.45c[x]	50.59a	1.99ab	14.71c	49.18a	1.90c
1 gal	3.15	42.63b	50.38ab	1.92b	22.09b	49.16a	1.84c
2 gal	5.15	47.68b	50.21b	2.18a	23.02b	49.34a	2.16b
3 gal	10.10	55.27a	50.22b	2.20a	30.26a	48.95a	2.43a

[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).

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

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

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. (36) 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 fluxes during warmer months. However, no increases in N_2O flux were 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 fluxes in non-saturated soils are generally small (31) 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.

Our results showed that loss of both CO_2 and N_2O were greatest in the largest containers, while CH_4 efflux was low regardless of container size. While CO_2 and N_2O losses were higher in larger containers, smaller containers would likely have higher total trace gas emissions on a per acre basis. For example on a 0.4 ha (1 A) production bed, #3 gallon containers spaced 15 cm (6 in) apart (about 26,000 plants) would

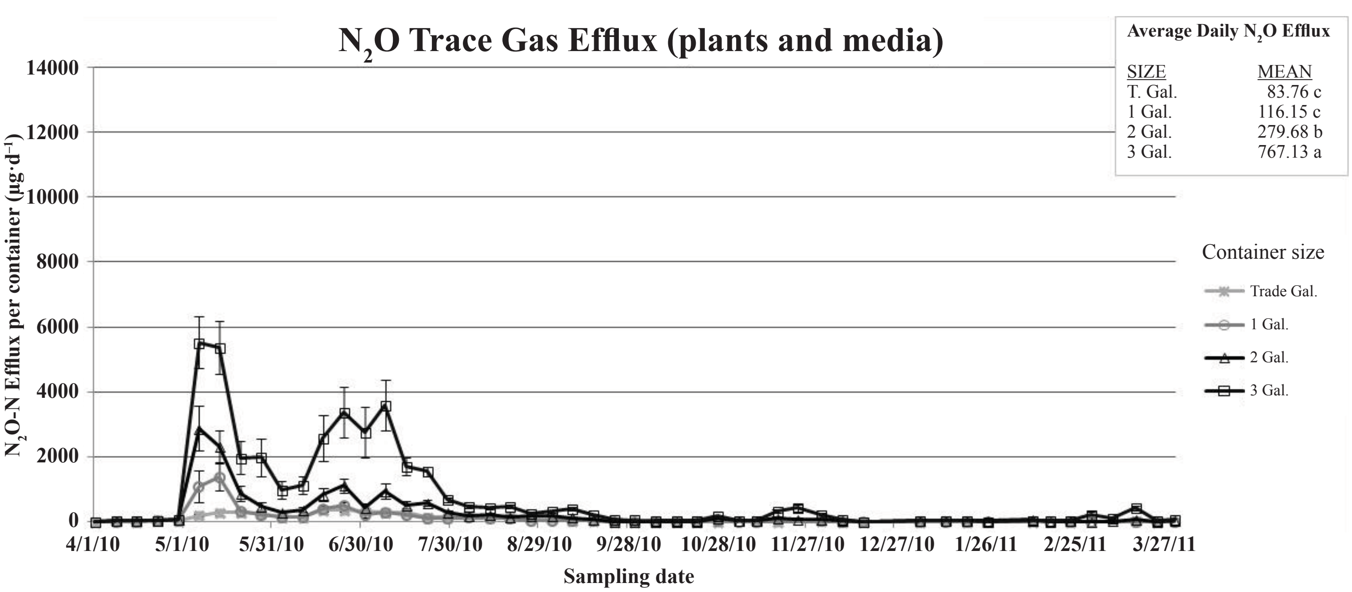

Fig. 4. N_2O-N efflux (µg·d^{-1}) for dwarf yaupon holly grown in four container sizes over one year (April 1, 2010–March 31, 2011). Means and standard errors are shown. The insert shows average daily efflux (means followed by the same letter are not significantly different from each other, $p \leq 0.05$).

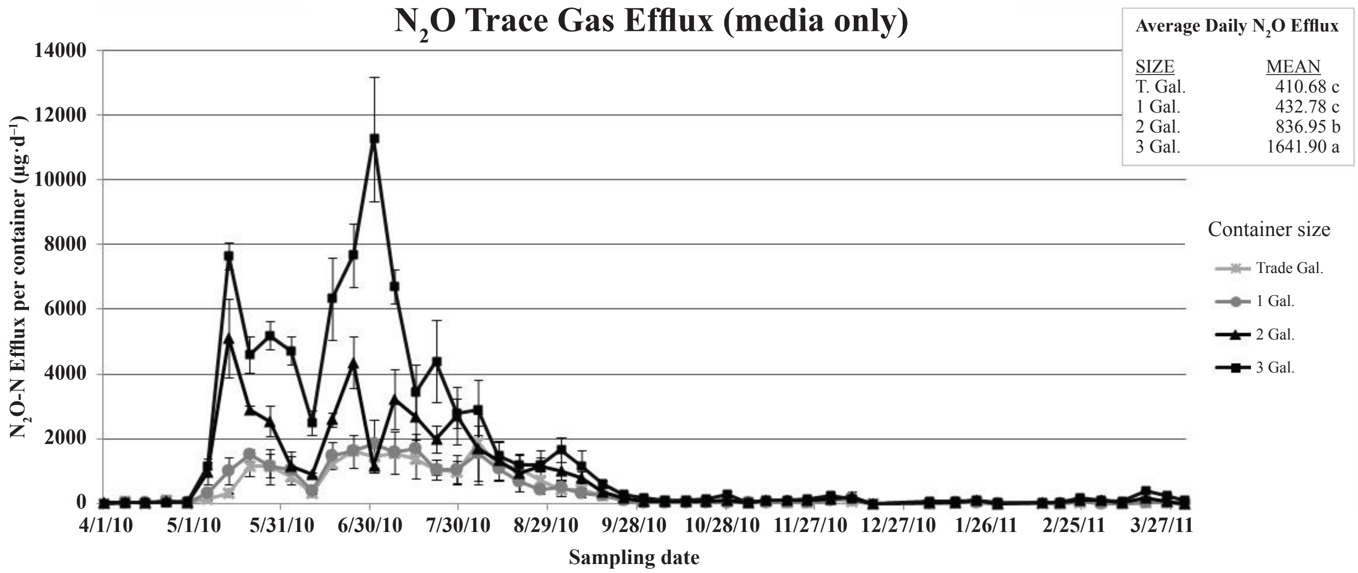

Fig. 5. **N_2O-N efflux ($\mu g \cdot d^{-1}$) from four container sizes (media only) over one year (April 1, 2010–March 31, 2011). Means and standard errors are shown. The insert shows average daily efflux (means followed by the same letter are not significantly different from each other, $p \leq 0.05$).**

have approximately half [50 kg (110 lbs)] of the cumulative CO_2-C efflux (Table 1) of TG containers [96 kg (212 lbs) of CO_2-C efflux] spaced 5 cm (2 in) apart (about 98,000 plants). 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 (5). 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 United States in 2007, compared with approximately 0.5 million acres of nursery stock (26). 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 flux 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 in 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 (23). 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 depend 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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