Effects of Fertilizer Placement on Greenhouse Gas Emissions from a Sun and Shade Grown Ornamental Crop[1]

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Abstract

The level to which ornamental plant production impacts rising atmospheric greenhouse gas (GHG) concentrations remains unknown. Research to date has focused on developing baseline estimations of GHG emissions from plant-pot production systems and their contribution to global warming potential. To date, pot size, irrigation delivery method and fertilizer application method have been evaluated in the production of common woody ornamental crops. In this study, two perennial herbaceous plants, full-sun-grown 'Stella D'Oro' daylily (*Hemerocallis* × 'Stella D'Oro' L.) and shade-grown 'Royal Standard' hosta (*Hosta* × 'Royal Standard') (*Hosta plantaginea* Aschers × *Hosta sieboldiana* N.Fujita) were grown utilizing one of three common fertilizer application methods (dibbled, incorporated or top-dressed). Plants were grown in 3.8 L (1 gal) nursery containers in a 6:1 pinebark:sand substrate with standard amendments. Gas samples were collected *in situ* according to standard GRACEnet protocols weekly for five months. Cumulative emissions for both CO_2 and N_2O were least for plant-pot systems using the dibbled fertilizer method, regardless of species. Cumulative CO_2 emissions were highest for plants fertilized by incorporation, followed by those fertilized by top-dressing. No differences were observed between N_2O efflux measurements for systems fertilized by either the incorporated or top-dressed methods. Results suggest that dibbling fertilizer could significantly decrease both CO_2 and N_2O emission.

Index words: carbon dioxide, nitrous oxide, methane, trace gas.

Species used in this study: 'Stella D'Oro' daylily (*Hemerocallis* × 'Stella D'Oro' L.); 'Royal Standard' hosta [(*Hosta* × 'Royal Standard') (*Hosta plantaginea* Aschers × *Hosta sieboldiana* N.Fujita)].

Significance to the Horticulture Industry

The ornamental plant production industry has the capacity to impact global climate change through a thorough review of its best management practices (BMP), and how each contributes to global warming through the emission of common greenhouse gases CO_2, N_2O and CH_4. Previous research has evaluated substrate alternatives, irrigation delivery method and fertilizer application method in an effort to determine efflux patterns associated with each BMP. The focus of this research is a continuation of those efforts, evaluating fertilizer application method (dibbled, incorporated or top-dresesed) with either a sun- or shade-grown crop. Emissions of CO_2 were highest for 'Royal Standard' hosta (*Hosta* × 'Royal Standard') as compared to full-sun-grown 'Stella D'Oro' daylily (*Hemerocallis* × 'Stella D'Oro'), which is to be expected considering the size differences in the larger shade-grown hosta as compared to daylily. By this same logic, N_2O emissions were confirmed to be lowest for shade-grown hosta, as larger plants would predictably require larger amounts of N, leaving less available for leaching. Results from this research showed that regardless of species, CO_2 and N_2O emissions were least for plant-pot systems fertilized with the dibble method. CO_2 emissions were highest for plant-pot systems fertilized by incorporation. No differences were observed between N_2O efflux measurements for systems fertilized by either the incorporated or top-dressed methods, as both were higher than N_20 emissions where the dibbled fertilizer method was used. Methane efflux throughout the study was negligible, and not significantly affected by treatments or their interactions.

Introduction

In an extensive series of reports in 2010, the greenhouse, nursery and floriculture industry in Alabama was recently valued at $629.2 million annually, supporting an estimated 7,943 jobs (ACES 2013). These nursery sales generated just over $20 million in indirect business taxes for the state. The economics are only value-added, given how the greenhouse, nursery and floriculture industries support potential C sequestration through their provision of ornamental trees and shrubs for landscape use in rural, suburban, and urban environments. Reports indicate that urban land, together with rural/suburban residential areas, account for more than 150 million acres in the United States (Lubowski et al. 2006). The planting of this acreage with ornamental trees and shrubs could dynamically increase potential C sequestration.

Challenges associated with estimating the effective contribution made to climate change by the ornamental nursery and greenhouse industry are numerous. Over the past decade however, researchers have made strides in developing baseline estimates for CO_2, N_2O and CH_4 efflux patterns from a number of ornamental crops, while simultaneously evaluating the manner in which common best management practices (i.e. - pot size, alternative substrates, irrigation method, fertilizer application method)

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affect these emissions (Marble et al. 2012a, 2012b, 2016, Murphy et al. 2018).

GHG emissions from dwarf yaupon holly (*Ilex vomitoria* 'Nana') grown in four container sizes were reported in 2012 (Marble et al. 2012a). As expected, CO_2 and N_2O emissions were highest in the largest containers [7.6 L (2 gal) and 11.4 L (3 gal)], as compared to the two smaller containers tested [(3.0 L (trade gal) and 3.8 L (1 gal)], with a positive relationship between container size and emissions of CO_2 and N_2O. As with nearly all research evaluating GHG emissions in soilless substrates, CH_4 emissions remained low throughout the study. While CO_2 and N_2O emissions were higher in the two larger containers, the authors noted that on a per area basis, larger containers would actually emit less CO_2 and N_2O, given that less of them will fit into a given area of production.

In work assigning value to the actual contribution each GHG makes to climate change, a specific scaling factor known as global warming potential (GWP) is established for each trace gas (Forster et al. 2007). These evaluators are based on the radiative forcing from 1 kg of the gas in question to 1 kg of CO_2 over a specific interval of time. Expressed as CO_2 equivalents, the GWP for CO_2 is 1, CH_4 is 25, and N_2O is 298. N_2O is formed naturally in soils and the ocean, but is also a major by-product in agricultural and fossil fuel combustion practices (Mathez 2009). Nearly 80% of the total N_2O emissions in the US are directly attributed to N-fixation associated with the production and use of synthetic fertilizers and leguminous crops (Mosier et al. 2003). Increased efficiency of N fertilization (both dosage and delivery) has been shown to reduce emissions of N-containing N_2O, ammonia and NO (Kroeze et al. 1999). Though the bulk of previous research has focused on agronomic crops, the principles apply to soilless systems as well. Even in systems where N_2O contributes a fraction to overall GWP as compared to CO_2, identifying specific ways to mitigate N_2O emissions could have the greatest impact for the nursery and greenhouse industries. Following work evaluating differences in trace gas emissions from plants in different container sizes, Marble et al. (2012b) evaluated the growth of gumpo azalea (*Azalea* × hybrid 'Gumpo White') using one of three common fertilizer placement methods (dibble, incorporated, and top-dressed). Again, CH_4 emissions were consistently low throughout the study. CO_2 emissions were generally lowest in plant-pot systems fertilized with the dibble method, as compared to both systems utilizing the incorporated and top-dressed methods. N_2O emissions were highest with plant-pot systems utilizing the incorporated fertilizer method, with no differences observed between those utilizing either the dibble or top-dressed methods.

N loss in ornamental crop production is affected by a number of factors, including N formulation, dosage, application method, temperature, and moisture (volume and delivery method). In an effort to evaluate the interactive effect of irrigation method (overhead vs drip) and fertilizer application method (dibble vs incorporated), estimates of GHG emissions from Japanese boxwood (*Buxus microphylla* Siebold & Zucc.) were measured over a nine-month period (Murphy et al. 2018). CO_2 emissions were not significantly affected by irrigation method, fertilizer placement, or the interaction of the two, though CO_2 emissions in drip irrigated plant-pot systems were reported to be 11% higher than those receiving irrigation from overhead impact risers. While statistically significant interaction effects were noted for N_2O efflux, the authors noted that delivering irrigation through micro-drip emitters significantly reduced N_2O efflux over the duration of the study, regardless of how fertilizer was applied. When limited to overhead irrigation however, N_2O emissions were significantly lower for plants fertilized by the dibble method.

The objective of the current research was to continue to evaluate fertilizer placement, while simultaneously evaluating light level and its effect on GHG efflux from the plant-pot system in ornamental plant production. Unlike previous studies that examined woody ornamental species, two perennial herbaceous species (shade-grown 'Royal Standard' hosta and sun-grown 'Stella D'Oro' daylily) were selected for the study due to their common use in the industry, as well as their economic importance.

Materials and Methods

The experiment was conducted on an outdoor nursery pad at the Paterson Greenhouse Complex on the campus of Auburn University. Two perennial herbaceous species, 'Royal Standard' hosta (*Hosta* × 'Royal Standard') and 'Stella D'Oro' daylily (*Hemerocallis* × 'Stella D'Oro'), were grown adjacently in either sun (daylily) or under 30% shade cloth (hosta). On April 23, 2015, 3.15 L (1-gal) containers were filled with a standard 6:1 pinebark:sand (v:v) substrate amended with 3.0 $kg \cdot m^{-3}$ dolomitic limestone. It should be noted that, since only a single species was used for each light level, it is not possible to distinguish between effects of light level from those caused by differences in species.

Fertilizer [16-5-10 Polyon – 12 month release with micronutrients (Harrell's LLC, Lakeland, FL)], at a rate of 25 g per container (equivalent to 6.5 $kg \cdot m^{-3}$), was either incorporated into, top-dressed onto, or dibbled into, substrate in each container. Dibbling was accomplished by pressing a wooden dowel with a tapered end (3.8 cm diameter) approximately 15 cm into the filled pot. Fertilizer was dropped in the hole, and a rooted cutting (daylily) or 1-2 eye bare root (hosta) was potted directly on top of the fertilizer. Irrigation events occurred three times daily, delivering 6.35 mm (0.25 in) water at each event through overhead impact irrigation risers.

Trace greenhouse gases (CO_2, CH_4, N_2O) emitted from plants and substrate were sampled weekly (*in situ*) for five months (April 23, 2015 to September 24, 2015) using the static closed chamber method (Hutchinson and Mosier 1981, Hutchinson and Livingston 1993). Measurements were taken at the same time on each sampling day, between 9:00 and 10:00 AM CST. Custom-made gas efflux chambers were designed and constructed based on descriptions in the GRACEnet protocol (Baker et al. 2003, Parkin and Kaspar 2006) to accommodate 1-gal

Table 1. Total cumulative CO_2, N_2O, and CH_4 efflux[z] over five months from two herbaceous species[y] utilizing three fertilizer application methods[x].

Main Effects				Cumulative Efflux		
Species Effect				CO_2-C (g/pot)	N_2O-N (mg/pot)	CH_4 (mg/pot)
Daylily				26.94 b	20.34 a	-1.03[ns]
Hosta				32.47 a	15.24 b	-1.22
			p:	*<0.001*	*<0.001*	*0.810*
Fertilizer Placement Effect						
Dibble				22.73 c	12.97 b	-1.22[ns]
Incorporated				34.61 a	19.13 a	-1.57
Top-Dressed				31.78 b	21.27 a	-1.58
			p:	*<0.001*	*<0.001*	*0.570*
Interaction Effects				**Cumulative Efflux**		
Species		**Fertilizer Placement**		CO_2-C (g/pot)	N_2O-N (mg/pot)	CH_4 (mg/pot)
Daylily	-	Dibbled		22.89 b[w]	13.86 b	-1.16[ns]
Daylily	-	Incorporated		29.90 a	22.15 a	-0.47
Daylily	-	Top-Dressed		28.03 a	25.02 a	-1.46
Hosta	-	Dibbled		22.57 c	12.07 b	-1.28[ns]
Hosta	-	Incorporated		39.31 a	16.12 ab	-0.67
Hosta	-	Top-Dressed		35.53 b	17.53 a	-1.71
			p:	*0.001*	*0.171*	*0.998*

[z]Cumulative efflux for five months (23 April 2015 to 24 September 2015) was calculated using the trapezoid rule (n=6).

[y]Daylily (*Hemerocallis* × 'Stella D'Oro') and Hosta (*Hosta* × 'Royal Standard') were potted into 4 L (1 gal) nursery containers filled with standard 6:1 (v:v) pinebark:sand substrate, amended with 3.0 $kg \cdot m^{-3}$ dolomitic limestone.

[x]The same fertilizer rate (25 g per container) (16-5-10 Polyon with blended minors - 12 month release) was either incorporated into, or top-dressed or dibbled onto, the substrate in each container. Dibbling was accomplished by pressing a wooden dowel with a tapered end (3.8 cm diameter) approximately 15 cm into the filled pot. Fertilizer was then dropped in the hole, and rooted cutting or bare root was potted directly on top of the fertilizer.

[w]Within a column, means followed by the same letter are not significantly different ($p \leq 0.05$) according to the LSMeans statement under the Proc Mixed Procedure of SAS. For interaction effects, letters designate differences within species only.

[ns]Not significantly different.

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. The top efflux chambers (25.4 cm inside diameter by 11.4 cm tall) were constructed of PVC, covered with reflective tape (3M™ Metallized Flexible Duct Tape 3350, 3M, St. Paul, MN), and contained a center sampling port. During gas measurements, the entire plant-pot system was placed inside the base cylinder. The top efflux chamber was placed on top, and a wide (10.4 cm) rubber band was fitted around the top-bottom interface to seal it. Gas samples were taken at 0, 20, and 40 min intervals following chamber closure, and analyzed using a gas chromatograph (Shimadzu GC-2014, Columbia, MD). Gas concentrations were determined by comparison with standard curves developed using gas standards obtained from Air Liquid America Specialty Gases LLC (Plumsteadville, PA). Gas effluxes were calculated from the rate of change in concentrations of trace gases in the chamber headspace during the time intervals while chambers were closed (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. Dry weights of both the above and below ground portions of the plants were measured at study termination. Shoot dry weights (SDW) (g) were determined by drying the above-substrate portion of the plant in a 76.7 C (170.0 F) forced air oven for 72 hours. Root dry weights (RDW) (g) were determined by removing the substrate from the root interface, and drying the within-substrate portion of the plant in a 76.7 C (170.0 F) forced air oven for 144 hours.

The experiment was conducted as a 2 by 3 factorial design (2 species by 3 fertilizer application methods) with six blocks (six plants per block, 3 of each species) located along the length of the outdoor nursery pad. Data analyses were conducted using the Mixed Models Procedure (Proc Mixed) of the Statistical Analysis System (Littell et al. 1996). Error terms appropriate to the factorial design were used to test the significance of main effects and their interactions. A significance level of ($P \leq 0.05$) was established *a priori*.

Results and Discussion

Statistically significant interaction effects between species and fertilizer placement were observed for cumulative efflux of both CO_2 and N_2O over the five-month sampling period (Table 1). Daylilies fertilized with the dibble method had less cumulative CO_2 emissions (22.89 g/pot) than both daylilies fertilized by either top-dressing (28.03 g/pot) or incorporation (29.90 g/pot), which were statistically similar. Similarly, cumulative CO_2 efflux was also least for hostas grown with dibbled fertilizer (22.57 g/pot), as compared to either hostas fertilized by top-dressing (35.53 g/pot) or by incorporation (39.31 g/pot). Regardless of species, cumulative CO_2 efflux

Table 2. Shoot and root dry weights[z,y] following five months of growth for two herbaceous species[x] utilizing three fertilizer application methods[v].

Main Effects						
Species Effect			**Shoot Dry Weight (g)**	**Root Dry Weight (g)**	**Total Dry Weight (g)[w]**	**Root:Shoot Ratio**
Daylily			6.80 b[u]	17.55 b	24.35 b	2.50 b
Hosta			10.30 a	45.10 a	55.39 a	4.47 a
		p:	*<0.001*	*<0.001*	*<0.001*	*<0.001*
Fertilizer Placement Effect						
Dibble			8.03[ns]	30.96[ns]	38.99[ns]	3.93 a1
Incorporated			8.41	30.71b	39.12a	3.31 ab
Top-Dressed			9.20	32.30b	41.50a	3.21 b1
		p:	*0.412*	*0.862*	*0.763*	*0.052*
Interaction Effects						
Species		**Fertilizer Placement**	**Shoot Dry Weight (g)**	**Root Dry Weight (g)**	**Total Dry Weight (g)**	**Root:Shoot Ratio**
Daylily	-	Dibbled	7.94[ns]	24.95 a	32.89 a	3.25 b
Daylily	-	Incorporated	6.33	12.75 b	19.08 b	1.94 a
Daylily	-	Top-Dressed	6.13	14.95 b	21.08 b	2.29 a
Hosta	-	Dibbled	8.12 b	36.97 b	45.08 b	4.61[ns]
Hosta	-	Incorporated	10.50 ab	48.67 a	59.17 a	4.67
Hosta	-	Top-Dressed	12.27 a	49.66 a	61.92 a	4.12
		p:	*0.001*	*0.001*	*0.001*	*0.095*

[z]Shoot dry weights (g) determined by drying the above-substrate portion of the plant in a 76.7 C (170.0 F) forced air oven for 72 hours.

[y]Root dry weights (g) were determined by removing the substrate from root interface, and drying the within-substrate portion of the plant in a 76.7 C (170.0 F) forced air oven for 144 hours.

[x]Daylily (*Hemerocallis* × 'Stella D'Oro') and Hosta (*Hosta* × 'Royal Standard') were potted into one-gallon nursery containers filled with standard 6:1 (v:v) pinebark:sand substrate, amended with 3.0 $kg \cdot m^{-3}$ dolomitic limestone.

[w]Total dry weight = Shoot dry weight + root dry weight.

[v]The same fertilizer rate (25 g per container) (16-5-10 Polyon with blended minors - 12 month release) was either incorporated into, or top-dressed or dibbled onto, the substrate in each container. Dibbling was accomplished by pressing a wooden dowel with a tapered end (3.8 cm diameter) approximately 15 cm into the filled pot. Fertilizer was then dropped in the hole, and rooted cutting or bare root was potted directly on top of the fertilizer.

[u]Within a column, means followed by the same letter are not significantly different ($p \leq 0.05$) according to the LSMeans statement under the Proc Mixed Procedure of SAS. For interaction effects, letters designate differences within species only.

[ns]Not significantly different.

for the entirety of the study was least for plants fertilized with the dibble fertilizer method (22.73 g/pot) (Table 1). An increase to 31.78 g CO_2/pot was observed for all plants top-dressed with fertilizer, while plants grown in substrates incorporated with fertilizer prior to planting had the highest cumulative CO_2 (34.61 g/pot). Differences in cumulative CO_2 efflux between species without regard to fertilizer placement were also observed (Table 1). As would be expected, shade-grown hosta, which was much larger (10.30 g SDW, 45.10 g RDW) than daylily (6.80 g SDW, 17.55 g RDW) at study termination, had higher cumulative CO_2 efflux (32.47 g/pot) than sun-grown daylily (26.94 g/pot) (Tables 1, 2). High daily CO_2 values at study initiation are consistent with results in previous studies, as high initial values are often synonymous with transplant shock (Fig. 1). As a general trend, daily CO_2 emissions were higher for shade-grown hosta than for sun-grown daylily, except for hosta grown with dibbled fertilizer. Both daylily and hosta grown utilizing the dibble fertilizer method were consistently low across all sampling dates.

Similar to results observed for CO_2 efflux, plants fertilized with the dibble method had the least cumulative N_2O efflux (12.97 mg/pot) among methods tested (regardless of species) (Table 1). No differences in cumulative N_2O emissions were observed between the incorporated (19.13 mg/pot) or top-dressed (21.27 mg/pot) fertilizer placement methods, though both were greater than values observed for the dibble method. Interaction effects within species were congruent with those observed for main effects. Daylilies fertilized with the dibble method had less cumulative N_20 emissions (13.86 mg/pot) than both daylilies fertilized by either top-dressing (25.02 mg/pot) or incorporation (22.15 mg/pot). Cumulative N_2O emissions were least for hosta grown with dibbled fertilizer 12.07 mg/pot), though emissions were statistically similar to those observed in hosta grown with incorporated fertilizer (16.12 mg/pot). Fertilizer is generally used more efficiently during the initial growth period for plants with dibbled fertilizer, given its proximity to plant roots, meaning N_2O loss is expected to be minimized in comparison to other fertilizer methods. Hosta top-dressed with fertilizer had significantly higher N_2O emissions (17.53 mg/pot) than those observed in hosta with dibbled fertilizer, but were similar to those as hosta fertilized by incorporation. As with cumulative CO_2 efflux, differences in cumulative N_2O efflux were also observed between species without regard to fertilizer placement, though emissions for N_2O were higher for daylily (Table 1). With regard to size alone, larger shade-grown hosta would predictably take up more nitrogen than smaller sun-grown

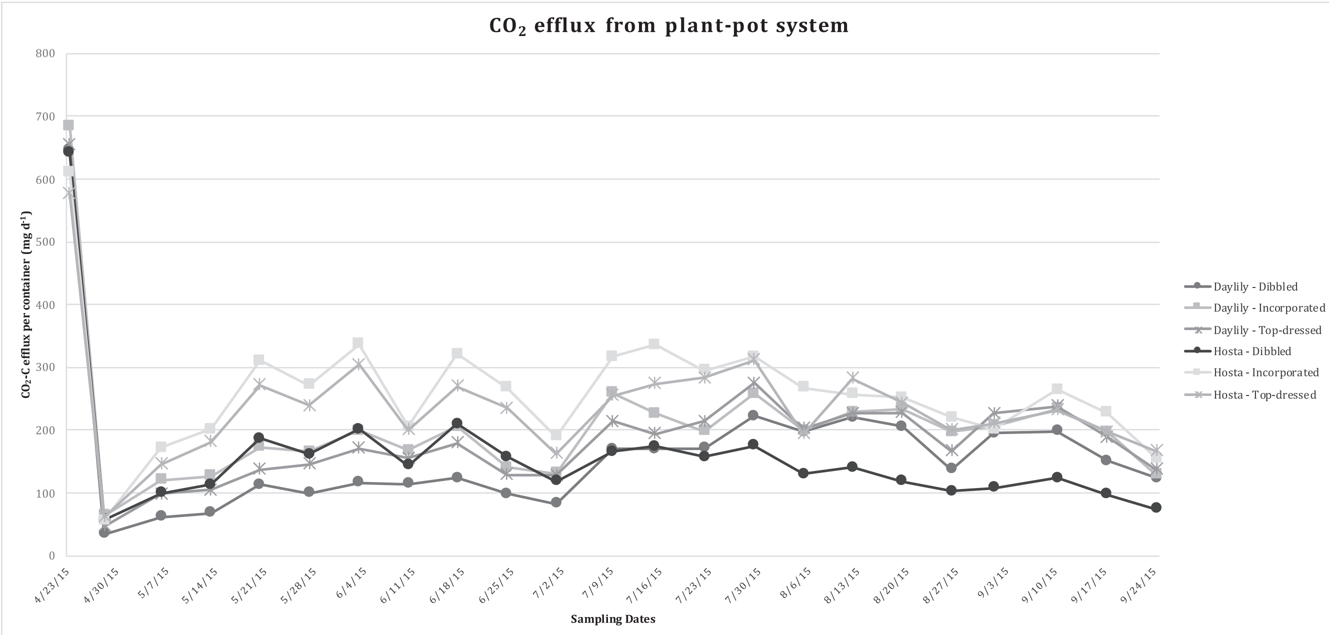

Fig. 1. Daily CO_2-C efflux for two perennial herbaceous species fertilized with one of three fertilizer application methods (either dibbled, incorporated or top-dressed). Measurements are for a time period of approximately five months (23 April to 24 September 2015).

daylily, resulting in less cumulative N_2O loss (15.24 mg/pot) than daylily (20.34 mg/pot). High initial values for daily N_2O values are expected and consistent with research results in prior studies, possibly exaggerated by high late spring and summer temperatures in east central Alabama (Fig. 2). Initial spikes in daily N_2O emissions were higher for sun-grown daylily than for shade-grown hosta, which contributed to higher cumulative N_2O emissions for daylily than for hosta.

Cumulative methane (CH_4) efflux, across the five-month sampling period, was minimal and not significantly affected by species/light level, fertilizer placement method, or their interaction (Table 1). Minimal to near-zero values for CH_4 loss are generally anticipated in studies occurring in well drained soilless systems, where anaerobic respiration is virtually non-existent. While negative values for net CH_4 emissions are not always observed, they are not unexpected due to the presence of methanotrophic bacteria that metabolize methane as a source of carbon (energy).

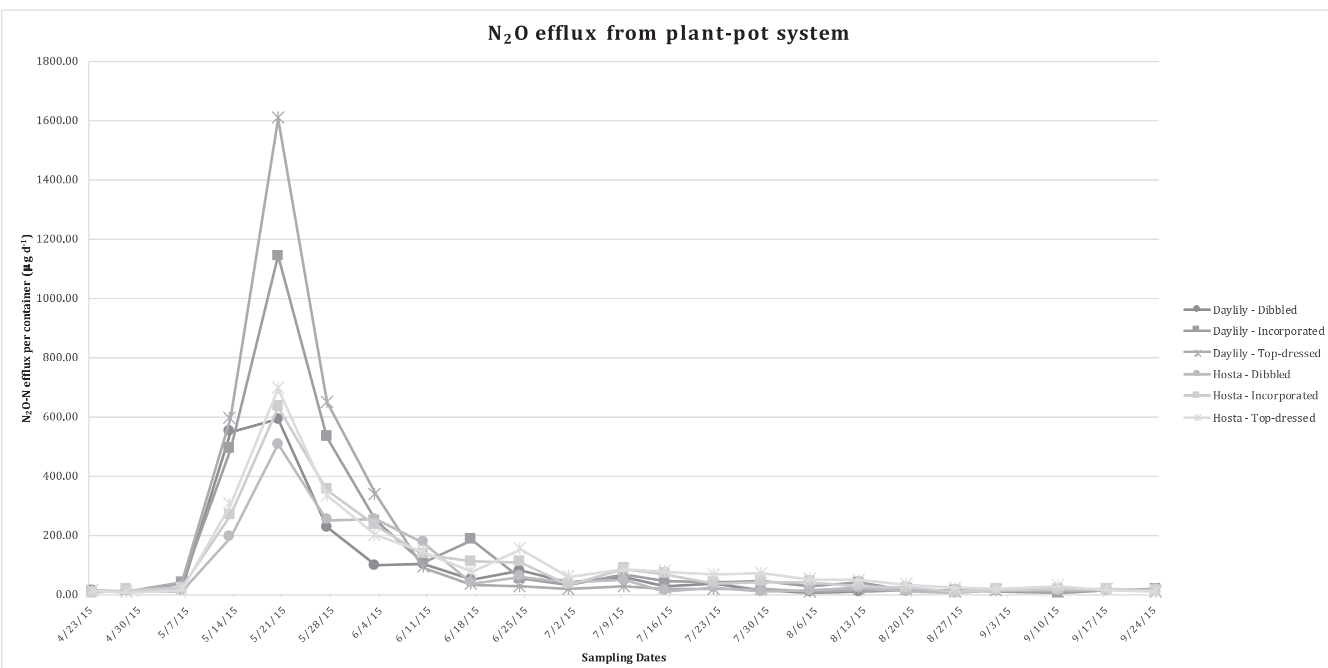

Fig. 2. Daily N_2O-N efflux for two perennial herbaceous species fertilized with one of three fertilizer application methods (either dibbled, incorporated or top-dressed). Measurements are for a time period of approximately five months (23 April to 24 September 2015).

Table 3. Percent contribution to Global Warming Potential[z] of two herbaceous species[y] utilizing three fertilizer application methods[x].

Main Effects			GWP	% Contribution CO_2-C (%)	N_2O-N (%)	CH_4 (%)
Species Effect						
Daylily			0.0330 b	82.00 b	18.09 a	-0.09[ns]
Hosta			0.0370 a	87.63 a	12.47 b	-0.09
		p:	*0.001*	*<0.001*	*<0.001*	*0.967*
Fertilizer Placement Effect						
Dibble			0.0266 b	85.65 a	14.48 b	-0.13[ns]
Incorporated			0.0403 a	85.72 a	14.32 b	-0.03
Top-Dressed			0.0381 a	83.07 b	17.04 a	-0.11
		p:	*<0.001*	*0.03*	*0.025*	*0.438*
Interaction Effects				**% Contribution**		
Species		**Fertilizer Placement**	**GWP**	**CO_2-C (%)**	**N_2O-N (%)**	**CH_4 (%)**
Daylily	-	Dibbled	0.0270 b[w]	84.87 a	15.25 b	-0.12[ns]
Daylily	-	Incorporated	0.0365 a	82.26 a	17.78 b	-0.03
Daylily	-	Top-Dressed	0.0354 a	78.86 b	21.25 a	-0.11
Hosta	-	Dibbled	0.0261 b	86.42[ns]	13.72[ns]	-0.14[ns]
Hosta	-	Incorporated	0.0441 a	89.17	10.86	-0.03
Hosta	-	Top-Dressed	0.0407 a	87.28	12.83	-0.11
		p:	*0.014*	*0.009*	*0.007*	*0.989*

[z]Global Warming Potential (GWP) is calculated on a per container basis from cumulative trace gas emissions across the entire study (23 April 2015 to 24 September 2015). Each trace gas has an established GWP based on the radiative forcing from 1 kg of a gas to 1 kg of CO_2 over a specific interval of time. The GWP, expressed as CO_2 equivalents, of each trace gas is as follows: $CO_2 = 1$, $CH_4 = 25$, $N_2O = 298$ (Forster et al. 2007).

[y]Daylily (*Hemerocallis* × 'Stella D'Oro') and Hosta (*Hosta* × 'Royal Standard') were potted into one-gallon nursery containers filled with standard 6:1 (v:v) pinebark:sand substrate, amended with 3.0 $kg \cdot m^{-3}$ dolomitic limestone.

[x]The same fertilizer rate (25 g per container) (16-5-10 Polyon with blended minors - 12 month release) was either incorporated into, or top-dressed or dibbled onto, the substrate in each container. Dibbling was accomplished by pressing a wooden dowel with a tapered end (3.8 cm diameter) approximately 15 cm into the filled pot. Fertilizer was then dropped in the hole, and rooted cutting or bare root was potted directly on top of the fertilizer.

[w]Within a column, means followed by the same letter are not significantly different ($p \leq 0.05$) according to the LSMeans statement under the Proc Mixed Procedure of SAS. For interaction effects, letters designate differences within species only.

[ns]Not significantly different.

Overall global warming potential (GWP), or the total measure of the impact that CO_2, N_2O, and CH_4 each have (measured in CO_2 equivalents) was higher for hosta than for daylily, regardless of fertilizer placement (Table 3). These results are expected, again given the comparison of sheer plant size. More interestingly, fertilizer placement had a significant effect on GWP. Utilizing the dibble fertilizer method (0.0266), GWP was reduced by just over 30% from that of plants utilizing top-dressed fertilizer (0.0381), and nearly 34% compared to GWP of plants utilizing incorporated fertilizer (0.0403). Percent contribution of each GHG to GWP was also affected by treatment. Given that N_2O is 298 times as potent as CO_2 (Forster et al. 2007), it is important to note that both the dibbled and incorporated fertilizer methods were similar in their propensity to contribute to GWP (14.32% for incorporated versus 14.48% for dibble). Both contributed less to GWP than plants utilizing a top-dressed method of fertilizer application (17.04%).

Though daylily RDW was heaviest for those plants utilizing the dibbled fertilizer method (24.95 g), as compared to both those grown in substrate top-dressed (12.75 g) or incorporated (14.95 g) with fertilizer, daylily SDW was ultimately unaffected (Table 2). In contrast, hosta fertilized with the dibble method had the least RDW (36.97 g) as compared to those fertilized by either incorporation (48.67 g) or by top-dressing (49.66 g). With regard to SDW however, plants fertilized by the dibble method (8.12 g) were smaller than only those fertilized by top-dressing (12.27 g). SDW of hosta fertilized by incorporation (10.50 g) was similar to those fertilized by the dibble method. With regard to overall plant dry weight, daylilies grown with dibbled fertilizer were larger than those grown with the other two placement methods (Table 2). In contrast, hosta grown with dibbled fertilizer were smaller than those grown with either incorporated or top-dressed fertilizer. Despite these statistical differences, it is unlikely that differences in plant size would have affected marketability.

Cumulative CO_2 and N_2O efflux results for the two perennial herbaceous species, regardless of fertilizer method, are useful in developing baseline estimates for greenhouse gas efflux constructed on plant size. Practically, however, findings suggest that the use of placement of fertilizer using a dibbling method could significantly decrease both CO_2 and N_2O emissions.

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