THE EFFECT OF INORGANIC VS ORGANIC FERTILIZER ON AN URBAN LAWN IN SALT LAKE CITY, UTAH

by

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ABSTRACT

While lawn management practices have altered the capacity for urban lawns to act as Nitrogen (N) sinks, there have been few studies of the effects of organic vs. inorganic fertilizer additions to urban lawns. We evaluated how foliar and soil N content and isotopic N composition ($\delta^{15}N$) varied as a result of different fertilizer treatment (inorganic, organic or control). We also evaluated differences in lawn above ground net primary productivity (ANPP) among fertilization treatments. We hypothesized that (1) lawn plots managed with organic fertilizer would exhibit lower leaf %N than inorganic fertilizer treatments due to N cycling and losses via leaching; (2) organic fertilizer would exhibit more enriched $\delta^{15}N$ in plant and soil tissue due to trophic level effects of animal derived N; (3) the fertilization effect on %N of grasses and soil would be strongest immediately following fertilization and taper off throughout the growing season due to N mineralization losses and immobilization; (4) if soils are N-limited prior to fertilization, fertilized plots – regardless of form (inorganic or organic) -- would have higher ANPP compared with control plots. We found that lawn plots managed with organic fertilizer had lower leaf %N than inorganic fertilizer plots, and that all fertilized plots showed a declining treatment effect on %N over time. However, treatment effects on $\delta^{15}N$ varied over time. We found that organic fertilizer plots had significantly lower foliar $\delta^{15}N$ than inorganic and control throughout the growing season. Finally, we found no differences in ANPP across treatments for plots. In this study, fertilizer treatments did not stimulate ANPP of grasses, suggesting that these lawns were not strongly N-limited prior to fertilization.

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INTRODUCTION

With large nitrogen (N) inputs from synthetic fertilization application, human activity has greatly accelerated the amount of bio-available N on the landscape (Howarth *et al*., 2002). This has led to increased concern about water pollution associated with inputs of fertilizer for lawn maintenance (Raciti *et al.,* 2008; Milesi *et al.,* 2005). The lasting effects of fertilizers on urban lawns remains a topic of continuous research, as excess N from fertilizer contributes to greenhouse gas emissions, eutrophication, and degraded air quality (Grubber and Galloway 2008). With the growing use of fertilizers, urban lawns have become enriched in their N content (Trammell *et al*., 2016) and evidence suggests that urban lawns have acted as sinks for atmospheric N deposition and fertilization practices (Raciti 2008; Smith *et al.,* 2018). Understanding the capacity for lawns to serve as N sinks is important for predicting and minimizing the impact of urban development on air and water quality.

The stable nitrogen isotope composition ($\delta^{15}N$) of plants and soils has been used as an indicator of N sources that have distinctive $\delta^{15}N$ signatures, as well as soil N processes that fractionate against ^{15}N (Robinson 2001). Units of $\delta^{15}N$ are expressed relative to an atmospheric N_2 standard, and therefore $\delta^{15}N$ of synthetic fertilizer, which is produced from atmospheric N_2, tends to be close to zero, with values commonly ranging between -2 and 2‰ (Kohl et al., 1971; Vitoria et al., 2004). In contrast, $\delta^{15}N$ of organic fertilizers, which include manure and compost-derived products, tends to range between +5 and 20‰ (Bedard-Haughn *et al.*, 2003; Choi *et al.*, 2003) and is more commonly associated with enhanced rates of ecosystem N cycling and volatilization that result in isotopic fractionation (Trammell *et al*., 2016). As a result, synthetic vs. organic fertilizers are commonly isotopically distinct, such that $\delta^{15}N$ can be a useful tracer of N cycling in lawns that are fertilized from different sources. However, there have been very few studies to date that have utilized differences in $\delta^{15}N$ between inorganic and organically fertilized lawns to quantify the impacts of different fertilizer sources on N cycling.

Similar studies have examined the effect of fertilizer treatment on ANPP in urban sites indicated significant increases in ANPP following fertilization (Kaye *et al*., 2005; Milesi *et al,*. 2005). More studies have shown ANPP for mown grass in urban lawns to known to fall in the range of 77-197 g Cm^{-2} y^{-1} (Jo & McPherson, 1995; Qian et al., 2003).

In this study, we measured grass and soil N content and isotopic composition before and after fertilization to understand the effects of fertilizer treatments on lawn N cycling. We hypothesized that lawn plots managed with organic fertilizer would have lower leaf %N than lawns managed with synthetic fertilizer due to ecosystem N cycling and loses via leaching (Bergström *et al.*, 1999). Previous studies have shown that N mineralization from organic matter may lead to substantial leaching losses of N when rainfall is high and evapotranspiration is low (Hall *et al.,* 2016). We also hypothesized that organic fertilizer addition would lead to more enriched $\delta^{15}N$ in plant and soil tissue than inorganic fertilizer addition due to trophic level effects of isotopic enrichment in animal tissue and manure (Bateman and Kelly 2007). We further hypothesized that regardless of fertilizer type, all fertilized lawn would show decline leaf %N over the growing season due to mineralization – immobilization turnover (Bergström *et al.*, 1999). Assuming that lawn soils were N-limited prior to fertilization, we hypothesized that inorganically fertilized plots would have higher ANPP compared with organic and control plots due to inorganic fertilizer having more bioavailable N for growth. Finally, we hypothesized that plots managed with inorganic fertilizer would initially exhibit higher NH_4^+ soil concentrations than control or organically treated plots (Smil, 1997). The results of this study will fill a data gap in the ecological effects of inorganic vs. organic fertilizer and inform lawn N management practices that minimize N losses and subsequent pollution effects.

METHODS

Site Description

The study was conducted southwest of the Sage Point dormitories on the University of Utah campus in Salt Lake City (SLC), Utah. SLC is located in the Salt Lake Valley, a mountain basin surrounded by the Wasatch Mountains to the east, the Oquirrh Mountains to the southwest, and the Traverse Mountain Range to the south. The valley is characterized by a semiarid continental climate, with a mean annual temperature of 11°C and annual precipitation of 410 mm, measured on the valley floor (WorldClimate 2008).

The focus of the study was a lawn consisting of *Poa pratensis* (Kentucky Blue Grass) and *Trifolium spp.* (Clover) in a 24 x 24 m square plot. The lawn received a total of 120 cm^3 of water per week, evenly distributed across all plots over 5 days a week (G. Debartolome: personal communication, facilities management, The University of Utah). Campus facilities management utilized Maxicom Irrigation (RainBird; Azusa, CA), which shuts down irrigation in the presence of rain. This occurred 3 times during the course of this experiment.

Experimental Design

To examine the effects of different fertilization treatments on grass and soil N content, we designed an experiment to test the effect of fertilizer type (organic *vs*. inorganic) on plant N uptake and soil N storage. We separated the lawn into 9 subplots, each 8 x 8m. We included a 1m non-fertilized buffer region along the length and width of each plot to prevent possible edge effects due to horizontal transfer of fertilizer (Fig. 1). We fertilized and then sampled within the 7 x 7m area, avoiding sampling and fertilization of the buffer region. Three plots were randomly chosen to be treated with organic fertilizer, three were treated with inorganic fertilizer, and three were controls with no fertilizer addition. Each fertilized plot received 1lb of fertilizer, with 38% total N for the inorganic fertilizer and 13% total N for the organic fertilizer, on July 6th, 2018. Control plots received the same amount of irrigation but no fertilizer. Organic Fertilizer was 13-0-3 Fertilizer with HumicDG (Andersons Plant Nutrient; Maumee, Ohio). Inorganic Fertilizer was Andersons G Products Fertilizer 38-0-0 with NS-52 (Andersons Plant Nutrient; Maumee, Ohio). Fertilizer was applied with Andersons 2000SR Stainless Steel Spreader (Andersons Plant Nutrient; Maumee, Ohio).

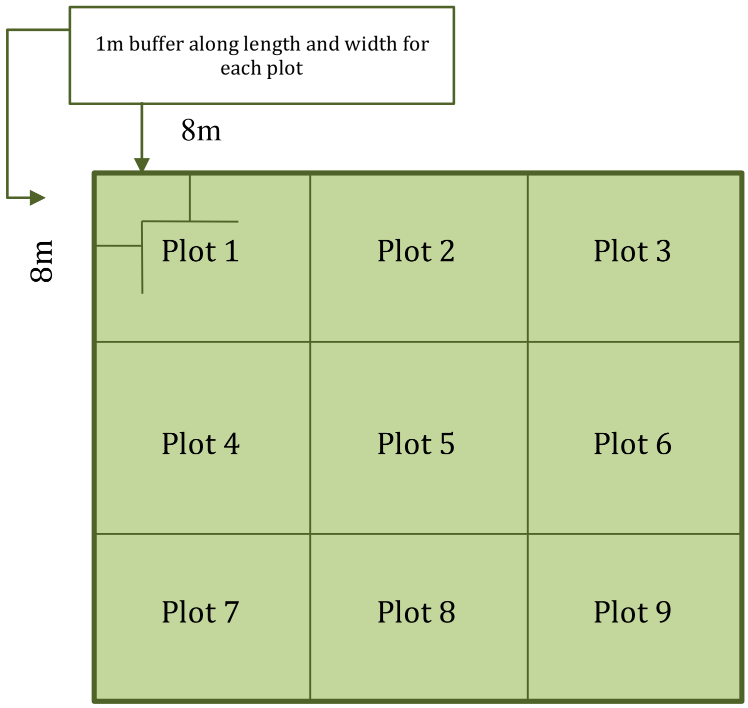

Fig 1: Experimental design of campus fertilization project. Each plot is 8m x 8m with a 1m buffer along the length and width of each plot to avoid horizontal transfer of fertilizer treatment on neighboring plots. Fertilizer treatment was determined via a random number generator.

Sample Collection and Preparation

We collected leaf and soil samples for N content one day prior to fertilization, one-week post fertilization, and each month after fertilization for a total of three months. We sampled soil and grasses at three random positions within each plot, avoiding buffer regions. We randomly sampled the soil to 10 cm depth. Soil cores from each plot were aggregated in the field and transported to the lab on ice. All soil samples were sieved in a two millimeter sieve. Gravimetric soil moisture was calculated using Aridlands Ecology Lab protocol (Castle, 2009). Briefly, we weighed empty weigh boats, tared, added approximately 10 grams of wet soil, recorded soil weight then placed samples to dry for 48 hours at 60°C, then recorded final dry weight of soil plus tin. We obtained NH_4^+

concentrations (ppm) from 2M KCl extractions (Castle, 2009) that were measured at the Brigham Young University (BYU) Environmental Analytical Laboratory.

For soil % N and $\delta^{15}N$, we dried each sample for a minimum of 48 hours at 60°C and ground them into a fine homogenous powder using a ball mill. We then placed a subsample into tin capsules and analyzed it with an elemental analyzer (Carlo Erba NA 1500 NC, Milan, Italy) coupled to an isotope ratio mass spectrometer (Thermofinnigan Delta Plus, San Jose, CA. USA).

Similar to the soil sampling protocol, we took three grass samples at three random positions within each plot. Grass samples from each plot were then aggregated, dried for a minimum of 48 hours and ground by hand to a fine homogenous powder and measured on the EA-IRMS for %N, $\delta^{15}N$, and C:N ratio. All samples were analyzed at the Stable Isotope Ratio Facility for Environmental Research (SIRFER) at the University of Utah and in all analytical runs the data met quality assurance and quality control requirements.

In order to calculate aboveground net primary productivity (ANPP), we collected above ground biomass every Monday, post fertilization, for three months. We clipped all the grass in a designated quadrat that measured 20 cm x 50 cm (1000 cm^2) to estimate ANPP. We then calculated cumulative NPP (g m^2) from weekly measurements.

Statistical Analysis

To evaluate the role of fertilizer presence and type on soil and leaf N content, we analyzed the difference between pre- and post-fertilization values for %N of leaves and %N and NH_4^+ concentrations of soils. Data points observed post-fertilization were subtracted from the pre-fertilization value from each plot to account for pre-treatment variation among plots. Whole dataset analysis was used on $\delta^{15}N$ and ANPP measurements. Because plots differed in soil and plant $\delta^{15}N$ fertilization, and fertilizer treatments themselves had different $\delta^{15}N$ values, we opted to conduct statistical analysis of $\delta^{15}N$ on the entire dataset rather than post - pre values. Additionally, statistical relationships between ANPP across treatment and time were only analyzed post-fertilization only because we did not measure ANPP pre-fertilization.

We employed a two-step linear mixed effects modeling procedure to test the effects of treatment and time during the growing season on %N of soil and grasses, $\delta^{15}N$ of soil and grasses, ANPP, and inorganic nitrogen (NH_4^+, NO_3^-). All mixed effects modeling procedures used the lmerTest package (Kuznetsova *et al.*, 2014). The first step involved a model selection procedure, in which we evaluated which of the following fixed effects - treatment (control, inorganic and organically treated plots), Julian day and the interaction term significantly improved model fit for each response variable. Sample ID, which was an individual sample from each triplicate plot on each data, was treated as a random effect, while treatment (control, inorganic and organically treated plots) and time (Julian day) were treated as fixed effects in the models. We first applied a model with the interaction term (treatment * Julian day) as the fixed effect, and then used a model without the interaction term, but with treatment and time as the fixed effects. In order to address whether the differences were the same across all sampling dates, we ran an analysis of covariance (ANCOVA) testing the role of treatment * time interaction (Goldberg and Scheiner, 2001). This logic was applied to determine if treatment and time were also significant *via* a competing models approach. Final models for each response variable included only the fixed effects that significantly improved model fit, and sample

ID as a random effect. All statistical analyses were completed in the software program R (R development core team, 3.0.2, Vienna, Austria).

RESULTS

$\delta^{15}N$ of inorganic and organic fertilizer was -0.3‰ and 0.7‰, respectively. For grasses, both the interaction (time * treatment) and time effect were significant for %N, with treatment being marginally significant. %N values varied from 0.8 – 2.50 %N with an overall mean of the whole dataset as 1.43% and stand deviation of 0.36 (Table 1). For all treatments, %N was significantly different over time (p=0.03, Table 3). Foliar %N of organically treated plots significantly decreased over time (Fig. 2). For $\delta^{15}N$ of grasses, there were significant effects of both fertilization treatment and time, with an increase in $\delta^{15}N$ over the growing season (p=0.04). Foliar $\delta^{15}N$ was significantly lower in organic fertilizer plots than in the inorganic and control plots throughout the growing season (p=0.04, Fig. 3.) There were significant treatment differences in foliar $\delta^{15}N$ of organic *vs*. control plots and organic *vs*. inorganic with p-values of 0.02 and 0.02, respectively (Table 3).

Table 1: Averages and ranges of Nitrogen content and isotope ratios in grasses and soils.

Dependent variable	Grasses	Soils
$\delta^{15}N$	0.06 ± 1.35 (-2.6–4.9)	0.09 ± 0.47 (-1.05–0.82)
%N *	-0.11 ± 0.37 (-1.0–1.0)	-0.03 ± 0.07 (-0.25–0.07)
NH_4^+ *	--	0.06 ± 1.78 (-.32–8.86)
Cumulative ANPP**	302.64 ± 162.75 (15–699)	--

Note. Mean ± standard deviation. Ranges are shown in parentheses. * indicates post-pre fertilization analysis was conducted on the dataset; ** indicates only post fertilization analysis was conducted on the dataset

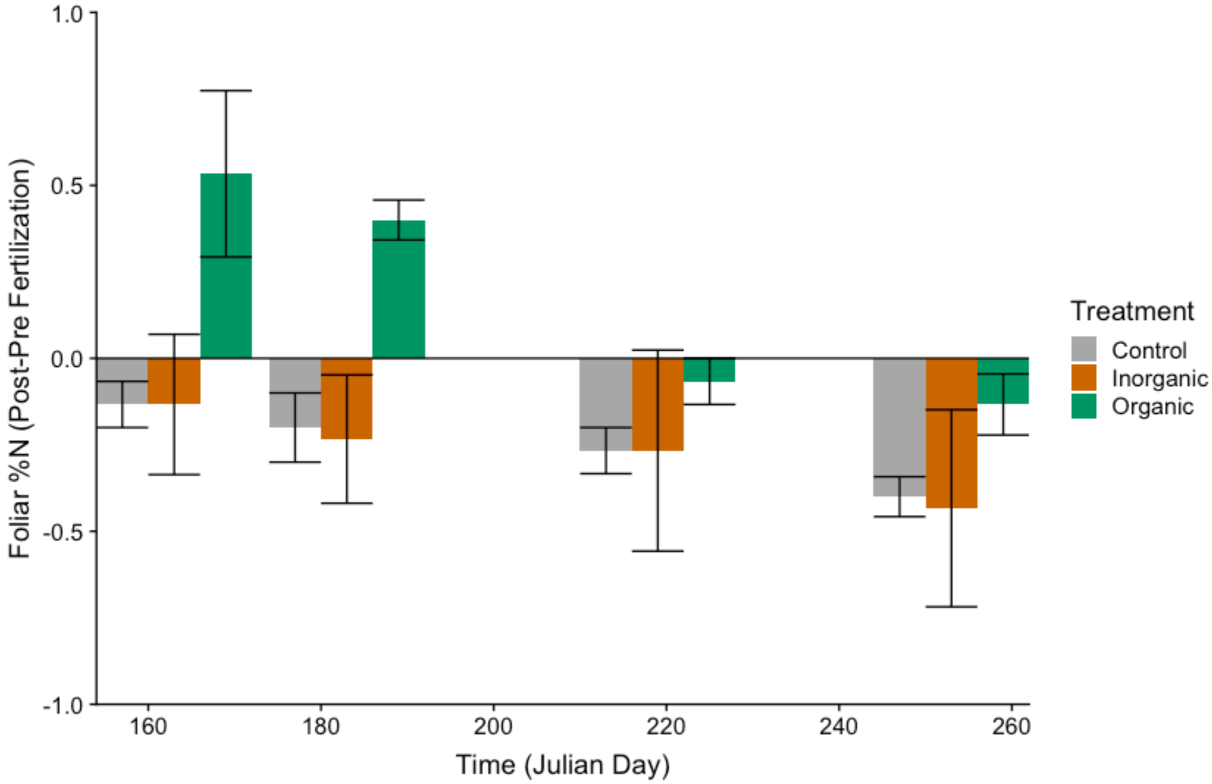

Fig 2. Post – pre fertilization %N of grasses as a function of time in Julian days. Error bars represent standard deviations. Treatments are designated in colors. Bars are averages for 3 treatment plots on given sampling (Julian) day.

Table 2: Model Selection: Table indicates what factors significantly affect change in $\delta^{15}N$, %N, NH_4^+, and ANPP following fertilization. Linear mixed effect models were used for each factor to determine significance via competing models approach. Sample ID was random effect and given factor(s) as fixed effect.

Dependent variable	Independent variable	p-value of models competing
$\delta^{15}N$ Grasses	Interaction	0.24
	Treatment	0.04
	Time (Julian Day)	0.04
	Interaction	0.01

%N Grasses*	Treatment	0.04
	Time (Julian Day)	$6.5 \cdot 10^{-6}$
δ^{15}N Soils	Interaction	0.02
	Treatment	0.12
	Time (Julian Day)	0.03
%N Soils*	Interaction	0.58
	Treatment	0.01
	Time (Julian Day)	0.72
NH_4^+soils*	Interaction	0.02
	Treatment	0.03
	Time (Julian Day)	0.12
Cumulative ANPP**	Interaction	$1.1 \cdot 10^{-5}$
	Treatment	0.98
	Time (Julian Day)	$2.2 \cdot 10^{-16}$

Note. * indicates post-pre fertilization analysis was conducted on the dataset; ** indicates only post fertilization analysis was conducted on the dataset

Table 3: Final model: table indicates p-values of linear mixed effect model output of significant response variables. Sample ID was random effect and given factor(s) as fixed effect.

		p-value		
Dependent variable	Independent variable	Inorganic *vs.* Control	Organic *vs.* Control	Inorganic *vs.* Organic
δ^{15}N Grasses	Interaction	N/A	N/A	N/A
	Treatment	0.56	0.02	0.02
	Time (Julian Day)		0.04	
%N Grasses*	Interaction	0.91	0.005	0.01
	Treatment	0.95	0.00048	0.002
	Time (Julian Day)		0.03	
δ^{15}N Soils	Interaction	0.24	0.52	0.12
	Treatment	N/A	N/A	N/A
	Time (Julian Day)		0.01	
%N Soils*	Interaction	N/A	N/A	N/A
	Treatment	0.02	0.17	0.01
	Time (Julian Day)		N/A	
NH_4^+soils*	Interaction	0.009	0.844	0.023
	Treatment	0.003	0.80	0.008
	Time (Julian Day)		N/A	
Cumulative ANPP**	Interaction	$7.8 \cdot 10^{-6}$	0.0002	0.45
	Treatment	N/A	N/A	N/A
	Time (Julian Day)		$1 \cdot 10^{-16}$	

Note. * indicates post-pre fertilization analysis was conducted on the dataset; ** indicates only post fertilization analysis was conducted on the dataset

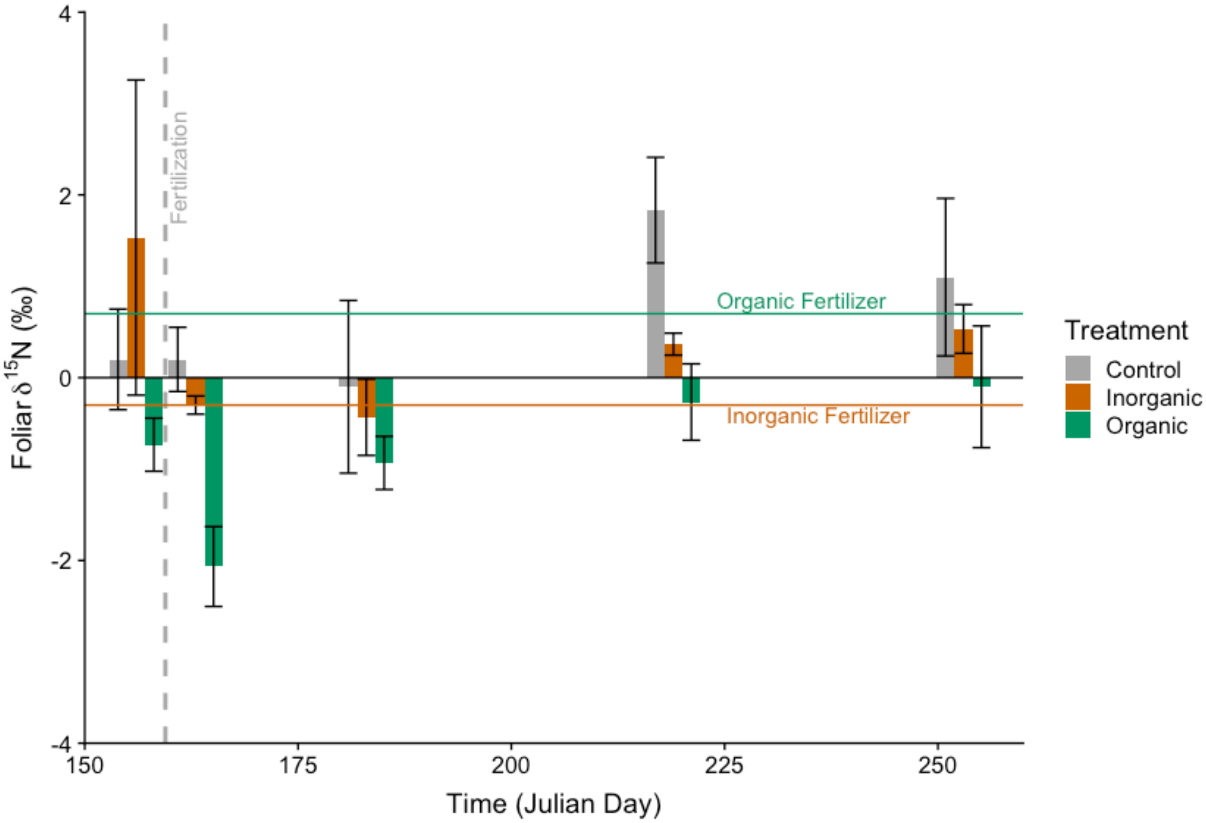

Fig. 3: $\delta^{15}N$ of grasses as a function of time in Julian days. Error bars represent standard deviations. Dashed line indicates when fertilization took place. Bars are averages for 3 treatment plots on given sampling (Julian) day. Colored horizontal lines indicate $\delta^{15}N$ values of organic and inorganic fertilizer sources.

Fertilizer treatment was significantly different for %N of soils (p=0.01), while time since fertilization (Julian day) or the interaction of these two factors was not. Inorganic *vs.* control and inorganic *vs.* organic showed significant differences with p-values of 0.02 and 0.01, respectively (Table 3). Inorganic %N content was consistently lower than pre-fertilization on all sampling dates (Fig. 4). Both the treatment * time interaction and time were significantly different for $\delta^{15}N$ of soils. There was a significant increase in soil $\delta^{15}N$ over the course of the growing season (p=0.03), and soil $\delta^{15}N$ was significantly different among treatments over time (p= 0.02; Table 2). However, treatment differences were not significant on some sampling days (p=0.12; Fig. 5). For soil NH_4^+ concentrations, there were significant interaction and treatment effects (Table 2). There were significant differences in inorganic *vs.* control plots and inorganic *vs.* organic plots with p-values of 0.003 and 0.008, respectively (Table 3).

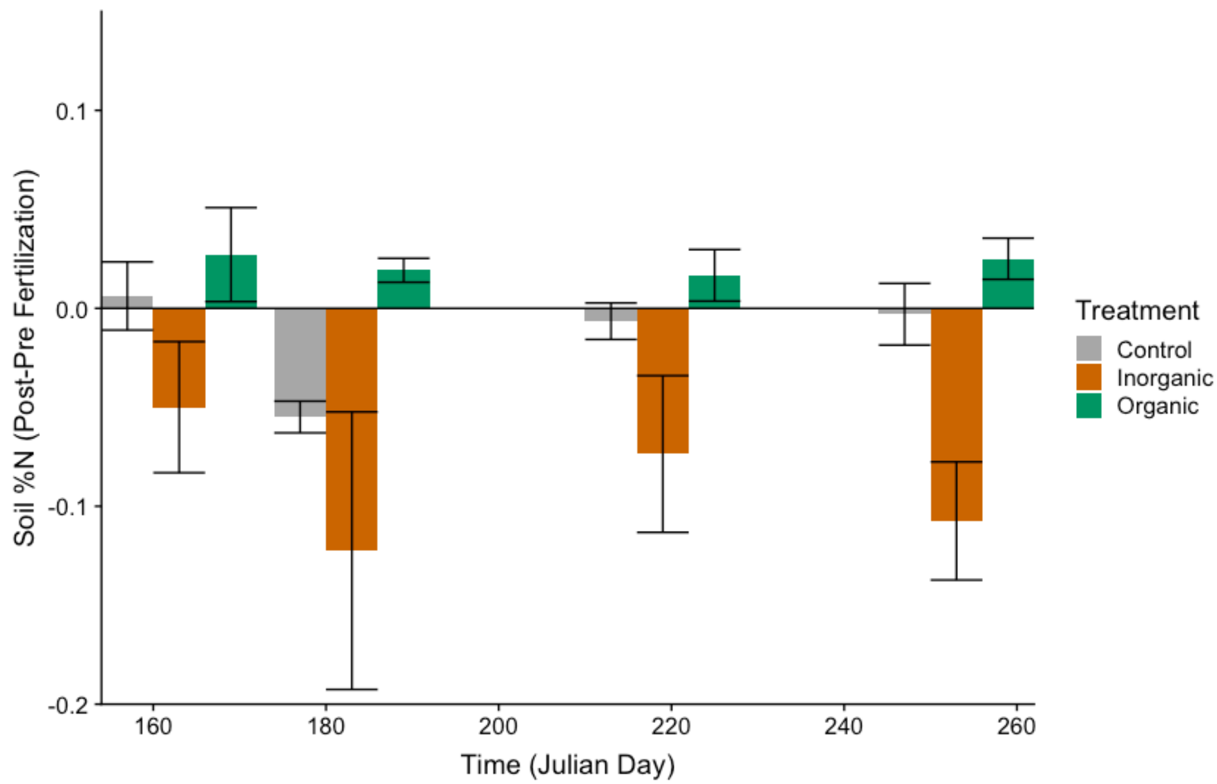

Fig. 4. Post – pre fertilization %N of soils as a function of time in Julian days. Error bars represent standard deviations. Treatments are designated in colors. Bars are averages for 3 treatment plots on given sampling (Julian) day.

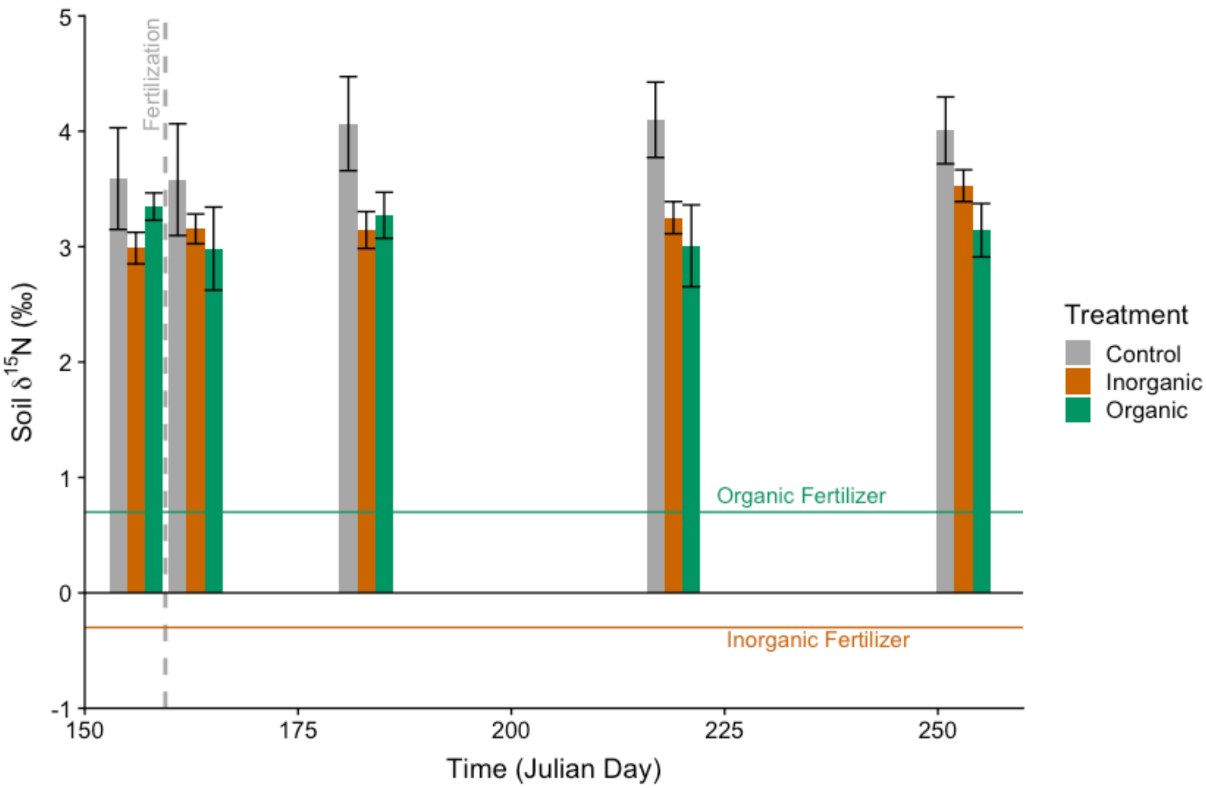

Fig. 5. Soil $\delta^{15}N$ as a function of time in Julian days. Error bars represent standard deviations. Treatments are designated in colors. Dashed line indicates when fertilization took place. Bars are averages for 3 treatment plots on given sampling (Julian) day. Colored horizontal lines indicate $\delta^{15}N$ values of organic and inorganic fertilizers.

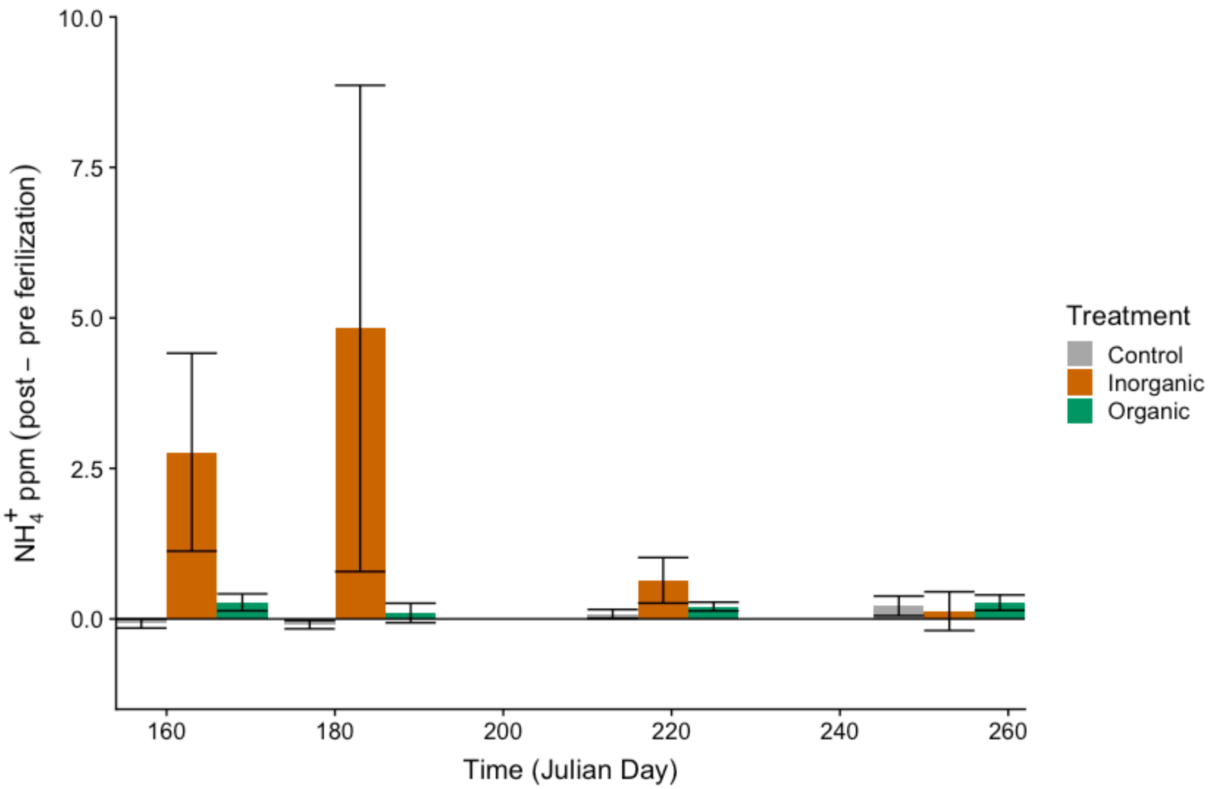

Fig 6. Post – pre fertilization NH_4^+ concentrations of soils as a function of time in Julian days. Error bars represent standard deviations. Treatments are designated in colors. Bars are averages for 3 treatment plots on given sampling (Julian) day.

Treatments were not different for ANPP (p=0.98; Table 2). However, there was a significant interaction term between treatment * time (p= $1.1 \cdot 10^{-5}$) on the model of cumulative ANPP.

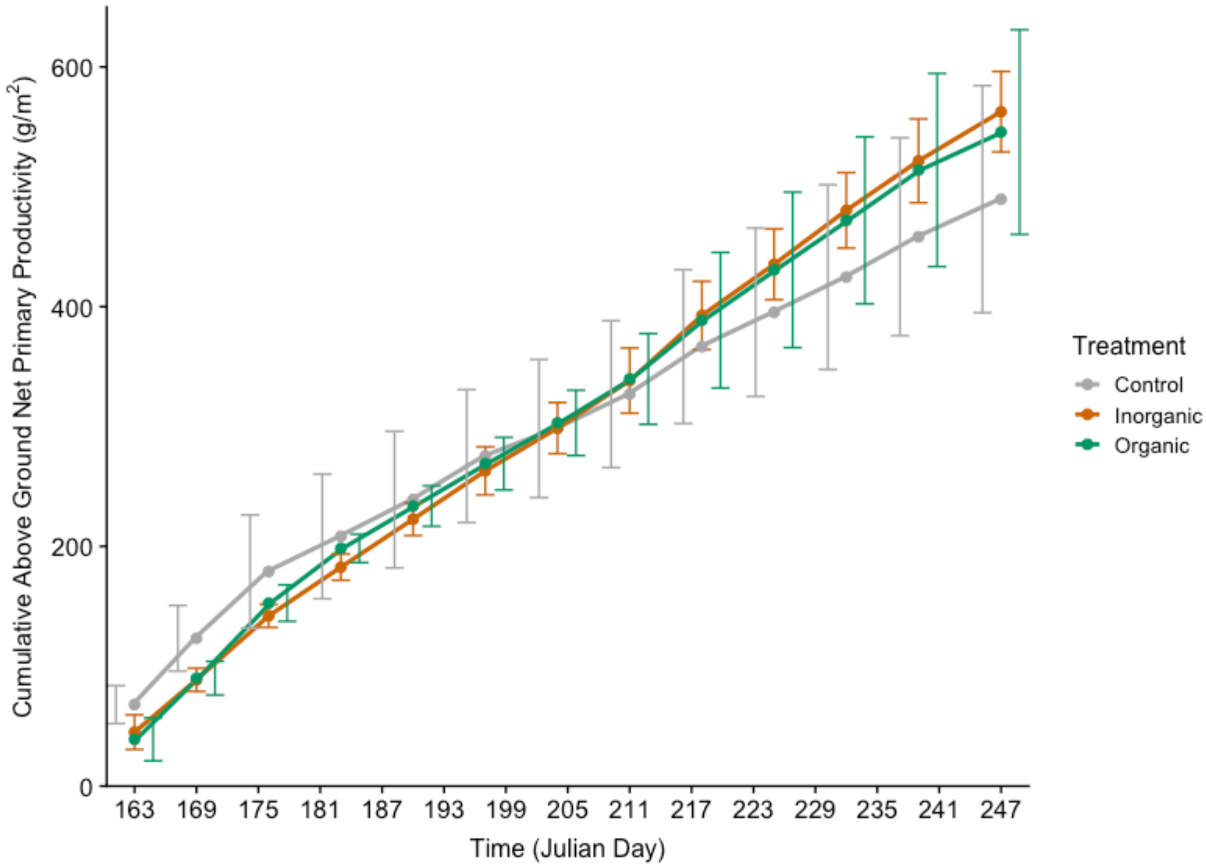

Fig 7. Cumulative ANPP as a function of time in Julian days. Error bars represent standard deviations. Treatments are designated in colors. Bars are averages for 3 treatment plots on given sampling (Julian) day, all post-fertilization.

DISCUSSION

The goal of this study was to evaluate the influence of inorganic or organic fertilizer on grass and soil N content and stable isotope ratios before and after fertilization. The results supported our hypothesis that lawn plots managed with organic fertilizer would exhibit lower leaf %N than plots managed with inorganic fertilizer, and that foliar N would decline during the growing season in all fertilized plots. However, treatment effects on $\delta^{15}N$ varied over time.

I. Grass Chemistry

To determine whether foliar N content and stable isotope composition vary as a result of fertilizer source, we compared N content and isotopic composition before and after fertilization and among fertilizer treatments. We observed a significant decrease in foliar %N over the course of the growing season, with significant decreases in organic fertilizer plots over time. Previous studies have shown that excess applications of organic fertilizer are associated with runoff and leaching of N into waterways (Good and Beatty, 2011; Eriksen *et al.*, 1999; Bergström *et al.*, 1999). Inorganic %N content of grasses was consistently lower than pre-fertilization. One explanation for the decrease in %N could be allocation of N to more aboveground or belowground biomass, although we did not find differences in ANPP across treatments ($p=0.98$, Table 2).

We observed an increase in foliar $\delta^{15}N$ over the course of the growing season (Fig. 2) This suggests that fertilized grasses acquired N with $\delta^{15}N$ close to the fertilizer source over the course of the growing season. Previous studies have reported inorganic and organic fertilizers as having $\delta^{15}N$ values between -2 and 2‰ (Kohl et al., 1971; Vitoria et al., 2004) and between +5 and 20‰, respectively. We expected to find that organic fertilizer plots would have higher foliar $\delta^{15}N$ because the organic fertilizer was slightly more enriched (0.7‰) than inorganic fertilizer (-0.3‰). However, organic fertilizer plots had significantly lower foliar $\delta^{15}N$ than inorganic and control plots throughout the growing season (Fig. 2), suggesting the isotopic composition of grasses differed from the organic fertilizer source until later in the season, like due to N cycling processes. This is contrary to our hypothesis that organically fertilized plots would exhibit more enriched $\delta^{15}N$ in plant and soil tissue due to trophic level effects of animal derived N (Bateman and Kelly 2007; Bergström *et al.,* 1999). This finding may differ from other studies due to the fact that $\delta^{15}N$ of the organic fertilizer in study was more depleted (0.7‰) compared to previously reported values (5 to 20‰) (Bedard-Haughn *et al.*, 2003; Choi *et al.*, 2003).

II. Soil Chemistry

To understand if soil N content and stable isotope ratios vary as a result of different fertilizer sources, we measured soil N content and chemistry before and after fertilization, and in response to different fertilizer treatments. We observed that the treatment effect was significant for %N of soils and inorganic bulk %N content was consistently lower than pre-fertilization %N content on all sampling days. This suggests that shortly after fertilizer application, soil decomposition and mineralization processes results in N losses. Raciti *et al.* (2008) suggested that the fate of N in lawns initially begins as immobilization in mineral soil organic matter (SOM) followed by rapid uptake and incorporation into plant and microbial biomass. We observed a significant increase in $\delta^{15}N$ over the course of the growing season for all plots. Control plots showed higher $\delta^{15}N$ than fertilized plots over the course of the growing season, contrary to our hypothesis that organically treated plots would exhibit more enriched $\delta^{15}N$ soil due to tropic level enrichment, as seen in previous studies (Choi *et al*., 2003; Bateman and Kelly 2007). We observed an increase in the soil NH_4^+ concentration of inorganic fertilizer plots following fertilization, in contrast to organic fertilizer plots which tended to maintain consistent NH_4^+ concentrations over the course of the growing season. This suggests that plants and microbes in inorganic fertilizer plots were readily able to take up the available NH_4^+ in the soil (Raciti *et al.,* 2008), supporting our hypothesis that inorganic fertilizer plots would initially exhibit higher NH_4^+ soil concentrations than control or organic fertilizer plots. In addition, volatilization of NH_4^+ in inorganic fertilizer plots may also partially explain these observations. Overall, these finding suggests lawns more effectively retain nutrients following organic fertilizer application than inorganic fertilizer application, which may result in large losses of N from inorganically fertilized lawns over the course of the growing season (Insam and Mershak 1997).

III. Cumulative Above Ground Net Primary Productivity

We found no significant treatment effect on ANPP, but there was a significant interaction effect of treatment x time. This suggests the fertilizer treatment affected ANPP differently throughout the course of the growing season, likely through N uptake utilized for grass growth. This is contrary to expectations that fertilized application – regardless of form (inorganic or organic) --would result in higher ANPP compared with control plots (Yahdjian *et al.,* 2011; Gao *et al.,* 2011). We observed that by 9 weeks post fertilization (Julian day: 211) fertilized plots (inorganic or organic) showed increased cumulative ANPP, though the differences were not statistically significant due to high variability among plots (Fig. 7).

The results from our study show that switching from inorganic to organic fertilizer would not have a significant change in the ANPP of lawns. This would suggest that the greenness of organic or inorganically fertilized plots would be similar. Based on this study, organically fertilized plots had greater N storage in soils (Fig. 4) than inorganically fertilized plots, potentially suggesting gaseous losses/volatilization of N in inorganic treated plots or N reallocation to foliar %N of inorganically treated plots (Fig. 2). This further explains the pulsating effect of increased inorganic NH_4^+ of soils following fertilization, following by a sharp decline later in the growing season (Fig. 6). By furthering our study, we could examine leaching and run-off effects following fertilization.

CONCLUSION

This study examined the effects of different fertilization treatments on grass and soil N content and stable isotope ratios and examined differences in grass growth rate between different fertilization treatments. We found that lawn plots managed with organic fertilizer had lower leaf %N than inorganic fertilizer plots, and that all fertilized plots showed a declining treatment effect on %N over time. However, treatment effects on $\delta^{15}N$ varied over time. We found that organic fertilizer plots had significantly lower foliar $\delta^{15}N$ than inorganic and control throughout the growing season. Finally, we found no differences in ANPP across treatments for plots. In this study, fertilizer treatments did not stimulate ANPP of grasses, suggesting that these lawns were not strongly N-limited prior to fertilization. This study provides an analysis of the fate of N added to urban lawns which is crucial for the management of water quality, air quality and greenhouse gas emissions.

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