Global Warming Potential of Urban Turfgrass Ecosystems

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Project Objectives

With this grant, we addressed the following questions:

1. Are turfgrass systems a net source or sink for the greenhouse gas (GHG) carbon dioxide (CO_2)?
   a. Are turf soils sequestering atmospheric CO_2 in the form of organic carbon (OC)?
   b. How does turf management for maintaining turf in the form of ornamental lawns or athletic fields, in particular the frequency of surface restoration, affect soil OC sequestration rates?
   c. What are the 'carbon costs' associated with turf maintenance? How high are CO_2 emissions resulting from gasoline use (e.g. mowers, trucks, leaf blowing equipment, tractors), fertilizer production, and irrigation?
2. Are turfgrass systems a net source or sink for nitrous oxide (N_2O), a GHG ~300 times more effective than CO_2?
   a. How high are N_2O emissions associated with fertilizer application and during periods without fertilization (background flux)?
   b. How does fertilizer type affect N_2O emissions?
   c. How does climate (soil temperature and moisture) affect N_2O emissions?
   d. How does turfgrass management (ornamental lawn vs. athletic field) affect N_2O emissions?
3. What is the net global warming potential (GWP) of urban turfgrass ecosystems in southern California?

Approach and Procedures

Study sites

The study was conducted in four parks located within a 7 km radius in Irvine, CA, USA (33°41'N, 117°47'W; MAT ~19°C; MAP 350 mm yr^{-1}). Previous to 1970, the area was under agriculture for over 100 years. Soils are loamy and formed from moderately alkaline and calcareous parent material [U.S. Department of Agriculture, 1978]. From surveys of remnant un-urbanized land, we know that these soils have very low (<1%) OC contents. The parks in the current study were established between 1975 and 2006. We assumed the parks represented a chronosequence of OC accumulation since urbanization. As with any chronosequence study, we cannot fully exclude differences in initial soil properties, but these are likely to be minor due to the close proximity of the parks to each other and because soils are scraped to bedrock before park development.

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Turfgrass management

Each park contains two turf types: ornamental lawns and athletic fields (soccer and baseball). Ornamental lawns are planted with Festuce (*Fescue* L.), which uses the C3 photosynthetic pathway. Athletic fields are covered with Bermudagrass (*Cynodon* RICH., C4) during the summer and Perennial Ryegrass (*Lolium perenne* L., C3) during the winter. Grass is trimmed and mulched weekly, and watered regularly with recycled wastewater based on local estimates of evapotranspiration. Athletic fields are subject to continuous surface restoration.

Soil OC sequestration

To assess OC sequestration, we sampled 8-12 cores to 20 cm depth in each park and each treatment every 10 m in linear transects in April of 2009. The number of samples taken in each turf type reflects the relative area covered by each type. Samples were dried at 60°C, weighed, and sieved to remove rocks >2 mm. Soil bulk density was measured on every sample and corrected for the mass of particles >2 mm. A sub-sample was ground to powder and acidified with 2M HCl for 24 hrs to remove carbonates. Total OC and nitrogen contents were quantified with an elemental analyzer (EA), and stocks were calculated using EA data and bulk density.

Carbon costs of managing urban turf

We estimate CO_2 emissions associated with the maintenance of turf from the fuel budget for the parks of the city of Irvine. Park management contractors use about 2700 gallons of gasoline per month to maintain a total park area of about 2×10^6 m^2 [Chiotti 2009, pers. Com.]. Carbon dioxide emissions from fertilizer production and for irrigation are based on literature values.

Nitrous oxide emissions

Nitrous oxide fluxes in each type of turf were quantified using 3 opaque static chambers (25 cm diameter) randomly placed atop the turf [Bijoor et al., 2008]. Chambers were kept atop turf for 28 minutes with air samples withdrawn through the top of the chamber at 7 min intervals starting at time = 0. Samples were withdrawn in 30 mL nylon syringes with plastic stopcocks and immediately transferred to pre-evacuated glass vials crimped with gray butyl rubber septa. Samples were analyzed within 24 hrs on a gas chromatograph with electron capture detector with N_2O standards bracketing expected concentrations. Fluxes were calculated from the slope of the line of N_2O concentration in each chamber vs. time. Regressions with $r^2 < 0.9$ were assumed to represent nil fluxes.

We sampled N_2O flux at an increased frequency during fertilization periods. A total of five fertilizer events were followed in both turf types, and we sampled daily starting one or two days prior to fertilization and continuing until fluxes returned to baseline levels (about 8 days). Fertilizers included sulfur-coated urea, calcium nitrate, Nitra King (19-4-4), and Turf Supreme (16-6-8).

To estimate background fluxes of N_2O, we sampled both types of turf in each of the four parks approximately once per month for one year (May 2008–2009), usually on separate days for each park. Over the entire experimental period, there was no significant difference in N_2O emissions between parks ($p < 0.05$) or turf type ($p < 0.05$), so baseline N_2O fluxes were calculated as the average of all of the flux measurements (3–12 chambers) from each measurement day. In parallel with N_2O fluxes, we measured air and soil temperature and soil moisture (at 5 cm depth).

Other measurements

In parallel with N_2O emissions, we monitored CO_2 fluxes (soil & plant respiration) using opaque, dynamic chambers (25 cm diameter, vegetation was not clipped). Respiration rates were measured by circulating the air in the chamber's headspace between the chamber and an infrared gas analyzer at a rate of 0.5 L min^{-1} (LI-8400, LI-COR Biosciences, Lincoln, NB, USA). Data was recorded with a data logger (LI-1400). Respiration rates are calculated from the slope of time vs. CO_2 concentration curves.

In addition to quantifying OC concentrations in soil samples, we also measured the stable isotope ratio ($\delta^{13}C$) of OC and the concentration and stable isotope signature ($\delta^{15}N$) of total nitrogen in each soil sample. A subset of samples from each park and turf type was analyzed for the radiocarbon content of OC.

Results

Sequestration of OC in urban turfgrass soils

A comparison of OC stocks in ornamental lawns with athletic fields along the chronosequence reveals striking differences in OC cycling (Fig. 1). Ornamental lawns had low initial OC stocks (1.2 kg C m^{-2} for the top 20 cm of soil), but sequestered OC at a rate averaging 0.14 kg C m^{-2} yr^{-1}. In contrast, athletic fields had higher initial OC contents (~3.5 kg C m^{-2}) but no consistent trend in OC content over the study period, although the oldest athletic field did have significantly more OC than the other fields ($p < 0.0001$) (Fig. 1). The difference in initial conditions can be attributed to the establishment method for the different turf types, as lawns and athletic fields at each point in Fig. 1 are located in the same park and on the same parent material. Ornamental lawns are established from seed on existing soil. Athletic fields are constructed from imported turfgrass sods that add allochthonous OC to the system, then are renovated extensively every year, including tilling and re-sodding to replace dead grass, and frequent aeration to offset compaction. Athletic field sod may have sequestered OC on the turf farm, but these fields do not store OC in situ until 30+ years after establishment.

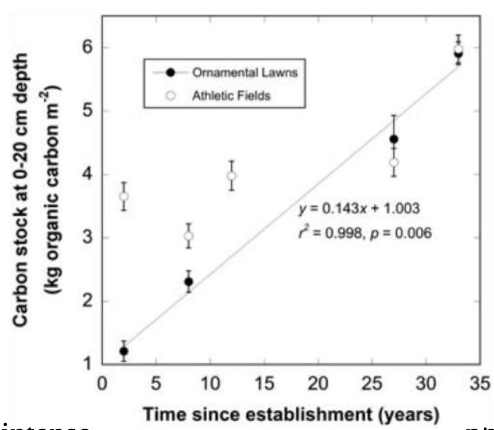

Fig. 1 Organic carbon (OC) in the top 20 cm of soil in ornamental lawns and athletic fields established within 2 and 33 years (average ± SE). There is a significant linear relationship between OC stock and lawn age in ornamental lawns (filled circles). (from Townsend-Small & Czimczik, 2010)

In the ornamental lawns, which are not subject to intense physical perturbations, the high productivity of the perennial vegetation overwhelms pre-existing differences between parks in soil type, density, and initial OC content, resulting in significant storage of OC in soils.

In contrast to OC, we found no significant accumulation of N in soils over time (ornamental lawns: $y = 0.01x + 0.17$, $r^2 = 0.85$, $p = 0.08$; athletic fields: $y = 0.008x + 0.26$, $r^2 = 0.57$, $p = 0.14$). Total N in soils was 0.35 ±0.2 kg N m^{-2} in ornamental lawns and 0.40 ±0.1 kg N m^{-2} in athletic fields (mean ± SD).

Carbon cost of managing urban turf

We assumed that one gallon of gasoline equaled 2421 g C [Environmental Protection Agency, 2005] and a combustion efficiency of 85% [Lal, 2004]. This results in CO_2 emissions from fuel usage of 122 g CO_2 m^{-2} yr^{-1}, or about 24% of the OC storage per m^{-2} shown in ornamental lawns (Fig. 3).

Pumping of irrigation water consumes energy at about 53 g C m^{-2} yr^{-1} [Schlesinger, 1999], or 193 g CO_2 m^{-2} yr^{-1} (Fig. 3b). Carbon dioxide is also formed during fertilizer production via the Haber-Bosch process and during transport and application, producing about 1.436 moles of C per mole of N produced [Schlesinger, 1999]. In the current study, this corresponds to emissions of 45 to 339 g CO_2 m^{-2} $yr^{-1}$for low and high fertilizer regimes (Fig. 3b).

Nitrous oxide emissions

The turf in the current study was a source of N_2O throughout most of the year. Soil moisture and temperature were relatively constant (20-50% of pore space), and the main driver of N_2O emissions was time since fertilizer application (Fig. 2b). There was no relationship between N_2O emissions and lawn type (ornamental vs. athletic fields), soil moisture content or soil or air temperature.

In order to estimate total annual N_2O emissions, we estimated the background flux of N_2O as well as pulses observed after fertilizer applications. To estimate background fluxes, we combined measurements from both types of turf taken more than two weeks after fertilizer applications (Fig. 2a). Fluxes ranged from ~0.5 to 33.0 ng N m^{-2} s^{-1}, within the range of values reported for agricultural grasslands (0–10 ng N m^{-2} s^{-1}) [Flechard et al., 2007]. The median N_2O flux was 2.0 ng N m^{-2} s^{-1} (Figure 2a).

To estimate the contribution of fertilizer-related N_2O emissions to the total annual flux, we measured fluxes immediately after fertilization events. Although the exact fertilizer amount applied by landscaping contractors is unknown, we were able to coordinate N_2O flux sampling with five fertilizer applications. The average increase in N_2O emissions lasted eight days and resulted in an average flux of 25.8 ng N m^{-2} s^{-1} (Fig. 2b). However, the response to fertilization was highly variable, with maximum observed fluxes of up to 200 ng N m^{-2} s^{-1}.

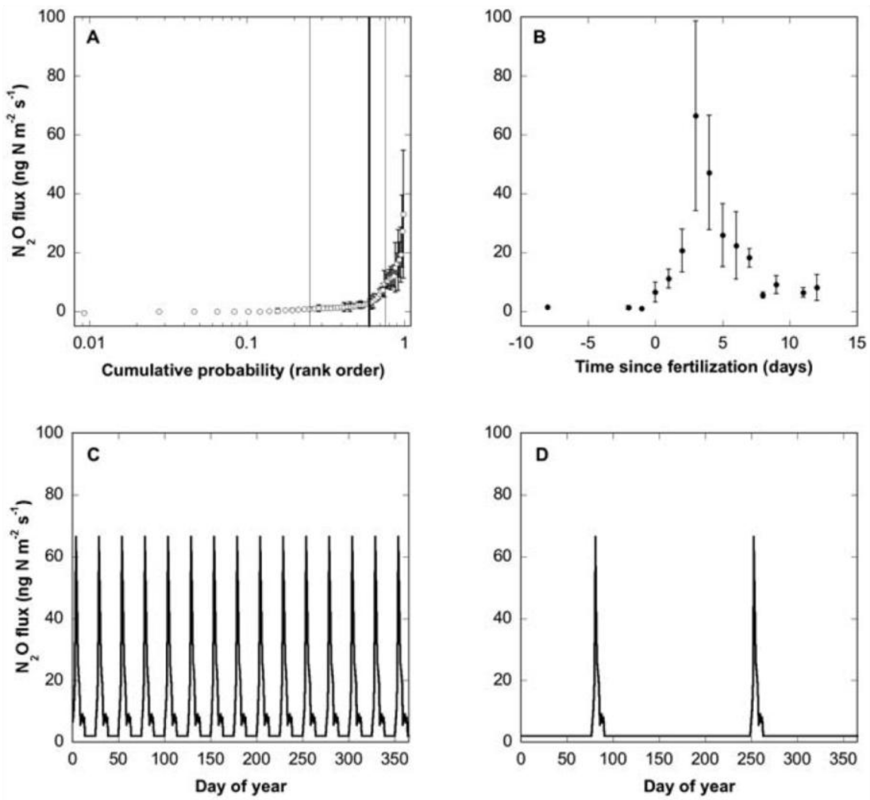

Fig. 2 (A) Background N_2O fluxes from ornamental lawns and athletic fields (average of 3–12 measurements ± SE), organized in ascending order such that a normally distributed dataset would fall along a straight line. Data are from two weeks or more after fertilization. The median N_2O flux was 2.0 ng N m^{-2} s^{-1} (dark line) with 50% of the values falling between 0.8 and 9.3 ng N m^{-2} s^{-1} (light lines). **(B)** N_2O fluxes in response to fertilizer application. Data are averages of five fertilizer chase experiments ± SE. The average response to fertilization lasted for eight days with an average flux of 25.8 ng N m^{-2} s^{-1} on each day, with low and high-end estimates (means ± SE) of 13.2 ng m^{-2} s^{-1} and 33.3 ng m^{-2} s^{-1}. **(C)** Conceptualized diagram of modeled annual flux of N_2O for a lawn that is fertilized 15 times per year. **(D)** Conceptualized diagram of modeled annual flux of N_2O for a lawn that is fertilized 2 times per year. (from Townsend-Small & Czimczik, 2010)

To estimate annual N_2O fluxes, we combined our results for N_2O pulse following fertilization with the median background flux. The City of Irvine recommends fertilizing 2 to 15 times per year at ~5 g N m^{-2} with a variety of synthetic, inorganic fertilizers.

Therefore, to estimate total annual N_2O emissions, we applied our average fertilizer pulse 15 times during the year (at 8 days for each pulse) for a high-end estimate (Fig. 2c), and twice during the year for a lower-end estimate (Fig. 2d). The remaining days were assumed to have the baseline flux of 2.0 ng N m^{-2} s^{-1}. The fertilization rate for the low-end estimate is approximately 10 g N m^{-2} yr^{-1} (2 yr^{-1} × 5 g N m^{-2}) and the high-end estimate is 75 g N m^{-2} yr^{-1} (15 yr^{-1} × 5 g N m^{-2}). Based on these estimates, the annual N_2O emissions range from 0.1 to 0.3 g N m^{-2} yr^{-1}, depending on fertilization rate (Fig. 3a).

Net GWP of urban turfgrass ecosystems in southern California

The total GWP of ornamental lawns ranges from -108 g CO_2 m^{-2} yr^{-1} for the low fertilization scenario (10 g N m^{-2} yr^{-1}) to +285 g CO_2 m^{-2} yr^{-1} for the high fertilizer scenario (75 g N m^{-2} yr^{-1}) (Fig. 3). In athletic fields, which do not store OC in soils, there is a positive GWP ranging from +405 to +798 g CO_2 m^{-2} yr^{-1} for the low and high fertilizer scenarios, respectively.

Our estimates of GWP also have errors associated with our measurements of OC sequestration and N_2O production (error bars in Figure 3). Ornamental lawn OC sequestration ranges from -513 ±37 to -513 ±73 g CO_2 m^{-2} yr^{-1}, with uncertainties estimated from calculating OC sequestration rates based on the standard error (SE) of OC stocks at each time point. Nitrous oxide emissions range from 45 ±108 to 45 ±25 g CO_2 m^{-2} yr^{-1} at a fertilization rate of 10 g N m^{-2} yr^{-1} and from 145 ±109 to 145 ±73 g CO_2 m^{-2} yr^{-1} at a fertilization rate of 75 g N m^{-2} yr^{-1}. Uncertainties in N_2O emissions were calculated from the SE of flux during 2 fertilizer pulses and the 25% or 75% interquartile of the baseline flux.

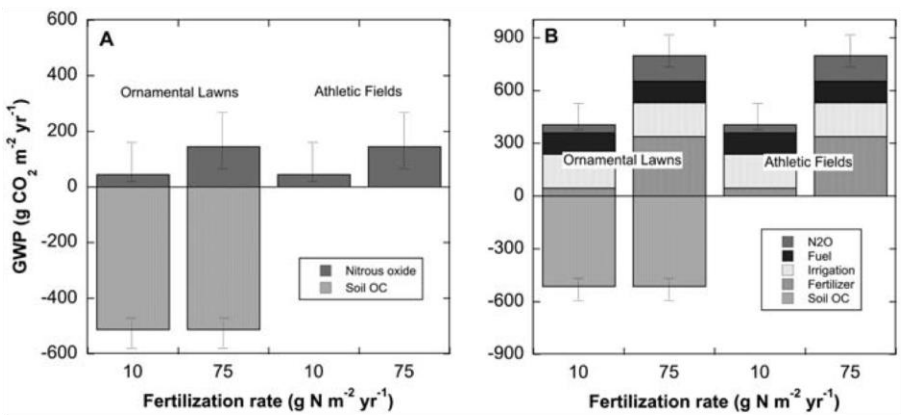

Fig. 3 (**A**) Global warming potential of soil OC sequestration and N_2O emissions in ornamental lawns and athletic fields. Error in GWP-N_2O is based on the mean fertilizer pulse ± its SE, ± the 25% or 75% interquartile of the baseline flux. Error in soil OC GWP is estimated from the mean OC stock at each time point ± SE. (**B**) Same as Fig. 3A, but including estimates of CO_2 emissions from fuel use, fertilizer production, and irrigation. (from Townsend-Small & Czimczik, 2010)

Discussion

Our study confirms that urban, ornamental lawns rapidly sequester OC [Pouyat et al., 2009]. OC accumulation in ornamental lawns in the current study is close to that observed in re-growing forests in the northeastern USA [Barford et al., 2001]. However, our study also shows that turfgrass management is key to whether OC sequestration occurs: We found no evidence for OC sequestration in soils underlying athletic that are renovated extensively every year with practices similar to those employed in conventional agriculture which disrupt soil OC accumulation [Matson et al., 1997; McLauchlan 2006].

Our study also clearly shows that urban turfgrass ecosystems significantly contribute to global N_2O emissions – in addition to agricultural sources. While our N_2O emissions (0.1 to 0.3 g N m^{-2} yr^{-1}) are substantially less than the annual N_2O flux from an intensively grazed grassland in Ireland (1.8 g m^{-2} yr^{-1}) [Scanlon and Kiely, 2003], they are higher than estimates for ungrazed, fertilized grasslands in Europe (median = 0.06 g m^{-2} yr^{-1}, range ~0.01 – 0.4 g N m^{-2} yr^{-1}) [Flechard et al., 2007].

Our annual N_2O emission estimates also fall within the range reported for urban turf in other studies (0.05– 0.6 g N m^{-2} yr^{-1}) that quantified N_2O fluxes with less spatial and temporal repetition [Guilbault and Matthias, 1998; Kaye et al., 2004; Groffman et al., 2009]. The high spatial and temporal resolution of our data provides a high degree of confidence that urban soils may represent a large portion of regional N_2O budgets. We also compared our results for N_2O emissions from ornamental lawns and athletic fields to N_2O emissions from agricultural fields in southern California (Fig. 4). We show that N_2O emissions from lawns and athletic fields are not significantly different from N_2O emissions from traditional corn agriculture. However, we do show that emissions from these three types of land cover are significantly greater than emissions from other row crops sampled at a small agricultural station (Fig. 4). These “other row crops” were fertilized at a significantly lower rate than the other three types of crops. The row crops were also fertilized with inorganic N dissolved in irrigation water, which may promote lower N losses as N_2O as compared with dry fertilizer application.

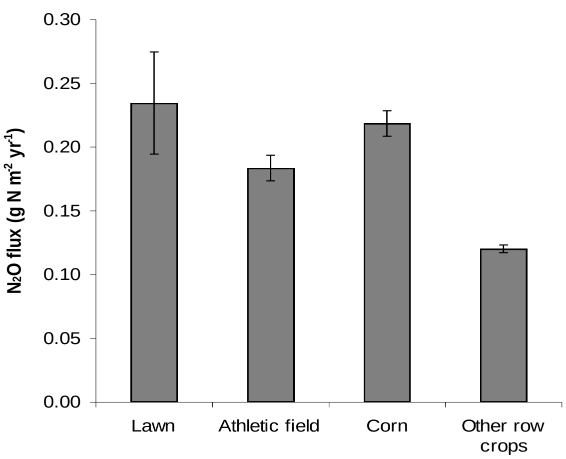

Fig. 4. Annual N_2O emissions from four types of fertilized land cover in southern California, USA. (from Townsend-Small et al., in review)

In coastal southern California, there may be a potential for urban ornamental lawns to be carbon neutral or even to sequester atmospheric CO_2 if they are managed conservatively. However, intensive management practices such as frequent application of inorganic fertilizers, irrigation, and fuel consumption from mowing and leaf blowing all decrease the likelihood that urban turfgrass ecosystems can mitigate greenhouse gas emissions in cities. More studies are needed to better constrain the carbon costs associated with turf management in different climatic regions and for different turfgrass species and soil types.

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