The effects human management on urbanized lawns with respect to nitrous oxide

Elizabeth de la Reguera\textsuperscript{1}

Mentor: Jim Tang\textsuperscript{2}

Semester in Environmental Science: Marine Biological Laboratory

\textsuperscript{1}Dickinson College, Carlisle, PA

\textsuperscript{2}Marine Biological Laboratory

17 December 2012
Abstract

Lawns are a dominant cover type in the United States. New England over the past 30 years has had a rise in suburban and urban lawns, which typically means fertilizer usage and mowing practices. An account was taken of three properties that fertilize their lawns and remove grass clippings, three that fertilize and leave grass clippings, three that don’t fertilize and remove clippings, and three that don’t fertilize and leave clippings, as well as an unmanaged grassland. Soil cores of 5cm samples were taken from each site, analyzed, and incubated for 20 days to determine net mineralization and nitrification rates. Three gas flux measurements (nitrous oxide and carbon dioxide) were taken a total of nine times per house over a 3-week time frame. Lawns that were not fertilized and had clippings removed had the highest net mineralization and nitrification rate followed by lawns that are not fertilized and clippings left. Nitrous oxide fluxes were highest in lawns that are not fertilized and have clippings left, followed by lawns that are not fertilized with their clippings removed. These findings illustrated that lawns that are not fertilized are possibly nitrogen deprived and losing nitrogen to leaching or the release of nitrous oxide. The data also illustrates the complexity of lawns and the need for further research in urbanization of lawns with a focus on management practices.

Keywords: urban lawns, mineralization, nitrification, turfgrass, grassland, nitrous oxide, soil, Cape Cod MA
Introduction

Urbanized lawns have been growing rapidly in the United States. Between 1982 and 1997, the extent of urbanized land has increased 47% in the United States (Fulton et al. 2001). In New England over the past 30 years, there’s been a decline in agricultural crop production and an increase in urban and suburban development. With the new development comes the replacement of cropland with turf (Guillard, Kopp 2004).

With a rise in urbanized lawns, come management practices. There are various components to managing a lawn, depending upon the geographical location. In New England and other places, typical practices include irrigation, herbicide and pesticide use, lime application, fertilization, and mowing. Different management practice regimes result in different outcomes of lawns; how they look. There’s assumed pressure to have a well-manicured lawn, which includes no weeds or brown patches, uniformly cut grass, as well as a green lawn. However, there is also a stigma with using fertilizer, herbicides, and pesticides because of their environmental impact. These components affect the nitrogen cycle because they add a significant amount of nitrogen to the soil. Residential systems typically receive higher nitrogen inputs than a natural system but also have a significant nitrogen loss, especially when overwatered and overfertilized (Raciti et al. 2011). By adding excess nitrogen into the system, it’s expected to increase mineralization and nitrification, which leads to increased denitrification. An increase in denitrification comes an increase in N₂O and NO release into the atmosphere. It is believed that denitrification could be an important pathway of nitrogen loss in lawns. It was seen at the Baltimore Long Term Ecological Research that there was significantly higher N₂O fluxes after 9 days from fertilizer application. This suggests that over long periods of fertilization of lawns, there’s a significant increase in N₂O fluxes. N₂O is “produced during microbial nitrification and denitrification and has a global
warming potential that is 298 times greater than CO$_2$ on a 100 year timescale” (Townsend-Small et al. 2011).

Although urbanized lawns and nitrogen fluxes have been relatively well studied, not much focus has been put on the affects of leaving or removing grass clippings. Different mowing practices can affect the nitrogen loss based on what is done with the grass clippings (Qian et al. 2003). It was stated that the “nitrogen in clippings returned to a turf system is not available to turfgrass until it is incorporated into soil organic matter and released via mineralization”.

In this study, the varying management practices examined were fertilized lawns that have their biomass removed after mowing, lawns that were fertilized and had the biomass left, lawns that are not fertilized and have the biomass removed after mowing, and lawns that are not fertilized and the biomass is left. The objectives were (a) to quantify net mineralization and nitrification rates amongst four managed lawns and one unmanaged grassland, (b) to evaluate N$_2$O fluxes of sampling sites, and (c) to compare managed lawns to an unmanaged grassland.
Methods

Study Site

This study was conducted within Cape Cod, Massachusetts during the month of November 2012 and first week of December 2012. Twelve homeowner’s lawns were chosen for the study as well as the Sandplain Grassland in the Frances A. Crane Wildlife Management Area. The lawns that were chosen were based off of data collected last year from a student participating in the Semester in Environmental Science at the Marine Biological Laboratory. The student had conducted a survey of approximately fifty homeowners in Falmouth and Woods Hole Massachusetts regarding the management of their lawns. This information allowed me to select homeowners for further inquiry of their lawn management for my study. Questions that were asked of the homeowners included how often their lawn was mowed in season and what they did with their grass clippings. They were also asked if they used fertilizer and if so, how often they fertilized. Whether they had an irrigation system or not and how often it was used was also an inquiry made, along with whether herbicides or pesticides were used on their lawn and if they apply lime.

Experimental design

There were four management practices with three properties per practice, fertilization of lawns and removal of biomass, fertilization and leaving of biomass, no fertilizer and removal of biomass, and no fertilization and leaving of biomass (Fig 1). The homes were in Woods Hole, Falmouth, and Pocasset in Massachusetts.

Measurements

Measurements were made on Sundays and Mondays starting on November 11 and ending on December 4, 2012. Six homes and the Sandplain Grassland were visited on Sunday and the remaining six houses were visited on Monday. Three soil cores from each property were taken on
the first visit out into the field, which was later used for the net nitrogen mineralization and nitrification rates. The soil cores had a volume of 287.27 cm$^3$. Each visit out into the field, three gas flux measurements at each location were taken with a Li-Cor 7000 CO$_2$/H$_2$O analyzer and the Los Gatos Research N$_2$O/CO Analyzer. The nitrous oxide and carbon dioxide effluxes were determined by multiplying the slope of the gases (dCv/dt) by the gas equation (PV/RAT). Temperature of the soil and the air were taken with a soil thermometer. The soil moisture was measured using a HydroSense II Soil Moisture Content Sensor.

Lab analysis

Upon collection of soil cores, the fresh weight of the core was weighed and recorded along with the pH of each sample. The soils were homogenized. An aluminum tin’s weight was recorded and then approximately 10g of wet soil was added to the tin. The weight was recorded and this was done for all samples. The tins were placed in a drying oven to be dried for at least 24 hours. The samples were then placed in an incubator at 60 degrees C for 20 days. The weight of the oven-dried soil was then measured which allowed for a determination of approximate soil moisture. A 140mL plastic cup was tarred and about 15g of wet soil was added and the weight was recorded. Then 100mL of 1M KCl was added to each cup as well as to five empty cups being used as blanks. All cups were placed in a shaker for one hour and then left to sit overnight to settle. The KCl extraction was withdrawn with a syringe filter (~50-60 mL) and then filtered using a swinnex with GFF ashed filter (~20mL) into a scintillation vial. The samples were frozen until analysis for NO$_3^-$ and NH$_4^+$ were ready. Ammonium was run the following day on a spectrophotometer and nitrates the following week on the Lachat QuikChem 8500 Series 2 FIA System. After 20 days, I repeated the same soil analyses of the incubated soil: KCl extraction, ammonium, and nitrate.
Results

Net nitrogen mineralization and nitrification rates

Each management practice of lawns had varying net nitrogen mineralization and nitrification rates. The time of incubation was 20 days and the growing season is assumed to be 180 days. For homes that fertilize their lawn and remove their grass clippings, the net N mineralization rate ranged from 8.7 to 1.6 gN m\(^{-2}\) yr\(^{-1}\) and the net nitrification rate ranged from 0.1 to 0.9 gN m\(^{-2}\) yr\(^{-1}\) (Fig 2a). The house on Tamarack Rd had a net mineralization rate of 8.7 gN m\(^{-2}\) yr\(^{-1}\) and a net nitrification rate of 0.1 gN m\(^{-2}\) yr\(^{-1}\). The mineralization rate at the lawn on Spinnaker Ln was 4.3 gN m\(^{-2}\) yr\(^{-1}\) and the nitrification rate was 0.9 gN m\(^{-2}\) yr\(^{-1}\). At the house on Marla Ln, the net mineralization rate was 1.6 gN m\(^{-2}\) yr\(^{-1}\) with a net nitrification rate of 0.3 gN m\(^{-2}\) yr\(^{-1}\). For all three houses, the net mineralization rate was significantly larger than the net mineralization rate. Figure 2b shows the net mineralization and nitrification rates of houses that fertilize their lawn and leave their grass clippings. The net mineralization and nitrification rates (1.0 gN m\(^{-2}\) yr\(^{-1}\) and 2.0 gN m\(^{-2}\) yr\(^{-1}\)) for Lawrence Farm and Greenwood are similar. Heather Ln is the only system where the net mineralization and nitrification rate are the same (0.2 gN m\(^{-2}\) yr\(^{-1}\)). Homes that do not use fertilizer on their lawn and remove their biomass follow similar trends amongst themselves (Fig. 2c). The net mineralization rate for Green Acres was 20.2 gN m\(^{-2}\) yr\(^{-1}\), for Lakeview it was 50.6 gN m\(^{-2}\) yr\(^{-1}\), and for Old Campus it was 38.6 gN m\(^{-2}\) yr\(^{-1}\). The net nitrification rates were 3.9 gN m\(^{-2}\) yr\(^{-1}\) for Green Acres, 5.8 gN m\(^{-2}\) yr\(^{-1}\) for Lakeview, and 3.4 gN m\(^{-2}\) yr\(^{-1}\) for Old Campus. The net mineralization rate for all three houses was an approximate 10-fold increase from the net nitrification rates. Figure 2d are homes that do not fertilize and leave their grass clippings, Little Island, James, and Sheeps Crossing. These three houses followed a different trend amongst each other. Little Island had a net mineralization rate of 11.0 gN m\(^{-2}\) yr\(^{-1}\) and a net nitrification rate of 7.5 gN m\(^{-2}\) yr\(^{-1}\). James’ net mineralization rate was 7.1
gN•m⁻²•yr⁻¹ and the net nitrification rate was -0.7 gN•m⁻²•yr⁻¹. Sheeps Crossing’s soil had a net mineralization rate of 7.1 gN•m⁻²•yr⁻¹ and a net nitrification rate of 1.6 gN•m⁻²•yr⁻¹. The Sandplain Grassland has no management in comparison to the twelve homes; there’s no mowing or fertilization of the Sandplain Grassland. The net nitrogen mineralization rate was 2.7 gN•m⁻²•yr⁻¹ and the net nitrification rate was 0.2 gN•m⁻²•yr⁻¹ (Fig. 2e).

In figure 3, the net nitrogen mineralization rate and nitrification rate was averaged amongst each treatment to equal an overall average for each management practice. Homes that don’t fertilize and remove their biomass have the greatest net mineralization (36.5 gN•m⁻²•yr⁻¹) and nitrification rate (4.4 gN•m⁻²•yr⁻¹) compared to all other management practices. Homes that don’t fertilize and leave their biomass have the second highest nitrification and mineralization rates (8.4 gN•m⁻²•yr⁻¹ and 2.8 gN•m⁻²•yr⁻¹). Homes with the lowest net nitrification and mineralization rates are ones that fertilize and leave their biomass after mowing. The net mineralization rate was 0.7 gN•m⁻²•yr⁻¹ and the net nitrification rate was 0.2 gN•m⁻²•yr⁻¹. The Sandplain Grassland net nitrification rate was only marginally higher than homes that fertilize and leave their biomass (0.3 gN•m⁻²•yr⁻¹). The net mineralization rate of the Sandplain Grassland was 2.7 gN•m⁻²•yr⁻¹. Homes that fertilize and remove their grass clippings after mowing had a net mineralization rate of 4.9 gN•m⁻²•yr⁻¹ and a net nitrification rate of 0.5 gN•m⁻²•yr⁻¹.

The amount of extractable nitrogen from the soil is an indicator of how much leachable nitrogen is present (Fig 4). Lawns that have not been fertilized and have their biomass removed or left have the highest extractable nitrogen from ammonium (4.0 gN•m⁻²•yr⁻¹). Lawns that aren’t fertilized and have the biomass left have the highest extractable nitrogen from nitrate (2.31 gN•m⁻²•yr⁻¹). The Sandplain Grassland had the lowest extractable nitrogen from both ammonium and nitrate compared to the managed lawns (2.70 gN•m⁻²•yr⁻¹ and 0.2 gN•m⁻²•yr⁻¹). Lawns that are fertilized and have the biomass removed have the second lowest extractable nitrogen from
ammonium (3.29 gN•m^{-2}•yr^{-1}), followed by fertilized lawns with the leaving of biomass (3.5 gN•m^{-2}•yr^{-1}). The nitrogen extractable from nitrate was lowest at the Sandplain Grassland, then fertilized lawns with the removal of biomass (0.37 gN•m^{-2}•yr^{-1}), followed by fertilized lawns with the leaving of biomass (1.8 gN•m^{-2}•yr^{-1}), and then non-fertilized lawns with the removal of biomass (2.03 gN•m^{-2}•yr^{-1}).

Gas Fluxes

Carbon dioxide and nitrous oxide were varying gas fluxes across each treatment and within different management practices. The Sandplain Grassland where there is no management was respiring at 1.9 micromol•m^{-2}•sec^{-1} and the nitrous oxide flux was .041 nanomol•m^{-2}•sec^{-1} (Fig 5a). Lawns that fertilize and leave their biomass, the properties on Lawrence Farm Rd and Greenwood St still have their systems photosynthesizing late in the season (-0.52 nanomol•m^{-2}•sec^{-1} and -2.26 nanomol•m^{-2}•sec^{-1}) (Fig 5b). The property on Heather Ln is the only one respiring (0.1 nanomol•m^{-2}•sec^{-1}). The nitrous oxide fluxes of these properties are less than 0.04 nanomol•m^{-2}•sec^{-1}. In figure 5c, it can be seen that the properties that fertilize and remove biomass, their systems are all respiring; the property on Tamarack Rd had a carbon dioxide flux of 0.58 micromol•m^{-2}•sec^{-1}, on Marla Ln it was 0.65 micromol•m^{-2}•sec^{-1}, and on Spinnaker Ln it was 1.98 micromol•m^{-2}•sec^{-1}. The nitrous oxide fluxes of all three properties are significantly lower than carbon dioxide fluxes. Properties that do not fertilize their lawns and leave the biomass are all respiring but have a higher nitrous oxide flux in comparison to the other managements (Fig 5d). The property on Sheeps Crossing Ln had a nitrous oxide flux of 0.28 nanomol•m^{-2}•sec^{-1}, the system on James St was 0.21 nanomol•m^{-2}•sec^{-1}, and the one on Little Island Rd was 0.037 nanomol•m^{-2}•sec^{-1}. All properties were respiring as expected, but at a higher flux than other managements; Little Island was 3.24 micromol•m^{-2}•sec^{-1}, James was 2.46
micromol•m⁻²•sec⁻¹, and Sheeps Crossing was 1.87 micromol•m⁻²•sec⁻¹. In figure 5e, the gas fluxes of homes that do not fertilize their lawns and remove biomass can be seen. The systems at both Green Acres Rd and Lakeview Ave are respiring (2.3 micromol•m⁻²•sec⁻¹ and 2.8 micromol•m⁻²•sec⁻¹) but at the property on Old Campus Dr, the system is photosynthesizing (-0.65 micromol•m⁻²•sec⁻¹). The nitrous oxide fluxes were low in comparison to the other systems that do not fertilize but leave biomass; Green Acres was 0.06 nanomol•m⁻²•sec⁻¹, Lakeview was 0.10 nanomol•m⁻²•sec⁻¹, and Old Campus was 0.02 nanomol•m⁻²•sec⁻¹.

Figure 6 shows the average gas fluxes of all management practices. It can be seen that systems that fertilize and leave biomass are photosynthesizing (-0.89 micromol•m⁻²•sec⁻¹) unlike all other systems that are respiring. The systems that are not fertilized biomass left had the highest carbon dioxide flux (2.52 micromol•m⁻²•sec⁻¹), and then the Sandplain Grassland (1.90 micromol•m⁻²•sec⁻¹). Systems that do not fertilize and remove biomass had a carbon dioxide flux of 1.47 micromol•m⁻²•sec⁻¹, which was followed by systems that are fertilized and biomass removed (1.07 micromol•m⁻²•sec⁻¹). The management practice that had the greatest nitrous oxide flux was the no fertilization and leaving of biomass (0.18 nanomol•m⁻²•sec⁻¹), followed by systems that do not fertilize and remove biomass (0.06 nanomol•m⁻²•sec⁻¹). Systems that fertilized and either removed or left the biomass had the same nitrous oxide flux (0.02 nanomol•m⁻²•sec⁻¹), which was then followed by the Sandplain Grassland, which had a nitrous oxide flux of 0.04 nanomol•m⁻²•sec⁻¹.

Soil temperature and soil moisture were measured out in the field (Fig 7). The Sandplain Grassland had the coldest soils on average (8.8 degrees C), which was followed by non-fertilized lawns that remove biomass (10.9 degrees C). Systems that are fertilized and have the biomass left (11.6 degrees C) was cooler than systems that are no fertilized and have biomass left (11.8 degrees C). The warmest soils on average were of lawns that are fertilized and have biomass...
removed. Soil moisture was the highest in non-fertilized systems that remove biomass (21%). Systems that were fertilized had the same soil moisture (17.1%), which was greater than the Sandplain Grassland (15.6%). The system that had, on average, the least soil moisture were systems not fertilized and biomass left (15.5%).

**Discussion**

*Net nitrogen mineralization and nitrification*

The results of this study suggest that lawns that are not fertilized and have their grass clippings removed have one of the highest amounts of extractable nitrogen (leachable N) and has the highest net mineralization rate by a four-fold. There is no specific explanation for why lawns that are not fertilized and have their biomass removed have such an extraordinarily high net mineralization and nitrification rates. Fertilizers are typically ammonium or nitrate based so it would be expected that lawns which are fertilized, have a high stock of nitrogen, but that’s not the case with this study. What was not accounted for was the type of fertilizer used (organic or inorganic). This differentiation between them could have an affect on the mineralization and nitrification rates because organic fertilizer would typically result in a higher mineralization rate. Ammonium based inorganic fertilizer would result in a higher net nitrification rate and nitrate based inorganic fertilizer would result in minimal net nitrification rate since the fertilizer is primarily nitrified already.

The three houses that fertilize their lawns and remove their grass clippings have a greater mineralization rate than homes that fertilize their lawns and leave their grass clippings. These results suggest that perhaps the microbes need to decompose any and all organic matter faster in order to provide grass with enough ammonium. This also could mean that systems not fertilized are nitrogen deprived and the microbes need to work more to provide the grass with nitrogen. It is
possible that the fertilized lawns are also nitrogen deprived but since they’re receiving fertilizer, the microbes are not working as hard to break it down. This could also explain why there is minimal leaching since the grass is taking up all of the nitrogen.

An aspect that was not accounted for in the survey was the type of grass the systems primarily had. Turfgrass requires more nitrogen than crabgrass and if different species were competing for nitrogen, mineralization and nitrification rates would be higher in those systems. Another possible reason the rates are lower for lawns that have left their biomass is because when biomass is initially introduced into the system, it immobilizes nitrogen out of the system. Depending on the last time the lawns were mowed and how long it takes for the biomass to be incorporated into the soil and decomposed, the mineralization rate could be higher later in the year. The Sandplain Grassland, which has no management practices implemented, has a greater net mineralization and nitrification rate compared to lawns that fertilize and leave their biomass. With no management, the only notable input of nitrogen is N deposition so it would be expected that the net mineralization and nitrification rate would be lower than lawns with fertilizer added to them but the Sandplain Grassland’s net mineralization rate and nitrification rate is lower than fertilized lawns that remove their biomass.

Lawns that have the most leachable nitrogen are ones that do not have fertilizer. The Sandplain Grassland has the least amount of leachable nitrogen, which is what was expected because there is no additional input of nitrogen into the soil, unlike fertilized lawns. It’s unexpected that lawns that are fertilized have smaller amounts of leachable nitrogen than unfertilized lawns, especially fertilized lawns with the leaving of biomass. This is because fertilizer is an additional amount of nitrate to the system, as well as biomass, which also contains nitrogen, so it would be expected that excess amounts of nitrate would not be retained within the soil and would begin leaching, but that does not seem to be occurring. It is believed that lawns
decrease the capability of retaining nitrogen as they age which could mean that the fertilized lawns are not as old as unfertilized lawns (Porter et al. 1980, Frank et al. 2006). There is no discernible reason why lawns that are not fertilized and have their biomass removed have such a high net mineralization rate and nitrification rate, as well as a significant amount of leachable nitrogen from the soil.

Gas fluxes

The majority of the systems that were looked at were respiring when the gas flux measurements were taken which is as expected. Being late in the season, November, plants are no longer photosynthesizing. Some systems still were which I’m unable to explain. It’s possible that there were sampling errors with the machine such as a leak between the chamber and collar or the collar and lawn.

The nitrous oxide fluxes are more interesting since they were not as anticipated. The management treatment with the greatest nitrous oxide flux was the unfertilized system that left biomass. It’s been assumed that this treatment was the best for the environment but its nitrous oxide flux is greater than that of an unmanaged location. However, the Sandplain Grassland is predominantly golden rod, not crabgrass or turfgrass. This could have some bearing on the nitrous oxide flux in comparison to urbanized lawns because of the various plant communities. It’s possible that not only does the denitrification and nitrification processes have an affect on nitrous oxide fluxes but also the plant species. However, based on the nitrification rates of the treatments, it’s reasonable that the nitrous oxide flux follows the same trends in unfertilized lawns. The nitrification process releases nitrous oxide from the system and the greatest net nitrification rates were in lawns that are not fertilized.
Conclusion

My hypothesis that no fertilization and leaving of biomass would reduce the flux of nitrous oxide was incorrect. It was also incorrect that no fertilizer and leaving of biomass would have a lower net nitrification and mineralization rate. The nitrous oxide fluxes are positively associated with nitrification rates, which were supported with my data. The data also shows that not fertilizing one’s lawn increases the net mineralization and nitrification rate, along with nitrous oxide fluxes. The data does not however justify fertilizing lawns; it shows that more research needs to be done in order to understand what else is going on in urbanized lawn systems. This study was done in November and December when there is no fertilizer application or mowing. A more extensive fertilization survey to quantify the amount of fertilizer used and what type would be beneficial. Accounting for the different grass species would also be valuable to further understand if one type requires more nitrogen and if there’s competition amongst the species.

Collaborators

Alice Carter, Kenneth Forman, Alexandra Guest, Carolynn Harris, Richard McHorney, Kate Morkeski, Christopher Neill, Timothy Savas.

Acknowledgements

Thank you to all the homeowners in Cape Cod that participated in the survey. A special thank you to the homeowners who allowed me on their lawn to take gas flux measurements and soil core samples three times.
Literature Cited


**Figures**

Figure 1: Experimental design of the four management practices with three properties per each treatment.

<table>
<thead>
<tr>
<th>Leave clippings</th>
<th>Remove clippings</th>
</tr>
</thead>
<tbody>
<tr>
<td>No fertilizer</td>
<td>Tamarack Rd</td>
</tr>
<tr>
<td>Greenwood St</td>
<td>Spinnaker Ln</td>
</tr>
<tr>
<td>Heather Ln</td>
<td>Marla Ln</td>
</tr>
<tr>
<td>Little Island Rd</td>
<td>Green Acres Rd</td>
</tr>
<tr>
<td>James St</td>
<td>Lakeview Ave</td>
</tr>
<tr>
<td>Sheeps Crossing Ln</td>
<td>Old Campus Dr</td>
</tr>
</tbody>
</table>
Figure 2a: Net nitrogen mineralization and nitrification rate (gN/m²/yr) of three homes, one on Tamarack Rd, East Falmouth one on Spinnaker Ln, Pocasset, and one Marla Ln, East Falmouth. These homes fertilize their lawn and remove their biomass after mowing.
Figure 2b: The net nitrogen mineralization rate and nitrification rate (gN/m$^2$/yr) of three homes, one of which is on Lawrence Farm Rd, Woods Hole, one on Greenwood St, East Falmouth, and one on Heather Ln, North Falmouth. These homes fertilize their lawn and leave their grass clippings after mowing.
Figure 2c: The net nitrogen mineralization and nitrification rates (gN/m²/yr) of three homes, one on Green Acres Rd, East Falmouth, one on Lakeview Ave, Falmouth, and one on Old Campus Dr, East Falmouth. These three homes do not fertilize their lawns and remove their biomass after mowing.

![Bar chart showing net nitrogen rates for Green Acres, Lakeview, and Old Campus streets.](chart.png)
Figure 2d: The net nitrogen mineralization and nitrification rates (gN/m^2/yr) of three homes, one on Little Island Rd, West Falmouth, one on James St, Woods Hole, and one on Sheeps Crossing Ln, Woods Hole. These three homes do not fertilize their lawns and leave their biomass after mowing.

No fertilization and leaving of biomass

<table>
<thead>
<tr>
<th>Street</th>
<th>Net N mineralization rate</th>
<th>Net nitrification rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Little Island</td>
<td>12.0</td>
<td>6.0</td>
</tr>
<tr>
<td>James</td>
<td>4.0</td>
<td>-2.0</td>
</tr>
<tr>
<td>Sheeps Crossing</td>
<td>6.0</td>
<td>2.0</td>
</tr>
</tbody>
</table>
Figure 2e: The net N mineralization and nitrification rate (gN/m$^2$/yr) of the Sandplain Grassland at the Frances A. Crane Wildlife Management Area in Cape Cod, MA.
Figure 3: The average net nitrogen mineralization and nitrification rate (gN/m²/yr) of the three homes in each management practice, and the Sandplain Grassland.

Average net mineralization and nitrification rate amongst all treatments

<table>
<thead>
<tr>
<th></th>
<th>Net N mineralization rate</th>
<th>Net nitrification rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sandplain Grassland</td>
<td>2.7</td>
<td>36.5</td>
</tr>
<tr>
<td>Fertilize and leave</td>
<td>0.3</td>
<td>0.7</td>
</tr>
<tr>
<td>Fertilize and remove</td>
<td>4.9</td>
<td>0.2</td>
</tr>
<tr>
<td>No fertilizer and leave</td>
<td>8.4</td>
<td>2.8</td>
</tr>
<tr>
<td>No fertilizer and remove</td>
<td>4.4</td>
<td>4.4</td>
</tr>
</tbody>
</table>
Figure 4: The averaged ammonium and nitrate initial values of each management practice averaged together. The total average of each management practice of the extractable nitrogen in the soils with respect to ammonium and nitrate (gN/m$^2$/yr).

**Averaged extractable nitrogen in soils of differently managed lawns**

<table>
<thead>
<tr>
<th>Streets</th>
<th>Extractable N from NH$_4$</th>
<th>Extractable N from NO$_3$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sandplain Grassland</td>
<td>2.70</td>
<td>0.2</td>
</tr>
<tr>
<td>Fertilize and leave</td>
<td>3.50</td>
<td>1.8</td>
</tr>
<tr>
<td>Fertilize and remove</td>
<td>3.29</td>
<td>0.37</td>
</tr>
<tr>
<td>no fertilizer and leave</td>
<td>3.99</td>
<td>2.31</td>
</tr>
<tr>
<td>no fertilizer and remove</td>
<td>4.02</td>
<td>2.03</td>
</tr>
</tbody>
</table>
Figure 5a: The carbon dioxide flux (micromol/m2/sec) and nitrous oxide flux (nanomol/m2/sec) of the Sandplain Grassland at the Frances A. Crane Wildlife Management Area.
Figure 5b: The carbon dioxide flux (micromol/m²/sec) and nitrous oxide flux (nanomol/m²/sec) of the systems that are fertilize and have biomass left. The properties sampled were a home on Lawrence Farm Rd, one on Greenwood St, and one on Heather Ln.
Figure 5c: The carbon dioxide flux (micromol/m²/sec) and nitrous oxide flux (nanomol/m²/sec) of systems that are fertilized and have biomass removed. The systems included a home on Tamarack Rd, a home on Marla Ln, and one on Spinnaker Ln.

Gas fluxes of homes that fertilize and remove biomass

- Tamarack
- Marla
- Spinnaker

Streets

CO2 flux (micromol/m²/sec)
N2O flux (nanomol/m²/sec)
Figure 5d: The carbon dioxide flux (micromol/m²/sec) and nitrous oxide flux (nanomol/m²/sec) of systems that do not fertilize their lawns and remove their biomass. The systems include a home on Little Island Rd, one on James St, and one on Sheeps Crossing Ln.
Figure 5e: The carbon dioxide flux (micromol/m2/sec) and nitrous oxide flux (nanomol/m2/sec) of systems that do not fertilize their lawns and remove biomass. These systems include a home on Green Acres Rd, one on Lakeview Ave, and another one on Old Campus Dr.

**Gas fluxes of homes that do not fertilize and remove biomass**

- **CO2 (micromol/m2/sec)**
- **N2O (nanomol/m2/sec)**
Figure 6: The average gas fluxes of carbon dioxide (micromol/m²/sec) and nitrous oxide (nanomol/m²/sec) of the three homes in each management practice as well as the Sandplain Grassland.

<table>
<thead>
<tr>
<th>Treatment</th>
<th>CO₂ (micromol/m²/sec)</th>
<th>N₂O (nanomol/m²/sec)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sandplain Grassland</td>
<td>1.90</td>
<td>-0.89</td>
</tr>
<tr>
<td>Fertilize and leave</td>
<td>1.07</td>
<td>0.02</td>
</tr>
<tr>
<td>Fertilize and remove</td>
<td></td>
<td>0.02</td>
</tr>
<tr>
<td>no fertilizer and leave</td>
<td>2.52</td>
<td>0.18</td>
</tr>
<tr>
<td>no fertilizer and remove</td>
<td>1.47</td>
<td>0.06</td>
</tr>
</tbody>
</table>

Average gas fluxes across all treatments
Figure 7: The average soil temperature (deg C) and soil moisture (%) of the three homes in each management practice as well as the Sandplain Grassland.