Effects of Fertilizer on Nitrogen Cycling in Residential Cape Cod Lawns

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Abstract

Lawns form a significant part of the United States, and are frequently maintained by the addition of nitrogen fertilizers. This project was conducted to find the effects of fertilizer on lawn nitrogen cycling and to determine both the prevalence of fertilization in Falmouth, MA, and the magnitude of lawn nitrogen inputs to aquatic ecosystems. 36 lawns were selected from homeowner surveys and divided into three fertilizer classes, and soil and grass samples were taken from each lawn. 6 native forests and 5 maintained fields were also sampled. Extractable nitrate and ammonium stocks did not differ significantly between lawn fertilization levels, but were higher in lawns and fields than in forests. Nitrification and N mineralization showed the same trends. Soil percent nitrogen did not differ significantly between site types. Grass percent nitrogen was positively correlated with fertilization, indicating that at least some fertilizer nitrogen was used by the lawn grasses. Using reflectance measurements and a chlorophyll index, 47% of Falmouth lawns were found to be fertilized. Scaling up to an entire watershed, 40% of all anthropogenic nitrogen loading to aquatic systems was found to come from lawns, both fertilized and unfertilized. This was significantly greater than the amount of nitrogen leaching from lawns predicted by the Valiela model due to several deviations between the model assumptions and measurements from this project.

Key Words
Falmouth, fertilizer, lawns, nitrogen cycling, suburbs

Introduction

Suburban areas are a large and increasing part of the United States, and they must therefore be considered as ecosystems with their own individual functions and patterns (Bormann et al, 2001). Lawns are a typical feature of suburban areas, and currently cover about 1.9% of the United States (Milesi et al, 2005). Because lawns are not native to or supported by the conditions in most areas, extra water and fertilizers are often used to sustain lawns.

There are several concerns associated with the addition of fertilizers to lawns, the most widespread of which is leaching of nitrogen into bodies of water. Excessive nitrogen inputs to aquatic ecosystems can cause eutrophication and shifts in ecosystem composition and function. Addition of fertilizer to lawns may increase nitrogen leaching by increasing nitrification rates and nitrate stocks (Raciti et al, 2011; Gold et al, 1990). Many fertilizers also contain ammonium, the addition of which may increase ammonium stocks and the abundance of mineralizing bacteria. Ideally the added nitrogen from fertilizers is mostly taken up into the grass, but if more is added than the plants are able to use, it may remain in the soil where it can be easily leached into the groundwater or be washed away by surface runoff.

In Minneapolis, Fissore found that over 70% of suburban lawns surveyed were fertilized (Fissore et al, 2011), while in the Falmouth area of Cape Cod, about 48% of lawns are fertilized (White, 2003). Lawn fertilization is clearly a widespread phenomenon, but varies between regions. This variation could be important to understand when creating models of nitrogen leaching.
budgets or making policy decisions about lawn care and nitrogen pollution goals. There are a few potential methods to determine the prevalence of fertilization, beyond relying on information from homeowners. Common synthetic fertilizers have been shown to have nitrogen isotope values close to zero while organic fertilizers have a much wider range of isotope values, which could provide a distinction between synthetically fertilized and organically fertilized or unfertilized plants (Bateman and Kelly, 2007; Bateman et al., 2005). The abundance of broadleaf species in lawns could also be an indicator of fertilization, as many lawn fertilizers include broadleaf weed killers and fertilized grass may be better able to outcompete weeds. It has also been suggested that frequently fertilized lawns are visibly greener than unfertilized lawns (Henry, 2002), and so it may be possible to correlate a vegetation greenness index with the fertilization rate of lawns.

In this project, I analyzed the soil and grass nitrogen characteristics of 36 suburban lawns in Falmouth, MA to find the effect of fertilizer addition on lawn nitrogen behavior and potential nitrogen leaching from lawns. I then correlated this nitrogen cycling information with nitrogen isotope fractionation, broadleaf percent cover, and grass greenness to find a method of making large scale fertilization estimates. Finally, I used my lawn nitrogen behavior data to find the magnitude of lawn nitrogen inputs to aquatic ecosystems.

Methods

Field sites were chosen based on a survey of homeowners in Falmouth, MA, which provided approximate fertilization rates for lawns at each site (Figure 1). Using these fertilization rates, I selected 36 suburban sites, 12 fertilized more than once a year (high), 11 fertilized once a year or less (low), and 13 never fertilized (none). I also chose 5 maintained fields and 6 native forests to sample as reference sites.

At each lawn, I took two adjacent 15 cm deep soil cores and one 10×10 cm grass clipping. I also estimated the percent cover of broadleaf species in a 50×50 cm quadrat on the lawn. Finally, I took reflectance readings at 5 locations (raked clear of leaves) in every lawn using a Unispec-Dual Channel spectral analyzer (PP systems, Haverhill, Massachusetts, USA). I also took soil cores at each field and forest site and grass clippings at each field.

The two soil cores from each site were assumed to be the same, and were individually homogenized. One core was weighed, dried, and reweighed to find the moisture content and bulk density of the soil in each lawn. A small subsample of the dried soil was then ground and run through a C:H:N analyzer (Series II CHNS/O Analyzer 2400, Perkin-Elmer Instruments, Shelton, Connecticut, USA) to determine soil percent N (Foreman, 2011). I found nitrate and ammonium stocks in the second soil core using KCl extractions with 10 g of fresh soil and 100 mL 1 M KCl, shaken for four hours. Soil nitrate and ammonium samples were extracted on the day of collection and again after a 15-day incubation at 25°C. In addition to KCl extractions, I also performed water extractions on each sample on the day of collection to find the amount of water-leachable nitrate and ammonium. For KCl and water extracted samples, nitrate concentrations were determined using a colorimetric method read with a lachat flow injection analyzer, and ammonium concentrations were found using the phenol-hypochlorite method read with a Shimadzu 1601 spectrophotometer (Wood et al., 1967; Solarzano, 1969; Strickland
The initial concentrations of nitrate and ammonium were considered to be the stocks in the soil. The nitrification rate in each soil was found by dividing the change in nitrate concentration by the amount of time between the two measurements, while the N mineralization rate was found by dividing the summed change in nitrate and ammonium by the amount of time between the two measurements.

The grass clippings were oven dried and weighed. Any non-grass species were then removed from the sample, and the remaining dried grass was ground and run through the C:H:N analyzer to determine grass percent N (Foreman, 2011). 21 of these grass samples were submitted for $\delta^{15}$N isotope analysis; 7 from unfertilized lawns, 6 from the low fertilizer class, and 9 from the high fertilizer class.

The reflectance data found using the UniSpec analyzer were used to calculate a chlorophyll index value for each lawn. The chlorophyll index was calculated as the difference between the reflectance at 750 nm and 705 nm divided by the sum of the reflectance at those two wavelengths. This index was then used to correlate the greenness of each lawn with its nitrogen characteristics.

Reflectance data were gathered using the same UniSpec method for 43 additional lawns, for which fertilization rates were unknown. Using the fertilization and nitrogen data from the original 36 lawns, a cutoff point of 4% nitrogen in grass was determined, above which lawns were considered fertilized and below, unfertilized. The additional reflectance measurements were then converted into grass percent nitrogen values using the linear relationship between chlorophyll index and grass percent nitrogen. The total percentage of lawns fertilized from both sampling sets was then calculated.

Finally, I considered the nitrogen input from lawns in the West Falmouth Harbor watershed to West Falmouth Harbor (Figure 2). ArcGIS (ESRI ArcMap 10.0, 2010) was used to find the total area of residential lots in the watershed, where only lots categorized as single, double, and triple family homes were considered. Lots under 0.3 acres were considered to be 57% lawn and lots above 0.3 acres were 26% lawn, as found by Ward (2011). The amount of nitrogen leached annually per square meter of lawn was found as the average nitrification rate for all sampled lawns, assuming that all nitrate produced was leached, no ammonium was leached, and nitrification occurred year round. This leaching amount was then multiplied by the total area of lawns in the watershed to find the annual nitrogen leaching from residential lawns. The input amount was attenuated according to the Valiela nitrogen loading model attenuation assumptions and then compared to the total anthropogenic nitrogen contribution predicted by the Valiela model (Valiela et al, 1997).

Results

The amounts of KCl extractable nitrate and ammonium were not significantly different between lawn fertilization levels ($p>0.1$; Figure 3). Lawn nitrate and ammonium stocks were higher than forest stocks and similar to field stocks, although all measurements were highly variable. There was also more ammonium than nitrate present in all soils. Water extracted 1.2 times as much nitrate as KCl did ($r^2=0.86$), while water extracted only about 0.1 of the ammonium extracted by KCl ($r^2=0.11$; Figure 4). Like the nitrate and ammonium stocks, the
nitrification and N mineralization rates did not differ significantly between fertilizer classes (p>0.1; Figure 5). Nitrification and N mineralization were higher in all lawn types and in fields than in forests, and were also more variable in fields than in lawns or forests. The percentage of nitrogen in soil did not differ between fertilizer classes (p>0.1), and also did not differ between lawns, fields, and forests (Figure 6). The percentage of nitrogen in grass, however, did differ significantly with fertilization (p=0.0008), and showed an increasing trend with increasing fertilization (Figure 7). Grass percent nitrogen is also higher in all three lawn types than in fields.

Of the potential fertilization indicators, broadleaf percent cover and chlorophyll index values were more strongly correlated with grass percent nitrogen than nitrogen isotope fractionation was (broadleaf $r^2=0.33$, Figure 8; chl index $r^2=0.28$, Figure 9; $\delta^{15}N$ $r^2=0.09$, Figure 10). The percent cover of broadleaf species in lawns decreased linearly as the percent nitrogen in the grass increased, and differed significantly between fertilizer classes (p=0.006; Figure 8). Chlorophyll index values increased linearly as percent grass nitrogen increased, but did not significantly differ between fertilizer classes (p=0.14; Figure 9). Nitrogen isotope fractionation showed a weak increasing trend with increasing grass percent nitrogen (Figure 10). Average nitrogen fractionation compared to fertilizer class did not show the same increasing trend (Figure 11). Instead, the high fertilizer class had the most variable $\delta^{15}N$, and the low fertilizer class was significantly lower than the unfertilized class (p=0.004), but neither were significantly different from the high class (p>0.1). From the original 36 lawns and additional 43 lawns and using the chlorophyll index method, a total of 47% of lawns were found to be fertilized (Table 1).

The average nitrification rate of all lawns was 55 g N·m$^{-2}$·yr$^{-1}$, which was used as the leaching rate for estimating nitrogen leaching from lawns into West Falmouth Harbor. In the 509 ha watershed, 33 ha were estimated to be lawn. The total nitrogen leached from lawns in the watershed was about 18,000 kg N/yr, which attenuates to 3,000 kg N/yr entering West Falmouth Harbor. Comparatively, about 550 kg N/yr enter the harbor from precipitation and about 7,000 kg N/yr enter the harbor from all anthropogenic sources. Therefore, the calculated lawn nitrogen contribution to West Falmouth Harbor was about 40% of the total anthropogenic nitrogen loading. This is much higher than the lawn nitrogen contribution predicted by the Valiela model (Table 2; Valiela, 1997).

**Discussion**

Lawn soils do not appear to show a legacy of fertilizer use, as shown by the similarity between nitrate and ammonium stocks in differently fertilized lawns. Because water is so effective at removing nitrate from soil, it is likely that rainfall and lawn watering have removed most nitrate from the soil through leaching, regardless of how much may have been added. Ammonium is not as easily removed from soil by water, but may not show significant variation between fertilizer levels because of nitrification and some leaching. The lack of difference in ammonium stocks could also be because none of the sampled lawns were fertilized with ammonium recently enough for fertilizer ammonium to still be present in the soil. Homeowners were not asked specifically what type of fertilizer they used or when they last fertilized, so I was not able to control for these variables.
Nitrification and N mineralization rates do not differ between lawn fertilization classes, indicating that the active bacterial communities responsible for cycling nitrogen are not significantly larger in fertilized lawns than in unfertilized lawns. However, cycling is more rapid in lawns than in forests, possibly indicating that a property of lawns other than fertilization causes increased nitrification and N mineralization compared to natural forest. The difference between lawns and forests could also be a longer term legacy effect from sod farming or application of starter fertilizers when seeding new lawns. The initial addition of fertilizers in the topsoil when grass is first added could allow larger nitrogen cycling bacterial communities to develop, and then those bacterial communities may persist regardless of later fertilizer addition.

Soil percent nitrogen again may not show significant variation between fertilizer classes because of leaching, but the percentage of nitrogen in soil also does not differ between lawns and forests. Grass percent nitrogen is affected by fertilization, and increased levels of fertilization cause higher percentages of nitrogen in the grass. The grass then is benefiting from fertilizer addition, and is incorporating at least some of the additional nitrogen into its growth, as desired. Since it is unknown exactly how much nitrogen was added to each lawn, it is not possible to say what proportion of fertilizer nitrogen was used by the grass. Nearly all fertilizer was either taken up by the grass or leached out of the lawn topsoil though, as no difference between fertilized and unfertilized lawn soils was observed.

Grass percent nitrogen corresponded best with fertilizer class, and so was used to evaluate the methods of determining grass fertilization. Grass percent nitrogen was used instead of fertilizer class to take into consideration variation within the fertilizer classes. Additionally, fertilizer classes were assigned based on survey results, which could contain inaccuracies, while grass percent nitrogen was a measured characteristic of each lawn.

Broadleaf percent cover was a good indicator of grass percent nitrogen and fertilization, suggesting that either most fertilizers used by Falmouth homeowners contain broadleaf weed killers, or that fertilizing lawns does improve their ability to outcompete weeds. Another possibility is that homeowners who frequently fertilized their lawns also more frequently maintained their lawns in other ways, such as the removal of weeds. From these results, it seems possible to judge the fertilization or maintenance level of lawns based on percent broadleaf cover for a large sample of lawns, although the high variability within fertilization classes would make correctly classifying single lawns more difficult.

Chlorophyll index values were also an indicator of grass percent nitrogen, confirming that more frequently fertilized lawns are in fact greener. This method was more variable than broadleaf percent cover, indicating that factors other than fertilization may have more of an effect on greenness than on broadleaf presence.

The high variability within fertilizer classes and the somewhat low correlation between broadleaf percent cover or greenness and grass percent nitrogen can be explained by variables besides fertilization that affect the appearance of lawns. Watering, for example, likely has an effect on both greenness and prevalence of broadleaf species, but was not measured or controlled for in this study. Sampling was performed in November, when water is not scarce, so water likely was not as important as it would have been in the summer. Lawns also differed in grass species composition, which may have affected both the greenness and the ability of broadleaf species to invade. Additionally, the greenness measurements could be affected by
the patchiness of the grass, as reflectance measurements were taken over a small area of lawn rather than just on grass, and so may be influenced by dirt, moss, and the density of grass in the area. To more accurately evaluate the effectiveness of measuring grass greenness as an indicator of fertilization, it may be useful to take leaf level reflectance measurements on a single species of grass in differently fertilized lawns and make these comparisons again.

The isotope fractionation results do not align with expectations, as there is no consistent trend between the fertilizer classes and only a weak correlation with grass nitrogen. This could be due to the lack of distinction between organic and synthetic fertilizers in the lawns sampled and to the wide range of isotopic values of organic fertilizers. If this study were to be repeated, it would be important to distinguish between lawns fertilized organically and those fertilized synthetically to see if they were isotopically different and if trends according to frequency of fertilization could then be observed. However, it is also notable that lawns reported as unfertilized fell within the same range as most synthetic fertilizers, and so it may not be possible to distinguish between fertilized and unfertilized lawns at all using nitrogen isotope fractionation data.

A total of 47% of sampled lawns were found to be fertilized, which is almost exactly the 48% found in a 2003 survey of 2327 lawns in the Falmouth, Mashpee, and Barnstable watersheds (White, 2003). This indicates that lawn fertilization practices have not differed much in the last 8 years and that the methods and assumptions used in this project to determine percent fertilization were reasonable.

The total contribution of nitrogen to West Falmouth Harbor from lawns was 40% of the total anthropogenic loading of nitrogen to the harbor. This is significantly more than predicted by the Valiela nitrogen loading model for three reasons. First, the Valiela model assumes the average single or double family home to have a 0.046 ha lawn, which brings the total area of lawn in the watershed to about half of what I calculated using GIS and percent cover data. Second, the model assumes only fertilized lawns leach nitrogen, and that 35% of lawns are fertilized. In Falmouth, about 47% of lawns are actually fertilized, and unfertilized lawns also have significant leaching contributions. Finally, the model assumes that fertilized lawns contribute 115 kg N·ha⁻¹·yr⁻¹, while I found that 550 kg N·ha⁻¹·yr⁻¹ leaches from all lawns. All together, these alterations make my calculated contribution of lawn nitrogen inputs to West Falmouth Harbor much higher than those predicted by the model.

From these results, it seems that nitrogen leaching from residential lawns is a significant contributor to nitrogen loading to aquatic ecosystems. Additionally, the lawn nitrogen contribution is not solely from fertilized lawns, but is significantly increased by unfertilized lawns as well. One complication with this scaling process that could significantly change the results is the possibility of temporary increases in leaching shortly after lawn fertilizers are applied. If fertilizer nitrogen is not being entirely used by the grass, then some of it leaches out of the soil within a short time of application, which could result in increases in nitrogen leaching when lawns are fertilized. These potential temporary increases were not captured by my data, but if they exist, they would further increase the nitrogen contribution of lawns and would also distinguish fertilized from unfertilized lawns.
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Literature Cited


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Figures and Tables

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Figure 4. Water extractable verses KCl extractable nitrate and ammonium.

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Chlorophyll Index

Grass % N

- none
- low
- high
Figure 10. Nitrogen isotope fractionation verses grass percent nitrogen. Point colors represent the fertilizer class of each lawn. Trendline $r^2=0.09$. 
Figure 11. Nitrogen isotope fractionation verses fertilizer class. Bars show the average $\delta^{15}$N of each class, with standard error shown as error bars.
Table 1. Number of original and additional lawns fertilized. Original lawns were divided into fertilized and unfertilized according to survey data, while additional lawns were divided based on reflectance data and the correlation between grass % nitrogen and chlorophyll index.

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<th>Additional</th>
<th>TOTAL</th>
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Table 2. Comparison of measured and modeled nitrogen loading to West Falmouth Harbor. Asterisks indicate columns calculated from the Valiela model (Valiela, 1997). All values were attenuated according to the Valiela model assumptions.

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<td>500 kg</td>
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