Consequences of nitrogen fertilization on CO$_2$ and CH$_4$ in a temperate deciduous forest and *Phragmites australis* plot

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Abstract

I investigated the affect of nitrogen fertilization on CO₂ and CH₄, greenhouse gases that contribute to global climate change. To measure and analyze gas flux from temperate deciduous forest soil and a *Phragmites australis* (Phragmites) plot, I collected gas samples to run via a gas chromatograph (GC). Results showed that nitrogen fertilizer increases CO₂ flux rate from temperate forest soil and decreases the rate at which forest soil consumes CH₄. Soil moisture positively correlated to CH₄ gas flux rates and soil pH positively correlated to CO₂ gas flux rates. Experimental error in this study was due to low sampling size as well as leaky syringes, which led to the escape of gas. This study suggests that there are consequences of N fertilization pertaining to global climate change.

Keywords

CH₄ flux, CO₂ flux, nitrogen fertilization, soil respiration

Introduction

One of the most challenging environmental crises facing the world today is global climate change. Global climate change is caused by many human activities such as fossil fuel burning and deforestation. These common practices around the world emit greenhouse gases into the atmosphere. Greenhouse gases trap the sun’s energy in the atmosphere and thus causing the atmosphere’s temperature to increase. Two infamous greenhouse gases that I focus on in this project are carbon dioxide (CO₂) and methane (CH₄). Global warming is leading to accelerated ice melting in the arctic and Antarctic, which threatens animals such as polar bears and penguins in these regions. Also, the existence of entire coastal and island regions such as Sri Lanka and Cape Cod are threatened due to the rising sea levels caused by melting ice. What may be even more frightening is that there are unknown consequences to global warming as well.

Biological activity typically controls CO₂ and CH₄ fluxes. In decomposing organic matter, microbes release CO₂, which later diffuses into the atmosphere. In temperate deciduous forests, CH₄ diffuses into soil, where it is oxidized by methanotrophic bacteria (Schlesinger 1997). This is an important process because though the concentration of CH₄ is far smaller than the concentration of CO₂ in the atmosphere, each CH₄ molecule has the potential to contribute about 25 times as much greenhouse warming as each CO₂ molecule (Schlesinger 1997). With increasing concentrations of greenhouse gases in the atmosphere, it is terrifying to think of the consequences of diminishing an important CH₄ sink by fertilizing.

Agricultural and commercial fertilization are common practices that also contribute to global climate change. Humans use fertilizer daily and across the globe on lawns, golf courses, farms, and more in order to spur the growth of grass and crops. Consequently, fertilizer may be a force driving the earth to a dire fate. This is because fertilizer increases microbial respiration of CO₂ from soil and also decreases soil consumption of CH₄ (Johnson 1994).

I conducted fieldwork at the Falmouth Wastewater Treatment Facility (FWTF). From 1988 to 2005 the FWTF irrigated parts of the forest located just behind the facility with nitrogen loaded wastewater that is comparable to fertilizer. For my project, I wanted to see how CH₄ and
CO₂ gas flux differed from the control sites compared to sites with a legacy of having been fertilized and irrigated (fertigated). I looked at three different sites with two main types of plants: oak trees and *Phragmites australis* (Phragmites). Two of the sites were oak forest sites. Oak forests are the most widespread and common forest types on Cape Cod. One of the oak sites was a control and the second was chronically fertigated. The third site was dominated by Phragmites. Phragmites is an invasive plant in the US and its growth may be facilitated by increased nitrogen, which explains its growth in the heavily fertigated area behind the FWTF.

Because CH₄ and CO₂ fluxes are controlled by biotic processes, I investigated how microbes react to newly applied fertigation in terms of changes in gas flux. The main study questions that I address in this paper are:

1) How does the legacy affect of fertigation impact CO₂ and CH₄ soil flux?
2) How does recent fertigation impact CO₂ and CH₄ soil flux in sites with a history of fertigation?

**Materials and Methods**

**Site Description**

The oak forest behind the FWTP has non fertilized plots, fertilized plots, and depressions between hills into which wastewater was sprayed and extra fertilizer from adjacent plots trickled. There is a clear physical difference between these sites. Oak trees make up the control plot (the plot that has never been fertilized); oak trees with dreadful prickly vines compose the fertilized plots; and *Phragmites australis* (Phragmites), an invasive reed that is common to saltwater marshes, densely populates the small depressions with a legacy of extreme fertilization. These three sites provide examples of a control site and two legacy sites along a fertilization gradient (Fig. 1). In each of the three sites, I established two 2x2 m plots, giving a total of six plots.

**Fertilization**

The N fertilizer was made of ammonium (NH₄⁺) and nitrate (NO₃⁻), two common ingredients of fertilizer as well as the most abundant compounds composing the wastewater once sprayed. The fertilizer used was a solution of 0.05 M NH₄NO₃ in deionized (DI) water. Using a watering can, I evenly distributed a total of 2.4 liters of fertilizer onto the 2x2 m plot. In each of the three sites, I sprayed N fertilizer on one of each of the two plots. So, there were three newly fertilized plots.

**In-situ soil respiration**

In each of the six plots, I laid out a couple of gas-collecting chamber collars in random places. These collars were then secured to the ground with three anchor pins to each collar. Because the focus of this project was soil respiration, I removed living herbaceous biomass within the collars by clipping them from the base of the plant.

To collect the gas samples, each chamber collar was covered with a gas chamber. The gas chamber had two holes at the top which I sealed with a rubber stopper in each. One of the
stoppers was completely sealed, but the other had a small hole through the stopper, into which I wedged a plastic stopcock.

Five minutes after closing the gas chamber, I took my first of four gas samples. Before taking the gas sample, however, I attached a large syringe to the stopcock on the gas chamber to draw air from the chamber. I then pumped the drawn air back into the chamber, thus mixing the air within the chamber. The “mixer” syringe was then replaced with a plastic syringe that was labeled with the date, site, plot, and sample number based on the time along the time series when I drew gas samples. I drew samples at 5, 10, 15 and 20 minutes after covering the chamber-collars. Each time, I drew 15 mL of gas from the chamber. Before removing the syringe from the chamber, I closed the stopcock on the syringe as well as on the chamber to ensure no gas loss. 5 minutes later, I repeated this process of mixing the gas within the chamber and then drawing it up into a syringe. This process was repeated until the 4 samples were drawn. Because I had two gas-chambers, I simultaneously drew gas from the two chambers in each of the plots. I took in-situ gas flux samples on the 17th and 19th of November as well as on the 8th of December.

I also measured soil moisture and temperature. Soil moisture was found using a soil moisture probe. I took 6 measurements of soil moisture in each plot because of the large variance between each measurement, even within a 2x2 m plot. Using a soil thermometer, I measured the soil temperature in the organic and mineral layers.

Laboratory soil respiration

In order to estimate gas flux in warmer climate, such as during the growing season, I conducted in-laboratory gas flux measurements. Three days after applying the fertilizer, I returned to the field with 18 containers of GladWare® in-tow. Using a gardening spade and a spatula, I removed the organic layer as well as a shallow portion of the underlying mineral layer to transfer into the GladWare®. I took three soil samples from each plot for a total of 18 GladWare® containers filled with soil from the oak control, oak fertilized, and Phragmites sites.

I brought the GladWare® back to the laboratory to weigh the collected soil and set it up for gas flux measurements. I let the GladWare® sit uncovered for two days before collecting the first in-laboratory gas samples. The lids of the GladWare® were drilled to create a hole similar to that on the gas chambers used in the field. I then inserted rubber stoppers with plastic stopcocks identical to the ones used in the field into the newly created holes in the lids. Hot glue was used to seal any open area between the rubber stopper and the GladWare® lid.

I collected gas samples from the GladWare® using the same procedure conducted in the field. 5, 10, 15, and 20 minutes after firmly situating the lid on the container with soil, I mixed the air in the gas samples and then drew 15 mL of gas into labeled syringes.

GC

A Shimadzu gas chromatograph (GC) was utilized to measure the CO₂ and CH₄ in the syringes. A Thermal Conductivity Detector (TCD) and a Flame Ionization Detector (FID) were used to measure CO₂ and CH₄ respectively (Tucker 2009). Helium was used as the carrier gas. I analyzed the samples with the GC within 24 hours of collecting the gas samples. Before running samples on the GC, I ran standards of 504, 1250, and 20,100 ppm CO₂ and 15.3, 100, and 2000 ppm CH₄ to conjure a standard curve. I then ran the samples by attaching them to the syringe port on the GC and monitoring the results on the integrator attached to the GC (Tucker 2009).
I converted GC results, which were in units of ppm, to units of µmol m$^{-2}$ using the following equations:

For *in-situ* gas measurements in field collars:

$$ umol \ m^{-2} = \left( \frac{mg}{L} \right) \left( \frac{mmol}{mg_{\text{gas}}} \right) \left( \frac{1000\mu mol}{mmol} \right) \left( \frac{L}{0.001m^3} \right) \left( 0.00925m^3 \right) $$

For incubation gas measurements in Gladware®:

$$ umol \ m^{-2} = \left( \frac{mg}{L} \right) \left( \frac{mmol}{mg_{\text{gas}}} \right) \left( \frac{1000\mu mol}{mmol} \right) \left( \frac{L}{0.001m^3} \right) \left( 0.000739m^3 \right) $$

N mineralization

A couple of days after fertilizing three of the six plots, I returned to the field to collect soil cores for N mineralization estimates. I collected three soil cores from 0-10 cm depth in each plot using a bulb corer. Each core was then put directly into a small plastic bag for transport to the laboratory (Neill Week 1 2009). After returning to the laboratory, I sifted through the soil to remove plant or animal matter and to homogenize the soil within each plastic bag. 15 g of soil were weighed and put into plastic cups. The remaining unused soil was placed back into the plastic bag that I had taken it from, sealed tight, and stored in a drawer for future use. I then added 100 mL of 1 M KCl to each of the cup including 1 cup without soil to serve as the blank. I covered each of the 19 cups (including the blank) tightly and placed them on a shaker table for 1 hour. Then, I put the cups into the refrigerator to let them settle overnight.

The following day, I filtered the samples using filter paper and funnels. I collected filtered solution using two scintillation vials for each of the 19 cups. One scintillation vial was filled with no less than 10 mL to be measured for NO$_3^-$ and the other scintillation vial was filled with no less than 5 mL to be measured for NH$_4^+$. I put the samples to be measured for NH$_4^+$ in the refrigerator and the samples to be measured for NO$_3^-$ in the freezer.

Three weeks after the initial N extraction, I repeated the methods for extracting N using KCl on the soil that was left in the drawer. In total, therefore, I had 19 initial samples for NO$_3^-$ measurements and 19 initial samples for NH$_4^+$ measurements and the same amounts for the final measurements. I transferred 10 mL of solution from the NO$_3^-$ labeled scintillation vials into falcon tubes. The falcon tubes were then analyzed for NO$_3^-$ using the Lachat device.

I used a 1:20 dilution factor to dilute the samples. Test tubes were then filled with 2.85 mL KCl and 0.15 mL of sample from the scintillation vial. I then added dyeing reagents, vortexing between each addition. The test tubes were then left to sit in the dark for one hour. After an hour, I used the spectrophotometer to suck up the sample and analyze for the NH$_4^+$.

Using a standard curve, I calculated the NH$_4^+$ concentrations. I subtracted the initial NH$_4^+$ and NO$_3^-$ concentrations from the final concentrations in the soil samples. Then, I divided those values by 21 days, which was the length of the incubation period, in order to calculate the N mineralization rate in units of g N m$^{-2}$ d$^{-1}$.

pH
In preparation for pH measuring, I used a spade to extract two organic horizon samples and two A horizon samples from each of the six plots. Each sample was put into a plastic bag and brought back to the laboratory. I filled plastic cups with 5 g of the organic layer soil and 10 g of mineral soil and then filled all of the cups with 50 mL DI water. Using a pH probe, I measured the pH of each of the soils, rinsing the probe with DI water between samples.

**Results**

Gas fluxes plotted directly from the GC

On November 17th, CO₂ emissions increased along the fertigation gradient (Fig. 2-4). CH₄ was consumed at -0.020 ppm min⁻¹ in the oak control plot (Table 1). CH₄ was consumed at a slower rate of -0.015 ppm min⁻¹ in the oak fertilized site. CH₄ was emitted from the Phragmites site at a rate of 0.005 ppm min⁻¹.

**In-situ** gas flux rates

November 17th: day of fertigation. CO₂ flux was lowest in the oak control site at 458 µmol CO₂ m⁻² s⁻¹ in the OC plot and 259 µmol CO₂ m⁻² s⁻¹ in the New Fert plot (Fig. 4). In each of the sites, the plots in which I sprayed (New Fert, ReFert, and Pfert) were lower than their control counterparts (OC, OF, and P, respectively). The oak fertilized site had the highest CO₂ respiration of the three sites at 668 µmol CO₂ m⁻² s⁻¹, though it was very similar to the Phragmites site. The standard error bars indicate that fluxes within sites are not significant. CH₄ was consumed in the oak control and oak fertilized sites (Fig. 5). The rate of CH₄ consumption decreased from an average of -2.25 µmol CH₄ m⁻² s⁻¹ in the oak control to an average of -1.3 µmol CH₄ m⁻² s⁻¹ in the oak fertilized site. The Phragmites site emitted CH₄ into the atmosphere at a rate of 0.8 µmol CH₄ m⁻² s⁻¹. The newly fertilized plots in the oak control and oak fertilized sites consumed CH₄ at a higher rate than their control counterparts.

Nov 19th: CO₂ fluxes varied far more greatly than on the 17th. There was a decrease in CO₂ flux from the OC to New Fert plot and an even greater decrease in CO₂ flux within the Phragmites site from the P to the Pfert plots (Fig. 6). The Pfert plot showed the lowest CO₂ flux at a rate of 311 µmol CO₂ m⁻² s⁻¹. In the oak control and oak fertilized plot, CH₄ consumption decreased from November 17th. The newly fertilized plot in the oak control forest consumed less CH₄ at -1.3 µmol CH₄ m⁻² s⁻¹ than the non sprayed OC plot which consumed -1.5 µmol CH₄ m⁻² s⁻¹ (Fig. 7). Contrastingly, in the Oak fertilized site, CH₄ consumption increased from -0.9 µmol CH₄ m⁻² s⁻¹ in the OF plot to -1.2 µmol CH₄ m⁻² s⁻¹. Error bars indicate that these trends are not significant. There was a significant increase in CH₄ emission from 0.7 µmol CH₄ m⁻² s⁻¹ in the P plot to 3.7 µmol Ch₄ m⁻² s⁻¹ in the Pfert plot. Overall, on November 19th, there was a decrease in CH₄ consumption and an increase in CH₄ production from the Pfert plot.

December 8th: CO₂ flux into the atmosphere decreased greatly in all of the plots from the previous sampling dates (Fig. 8). The OF plot had the highest CO₂ flux at 458 µmol CO₂ m⁻² s⁻¹. Unlike the other sampling dates in which both oak forest sites (control and fertilized) consumed CH₄, CH₄ was emitted from the OF plot in the Oak Fertilized site (Fig. 9). CH₄ continued to be emitted from both plots in the Phragmites site.
pH

pH generally increased along with increased fertigation (Fig. 10). Exceptions to this overall trend were seen from the slight decrease in soil pH from 4.39 in the OC plot to 4.35 in the New Fert plot and 5.79 in the P plot to 5.51 in the Pfert plot. In the Oak Fertilized site, pH increased from 4.90 in the non-sprayed OF plot to 5.16 in the sprayed ReFert plot. There was a strong correlation between pH and CO$_2$ (Fig. 11). pH increased along with CO$_2$ across the legacy fertigation gradient from the Oak control to Oak fertilized to Phragmites site.

N mineralization

N mineralization increased from the un-sprayed plots to the sprayed plots in each of the respective sites (Fig. 12). N mineralization increased from 0.44 g N m$^{-2}$ d$^{-1}$ in the OC plot to 1.8 g N m$^{-2}$ d$^{-1}$ in the NewFert plot. In the Oak fertilized site, N mineralized increased from 1.4 g N m$^{-2}$ d$^{-1}$ in the OF plot to 2.3 g N m$^{-2}$ d$^{-1}$ in the ReFert plot. Overall, N mineralization was highest in the Oak Fertilized site than in the Oak Control site and the Phragmites site. In the Phragmites site, N mineralization was lower in the sprayed plot at 0.36 g N m$^{-2}$ d$^{-1}$ than in the control plot where it was 0.99 g N m$^{-2}$ d$^{-1}$.

Soil moisture

Soil moisture ranged from 13.7 to 16.2% in the Oak Control and Oak Fertilized sites (Fig. 13). In the Phragmites site, there was a major increase in soil moisture. Soil moisture was 38.0% and 28.3% in the P and Pfert plots respectively. Soil moisture correlated with CH$_4$ flux (Fig. 14). The Oak Control and Oak Fertilized sites, where I measured relatively low soil moisture with an average of 14.8%, were the sites that consumed CH$_4$. Contrastingly, the Phragmites site, with its high soil moisture, emitted CH$_4$.

Incubation experiment

CO$_2$ flux rates displayed an overall decrease along the fertigation gradient (Fig. 15). Rates were 527, 488, 360, 314, and 90 µmol CO$_2$ m$^{-2}$ s$^{-1}$ in the OC, New Fert, OF, ReFert, and P plots respectively. The rate was slightly higher in the Pfert plot at 441 µmol CO$_2$ m$^{-2}$ s$^{-1}$. CH$_4$ flux rates decreased overall from the OC to Pfert plot (Fig. 16). Rates were 0.34, 0.09, 0.11, -0.06, 0.08, 0.09 µmol CH$_4$ m$^{-2}$ s$^{-1}$ in the OC, New Fert, OF, ReFert, P, Pfert plots respectively.

Evidence of error

Spikes in the data indicated syringe leaking (Fig. 17). CO$_2$ plummeted from 547 to 188 and then rose to 518 ppm in 10 minutes indicating a leaky syringe at time elapsed=20 minutes. Comparably, CH$_4$ dropped from 2.4 ppm at time elapsed=15 minutes to 1.1 ppm at time elapsed=20 minutes and then increased to 2.3 ppm at time elapsed=25 minutes.

Discussion
Soil characteristics and correlation to gas flux across sites

I analyzed soil characteristics such as soil moisture, N mineralization rates, and pH to better understand the soil gas flux rates of CO$_2$ and CH$_4$. The peak in soil moisture in the Phragmites plot is due to the location of the Phragmites site in a small land depression that receives more water than the higher land areas. Water trickles from the higher land to the small depressions where it collects while slowly seeping into lower soil horizons. High moisture levels increase anaerobiosis. Anaerobic settings generally produce CH$_4$ because in microbial decomposition of organic carbon, the lack of oxygen leads to methanogenesis (Crill 1991). Thus, we see methanogenesis only in the lowland, highly moist soils where the Phragmites grows.

N mineralization is the process of releasing inorganic forms of nitrogen such as NH$_4^+$ and NO$_3^-$ from organic matter. High N mineralization indicates high N cycling rates. In many processes, the N cycle directly relates to the carbon (C) cycle because in terrestrial ecosystems N is typically limited compared to C. As expected, within the sites there is an increase in N mineralization from the OC to the New Fert, and from the OF to the ReFert plots as well as an overall increase from the oak control site to the oak fertilized site. We would expect to see this trend of increased N mineralization rates along with increased N fertilization to continue into the Phragmites site, but that is not the case as seen in the decrease of the line graph. This may be because of the higher moisture content which implies increased leaching of water through the soil, carrying the ions along as well. Another explanation is that the anaerobic conditions in the Phragmites site are not favorable for N mineralization. Furthermore, N addition increases decomposition, because as N is generally limited in terrestrial ecosystems, the large amount of fertilizer in the Phragmites site exhausts the oxygen content.

There is a strong correlation between pH and CO$_2$ flux, where pH increases along with CO$_2$ along the fertigation gradient from (Fig. 11). I expected to see increasing acidity with increased fertigation but the results showed the opposite trend (Fig. 10). Microbial communities generally prefer soils with neutral or slightly acidic pH (Schlesinger 1997). High microbial decomposition because of the relatively high pH, therefore, may explain the relatively high CO$_2$ flux rates. The observed trend of increasing pH from the oak control to the oak fertilized to the Phragmites site may be correlated to the decrease in methanotrophy and increase in methanogenesis along the same fertigation gradient. Soil CO$_2$ may react with the increase in H$^+$ ions in the soil (that are left from oxidation of NH$_4^+$ to NO$_3^-$) to form CH$_4$ and H$_2$O.

_In-situ_ Soil gas flux

On Nov. 17$^{th}$, I trekked to the field with fertilizer and gas flux measuring tools at hand. The purpose of this trip was not only to fertilize the plots, but to see the immediate response in terms of CO$_2$ and CH$_4$ gas fluxes to fertilization. I found that there was not a great difference in gas fluxes between the sprayed and not sprayed plots within the three sites. In fact, there was not a significant difference in CO$_2$ flux between the three sites either. I believe that the microbial community did not respond immediately to the addition of fertilizer. CH$_4$ consumption rates in soil are, on average, -0.6 μmol CH$_4$ m$^{-2}$ s$^{-1}$ (Schlesinger 1997). The CH$_4$ consumption rates that I measured in the field were higher than the average rates. Temperate forest soils are natural CH$_4$
sinks. The CH\textsubscript{4} consumption rates that I measured are higher because the global average values may take into account a vast diversity of soils with lower consumption rates.

I returned to the field a couple of days after fertilizing to measure gas fluxes. CO\textsubscript{2} fluxes varied from plot to plot more than on the previous sampling date leading me to believe that there was, within days of fertilizing the soil, a response from the microbial community. Because there was variation in all of the plots, including those that I did not spray, I cannot declare a definite response from the microbial community to the fertilization alone. Temperature and soil moisture, which I did not control, are important factors that affect gas flux. The oak control and oak fertilized sites did display results that I was expecting to see: relative constancy from the gas flux results on the 17\textsuperscript{th} in the OC and OF plots and an increase in gas flux from the newly sprayed plots. The most noticeable changes from the previous day’s results occurred in the Phragmites site. Comparing the CH\textsubscript{4} flux and CO\textsubscript{2} flux rates in the Phragmites site, we see that where there is a relatively low CH\textsubscript{4} flux in the P plot, there is a relatively high CO\textsubscript{2} flux and vice versa in the Pfert plot. This seems to be related to the negative correlation between soil CH\textsubscript{4} and CO\textsubscript{2} concentrations found by Crill (Crill 1991). Another reason that the Phragmites site differed from the oak sites is the intrinsic soil differences due to the different overlaying plant species.

In general, trends seen on the previous sampling dates were not detectable on December 8\textsuperscript{th}. The first (and second) frost had already beset and the soil temperatures were very low. Low soil temperature slows microbial CH\textsubscript{4} oxidation, which leads to CH\textsubscript{4} diffusing deeper into the soil (Crill 1991). Due to the cold, there was a decrease in microbial respiration and therefore an overall decrease in CO\textsubscript{2} emission rates from the soil.

Incubation experiment

I conducted the incubated experiment in order to simulate an environment with temperature higher than that in the field; for example, outdoor temperatures as we might feel during the growing season. Because of experimental design, however, I will use this part of the experiment to discuss flaws that led to erroneous results. The containers in which I collected soil were too small to collect enough soil for the experiment while also providing enough head space for gas to collect when the lids were closed. The decline in CO\textsubscript{2} as seen in Figure 18 implies that CO\textsubscript{2} was diffusing back into the soil. This can be explained by Fick’s gas diffusion law, which states that gas diffuses from regions of high gas concentrations to regions of lower gas concentrations (Jaynes 1983). For the incubation experiment, larger quantities of soil would have decreased the soil disturbance and therefore disturbance of the microbial community. Leaks in the soil containers as well as in the syringes were also common problems that led to spikes in the data (Fig. 17). In the future, I would like to carry out a similar experiment with, I hope, less experimental error having learned from blunders in this study.

Conclusions

In conclusion, I found that the legacy affects of N fertilization include an increase in CO\textsubscript{2} flux rates from soil along the fertigation gradient from the oak control to oak fertilized to Phragmites sites. N fertilization inhibited soil CH\textsubscript{4} consumption and even after the termination of fertilization, as occurred four years ago at the FWTF, CH\textsubscript{4} consumption remained reduced compared to CH\textsubscript{4} consumption in the control site. In the Phragmites site, where there was a history of heaviest fertigation as well as land disturbance due to forest clearing, there was
evidence of methanogenesis. Fresh fertigation instigated increased microbial activity as seen in the change in gas flux. I found that soil moisture and pH positively correlated to CO$_2$ and CH$_4$ gas flux rates. Though further research is necessary, from this study we can imagine the consequences of fertilizer on global climate change by increasing atmospheric CO$_2$ and CH$_4$.

Acknowledgements

I truly thank my mentor Jim Tang for encouraging me to work independently but always being there for guidance when I needed it. I devote so much appreciation to Rich McHorney for helping me throughout the entire semester and always being there to lend comforting words and advice and to Maya Wei-Haas for sticking with me during long hours on the GC. I thank Jane Tucker for teaching me how to use the GC and Linda Deegan for helping me come up with a project that really excited me. I thank my mom for her support and love. I thank Amy Cantor for being the greatest collaborator and friend. Finally, thanks to the whole SES family for an amazing semester full of laughter!

Literature Cited


Figures

Figure 1: Site and Plot description

Table 1: Summary of gas flux rates from Figures 2-4 below

<table>
<thead>
<tr>
<th></th>
<th>CO₂ (ppm min⁻¹)</th>
<th>CH₄ (ppm min⁻¹)</th>
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<tbody>
<tr>
<td>Oak Control</td>
<td>6.5</td>
<td>-0.020</td>
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<tr>
<td>Oak Fertilized</td>
<td>8.1</td>
<td>-0.015</td>
</tr>
<tr>
<td>Phragmites</td>
<td>9.6</td>
<td>0.005</td>
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Site and PLOT diagram with Falmouth Wastewater Treatment Facility (FWTF) and Fertigation Gradient.
Figures 2-4: CO$_2$ and CH$_4$ across sites on November 17$^{th}$ as plotted directly from GC

Figure 2:

- **Oak Control**
  - $y = 6.47x + 465.42$
  - $R^2 = 0.86$

- **Oak Fertilized**
  - $y = -0.020x + 2.7469$
  - $R^2 = 0.857$

Figure 3:

- **Oak Fertilized**
  - $y = -0.015x + 2.869$
  - $R^2 = 0.836$

  - $y = 8.10x + 455.88$
  - $R^2 = 0.93$

Figure 4:

- **Phragmites**
  - $y = 9.60x + 418.74$
  - $R^2 = 0.94$

  - $y = 0.005x + 2.659$
  - $R^2 = 0.325$
**Figures 4 - 9:** Gas flux across plots on three sampling dates

**Figure 4:**

CO$_2$ flux on Nov. 17th

**Figure 5:**

CH$_4$ flux on Nov. 17th

**Figure 6:**

CO$_2$ flux on Nov. 19th

**Figure 7:**

CH$_4$ flux on Nov. 19th

**Figure 8:**

CO$_2$ flux on Dec. 8th

**Figure 9:**

CH$_4$ flux on Dec. 8th
Figure 10: Soil pH across plots measured on November 19th

![Soil pH graph]

Figure 11: soil pH and CO$_2$ flux measured on November 19th

![CO$_2$ flux graph]

Figure 12: N mineralization across plots

![N mineralization graph]
Figure 13: Average soil moisture across plots

Figure 14: Soil moisture and CH$_4$ flux measured on November 19$^{th}$
Figures 15-16: Gas flux across plots in incubated experiment

**Figure 15:**

**CO₂ flux across plots**

<table>
<thead>
<tr>
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<th>CO₂ (µmol m⁻² s⁻¹)</th>
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<tr>
<td>OC</td>
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<tr>
<td>New Fert</td>
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<td>OF</td>
<td></td>
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<tr>
<td>Refert</td>
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<td>P</td>
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- OC: Oak Control
- New Fert: Oak Fertilized
- OF: Phragmites
- Refert: Phragmites

**Figure 16:**

**CH₄ flux across plots**

<table>
<thead>
<tr>
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- OC: Oak Control
- New Fert: Oak Fertilized
- OF: Phragmites
- Refert: Phragmites
Figure 17: Example of experimental error

![Graph showing concentration of CO2 and CH4 over time.]

Figure 18: Example of experimental error

![Graph showing concentration of CO2 and CH4 over time.]