

## Decomposition of Compost Addition on California Rangeland Soil

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### ABSTRACT

Grasslands, which occupy over 40% of California land area, provide excellent opportunities for land management to sequester carbon. Compost addition is a technique explored by the Marin Carbon Project to measure carbon uptake. Studies have observed increased soil respiration contributed by root respiration, microbial respiration, or compost decomposition. My main objective is to measure the compost decomposition rate and the greenhouse gas respiration accompanying it. We acquired samples from the Sierra Foothills grasslands and incubated them at constant temperature and moisture. I employed 25 replicates for each treatment, including control (soil only) and two treatments (compost, soil plus compost). I measured each replicate for gas flux weekly and then biweekly and I destructively sampled to determine mass loss from 5 jars of each treatment every 4 to 8 weeks. The main greenhouse gases observed were methane, carbon dioxide, and nitrous oxide. Carbon dioxide was initially high then declined for soil only and compost plus soil, but soil control consistently displayed higher fluxes than the treatments. Nitrous oxide showed an initial pulse in soil plus compost which was not observed in the control and the other treatment. Cumulative gas emissions showed significant impact of nitrous oxide with the scaling of Global Warming Potential. Compost mass loss was slow at only 4% and 7% in 6 months for compost only and soil plus compost respectively. This data are consistent with model predictions of slow compost decomposition and use of compost as slow release nutrient for carbon sequestration.

### KEYWORDS:

Carbon dioxide, nitrous oxide, land management, greenhouse gas emission, carbon sequestration

## INTRODUCTION

Increased greenhouse gas concentrations in the atmosphere have a direct effect on global climate. Humans have accelerated climate change through industrial and commercial greenhouse gas production (IPCC 2007). To offset the increased greenhouse gas concentrations in the atmosphere, numerous terrestrial carbon sequestration techniques have been proposed to transfer atmospheric carbon into soil and vegetation. Techniques range from reforestation of croplands (Post and Kwon 2000) and altered grazing practices (Conant et al. 2001) to the application of organic supplements such as compost or biochar to soils (Smith 2004). These organic supplements can increase the soil carbon pool and the residence time of carbon in the soil. Adding compost to soil is a promising sequestration technique because it is a cheap and effective way to increase plant productivity while storing more carbon in the soil (Hubbe et al. 2010).

Compost offers a sustainable alternative to improving soil quality while limiting the amount of greenhouse gas emissions compared to synthetic chemical fertilizers. The process of composting is the conversion of mixed organic material into stable forms in a controlled environment that can be later added into the soil as nutrients (Hubbe et al. 2010). Composting is most effective in aerobic environments, and can vary from small bucket scale to large industrial mounds. Benefits of compost amendment to soil include increased soil water holding capacity, addition of essential nutrients, improved plant root growth, and enhanced microbial activity (Bertoldi et al. 1983). Since compost improves soil quality, less chemical fertilizers are needed, therefore reducing the greenhouse gas emissions from fertilizer production (Lou and Nair 2009). However, compost also contributes to greenhouse gas emissions by emitting carbon dioxide, methane, and nitrous oxide during the composting process and after it has been applied to the soil. Depending on the level of greenhouse gas emissions, compost addition could negate its positive effects of carbon sequestration benefits in the soil.

Each greenhouse gas has a global warming potential (GWP), a measure of the potential warming effect over a given time period (Elrod 1999). Even though carbon dioxide (CO<sub>2</sub>) is present in the atmosphere at higher concentrations, other greenhouse gases such as methane (CH<sub>4</sub>) and nitrous oxide (N<sub>2</sub>O) have higher Global Warming Potential, making them more potent even at lower concentration levels (Hughen et al. 1996). According to IPCC report, CH<sub>4</sub> is scaled up 25 times in a 100 year period and N<sub>2</sub>O is scaled up 298 times. While compost amendments

generally increase soil carbon storage, these sequestration benefits may be offset partially or entirely if the amendments increase  $N_2O$  or  $CH_4$ . Because most compost research is focused improving compost efficiency, few have looked at the soil greenhouse gas emissions after application of compost (Lou and Nair 2009). A long term study site is needed to look at the compost greenhouse gas emissions after its application into the soil.

California's rangeland is an ideal location to provide the long term study of compost greenhouse gas emissions. Much of the carbon is stored belowground in the soil, and the vast area of rangelands in California and the United States in general create a huge potential for carbon storage (Silver et al. 2010). There are currently projects already using California's rangelands as sites to sequester carbon through the application of compost, so using similar sites for a long term greenhouse gas emissions study will be beneficial for comparison purposes (Wick and Haskel 2009). Current results from the Marin Carbon Project have shown an increase in soil carbon after the application of compost, but there has also been an increase in soil  $CO_2$  emissions, which could be due to plant growth, microbial metabolism, decomposition of compost organic matter, or a combination of these three sources (Ryals and Silver, in review). There are currently no data on the proportional contribution of each source, but previous studies have shown that decomposition of organic material may have a significant impact on global  $CO_2$  production. Because of the huge gap in knowledge between these different sources, further investigation is needed on the contribution of compost to total greenhouse gas emissions to determine the net benefit of compost in aiding carbon sequestration in real world application (Jenkinson et al. 1991).

My main objective is to isolate the decomposition of compost into the atmosphere from the overall emissions of soil and microbes. The compost will be analyzed in isolation and in the presence of soil to detect changes in greenhouse gas fluxes with and without soil interactions. As part of the Marin Carbon Project, my data will identify the maximum rate of decomposition of the compost and measure soil greenhouse gas emissions generated from compost amendments. DayCent models have generated predictions on compost decomposition, but additional information from this experiment will increase the accuracy of future predictions on soil carbon levels and more adequately quantify potential greenhouse gas costs of compost amendments (Ryals and Silver, in review). I hypothesize that compost in combination with soil will show an increase in decomposition rate relative to compost without soil, due to microbial activity

provided by the soil. I also hypothesize that compost will generate greater greenhouse gas emissions compared to soil.

## METHODS

### Sampling Setup

The Sierra Foothills Research Extension Center site is located in central California approximately 50 miles west of Lake Tahoe. This area experiences a Mediterranean climate with dry hot summers and cool wet winters. Most common plant communities include tall annual grasses and forbs, shrubs, and oak trees. Both the soil and the grasses were dry when I took the samples in September 2011. I removed the vegetation before taking approximately 2 kg of samples from the top 10 cm of soil. To homogenize the soil, I sieved the soil using a 2 mm screen to break up large soil chunks and removed rocks. Approximately 300 g of homogenized soil was added to 50 jars and packed to a bulk density of 1 g/cm<sup>3</sup>. Jars were randomly assigned to one of three treatments: soil, compost, and soil plus compost. I measured greenhouse gas emissions on a weekly to biweekly basis and then analyzed the compost decomposition through destructive sampling on a monthly basis, as described below.

### Pre-incubation

Previous experiments have shown a large gas flux when moisture is first added to dry soils; therefore I conducted a pre-incubation experiment to wait for the soil CO<sub>2</sub> emissions to stabilize before adding compost (Chou et al. 2008). The soils were very dry at 2 to 3 % moisture, so I brought them up to field capacity of approximately 30% moisture. Only the soil and soil plus compost jars were part of the pre-incubation experiment because only those samples included soil. I incubated samples in the dark at room temperature and added moisture every week to keep samples constant at field capacity. Furthermore, I removed any plant growth during pre-incubation every 2 days to prevent changing soil properties. Once a week I took gas samples from all the jars to measure the rate of CO<sub>2</sub>, N<sub>2</sub>O, and CH<sub>4</sub> emissions, which stabilized after 3 weeks.

## Experimental Design

To have soil and compost physically interact but still able to weigh them separately, I made polyester pouches that could hold the compost in and keep soil out. I filled these pouches with 30g of compost and then placed them on top of the soil to facilitate interaction. I acquired the compost from Feather River Organics, the same source as the compost used throughout the Marin Carbon Project. The carbon percentage in my samples was comparable to the levels in Marin Carbon Project samples (approximately 21%). The compost was at around 20% moisture level, and I brought it up to field capacity of approximately 40% moisture when placed in incubation jars. To account for confounding factors of the pouch, I placed empty pouches into the soil treatment. To keep moisture level at field capacity for the soil and the compost, I added water once a week, a day before each gas sample was taken. I incubated the jars in the dark by covering the jars with aluminum foil to prevent plant growth which could alter the soil composition and the gas fluxes.

## Greenhouse Gas Measurements

I measured CO<sub>2</sub>, CH<sub>4</sub>, and N<sub>2</sub>O fluxes on a weekly basis for the first eight weeks and biweekly for an additional twelve weeks. For the gas flux, I sealed the jars and took gas samples twice, one at the start and one in 3 hours. I ran these gas samples through the Shimadzu Gas Chromatography Analyzer GC-14A to detect the concentrations of greenhouse gases. I assumed that the gas is generated at a constant rate. Therefore, the gas fluxes are equal to the change in gas concentration over time. I used linear interpolation between sampling time points and summed the resulting data as an estimate of the mass of C or N per unit area over the six month incubation. CH<sub>4</sub> and N<sub>2</sub>O emissions were multiplied by the GWP factors to convert to CO<sub>2</sub> equivalent factors.

## Compost Decomposition Rate

To determine the maximum decomposition rate of the compost, I harvested 5 jars from each treatment after 4, 12, and 25 weeks. During each harvest, I extracted the polyester pouches from each jar. I then removed all the moisture by drying the jars in the oven at 65 °C and then measured the dry mass of the compost. I plotted the mass of compost remaining as a percentage of initial dry mass against time. I use an exponential curve to model the rate of mass loss through time.

## Analysis

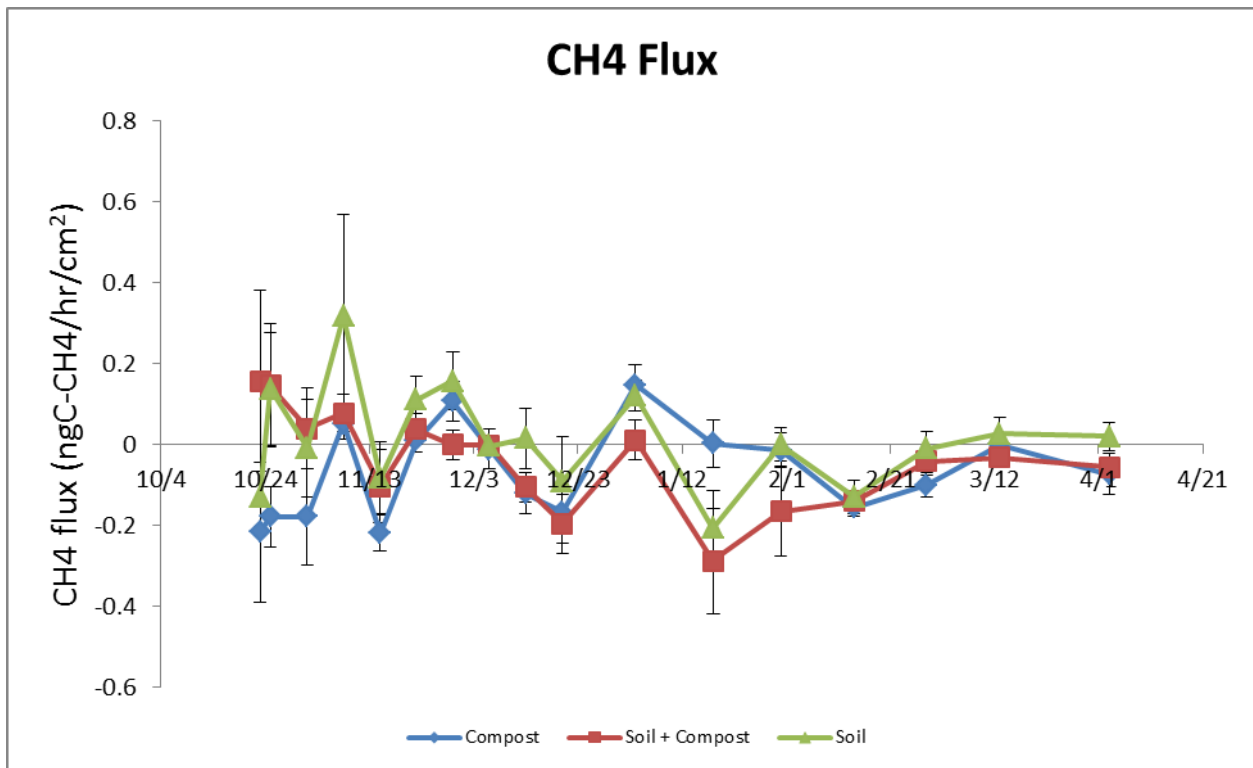
All of my raw data were converted to flux as emission per area over time for comparison through time. I calculated the averages for each treatment and then calculated the standard error and plotted the data through time. The times were interpolated into total emissions and analyzed given GWP values also. Each treatment had 5 replicates per time point of destructive sampling, and I averaged the five replicates for each treatment for analysis. Then I performed t-test on each of the harvest time points to determine the significance between the two treatments. To investigate the difference between greenhouse gas fluxes from the three treatments, I used a univariate repeated measures ANOVA to test whether the average fluxes are statistically different.

## RESULTS

### Gas Flux Measurements

The weekly to biweekly greenhouse gas flux measurements differed between the gases. I observed low levels of methane production throughout the experiment, averaging around 0 ngC/cm<sup>2</sup>/hr (Fig. A). I observed expected outcome during the pre-incubation phase, with the peaking of carbon dioxide flux in the beginning and gradual decline until stabilized at the end of pre-incubation. Minimal changes were observed for nitrous oxide and methane during the pre-incubation phase. Nitrous oxide pulse was observed during the start of the incubation experiment

for only soil plus compost, but not the soil or compost treatments (Fig. C). Carbon dioxide was initially high for control and soil plus compost treatment, but a consistently higher flux was observed for the control throughout the entire experiment (Fig. B). Repeated ANOVA yielded significant results for nitrous oxide ( $p < .0001$ ) and carbon dioxide flux ( $p < .0001$ ) but insignificant results for methane ( $p = .1375$ ) through time. I calculated cumulative gas emissions through linear interpolation of gas flux data through time with ANOVA test showing insignificant differences ( $p = .4434$ ) between the different treatments (Fig. 1). Even when I took into account of GWP scaling the result is still not significant ( $p = .3582$ ) between different treatments (Fig. 3).



**Fig. A.** CH<sub>4</sub> gas fluxes of 3 treatments from Oct. 22<sup>nd</sup> 2011 to April 3<sup>rd</sup> 2012. Symbols are treatment averages and bars represent standard errors.

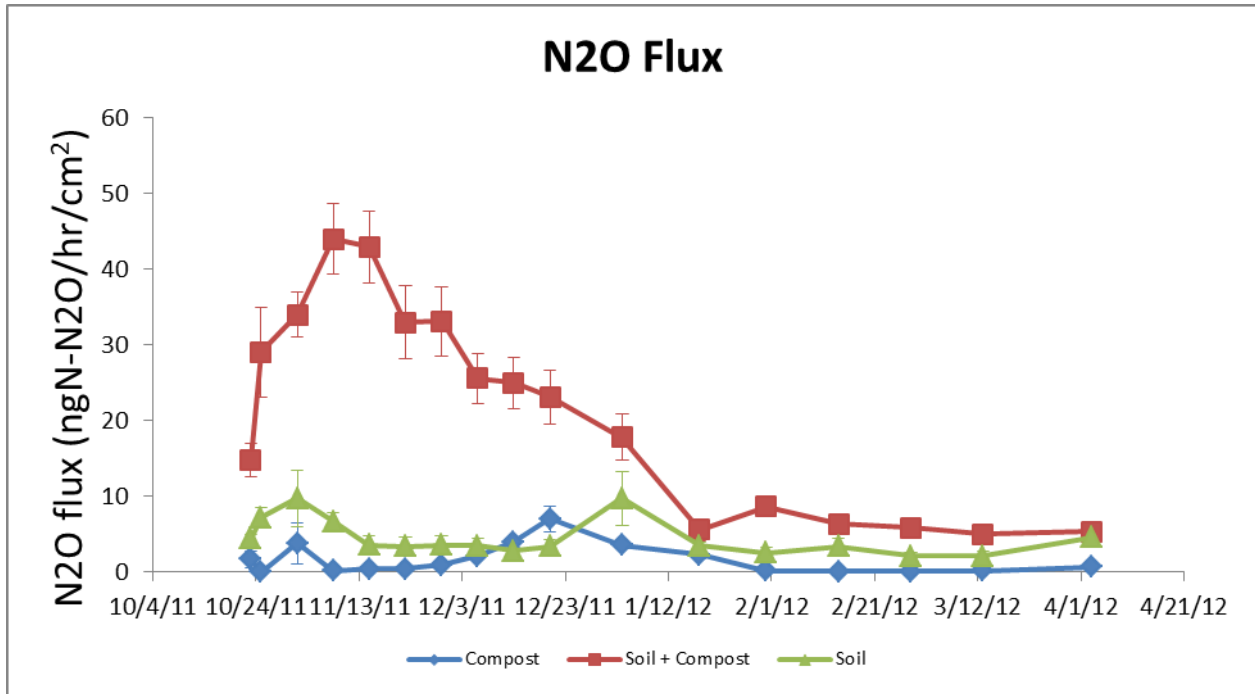


Fig. B. N<sub>2</sub>O gas fluxes of 3 treatments from Oct. 22<sup>nd</sup> 2011 to April 3<sup>rd</sup> 2012. Symbols are treatment averages and bars represent standard errors.

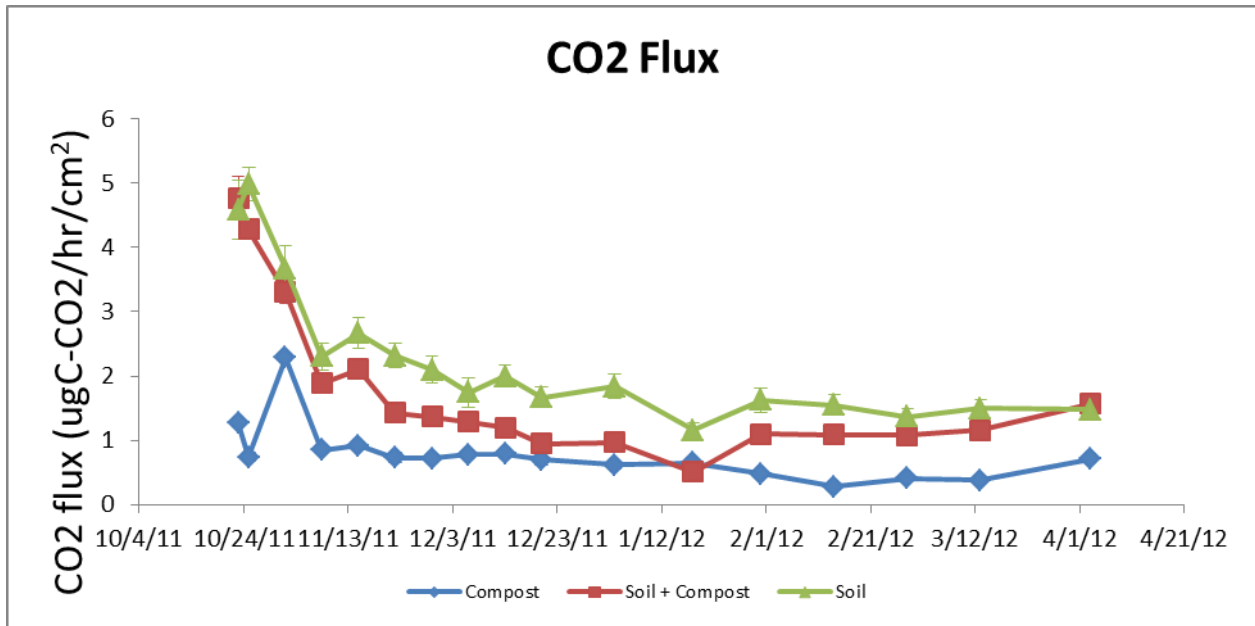


Fig. C. CO<sub>2</sub> gas fluxes of 3 treatments from Oct. 22<sup>nd</sup> 2011 to April 3<sup>rd</sup> 2012.



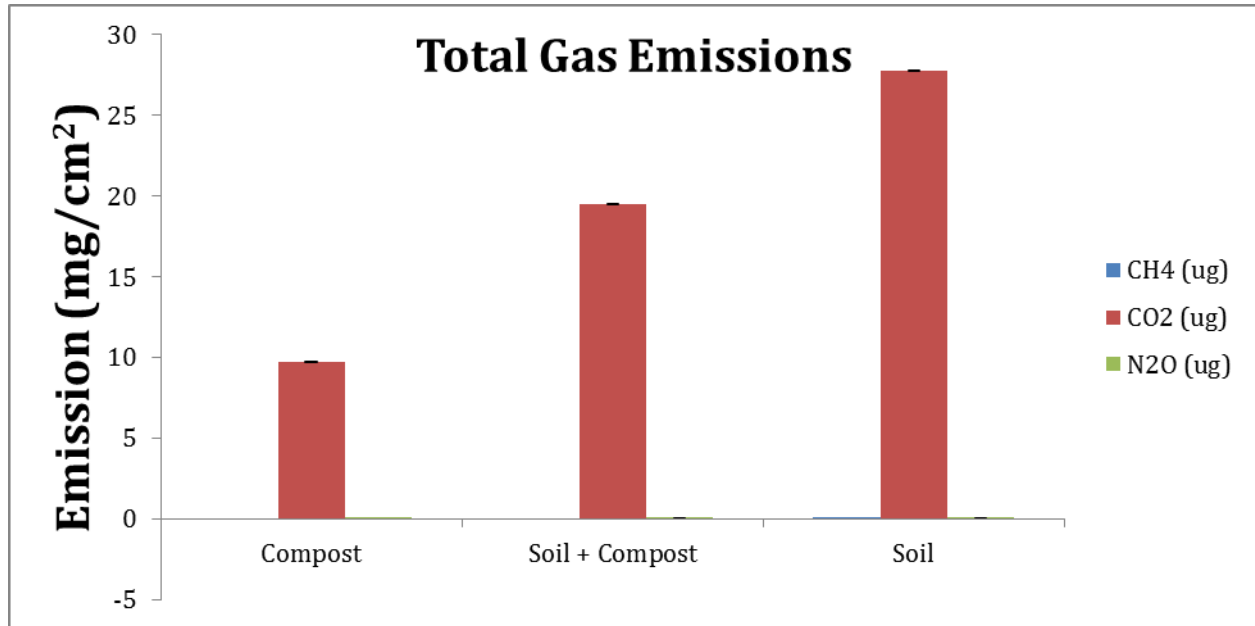


Figure 1. Cumulative emission of CH<sub>4</sub>, N<sub>2</sub>O, and CO<sub>2</sub> (mean  $\pm$  1 standard error) based on gas samplings from Oct. 22<sup>nd</sup> 2011 to April 3<sup>rd</sup> 2012.

### Mass Loss

Compost decomposed very slowly throughout the 25 weeks of the experiment. However, the rate of decomposition in the compost plus soil treatment was 75 % faster than the compost only treatment. Data showed approximate 4% and 7% compost mass loss for compost and soil plus compost respectively (Fig. 2). I did t-test for each time point and insignificant data was observed on week 4 ( $p = .4731$ ) and week 12 ( $p = .0536$ ) time points but the last time point on week 25 was significant ( $p = .0009$ ).

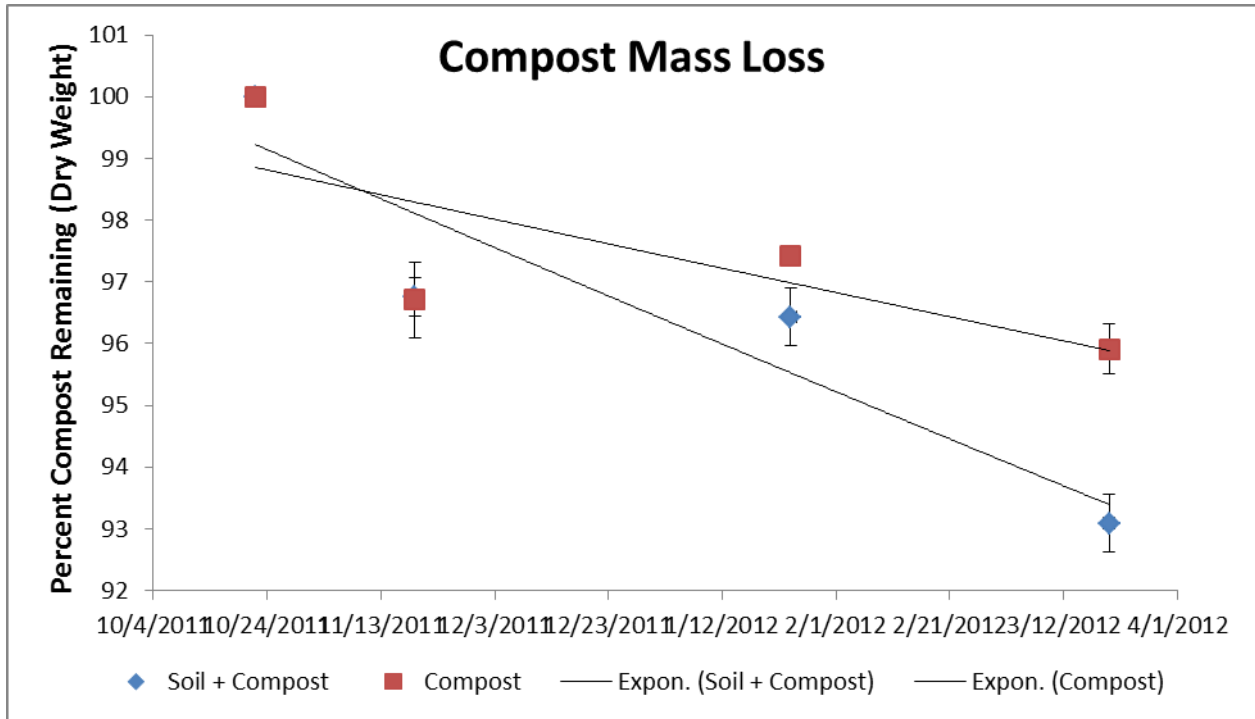


Figure 2. The percentage of compost mass retained from Oct. 22<sup>nd</sup> 2011 to Mar. 20<sup>th</sup> 2012.

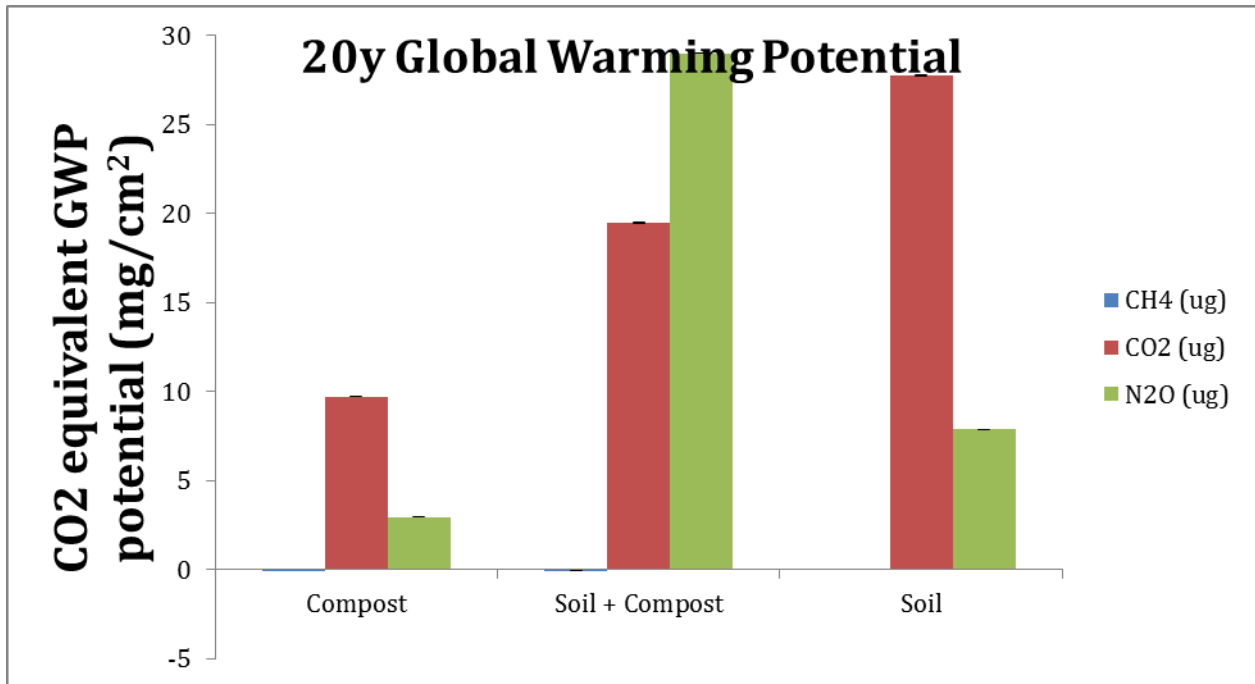


Figure 3. Cumulative emission of CH<sub>4</sub>, N<sub>2</sub>O, and CO<sub>2</sub> with GWP scaling based on gas samplings from Oct. 22<sup>nd</sup> 2011 to April 3<sup>rd</sup> 2012.

## DISCUSSION

The main objective of this experiment was to identify the decomposition rate of compost applied on topsoil and to measure greenhouse gas emissions upon application of compost to soil. When testing for differences in decomposition rate between compost only and soil plus compost treatments, I observed increased decomposition rates in the soil plus compost treatment suggesting that soil stimulates decomposition of compost. I also observed an interactive effect of soil and compost compared to either treatment in isolation. The majority of my results confirm trends seen in previous studies at similar sites, but a few irregular patterns stood out as interesting points of discussion.

### Soil Greenhouse Gas Emissions

Results from gas flux measurements point to higher nitrous oxide activity than carbon dioxide or methane, but only when taken GWP into consideration. The methane flux varied from slightly positive to slightly negative at different time points in no observable pattern. The lack of methane activity could be due to the lack of methanogens in the soil (Keller & Reiners 1994). Significant flux results were observed for carbon dioxide and nitrous oxide emissions for both treatments suggesting an active role for compost in gas emissions. The difference between the gas emissions from the two treatments can be attributed to the transfer of nutrients between soil and compost and contribution of soil microbial activity (Bolan et al. 2004). The initial pulse in N<sub>2</sub>O emission from soil plus compost jars points to immediate interaction between compost and soil through microbial interactions whereas neither compost nor soil jars showed similar spikes. The CO<sub>2</sub> fluxes between the soil and soil plus compost treatments remained parallel throughout the experiment, but the soil plus compost CO<sub>2</sub> flux remained consistently below soil only which was not observed in any previous study. One possible explanation would be an inhibitory effect due to the change of soil from its normal environment.

The total gas emissions of CO<sub>2</sub>, CH<sub>4</sub>, and N<sub>2</sub>O throughout the entire experiment showed long term level differences in emission. CO<sub>2</sub> remains the main emitter by mass, but when taking global warming potential of each gas into account, N<sub>2</sub>O overtakes CO<sub>2</sub> as the main influence in

soil plus compost treatment (Fig. 3). However, because the N<sub>2</sub>O pulse eventually stabilized, CO<sub>2</sub> will continue to be the most influential greenhouse gas over a longer time span.

### **Mass Loss**

I observed low levels of mass loss in all the treatment jars. Previous studies in litter decomposition observed an initial exponential decrease in mass followed by a stabilized linear decrease (Harmon et al. 2009). By contrast, my data consistently reflected a linear rate of decomposition for the compost. However, because the organic material underwent initial rapid decomposition during the composting process, it makes sense that the end compost product is in the stabilized phase, which would be consistent with the observed linear decomposition rate (Harmon et al. 2009). The higher rate of mass loss from soil plus compost treatment was consistent with my hypothesis, and confirms preliminary modeling efforts with the DayCent ecosystem model used in the Marin Carbon Project (Ryals et al., in prep).

### **Limitations**

This study provides estimates of compost decomposition and greenhouse gas emissions resulting from the addition of compost to soil. This type of information is difficult to acquire in field conditions and invaluable for modeling efforts to predict grassland management impacts on the climate through time. Over the course of this experiment, I observed surprisingly slow rates of compost decomposition, even under conditions ideal for decomposition. After 25 weeks, I estimated that 93 to 96 % of the initial compost mass remained, with greater rate occurring with the presence of soil. Further observations through time should be made to determine if decomposition rates remain linear and different across treatments. The results from this study inform ongoing efforts exploring the potential for climate change mitigation through compost amendments to grassland soils in California. Controlled laboratory incubations could be replicated using a range of soils to determine if these results are robust across ecosystem types.

## **Future Directions**

My study observed a slow decomposition rate of compost, but the rate significantly increased when applied to soil. The large amount of nitrous oxide flux and soil nitrogen activity I observed can be a starting point for further study to follow the nitrogen path. My existing project could also be extended to be a long-term study as part of the Marin Carbon Project. This would require more replicates due to the nature of destructive sampling. To make the study more applicable to real life situations, a long term on site experiment could be designed to investigate the potential changes weather patterns would have on gas fluxes and mass loss. It would also be relevant to investigate normal grassland moisture levels in varying conditions instead of a controlled environment in the lab.

## **Conclusion**

The slow rate of compost decomposition suggests a great alternative to artificial fertilizer and other processed soil nutrient additions. From my study, I observed relatively little change in methane emissions and unexpected inhibitory effect on carbon dioxide emissions from compost plus soil treatments. There was significant nitrogen activity in the form of nitrous oxide; this may be offset by increased plant productivity from increased nitrogen availability (Silver et al. 2010). The slow decomposing nature of compost brings long term improvements to the soil, but it does have a major influence on greenhouse gas emissions, at least for N<sub>2</sub>O in the short term (Larney and Angers 2012). With the results I have acquired for the decomposition rate of compost, I can input the data into different models to predict the effectiveness of carbon sequestration on grassland. Overall, the addition of compost on grassland soil will improve productivity and reduce resource use that would otherwise be used to improve the soil. Furthermore it has the benefits of low contribution to greenhouse gas emissions and improves carbon sequestration capacity of grasslands.

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