The Climate Change Mitigation Potential of Food Waste Compost Application to Grassland Soils

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ABSTRACT

To slow the harmful effects of global climate change, it is increasingly important to understand how to lower anthropogenic greenhouse gas emissions as well as remove CO_2 from the atmosphere. One method to remove atmospheric carbon is to store it in soil. Soil carbon sequestration can be achieved through multiple approaches, but one particularly promising approach is through compost applications, including composting food waste, a large source of greenhouse gas emissions. However, few studies have tested the effects of food waste compost application to grassland soils. We used a controlled laboratory incubation experiment to test the response of soil greenhouse gas emissions to the application of food waste compost to grasslands soils. Additionally, we used the biogeochemical model DayCent to project the long-term changes in soil carbon stocks following the application of food waste compost to grassland soils, and tested the impact of future climate change by simulating the treatments under two climate warming scenarios. The 7-week incubation experiment showed that total weekly emissions were significantly higher in the compost treatment compared to the control ($P < 0.0001$). Soil CO_2 contributed 99% of the total cumulative emissions over the 7 weeks. We observed no significant change in CH_4 and N_2O emissions following the application of food waste compost, nor was there any significant changes in soil C in the incubation study. The model output predicted that total soil organic C would increase immediately following the application of food waste and persist for more than a decade. All three modeled soil carbon pools (slow, passive, and active) experienced a net gain in C under both climate warming scenarios. When compared to the emissions produced by the application of raw cow manure and green waste compost, food waste produced much lower emissions while still increasing soil C, suggesting a greater potential to mitigate climate change.

KEYWORDS

California grasslands, carbon sequestration, DayCent modeling, Greenhouse gas emissions, soil respiration.

INTRODUCTION

Climate change continues to cause rising temperatures, ocean acidification, and accelerated losses of biodiversity (IPCC, 2014). Managing ecosystems to draw down and store carbon from the atmosphere can help mitigate climate change, when coupled with emissions reduction. The world's soils are capable of storing at least three times the amount of carbon in the atmosphere (White et al. 2000). Unfortunately, land use changes due to large scale agriculture and urbanization have interrupted biogeochemical cycles, reducing carbon and nitrogen storage in soil (Sanderman et al. 2017). However, with proper management, soil and vegetation could remove large amounts of carbon from the atmosphere and help mitigate climate change (Brown et al. 2011).

Compost application to grassland soils has potential to reduce atmospheric carbon dioxide (CO_2) because it has been shown to have a lasting positive effect on soil carbon storage and plant productivity (Ryals et al 2014). The added organic matter the soil receives from compost stimulates growth of vegetation, which increases carbon capture by photosynthesis (Ryals et al. 2015). For example, a single application of compost on coastal grasslands in California increased the soil carbon pool by 37% and continued to enhance soil carbon sequestration over three subsequent growing seasons (Ryals and Silver 2013).

Although compost application offers many benefits to degraded soil, it could also increase the emissions of greenhouse gases including CO_2, methane (CH_4), and nitrous oxide (N_2O). Methane and N_2O are much more potent greenhouse gasses than CO_2. Methane has a climate warming potential that is 34 times that of CO_2. Even more potent than CH_4 is N_2O, which holds a climate warming potential 298 times that of CO_2 (IPCC, 2014). Compost has been shown to increase soil respiration which is the release of CO_2 by soil microbes and plant roots (Brown et al 2011). A study of grasslands found that soil respiration was significantly higher in amended soils than in control plots (Ryals et al. 2015). Different types of soil amendments may vary in the amounts of greenhouse gas emissions they produce, as well as the amounts of carbon sequestration in the soil. A life cycle assessment model developed by Delonge et al (2013) found that manure and nitrogen fertilizer amendments were net greenhouse gas sources. The added manure and nitrogen fertilizer increased the availability of nitrogen, stimulated the production of N_2O (Chang et al. 1998), and curbed the consumption of CH_4 (Bodelier and Laanbroek 2004). In contrast, green waste compost applications helped soils become a net greenhouse sink (DeLonge et al. 2013). In order for compost application to grassland soils to be considered a climate mitigation strategy it is important to find an amendment that can maximize the benefits of increasing soil carbon storage while minimizing the release of greenhouse gasses.

Recent studies have primarily tested the effects of manure and plant waste compost (Ryals et al 2015), but we could find no published research that has tested the net flux of greenhouse gas emissions from food waste compost when applied to grassland soils. As more cities across the United States begin to compost and pledge to the zero-waste movement, food waste is becoming an available and affordable resource (Pollans et al. 2017). This study aimed to understand the effects of food waste compost application on the net flux of CO_2 equivalents (CO_2e) between the atmosphere and soil carbon stocks. Carbon dioxide equivalents takes into account the different warming potentials of different greenhouse gasses and converts them to a common unit for comparison. This study also compared the results of food waste compost with other available compost compositions in order to explore the range of CO_2e fluxes that compost can induce. Other soil amendments that have been tested for their effects on the net CO_2e flux include raw cow manure, green waste compost, and a mixed manure and green waste compost (Mayer, unpublished data). We tested the hypothesis that food waste compost will have a lower CO_2e flux than green waste compost, but more net CO_2e savings than the application of raw cow manure. We predict that the driving mechanism will be the C:N of food waste compost, which is higher than cow manure and green waste compost and thus is expected to have lower N_2O fluxes (Ryals et al 2015). Food waste compost also has a similarly complex organic matter structure to green waste compost amendments, acting as the slow-release fertilizer causing us to predict that food waste will lead to higher carbon sequestration over time. Better understanding of the effects of compost application on soil carbon sequestration could facilitate the adoption of compost application on grasslands, and thus help to mitigate the impacts of climate change.

METHODS

Study site

We conducted the incubation study using soils from the Nicasio Native Grass Ranch in Nicasio, CA (38.0834° N, 122.7633° W); all lab work was conducted at the University of

California, Berkeley, CA. We selected this field site to make our results comparable to another study that tested the effects of different soil amendments on soil carbon storage and other ecosystem processes (Ryals et al 2015). Nicasio is a well-studied site that has been used for pioneering soil carbon sequestration research since 2008 (Ryals and Silver 2013). The site experiences a Mediterranean climate with an average annual precipitation of 950 mm/y and temperatures ranging from 6 °C in the winter and 20 °C in the summer (Ryals and Silver 2013). The landscape contains both native perennial grass species (*Stipa pulcra, Danthonia californica*) and non-native annual grasses (*Avena barbata*, *Festuca perennis*) (Ryals and Silver 2013).

Soil Sampling

Previous studies applied compost to large plots of land under field conditions (Ryals et al 2015). We used a smaller scale, controlled approach that incubated soil with food waste compost in glass jars. To collect the soil, we first cleared vegetation with scissors then dug a trench 10 cm deep that was wide enough to yield 4.5 kg of top soil. We chose to dig one trench rather than collect separate 0 – 10 cm soil samples in order to minimize variation in soil properties between samples. We stored the soil in air tight and water tight Ziploc bags and transported them back to the lab in a cooler.

Soil Incubation and Compost Application

Compost Sourcing

The food waste compost we sourced for this research project came from the West Marin Compost Facility and was made from food waste scraps provided by Recology and mixed with wood chips. We collected scoops from three different sections of the industrial scale compost pile in order to achieve a representative sample. We sampled enough compost to fill two 1- gallon airtight and water tight Ziploc plastic bags. We transported the compost in a cooler to the lab.

Experimental Set Up

We waited one week after collection before handling the soil. When soil is disturbed it tends to increase its microbial respiration and we did not want this to affect our results. To increase homogeneity, we lightly mixed the collected soil and then sieved it through 4.75 mm mesh to maintain microaggregate stability. We removed stones, coarse roots, and plant matter. We added 300 g of field moist soil to each of the 14 1-quart mason jars and adjusted the volume to 1 g/m^3 bulk density. We added food waste compost to 7 jars to mimic the field application rate of 14 Mg C per hectare, based on C content from preliminary samples. In order to avoid plant growth, we stored the jars in the dark at room temperature. To measure net N mineralization, we performed a KCl extraction on the soil prior to amendment application, and also on destructively sampled soils from one treatment and control jar at weeks zero, three, and seven. We added 2M KCl to 15 g of dry weight of the soil sample or 5 g of compost amended sample. We left the samples to shake for an hour, then filtered, and then analyzed them on the Lachat Quik Chem Flow Injection Analyzer (Milwaukee, WI). We also measured moisture content and pH of the soil and compost. We collected additional subsamples of the soil and compost and analyzed them for total C and N concentration on the Carlo Erba Elantach elemental analyzer (Milan, Italy).

Greenhouse Gas Emission Measurements

To determine the impact of compost amendments on greenhouse gas emissions, we directly measured the CO_2, CH_4, and N_2O emissions from soil applied with food waste versus a control scenario that had received no food waste application. To measure the total greenhouse gas emissions produced by the soil in each jar, we sealed the jars and sampled the headspace at time zero (T0) and after 3 hours (T3), and injected the samples directly into a Shimadzu GC-14A gas chromatograph (Pleasanton, CA). We repeated the gas sampling once weekly for seven weeks. Each sample was weighed and maintained at initial field moisture by rewetting weekly after gas samples were taken. At the end of the 7-week incubation, we carefully separated the compost amendment from the soil material by hand and analyzed subsamples of the remaining soil for total C and N concentrations using the elemental analyzer. This measurement allowed us to calculate the change in soil C due to the compost treatment.

Modeling of GHG and Carbon Storage

DayCent is a biogeochemical computer model that is used to stimulate carbon and nitrogen fluxes between the atmosphere, vegetation, and soil. Model inputs include site-specific weather data (daily maximum and minimum temperatures and precipitation), soil texture and soil chemical characteristics, grazing management, and amount and timing of nutrient amendments on a daily timestep (Parton 1998). In this experiment we used DayCent to simulate the effect of one application of food waste compost to rangeland soil on the net flux of carbon and nitrogen over time. The model was previously parametrized with site specific information by Rebecca Ryals (2013), the only change we made was to adjust the organic matter addition parameter to simulate a different chemical composition of the compost for food waste. We ran the model under two different climate warming scenarios for each treatment. The first climate scenario is the high emissions scenario assuming a business as usual baseline. For this we assume a Representative Concentration Pathway (RCP) of 8.5. The second climate scenario assumes some emissions reductions (RCP 4.5). We used projected daily weather data for each climate scenario specific to the 2.8° x 2.8° grid cell as extracted from the CanESM2 Earth System Model. We spun up the model for thousands of years until soil carbon pools reached steady state. We ran the control and treatment simulations until the year 2100. DayCent was run a total of four times, under each time period including testing a control scenario that received no compost application in order to account for the site with compost application and without compost application. Both the treated and non-treated simulations were run under both the RCP 4.5 climate scenario and the RCP 8.5 climate scenario. DayCent outputs the results including the total stock over time and the N_2O emissions stimulated by the compost application. We used the incubation results to inform and validate the outputs of the model.

Data Analyses

Analysis of variance (ANOVA) was the main form of statistical analyses used for my study. We conducted an ANOVA to analyze if there was a significant difference between the amount of soil C storage with food waste compost application and without food waste application among the 14 jars. We used the same test to understand the differences between greenhouse gas emissions between food waste compost and the control scenarios. We ran another ANOVA to compare the total carbon storage of multiple different composts: food waste compost, green waste compost, and a manure compost mixture.

RESULTS

Jar Incubation

Total weekly emissions of CO_2e were significantly higher in the treatment jars compared to the control jars ($P< 0.0001$, Fig. 1). When broken down by individual greenhouse gases only CO_2 fluxes were significantly higher in treatments jars than control jars ($P < 0.0001$). Soil CO_2 fluxes contributed 99% of the total cumulative emissions over the 7 weeks. Immediately after compost application, we observed a spike in CO_2 emissions (Fig 2a). Over the course of the remaining weeks, the CO_2 emissions for the treatment decreased but remained significantly above the control emissions of CO_2. There were low CH_4 emissions in some weeks and consumption of CH_4 in other weeks, but overall we found no significant difference in CH_4 emissions between the control and treatment (Fig 2a). Additionally, we observed no significant difference in N_2O emissions between the treatment and control scenarios (Fig. 2b). Following the completion of the 7-week soil incubation, there was no significant change in soil C stocks between the treatment and control soils (Fig 3).

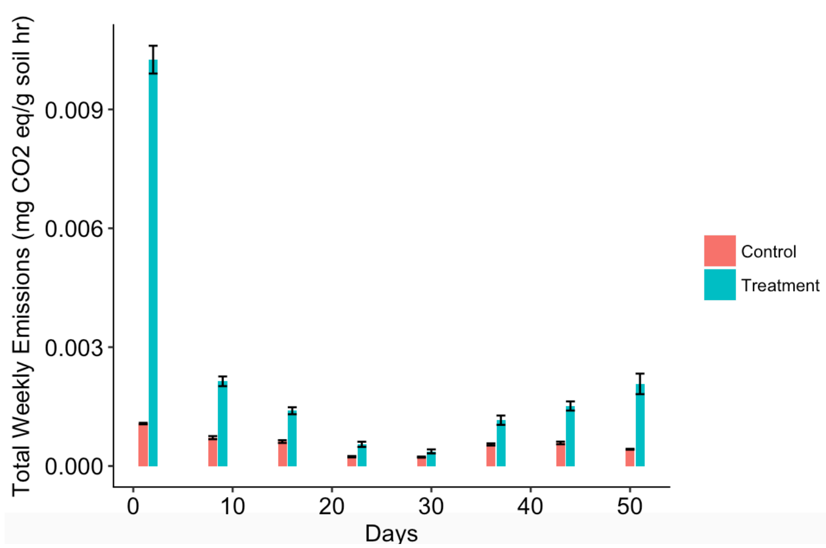

Fig 1. **Total weekly emissions from all greenhouse gasses.** Nitrous oxide, methane, and carbon dioxide were converted to CO2 equivalents using global warming potentials and added together each week. ($P< 0.0001$)

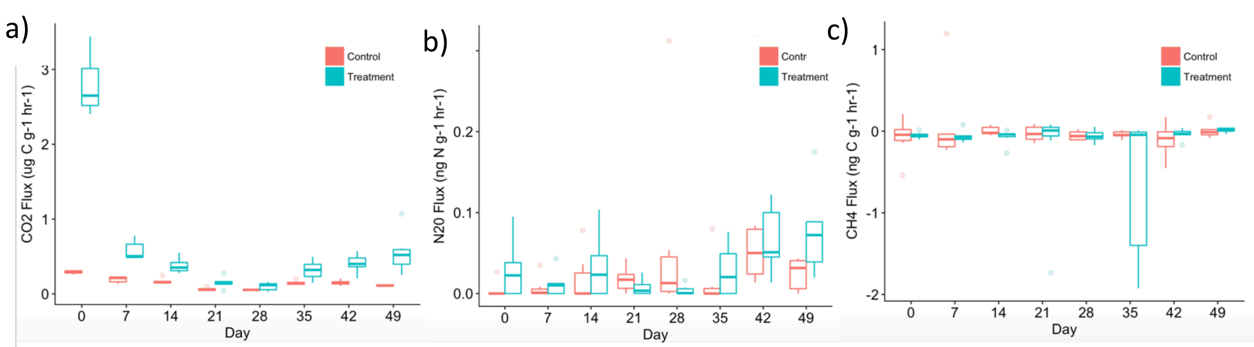

Fig 2. Total weekly emissions by individual greenhouse gas. (a) Weekly CO_2 flux over the course of the 7 week incubation ($P< 0.0001$). (b) The weekly N_2O flux over the course of the 7 week incubation. (c) The weekly CH_4 flux over the course of the 7-week incubation.

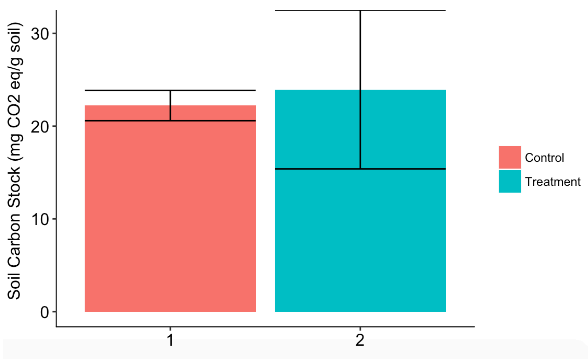

Fig 3. Total soil carbon following the completion of the jar incubation. No significant change in soil C over the 7-week incubation.

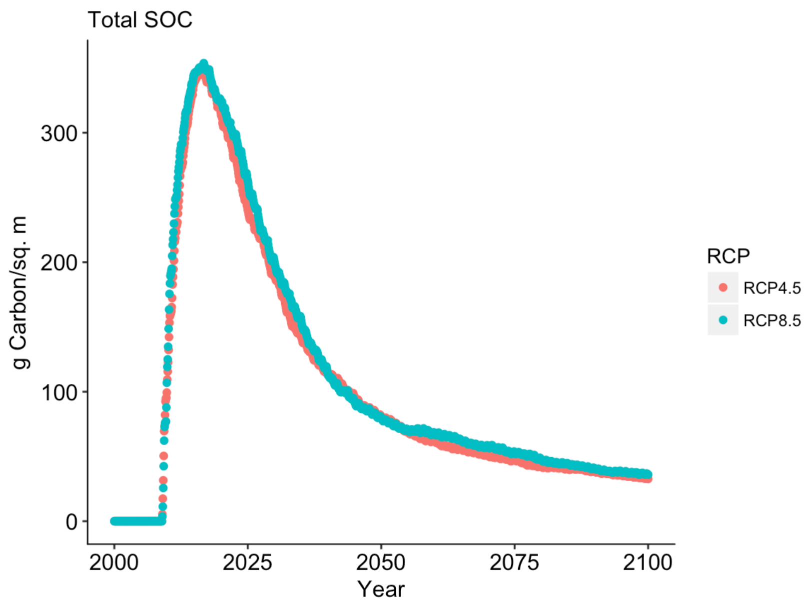

Fig 4. Total modeled relative change in soil organic carbon. This graph follows the changes following the application of food waste to grassland soils in Nicasio, CA under two different climate warming scenarios (RCP 4.5 and 8.5).

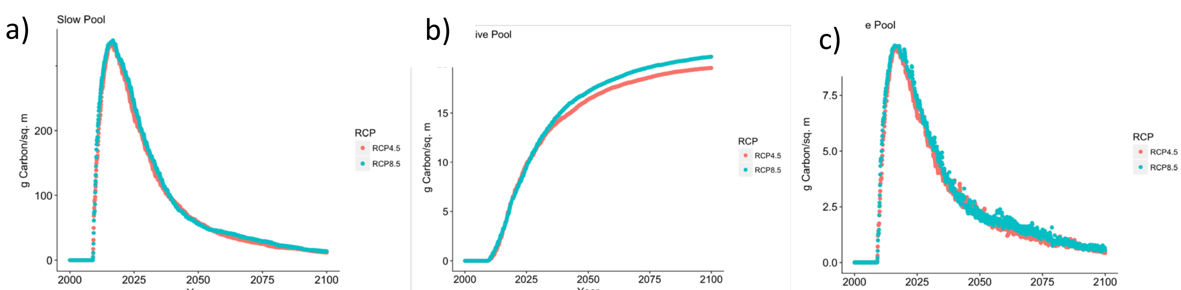

Fig 5. Modeled relative change in soil organic carbon. Changes in the slow (a), passive (b), and active (c) soil carbon pools under two different climate warming scenarios.

Modeled Changes in Soil C

The DayCent model simulated the effects of food waste compost application to grasslands soils in Nicasio, CA until the year 2100. The model outputs showed that total soil organic C in the treatment relative to control increased immediately following the application of food waste under both climate warming scenarios (Fig. 4). All three soil C pools (slow, passive, and active) experienced a net gain in C under both climate warming scenarios. The compost-treated simulation consistently contained more C in each pool compared to the control throughout the entire century. The passive soil C pool continued to gain C throughout the 100-year simulation (Fig 5b). The largest gain in carbon was observed in the slow pool (Fig. 5a). None of the three pools experienced net losses in soil C.

DISCUSSION

Prior to this study we knew of no published research that had tested the effects of food waste compost application to grasslands. Compost types that had been tested include raw cow manure and green waste compost (Ryals and Silver 2013, DeLonge 2013). The results of this project show that food waste compost application to grassland soils has the potential to mitigate climate change.

GHG emissions of soil

Despite the fact that greenhouse gas emissions were increased, 99% of these emissions were CO_2 and we observed no significant contribution of N_2O and CH_4 emissions between the control and the treatment.

While the addition of organic matter to soils has been shown to increase methanogenesis, the addition of composted organic matter has had minimal effect on the production of CH_4 (Favoino and Hogg 2008). Most CH_4 production in soils occurs through the process of methanogenesis which occurs in anaerobic conditions, but methanotrophs who consume CH_4 can be active in aerobic conditions (Wendlandt et al 2010). It is likely the incubation favored aerobic conditions which is which is why there was no significant increase in methanogenesis.

Changes in Soil C

In the short-term incubation, food waste compost application resulted in no change in soil carbon stocks. In the field and over the long-term, amendments have been shown to significantly increase soil carbon stocks (Ryals et al. 2015, Ryals 2013). Studies looking at the effect of green waste compost on grasslands at the same study site in Nicasio, CA have observed a significant increase in soil carbon storage in the field (Ryals 2015). Unlike the incubation study, these studies were carried out in the field and include the added carbon input from plant root and plant litter.

In contrast to the incubation, the modeling results show a long-term increase in soil carbon following the application of food waste compost. The modeling results follow similar trends to a study that modeled the effects of green waste compost (Ryals et al 2015). Both results show the increase in soil carbon occurs immediately following the addition of food waste and persists for several years. At no point did the added organic matter result in soil carbon losses when compared to the control scenario. Compost amendments increase net primary productivity, which increases the carbon capture via photosynthesis showing that soil receives most of its carbon gains through above and belowground productivity of vegetation (Ryals et al 2015). This is likely because grasslands can often be limited by low nitrogen level, thus the added N from compost amendments increases net primary productivity (Harpole et al 2007). The modeling results indicate that a single application of food waste compost has long term benefits for soil carbon storage. The fact that carbon gains were only seen in the modeling component of this experiment suggest food waste compost is a slow release amendment with effects best studied in the long term.

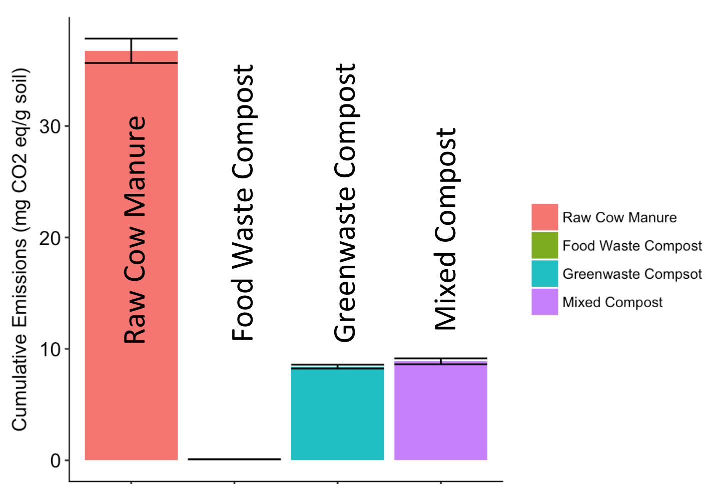

Fig 6. A comparison of greenhouse gas emissions. The total emissions from different compost amendments when applied to grassland soils.

Comparison of Composts

Food waste compost followed similar trends in greenhouse gas emissions to green waste compost by significantly increasing CO_2 emissions but not increasing N_2O or CH_4 emissions (Ryals et al 2013). Food waste compost application is distinct from all other tested soil amendments due to much lower emissions, suggesting a greater potential to mitigate climate change (Fig. 6). We expected that the food waste compost would likely have less greenhouse gas emissions than green waste compost because it has a higher C:N ratio than the previously tested green waste. Our results support this hypothesis. Although, the application of food waste compost increased soil respiration by approximately 3 times the emissions of control soil these emissions were only 1% of the emissions of green waste and mixed composts, and 0.25% of the cow manure emissions. The data comes from a similar study that followed the same incubation method but compared the greenhouse gas emissions of raw cow manure, green waste compost, and mixed (cow manure and green waste) compost when applied to grassland soils (Mayer, unpublished data). Raw cow manure had significantly higher emissions when compared to mixed manure compost and other tested composts, due to high N_2O emissions, showing that only composted organic matter amendments have the potential to mitigate climate change (Delonge et al 2013). Of all the composts tested, food waste showed the greatest potential to minimize greenhouse gas emissions.

Limitations

The combination of a controlled incubation experiment and model simulation of food waste application to grassland soils gives us targeted information, but only represents a small aspect of the greater lifecycle of food waste compost. Incubated samples of grassland soil without vegetation are not representative of the whole grassland ecosystem. For this reason, it is not surprising that the incubation did not show a change in soil C like the long-term model showed following the application of food waste compost. Another limitation of this study is that it relied on the outputs of a model. Models are not a true representation of ecosystem processes and serve only to inform possible outcomes. For this reason, it is important that research on this topic is continues.

Future Directions

Due to the limitations of this project, it is critical that this study is validated with field measurements in order to build a better picture about how food waste compost application to grassland soils effects soil carbon storage and greenhouse gas emissions. A field-scale study is currently underway to measure emissions and carbon sequestration in a California grassland after application of the same food waste compost examined in this study. Above all, it's important to advance research in this area to inform the life cycle assessment from the processing of food waste to the final application on grassland soils. Further understanding about food waste compost will help to better understand the climate change mitigation potential of food waste compost as a soil amendment.

Due to the anaerobic nature of landfills, food scraps produce a large amount of CH_4 emissions when they are decomposed by microbes (Serrano-Silva et al 2014). Food scraps, more than any other organic waste, generate the highest CH_4 emissions in landfills (Krause 2018). Moving forward, it is urgent for research to inform citizens and policy makers on the impact that diverting food scraps from the landfill for compost can have on reducing greenhouse gas emissions and mitigating climate change.

Food waste compost application to grasslands is also relevant to current policies in effect in California. Agriculture is a large contributor of greenhouse gas emissions in California. Under AB 32, the California Air Resources Board invests the profits of Cap and Trade in projects in California that aim to reduce emissions, including sustainable agricultural projects. If farmers commit to using food waste compost on crops as an effort to offset emissions from agriculture, they could be eligible to receive funding from the government to continue carbon footprint reducing practices.

Broader Implications

At this moment in time, even if all emission sources of fossil fuels were stopped, the effects of climate change would not be reversible (Kennel et al. 2012). For this reason, it is important to promote and make solutions accessible that provide negative emissions that work to reduce the concentration of greenhouse gas emissions in the atmosphere. Food waste compost is a powerful and important soil amendment because it can reduce emissions in multiple industries while also restoring soil and increasing its capacity to retain water. Such characteristics are becoming extremely important for soil as climate change continues to affect the length and severity of droughts in California (AghaKouchak et al. 2014). Making compost out of food waste will divert food from the waste stream, reducing the harmful CH_4 emissions generated by anaerobic decomposition in landfills (Delonge et al. 2013).

The results from this study are promising for informing the climate change mitigation potential of food waste compost application to grassland soils. The emissions from food waste compost do not stimulate significant N_2O or CH_4 emissions and total emissions are an order of magnitude lower in comparison to other composts that have been applied to grasslands. Long-term field studies involving food waste compost and the completion of a life cycle assessment of food waste compost emissions will continue to evolve the understanding about food waste and its climate change mitigation potential.

ACKNOWLEDGEMENTS

Thank you so much to everyone at the Silver Lab for all of the support. Thank you especially to Allegra Mayer and Whendee Silver for mentoring me during the whole of this project. Allegra, you have taught me so much and have especially motivated me throughout this process to make impactful science. Also, a major thank you to the teaching teams behind ESPM 175 and ESPM 100es. Tina Mendez and Leslie Mcginnis your hard work is greatly appreciated.

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