WORK PLAN

Research to Evaluate Nitrous Oxide (N₂O) Emissions from Compost In Support Of AB 32 Scoping Plan Composting Measure

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Introduction/objectives

The anthropogenically caused increase in atmospheric nitrous oxide (N_2O) and methane (CH_4) is beyond dispute and is significantly related to agricultural activities and organic waste management (USEPA, 2006). Nationally, agricultural soils and waste management are estimated to account for up to 75% of the total U.S. N_2O emissions, equivalent to annual 386.7 Tg CO_2. In California, 55% of all N_2O emissions have been estimated to come from agricultural soil and waste management, and N_2O may contribute as much as 50% to the total net agricultural greenhouse gas (GHG) emissions (California Energy Commission, 2005). Waste management such as dry storage, lagoon holding and composting can be sources of GHG, particularly N_2O and CH_4. The California Global Warming Solutions Act of 2006 (AB 32) mandates that the State develops comprehensive strategies to reduce GHG emissions by 2020. Therefore, sustainable agricultural practices and waste management practices that minimize GHG emissions while maintaining optimal production must be developed. For agriculture, the reduction in N_2O and CH_4 emission is key to reducing overall GHG emissions. In this work plan I will address the following objectives.

1. Determine the emission of N_2O and CH_4 from static and forced air composting operations of yard waste and food scrap materials.
2. Assess the significance of mature compost applications to agricultural soils to mitigate N_2O emission and consume atmospheric methane.
3. Prepare a report documenting the potential for diverting the waste stream of green waste materials from landfills through composting and application to agricultural soils to mitigate GHG emissions.

Compostable organic materials currently comprise over 25 percent of the waste stream disposed in California landfills. Once in the landfill, these materials break down anaerobically, releasing primarily CH_4 but also N_2O and other gases. Exposing the waste to oxidative conditions of composting can reduce GHG emissions (Brown et al., 2008). Composting biodegradable organic materials turns them into a soil amendment that can positively alter soil properties that increase water holding capacity and tilth, and provide a source of important crop nutrients. Composting therefore may represent the best use for organic wastes; however, compost pile contributions to GHG and its effect on soil GHG emissions following application are not well understood.

Both CH_4 and N_2O have been observed coming from compost piles (Hao, 2001, Sommer and Moller, 2000, Lopez-Real and Baptista, 1996). Methane forms under anaerobic conditions, often found at the bottom of piles, in areas with excessive moisture from water additions and due to oxygen depletion in areas of rapid decomposition. Much of the methane is oxidized to CO_2 before it leaves the pile through convective pathways, however the length of the pathway is critical in determining actual emissions (Brown et al., 2008). The amount of emissions depends on the initial water content, the size and shape of the pile and the frequency of pile turning. Therefore, proper management that avoids excessive anaerobic sites through careful moisture monitoring, pile configuration and frequent pile turning would reduce GHG production. The compost pile conditions leading to N_2O formation are less well understood, occurring closer to the surface where oxygen is limited but not absent and where nitrogen (N) as nitrate (NO_3^-) is in excess. Composting of green wastes with high carbon to nitrogen ratios likely reduces N_2O

emissions through high immobilization of N by microorganisms. The use of food scraps or other N sources would likely increase N_2O production. Higher nitrogen ratios would likely increase CH_4 production through increased decomposition activity, resulting in oxygen depletion. Therefore, small changes in N availability and moisture would likely affect N_2O emissions during the composting process. N_2O and CH_4, which have a global warming potential 300 and 25 times greater than CO_2 over a 100-year period respectively, are emitted during compost production, and it is important to know the rate of emissions and the processes and management affecting their production. The CO_2 released during composting is considered biogenic, not anthropogenic, so is not considered in GHG calculations.

The potential impact of compost use on N_2O emissions following agriculture land application has been inadequately quantified. This dearth of information has made it difficult to assess whether composting is the most beneficial way to divert waste from landfills to other purposes such as an agricultural amendment. According to the California Air Resources Board inventory, emissions of N_2O from the application of synthetic nitrogen fertilizers on California cropland resulted in roughly 4.7 million tons of CO_2 equivalent emissions in 2006, about 17 percent of all agricultural greenhouse gas emissions. Ergo, improving soil properties through compost amendments to reduce N_2O emission is very appealing.

Under the statutory authority of AB 32, the Department of Resources Recycling and Recovery has identified research that assesses N_2O and CH_4 emissions from the composting process for inventory purposes and to determine whether N_2O emissions can be mitigated by the application of compost to agricultural lands. This Work Plan is for a research project to determine N_2O and CH_4 emissions from the compost life cycle, starting with emissions during the production of compost in open piles and windrows, to quantifying the impact on soil emissions when compost is applied to agricultural lands. The impacts of compost use on N_2O and CH_4 emissions from agricultural soils will be measured in plots where compost is used alone, and where is it used in conjunction with synthetic nitrogen fertilizers. We will supplement field trials on compost-amended lands with laboratory tests to determine plausible rates of CH_4 uptake for compost amended soils. This research is compatible with and builds upon work being undertaken by the California Air Resources Board (ARB), the California Energy Commission and the California Department of Food and Agriculture to set baseline N_2O emissions rates for California agricultural soils.

Work to be performed

The work performed will provide information on how nitrification and denitrification, and methanogenesis and methane consumption processes work in compost piles and in compost-amended soils. In addition, the results from this project will provide insight into factors that can be altered or controlled to conserve N and reduce N_2O and CH_4 emissions in both the composting process and compost-amended agricultural soils. In addition, this research will determine whether compost application, in conjunction with applications of synthetic nitrogen fertilizer and or cover crops, may increase the efficiency of synthetic fertilizer use, thereby reducing the amount of fertilizer needed for agricultural application. The results of the study will help determine whether composters or farmers who use compost may qualify for GHG gas credits through the determination of GHG emission during the composting process and potential mitigative impacts of compost on soil GHG emission. The study will produce a report and supporting documents of sufficient quality and scientific rigor to be accepted by key stakeholders such as CARB and for presentation in the scientific literature.

In this project, we will address the following tasks: (1) select compost facility and representative fields of row crops and specialty crops for GHG monitoring; (2) implement compost facility and field research projects; (3) analyze GHG emissions in compost amended soils in laboratory incubations; (4) provide regular updates to DRRR staff and other stakeholders.; and (5) submit draft and final reports.

Tasks

Task 1: Work Plan and Compost and field Site Selection.

This task is composed of two subtasks; the production of this work plan, and the selection of a compost facility and farm sites at which we will monitor emissions.

Task 1a: Select compost facility to monitor GHG from composting process.

In consultation with DRRR staff a compost site was selected to conduct GHG emission studies from both static and forced air compost of yard wastes and food scrap materials. The site is:

Northern Recycling Compost - Zamora

11220 County Road 94
Zamora, CA 95698

The Zamora compost facility feedstock is green waste from the City of Napa, CA and surrounding area and includes grape pomace wastes from Napa Valley wine operations. Additional feedstock materials from Marin County include green waste and food scraps. The facility uses a mechanically turned windrow system of composting green waste and grape pomace, and is expanding into enclosed forced air composting of a mixture of green waste and food scraps. The amount of food waste in the compost feedstock ranges from 5 to 15% of the total feedstock. The methodology employed will specifically follow feedstocks through the entire composting process, from delivery of organic wastes at the facility, to screening of finished product. Established methods to measure the weight and mass of the original feed stocks and the finished compost will be done to develop emissions factors and calculate the loss of carbon (C) and nitrogen (N) during the composting process. The study will investigate variables such as altering initial C:N ratios, or closely monitoring pile temperature, moisture content and or oxygen rates which might impact N_2O and CH_4 emissions. The likely variables to be monitored at each GHG sampling event will be C to N ratio, moisture and temperature of the compost. The concentration of CO2 will be used as a proxy to estimate oxygen content. These variables will be examined in traditional windrows and closed windrow systems. Instrumentation and gas handling structures will be deployed to directly analyze emissions in real time, or to capture gas samples from selected air emissions of compost piles for subsequent analysis in Dr. Horwath's laboratory (See Task 2 for more detail).

Task 1b: Select field sites to assess compost effects on GHG emission from soil.

Field investigations to monitor emissions of N_2O, CH_4 and CO_2, from applications of compost to California agricultural land will be conducted during the project. Compost will be used alone and in combination with synthetic nitrogen fertilizers and with or without cover crops. Fertilizer

application rates will be determined by cooperators and reflect existing fertilizer recommendation rates (rates described below). In addition, NO_x will be measured infrequently to provide information on its' role in the total N budget.

A site located at Russell Ranch Sustainable Agricultural Facility (RRSAF) at UC Davis has been chosen and represents a long-term tomato-based row-crop rotation. The UC Davis site represents a long-term study of 16 years comparing conventional, cover cropping and organic agricultural systems. The long-term study is designed to elucidate the linkage of soil C content, irrigation practices, and other factors (soil moisture, temperature, soil nitrate content, etc.,) and on soil sustainability. In addition, the study is extremely useful to assess the effects of cropping system practices on soil N_2O emissions and nitrate leaching. The plots at the RRSAF will be complimented with additional sites on farm to reflect more applied agronomic management. On farm field sites will be selected with the approval of the contract manager. These sites will include both an additional tomato crop rotation and likely an almond orchard. On farm compost application rates for row crops are similar to described for the RRSAF plots while specialty crop application rates range from 10 to 20 tons per acre approximately every 3 years.

The study will be conducted in a row crop rotation and in specialty crop agricultural systems, and will cover multiple growing seasons and crop cycles (summer and winter). Multiple growing seasons will include periods of cover crop growth. Compost will be applied at high and low agronomic rates, and will be incorporated into the soil in the row crop rotation. Typical rates vary in the range of 4 to 16 tons (wet weight) per acre. Generally, 4 to 8 tons are applied once over a 3-year period. In the specialty crop systems, the compost will be used in the manner it is typically used for the specific crop, either as mulch or incorporated into the soil. In almonds, the crop likely to be examined in this study, the compost is incorporated to avoid loose organic material at the soil surface that could interfere with almond harvest. In the row-crop rotation, we will compare varying rates of application of both compost and commonly used synthetic nitrogen fertilizers, with or without cover crops. A representative sample of all compost which is applied will be brought to Dr. Horwath's laboratory in Davis for investigation of basic parameters and nutritive values (see details below).

On-site characterization of soil parameters will be conducted prior to final selection of monitoring sites. Critical variables to be determined are soil C and N content, soil texture, bulk density, and pH. The areas selected should reflect typical soil conditions and agronomic management of each crop. Soil texture and climate, which differ among regions, influence N_2O emissions mainly through their effects in controlling the duration of water-filled pore space after soil-wetting events. Overall, the site selection process will be based on a variety of information, such as management practices, site management histories, soil characteristics and regional climate.

Task 2: Implement compost facility and field research projects:

This task is composed of two subtasks; monitoring of compost facility and agricultural compost amended field sites for GHG emissions (Task 2a and 2b, respectively).

Task 2a: Monitoring of compost facility GHG emission.

The monitoring of GHG emission from the composting process and handling will be done primarily at the Zamora composting operation. Some monitoring may occur at the UCD Student Garden facility to test monitoring protocols and equipment. The research will include evaluating

the starting feedstock materials for total C and N, dissolved organic C and N, extractable P, N (NO_3^- and NH_4^+), moisture content, pH, and major cations (Ca, Mg, K, S, Na). Once the compost piles are constructed, the total C and N content, temperature and moisture content will be monitored throughout the entire composing process. The ash content of compost samples taken through the composting process will be determined at 450°C for one hour. The ash content of the starting material will be related to changes in C and N content to estimate their losses over time since the ash content remains constant while C, N, hydrogen and oxygen are mineralized through the decomposition process. To complete the C balance calculations for the chamber and gradient approaches described below, we will use litter bags to determine the actual mass loss occurring during the composting process (Horwath et al., 1996). Samples of yard waste are placed into sealed nylon small mesh (slightly smaller than window screen material) and inserted into the compost pile at various depths to reflect C and N loss as a function of windrow spatial location. The litterbags are removed periodically and destructively sampled to determine mass loss (Horwath et al., 1996). .

The monitoring of GHG emission during the composting processes is done with a variety of methods. Some of the more common approaches include using static chambers (Beck-Friis et al., 2000), gradient approach (access tubes; Hellebrand 1998), and micrometeorological techniques (Sommer et al. 2004). The use of a dynamic plume method to measure GHG at the facility level is very much desired and will be discussed with the contract manager and the Air Resources Board. The dynamic plume approach requires the cooperation of ARB and the use of their mobile emissions monitoring platform. No resources are allocated to this approach in this project.

Chamber Approach

A dynamic chamber approach using a defined amount of headspace air to flush the chamber has rarely been used in compost studies. The static chamber and gradient approaches to assess GHG emission from compost piles by far dominate the reports seen in scientific literature over the last two decades. Micrometeorological and dynamic plume techniques have been used in the last decade but represent relatively few studies compared to the other approaches. The micrometeorological and dynamic plume approaches generally give higher GHG emission estimates (Sommer et al., 2004; Anderson et al., 2010) and appear to more accurately reconcile the loss of C from the compost as CO_2 (mass balance). However, the consensus that the micrometeorological and dynamic plume approach are the best techniques to measure GHG from compost piles is not established in the literature, mainly because of the limited number of studies comparing all approaches. In this project, we will use the static chamber, gradient and micrometeorological approach. The dynamic plume approach is desired to complement this work; however, as stated above, this requires the cooperation of the Air Resources Board and the use of its mobile GHG platform, which is still being negotiated.

The use of static chamber and gradient approaches are the most common methods used to measure GHG from the composting process as mentioned above. The approaches are economical and technically not challenging. They are generally accurate but are challenged in their ability to scale the emission results to the compost pile level, largely due to the inability to estimate the convective flow of air through the compost pile during various stages of the heating process. We will employ static chambers and the gradient approach as a routine measurement of GHG from compost piles. The advantage of these approaches is that they provide insight into

the influence of the composting process on GHG emissions. For example, the gradient approach allows for the in depth analysis of pile structure, location and density on GHG formation potential. Similarly, the static chamber approach can determine the location of GHG emission from the compost pile and provide insight on how pile structure (height, width, and density) act together to influence convective flow through the pile. Together these common analytical approaches provide information on pile management effects on GHG emissions and to provide insight on how to optimally manage piles to reduce GHG emission.

The static chamber approach has been used successfully to monitor GHG from soil (Hutchinson and Mosier 1981). The approach uses a vented chamber to allow the equilibration of GHG diffusing unimpeded into a vented chamber. The rate of increase of the concentration of gas of interest, measured over time, is used to estimate an emission rate. The approach is designed for static conditions where airflow or changes in atmospheric pressure are minimal. This is often not the case in compost piles where convective airflow at the top of the pile can violate these prerequisites, especially early in the composting process when maximal pile temperatures occur. To account for convective gas flow conditions in the compost pile, the size of the vent or a dynamic airflow system can be applied to account for mass airflow from the pile (Denmead 2008). We will design a chamber system by configuring the size of the vent or provide mass airflow assist through the chamber to measure GHG emission from specific locations on the compost pile. Though adjusting the size of the vent would be the simplest approach, it may not adequately allow free flow of air from the pile through the chamber and finally through the vent to the atmosphere. In this case, we will provide an airflow assist that will sweep the chamber without affecting the emission rate of CH_4, CO_2 or N_2O from the surface of the compost pile (Denmead 1979). Basically, the approach involves installing vents at the topside of the chamber and installing a larger diameter tube (~20mm) with fan assist suction out of the chamber. The size of the vent and tube are adjusted to maintain zero pressure within the chamber allowing the convected air from the pile to move into the chamber unimpeded. A mass airflow detector is placed inline in the tube and the concentration of GHG is monitored by taking samples of the air stream in Vacutainers (Becton-Dickinson, Rutherford, N.J.). Regardless of which chamber technique is used, the chambers will be deployed every 1 to 2 meters from the bottom to the top of the pile to account for areas of air ingress and escape from the pile caused by the convective pathways from the heat produced during the decomposition process. In this way, we can determine the entry and consumption of N_2O and CH_4 into the pile and by difference estimate production of these GHG emitted from within the pile. During each sampling period, air is collected from the chamber headspace at 0, 5, 10, 20 and 30 min using syringes and transferred to a Vacutainer. The samples are then transported to the Horwath lab and analyzed on a Shimadzu gas chromatograph (Model GC-2014) linked to a Shimadzu auto sampler (Model AOC-5000). The calculations to estimate emission rate using the chamber approach are described in Hutchinson and Mosier (1981). Emission (mg N or C m^{-2} s^{-1}) is calculated by fitting the concentration of the gas versus time for each chamber with a second-order polynomial equation ($y = a + bt + ct^2$) and multiplying the first derivative b (mg N or C m^{-3} s^{-1}) by V=A (m). Emission rates from the pile will be calculated based on zones where the chambers were employed to scale the results to the pile level. This is similar to the approach used to zone specific emission rates on row crop beds described in Kallenbach, Rolston and Horwath (2010). The sampling for GHG will occur after turning events and during aging as proposed in Table 1.

Product: *Determine zone specific GHG emission rates in compost piles during the composting process. The composting process takes about 12 weeks to complete. During this time the pile is turned up to 10 times to facilitate the completion of the decomposition process. We will monitor these event-based disturbances and baseline emission rates to develop a total GHG emission budget using this approach.*

Gradient Approach

The gradient method is technically the easiest method and requires few resources and less time to conduct the monitoring. The approach requires inserting gas sampling tubes to access specific locations in the pile including bottom, middle and top and across the width of the pile. Access tubes should sample a maximal area of 1.0 m^{-3} within the compost piles, representing the different locations within the pile (top, bottom, middle, sides). Sampling intervals by depth and width will be spaced at intervals of 50 to 100 cm depending on location in the pile (Beck-Fris et al. 2000; Horwath et al. 1994). The results will be used to create GHG profiles within the compost pile during different stages of the composting process, as described above. The main issue in the literature with this approach is the data is not used to its full potential.

Ideally, the gradient data needs to be used in a transport model in conjunction with the C balance of the decomposing substrate (Hellebrand 1998). The conditions needed to be met by the transport model are that the movement of GHG molecules must be greater than that caused

Table 1. Proposed schedule of GHG sampling from compost windrows using various gas sampling protocols and composting techniques.

Day	Compost process*	Flux Chamber method	Gradient method	Mircomet method	Vacuum method
			Activity		
0	Pile formation	X	X	X	X
3		X	X	X	X
6	Turn	X	X	X	X
8		X	X	X	X
14	Turn	X	X	X	X
16	Turn	X	X	X	X
21	Turn	X	X	X	X
23	Turn	X	X	X	X
28	Turn	X	X	X	X
30		X	X	X	X
37	Turn	X	X	X	X
39		X	X	X	X
44	Turn	X	X	X	X
46		X	X	X	X

51	Aging	X	X	X	X
57	Aging	X	X	X	X
66	Aging	X	X	X	X
75	Aging	X	X	X	X

* The indicated turning schedule is hypothetical. During the composting process the Process for Further Compost Reduction of Pathogens requires 5 turns to occur during a 15-day period where the compost pile temperatures are maintained at 131° F or greater.

by diffusion. Due to the heating in the compost pile, air flows convectively, causing mass flow of air (mass transport). We will use the transport model described by Hellebrand (1998) to estimate emission rates of GHG from the compost piles. Firstly, the release of a particular GHG ($\Delta GHG/\Delta t$, t is time), is the product of the concentration [GHG] and the volume (V) of air flow ($\Delta V/\Delta t$), therefore,

$$\Delta GHG/\Delta t = [GHG]\,(\Delta V/\Delta t) \tag{1}$$

In a compost pile convective airflow is caused by heating, which increases the movement of GHG molecules beyond the rate of diffusion. However, in realty there is no uniform flow rate and the flow path is not known. This can be approximated if the airflow is considered uniformly distributed. This assumption can be made if the decrease in C content over time is equal to the C mass flow (C-CO_2) leaving the compost pile ($\Delta C/\Delta t$). Using this relationship, the mean C concentration [C] of CO_2 in the pile can be expressed as

$$\Delta C/\Delta t = [C]F(\Delta V/\Delta t) \tag{2}$$

where the transport function $F(\Delta V/\Delta t)$ is determined by pile structure (convective air flow from bottom to top of pile) and is not dependent on the GHG molecule properties. For example, the diffusion constants for N_2O and CO_2 are equal. Therefore the emission rate of N_2O (N), for example, ($\Delta N/\Delta t$) can be derived as

$$\Delta N/\Delta t = [N](F(\Delta V/\Delta t) \tag{3}$$

where [N] is the measured concentration of the N_2O in the pile at various locations. Using equation (2), the emission rate of N_2O is estimated by

$$\Delta N/\Delta t = [N](\Delta C/\Delta t)/[C] \tag{4}$$

According to Fick's law, the diffusive mass transport is directly proportional to the concentration gradient. Assuming GHG are constant outside the pile and a steady state flow of GHG molecules exists in the pile, the diffuse-controlled transport of GHG can be expressed as

$$\Delta GHG/\Delta t = D_{ghg}/D_{CO2}[GHG](\Delta C/\Delta t)/[C] \tag{5}$$

where D_{ghg} is the diffusion coefficient of the GHG and D_{CO2} is the diffusion coefficient of CO_2. Using this approach, the estimated relative error in emission rates is assumed to be lower than 50%. The error is associated with GHG solubility, in the case of N_2O, compost turning,

estimation of C content of the feedstock over time, changes in heating over time affecting convective flux and changes in compost density over time. The sampling for GHG using the gradient approach will occur after turning events and during aging as proposed in Table 1. Overall, the above equations are used to estimate GHG flux based on the change in the concentration gradient of the gases within the pile.

> **Product:** *These results will be used in combination with the chamber measurements to estimate GHG emission from the piles over time. The emission rates are estimated rather than determined through the flux approach described above. Additional information garnered from this approach will be used to assess locations within compost piles responsible for active GHG production. The information can be used to adjust management to reduce GHG emission during the compost process.*

Micrometeorological Approach

Micrometeorological approaches for measuring GHG from compost piles have rarely been reported (Sommer et al. 2004). The technique has advantages over the chamber and gradient methods in that it is measuring GHG emissions from large sections of the compost pile rather than from points on and within the pile, and therefore requires minimal scaling. Though no resources have been specifically set aside in the current budget to conduct this approach, it may be possible to construct a simple system to conduct monitoring over the 10- to 12-week period of the composting process. The approach is an integrated horizontal flux and backwards Lagrangian stochastical dispersion micrometeorological technique to measure CH_4, N_2O and CO_2. The method calculates the average surface flux of GHG (Q; $\mu g\ m^{-2}s^{-1}$) by the difference in the horizontal flux of gases across downwind and upwind boundaries (Denmead 2008). The approach is shown in Figure 1. A number of gas sampling access points are positioned on suspended poles to take air samples vertically across the pile to about twice the height of the pile. At each sampling point up and down-wind anemometers are mounted to record wind speed across the pile. The readings of airflow across the pile is continuously monitored and recorded by a data logger. The poles are attached to a rotating bar that is attached to a large wind vane (Figure 1). The wind vane controls the orientation of the poles with air intakes and samplers relative to the compost pile to ensure the downwind pole is positioned downwind. Gas sampling upwind and downwind of the compost pile is accomplished by diverting gas samples from air intake ports to a manifold where individual gas samples representing each point on the suspended poles on either side of the compost pile (Figure 1). I estimate that 3 complete gas samples from each point can be taken over a 2 to 3 minute period. Real time gas sampling may also be possible using an acoustic gas analyzer, but the frequency of measurement is likely no faster than taking manual samples, and likely would be slower. Calculation of emission rates involves a complex number of equations described by Denmead (2008) not shown here. We will have to write a number of computer programs using these equations to integrate the results. This work would be done in collaboration with K.T. Paw U, a biometeorologist in the Department of Land, Air and Water Resources at UCD. Dr. Paw U has experience in measuring GHG with a similar micrometeorological approach in agricultural row crop systems.

Sampling for GHG with all the above methods will be done using Vacutainers (Becton-Dickinson, Rutherford, N.J.). The samples are then transported to the Horwath lab and analyzed on a Shimadzu gas chromatograph (Model GC-2014) linked to a Shimadzu auto sampler (Model

AOC-5000). The sampling for GHG using the micrometeorological approach will occur after turning events and during aging as proposed in Table 1.

> *Product: We feel the micrometeorological approach has merit and would be appropriate to compare with the chamber and gradient approaches to estimate GHG from compost piles. Limited monetary and technical resources to conduct this approach may result in not using or using this approach on a very limited basis. However, the results of the micrometeorological approach may potentially provide a more realistic estimate of whole pile emissions compared to the more commonly used chamber and gradient approaches, and we will make an attempt to implement this approach. We will compare the results of the open pile versus the closed pile method to estimate GHG emission from the two different windrow composting approaches.*
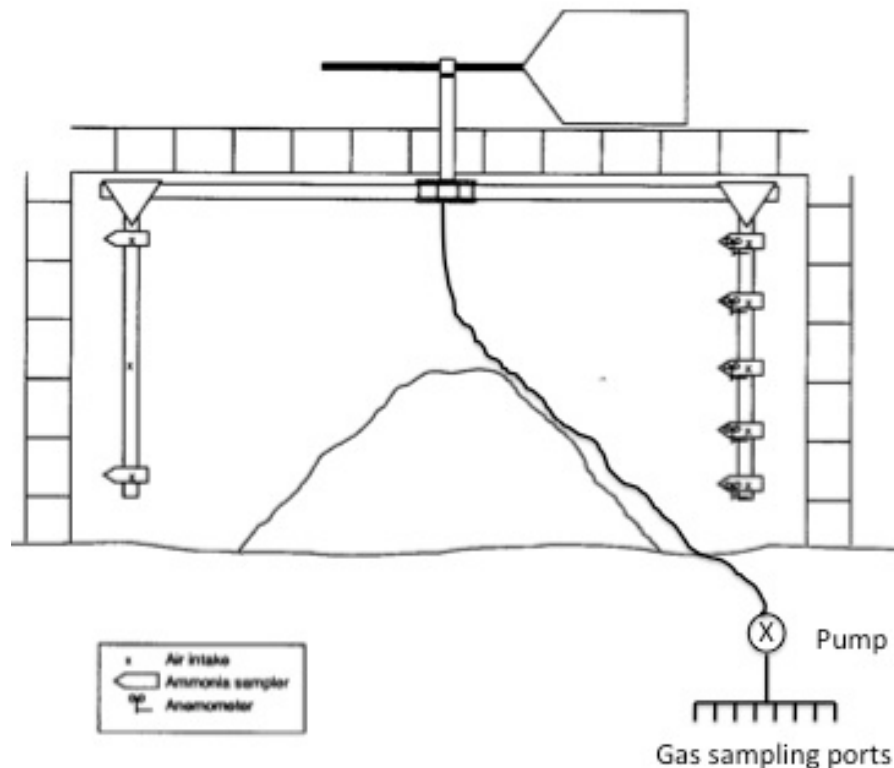

Figure 1. Schematic of a measurement system for the net horizontal GHG flux from a compost pile (Sommer et al. 2004).

Closed Compost System Monitoring

The estimation of GHG from forced aeration compost systems is more straightforward. The use of forced air--either pushing into the pile (positive aeration) or pulling out of the pile (negative aeration)-- is becoming more common as a method to mitigate the emission of volatile organic compounds (VOC) during the composting process. VOCs create air quality concerns through the formation of ozone, which is a serious threat to humans and plants, and is a criteria pollutant under the federal Clean Air Act. We will measure airflow through the compost pile by measuring the exhaust from the compost pile fan/suction system before the air is forced through a biofilter to remove VOCs. We will also measure the exhaust gas following biofiltration to

determine if the biofilter affects the emission of CH4 and N2O from the entire aerated composting process. It is assumed that greater than 90% of the compost GHG emission would be captured and directed through biofilter to VOC. We will measure the airflow using a mass flow air meter, and will work with the compost facility to install the meter into the exhaust pipe to continuously monitor airflow. In the vicinity of the airflow meter we will install a gas sampling port where a sample of air can be taken and placed into vacutainers. We will take air samples from the exhaust of the biofilter and use the flow rate measured in the exhaust pipe to determine load and potential changes to CH_4 and N_2O concentrations from the enclosed composting process. We will take frequent gas samples during the composting process according to the schedule proposed in Table 1 to determine GHG concentrations and analyze them on a Shimadzu gas chromatograph (Model GC-2014) linked to a Shimadzu auto sampler (Model AOC-5000) as described above. The results will be used to calculate the load of N_2O and CH_4 for the entire composting process. The sampling for GHG using the from the closed air compost system approach will occur after turning events and during aging as proposed in Table 1.

> ***Product:*** *We will compare the results of the open pile versus the closed pile method to estimate GHG emission from the two different windrow composting approaches. In summary, the effort in Task 1a will provide estimates of total GHG emissions from piles during the composting process, aging and storage of the compost.*

In addition, to measuring GHG gases from the compost process, we will gather information on fuel use from compost turners and loaders, water use and electrical use from the vacuum pile system. The compost operators will provide this information and no guarantee can given on the accuracy of the data.

Task 1b: Monitoring of agricultural compost amended field sites for GHG emissions.

The effect of field compost addition on N_2O emissions will be monitored at up to three locations. The locations include the RRSAF at UC Davis and two farmer cooperators. One potential farmer cooperator has been identified who is working on a different soil type and is using a tomato based rotation similar to the RRSAF. A third site in a specialty crop system, such as almonds, will be selected by October 2010.

At the RRSAF, microplots will be set up in a randomized complete block design (3 plots, each containing 6 microplots). We will use conventional and winter cover crop systems to determine the effect of compost on GHG (N_2O emission and CH_4 consumption). The compost treatments will be applied to microplots (typically on the order of 5 x 5 m, depending on bed and furrow configurations) at rates ranging from 0, 8 tons and 16 tons per acre wet weight. This configuration of compost, cover crop and replicates comprises 18 total experimental plots.

This work should be complemented with a fertilizer rate trial which will provide information on the effect of compost on the fate of excess fertilizer N. The fertilizer trial would ideally have 5 fertilizer N rates ranging from 0, 50, 100, 150, and 200 lbs per acre. However, the addition of the fertilizer treatments with the above cover crop and replicates would increase the number of experimental plots to 90, which would not be feasible to monitor GHG both in terms of human and technical capacity. Therefore, the fertilizer rate trial will intersect with the microplots at the 8 tons per acre of compost level, leaving four additional plots and three replicates in the fertilizer

rate trial. Table 2 describes the microplots for both field trials at RRSAF. It is important to determine whether the emission of excess N in soil would alter the ratio of N_2O to N_2 emitted (McSwiney and Robertson 2005). Segments (conventional soils only) of the compost addition experiment were initiated in the Spring of 2010 (using other funds) and data will be collected through March 2012 (see Project Schedule). See below on sampling protocols for GHG.

Table 2. Schematic of Microplots for Compost Rate Experiment (3 replicates)

Conventional treatment 0 tons per acre compost	Conventional treatment 8 tons per acre compost	Conventional treatment 16 tons per acre compost
Cover crop treatment 0 tons per acre compost	Cover crop treatment 8 tons per acre compost	Cover crop treatment 16 tons per acre compost

Schematic of selected micro plots for fertilizer rate experiment (3 replicates)

Fertilizer level 1 8 tons per acre compost	Fertilizer level 2 8 tons per acre compost	Fertilizer level 3 8 tons per acre compost	Fertilizer level 4 8 tons per acre compost

The monitoring on farmer fields will be a comparison of compost-amended versus non-amended soil. Compost will be applied at the rate of 8 to 16 tons (typical agronomic rates) and will be incorporated into the soil as described in previous section. The inclusion of a fertilizer rate trial as is described for the Russell Ranch Sustainable Agricultural Facility plots is desirable and will be discussed with growers, however growers are often not keen on this type of study because of the logistics of small plot experiments are often overwhelming and difficult to implement. At the specialty crop site, compost will be applied at the rate of 10 to 20 tons per acre (wet weight) and incorporated into the soil.

For all farm sites, we will obtain yield information. For small plot work at the RRSAF, 3 tomato plants from each microplot will be harvested, and the fruit and biomass weight determined. In addition, fruit quality will be determined through an independent laboratory. At the grower sites, 3 to 5 tomato plants will be harvested for fruit and plant biomass measurement. For specialty crop yields, we will rely on the grower to provide yield estimates. For all crops, C and N analysis will be done on harvested material, plant biomass (probably not for tree crops) and soil to complete C and N budgets.

We will measure N_2O flux intensively on all plots when the potential for N_2O emissions is high, but less frequently when N_2O emissions can be expected to be low. Episodes of high N_2O emissions occur when both soil NO_3^- concentrations and water-filled pore space (WFPS) are high, for example during irrigation or after rainfall events following N fertilization, or after harvest (residual fertilizer N) (Bronson and Mosier, 1993; Burger et al., 2005; Dobbie et al., 1999; Simojoki and Jaakkola, 2000). The incorporation of residue also stimulates N_2O flux, especially if followed by soil wetting (Baggs et al., 2003; Burger et al., 2005; Kaiser et al., 1998b; Velthof et al., 2002). Emissions of N_2O will be monitored in the winter because California's mild winter temperatures and seasonal rainfall patterns may be conducive to sporadic high N_2O emissions in the winter (Kallenbach, 2010). Examples of sharp spikes of N_2O fluxes in response to increases in soil moisture and N and C inputs in tomato systems in Yolo County are shown in Figure 2

Frequent N_2O flux sampling will take place immediately before and after N fertilization and irrigation or rainfall events with the goal of capturing the extent of elevated N_2O fluxes until

the fluxes subside to background levels. When N_2O flux has receded and soils are relatively dry, measurements will be taken less frequently (e.g. weekly). We will also estimate the magnitude of diurnal fluctuations through short term, detailed time-series measurements of N_2O flux. The information from the diurnal measurements will be useful for choosing the sampling time most representative for the average daily N_2O flux.

Nitrous oxide flux will be measured using a static chamber technique (Hutchinson and Livingston, 1993). Round PVC chambers (25.4 cm diameter) will be used to monitor emissions. The chamber height will depend on whether plants will be enclosed, but most often the chambers will be 15cm in height and exclude plants. The chambers will be vented (4.8mm dia., 10 cm long tubes) and insulated. Chamber bases will be placed to a depth of about 8 cm in a distribution representing conditions in the field (top of soil beds, furrow bottoms, etc.). The bases will be left in place unless field operation requires their temporary removal. The chambers will be fitted onto the bases and headspace air will be removed from a sampling port with butyl rubber septa via syringe and needle after 0, 30 and 60 min, and stored in vacutainers with grey butyl rubber septa. Air temperature during sampling will be recorded, along with other environmental variables (soil temperature, soil moisture, soil nitrate). The headspace air samples will be analyzed on a Shimadzu gas chromatograph (Model GC-2014) linked to a Shimadzu auto sampler (Model AOC-5000). The system will be calibrated daily using analytical grade N_2O standards. The number of daily samples generated at the 3 sites during an intensive sampling period can be processed in a 24-48 hour period.
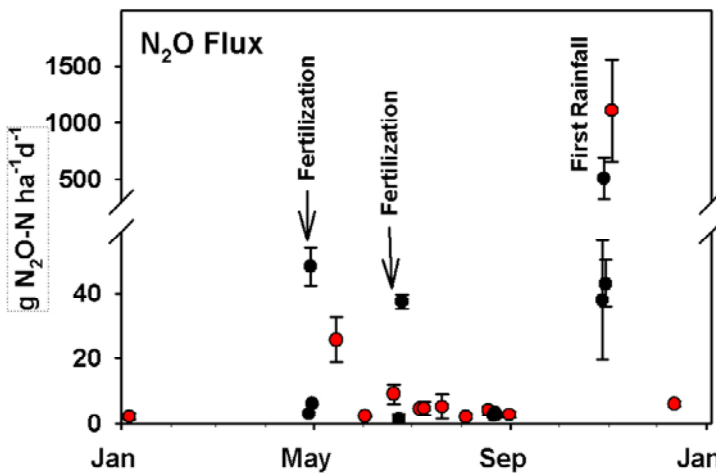

Figure 2. Nitrous oxide flux in response to management events in conventionally managed tomato systems at the UC Davis Russell Ranch Sustainable Agriculture Research site in Yolo County. The red and black symbols represent N_2O flux measurements in different years. Standard errors shown as line bars. n=3.

Gas fluxes will be calculated from the rate of change in chamber concentration, chamber volume, and soil surface area (Hutchinson and Mosier, 1981). If the rate of change of headspace trace gas concentration is not constant, then an algorithm appropriate for curvilinear concentration data with time will be used (Hutchinson and Mosier, 1981). Chamber gas concentrations determined by GC (volumetric parts per million) will be converted to mass per volume units assuming ideal gas relations using the air temperature values during sampling. The annual N_2O emissions will be calculated by assuming that the measured fluxes represent mean daily fluxes, and that mean daily fluxes change linearly between measurements. Differences between N fertilization treatments will be assessed using one-way ANOVA and standard mean

separation procedures. Transformation of the N_2O emission data will be carried out for the statistical analysis if the data will not be normally distributed. The N_2O flux data generated in the proposed research and the ancillary variables measured during gas sampling will also be used to calibrate and validate modeling of N_2O emissions by our collaborators.

Emission factors (EF) will be estimated by the difference in total N_2O-N emissions between compost-amended treatments and the control (0 compost applied) divided by the amount of compost and/or fertilizer N applied. This analysis also allows for calculation of an emission factor (EF) per growing season, rainy season, all year, and for a specific event or fertilizer N level, i.e. a range of crop specific EFs will be determined.

The IPCC (tier 1) approach uses an (EF) of 1%, i.e. the fraction of the applied fertilizer N lost as N_2O to the atmosphere. This is a statistically derived value based on a meta-analysis of available data (Bouwman et al., 2002). Estimates of EFs reported in the literature range from 0.2 (Dobbie et al., 1999) to 15.5% (Jungkunst et al., 2006). Some studies found EFs <1% from small-grain cereal systems and relatively higher EFs (2.6-5.7%) in broccoli, potato, and sugar beet systems (Dobbie and Smith, 2003; Kaiser et al., 1998a). In Santa Barbara County, CA, EFs in vegetable systems (lettuce, broccoli, cauliflower, artichokes), which received 290-665 kg N ha^{-1}, ranged from 4.0 to 9.3% (Ryden and Lund, 1980). In addition to NO_3^- levels and soil moisture, local factors relating to soil conditions and weather patterns influence N_2O emissions. Ruser et al., (2001) reported that up to 58% of annual emissions in wheat, potato, and corn systems occurred outside the cropping period. This suggests that offseason monitoring must be done to determine the residual fertilizer effect from previous crops.

A non-linear increase in N_2O emissions may occur when N fertilizer inputs are in excess of crop N need. Meta-analyses based on over 1000 studies found that increasing fertilizer N application rates significantly increase N_2O emissions, (Bouwman et al., 2002; Eichner, 1990; Stehfest and Bouwman, 2006), and this trend is more pronounced at the high end of N application rates (>200 kg ha^{-1}). However, several studies have shown that N_2O emissions increased sharply in response to N inputs that exceeded crop N requirements or economic N yield (Edis et al., 2008; McSwiney and Robertson, 2005). Fertilizer N inputs greater than at levels where yield is maximized seem prone to result in drastic increases of N_2O emissions. For example, N_2O flux increased from 20 to 50 g N_2O-N ha^{-1} d^{-1} with an increase in N fertilizer of only 33 kg N ha^{-1} above the economic N yield (McSwiney and Robertson, 2005). In a modeling study, Grant (2006) reported a non-linear rise in N_2O emissions where mineral N availability exceeded crop N demand. The difference between the mineral available N and crop N uptake seems to have a greater influence on N_2O emissions than the absolute amount of fertilizer applied. Sehy et al. reported a 34% decrease in N_2O emissions over a 10-month period with a 17% decrease in N fertilizer input at a low-yielding site in a maize field, whereas an increase in 17% N fertilizer at a high-yielding site had no effect on N_2O emissions (2003). Other studies showed that the residual N not taken up by a crop lead to higher N_2O emissions than those in crop systems with lower post-harvest NO_3^- levels (Ruser et al., 2001; Smith et al., 1998). In this study, one of the questions we are attempting to answer is whether the application of compost will immobilize excess available N and reduce N_2O emissions overall. The reduction in N_2O emissions can result from changes in soil structure affecting water filled pore space, a more viable microbial community with the ability to immobilize more N, etc.

Soil moisture and soil N availability, in addition to C availability, largely control the magnitude of N_2O emissions. The application of compost changes both the moisture holding capacity of the soil and its aeration status. Ideally, compost additions would create conditions

less conducive to denitrification. However, the input of C from the compost may serve as a substrate for denitrifiers. Denitrification occurs under oxygen (O_2) limitation, typically when diffusion of O_2 from the atmosphere into the soil is limited at high soil water content, for most soils at a water-filled pore space (WFPS) >60% (Linn and Doran, 1984). Heterotrophic bacteria use NO_3^- instead of O_2 as an electron acceptor, thereby reducing NO_3^- to N_2 via the obligate intermediates nitrite (NO_2^-), nitric oxide (NO) and N_2O. The proportion of N_2O that is not consumed and escapes to the atmosphere is regulated by O_2 via WFPS, decreases with a water content near saturation (WFPS >90%), and increases with decreasing water content (Firestone et al., 1982). The highest N_2O fluxes occur at WFPS 60-90% (Davidson, 1992; Dobbie et al., 1999; Linn and Doran, 1984; Simojoki and Jaakkola, 2000). The availability of C stimulates microbial activity, thereby decreasing the available O_2 in the soil and increasing NO_3^- demand and N_2O production (Weier et al., 1993). Nitrous oxide is also produced during nitrification, although the exact mechanisms and environmental conditions are not as well understood as those of denitrification. Nitrification, the conversion of NH_4^+ to NO_3^- via the intermediate NO_2^-, is carried out by autotrophs and occurs mostly under aerobic conditions, i.e. at lower WFPS, but there is evidence of denitrification by nitrifiers under O_2 limitation (Wrage et al., 2001). The main driver of nitrification is NH_4^+ availability. Low pH may stimulate N_2O production under aerobic conditions (Venterea and Rolston, 2000b).

Soil temperature, in addition to air temperature and soil moisture, will be recorded during each gas sampling. At each sampling event, inorganic N to a depth of 15 cm will be determined in soil extracts. , Soil pH will be measured in soil slurries on a seasonal basis. Bulk density in the 0-15 cm layer will be determined to calculate the soil water-filled pore space, a useful predictor for N_2O flux, from soil moisture values. The quantity and C/N ratio of incorporated crop residues will be determined (see above plant biomass discussion) because both C and N inputs potentially stimulate N_2O production. Soil temperature will be measured using soil temperature probes inserted to 5-cm depth. Air temperature will be measured by thermocouples. Air temperature measurements will also be compared to temperature available from local weather stations. Soil moisture in the 0-15 cm layer of soil will be determined via TDR (time domain reflectometry) probes at every sampling. The TDR-based measurements of soil moisture will be calibrated by periodic determination of gravimetric soil moisture and soil bulk density. Gravimetric soil moisture will be calculated from wet and oven-dry (105ºC) masses of soil collected in the 0-15cm layer using a 1.83-cm steel corer. The bulk density will be measured by collecting 10 cm dia. x 10 cm long cores in the 5-15 cm layer of soil, followed by drying to 105ºC. Soil cores to 15 cm depth will be collected in each microplot of each crop system. These soil samples will be extracted with 2 M potassium chloride (KCl) at a liquid to soil ratio of 5, and the extracts will be analyzed colorimetrically for ammonium (NH_4^+) and nitrate (NO_3^-) by a Shimadzu spectrophotometer (Model UV-Mini 1240) in Dr. Horwath's laboratory. For determining NH_4^+, the phenate (indophenol blue) method will be employed (Forster, 1995). Nitrate will be reduced to nitrite (NO_2^-) with vanadium chloride, and NO_2^- will be analyzed by diazotizing with sulfanilamide, followed by coupling with N-(1-naphthyl) ethylenediamine-dihydrochloride (Doane and Horwath, 2003). The pH will be measured in supernatant of soil slurries of 1M KCl and an equal mass of soil by a pH meter (Model 220, Denver Instrument Co., Arvada, CO) in Dr. Horwath's laboratory (Venterea and Rolston, 2000).

Product: In this task, the effect of compost on N_2O emissions will be determined for a tomato row crop rotation and a specialty crop. Other data

collected during N₂O sampling events will be used to characterize the environmental factors that control N₂O emissions as a function of compost application. Though not discussed above, the measurement for carbon dioxide and methane will also be done. Methane monitoring will be done on compost amended soils to assess the ability of compost to increase or decrease the rate of methane consumption.

Task 3: Analyze GHG emissions in laboratory incubations.

The laboratory incubations are designed to provide additional information to the field results so that the interpretation of the results can be made more broadly, since the field trails will be limited to a few crops and two seasons of observation. The lab incubations will cover a range of soil conditions not possible to observe in the field component of this project (Table 1). The incubations will concentrate on different rates of fertilizer, fertilizer type, compost application rates, compost maturity, influence of cover crop C to N ratio, changes in soil moisture and different soil types.

Results from the literature vary widely as to the effect of yard waste compost on GHG emission from soils ranging from decreasing N_2O emissions (Dalal et al., 2009) to increasing emissions (Mondini et al. 2007). For this reason, generalizing the effects of green waste compost on N_2O emissions from previous studies is generally not possible. Since N_2O production is highly positively correlated to temperature and moisture, the effect of compost in California agriculture may act to increase N_2O production. Compost addition to soils may maintain optimal soil moisture conditions longer and favor denitrification. In contrast, improving soil moisture status may maintain lower soil temperatures and prolong N_2O solubility, leading to greater reduction potential to dinitrogen. However, no data exists to substantiate these hypotheses. Conversely, since compost C is not readily available to microorganisms, one could hypothesize that compost additions have no effect or reduce N_2O emissions from soils. These factors will be the primary considerations in designing and interpreting the results of the lab incubations.

Laboratory incubations will be done to assess the effect of compost on denitrification under controlled conditions. It is assumed under conditions found in row crop systems that CH_4 production is non-existent. Rather, agricultural soils generally consume CH_4. Significant oxidation potentials have been observed in a range of agricultural and forest soils (Le Mer and Roger 2001). For this reason, our lab incubations will include analysis for CH_4 oxidation potential. The application of compost to soil likely creates conditions--such as prolonged ideal water content, better aeration and increased microbial activity--that would lead to the consumption of CH_4 through oxidation. These results will be compared to the field results to better understand the potential of compost applied to soils to consume CH_4.

A series of incubations will be conducted to examine the effects of compost rate, compost maturity, cover crop C:N ratio, soil moisture, and fertilizer N rates on a broader range of soils than encountered in the field study (Table 2). If differences in fertilizer types are minimal then ammonium-based fertilizer will be used exclusively. Soils, up to 3 representing different textures from sandy loam to loam to clay loam, will be chosen representing the range of soil textures typical of row and specialty crops in California. In the lab incubations, we will determine whether compost additions increase/decrease the denitrification of fertilizer N and whether compost N serves as a substrate for denitrification. This will be achieved through the addition of isotopically labeled ^{15}N fertilizer in the form of NH_4^+, NO_3^- and urea-N. The study involves

adding ^{15}N labeled fertilizer and unlabeled fertilizer to soils with various treat combinations (i.e., varying combinations of fertilizer rates, soil moisture, compost, cover crop residue). The comparison of labeled and unlabeled fertilizer treatments allows for the estimation of the contribution of different sources of N (fertilizer, soil, compost) to N_2O production. Ideally, labeled ^{15}N compost would provide a more accurate estimate of the contribution of compost N to N_2O production; however, production of labeled compost similar to facility produced compost is not feasible.

The incubations will be conducted in Mason Jars outfitted with modified lids containing rubber septum to allow for headspace gas sampling. Generally, 20 to 40g (dry wt.) of soil will be used, with 3 replications per treatment combination. Soils will be put in standard specimen cups and placed in the Mason Jar containing 5 ml water to maintain soil moisture throughout the incubation. Compost and fertilizer amendments will be applied at field rates mention in the previous subtask as well as the additional rates shown in Table 2.

Soil respiration measurements (CO_2) will be done frequently (every 3 days) during the first 15 days of the incubation and less frequently (every 5 to 10 days) up to 60 days in total. Nitrous oxide monitoring will occur concurrently with soil respiration measurements. On days 10, 30 45 and 60, 5 ml of 5ppm CH_4 will be added 4 hours prior to headspace sampling. All three gases (CO_2, CH_4 and N_2O) will measured on a Shimadzu gas chromatograph (Model GC-2014) linked to a Shimadzu auto sampler (Model AOC-5000) as described for the field studies. All incubations will be done at the standard temperature of 22°C. Results will be extrapolated to kg/ha to make them comparable to field observations. Using a broader range of soil types and moisture contents will allow us to generalize the data obtained from field studies and extrapolate them to a broader level.

> **Product:** *The lab incubations will provide data covering a broader range of conditions than possible to observe under field conditions. Though the constant monitoring under field conditions will produce a range of conditions (i.e., soil moisture and temperature), the lab incubations will provide data on the effect of fertilizer and compost rates not included in the field studies. Together the field and lab results will be used to indicate optimal conditions and performance parameters for compost use in the field.*

Task 4: Provide regular updates to DRRR (CalRecycle) staff and other stakeholders.

We will provide progress reports on a quarterly basis and participate in conference calls to discuss the progress reports when requested. The progress reports will include information collected during the designated reporting period, as well as interpretation. The CalRecycle contract manager will be apprised of the monthly management meetings in advance, and will be invited to participate when appropriate. The Project Manager or his designee will participate in the quarterly N_2O PI meetings organized by the Air Resources Board. In addition, the Project manager or his designee will arrange quarterly site visits for the CalRecycle contract manager during times of particular activity or interest, in order to allow the contract manager to observe work being conducted.

Table 2. Fertilizer N rates and source, soil moisture (%) and compost additions (t/ha) to be used in lab incubations

Experimental variable	Experimental rate
Fertilizer (NH_4^+, NO_3^- and urea-N)*	($Kg\ ha^{-1}$)
	0
	50
	100
	150
	200
	250
Soil Moisture	Water holding capacity (%)**
	25
	50
	75
Compost addition***	($t\ ha^{-1}$)
	4
	8
	16
	32
Soil Type	Texture
	Sandy loam
	Loam
	Clay loam

* Each compound to be used in separate incubations.

** Defined as the ratio (%) of water to total soil pore space.

*** Includes two types; mature and immature (taken immediately after last turning event).

Task 5: Draft and final reports.

Quarterly progress reports will be submitted to DRRR. The draft final report will be submitted 3 months prior to the expiration of the grant. The report will include the field study approach and methodology and present the results. The executive summary of the report shall contain a summary of the field study and a table summarizing key findings. The report shall present and fully document all methodologies used and explain findings or calculations critical to the development of conclusions about N_2O and CH_4 emissions from the production and use of compost in agriculture, including justification for making any assumptions. We will include supporting technical documents and calculations in the report as appendices. The report will contain at least one chapter, which suggests compost facility management practices that can achieve reduction of N_2O and CH_4 emissions or conservation of N in finished compost products. We will format the documents for inclusion on the DRRR's website. In addition to following the Board's *Guidelines For Preparing DRRR Report*, we will include appropriate object/image tagging that allows for wider public accessibility.

Project Schedule

Task 1: Compost and field Site Selection.
Task 2: Implement compost facility and field research projects:
Task 3: Analyze GHG emissions in laboratory incubations.
Task 4: Provide regular updates to DRRR staff and other stakeholders.
Task 5: Draft and final reports.

2010	MONTH	1	2	3	4	5	6	7	8	9	10	11	12
TASK 1										■	■	■	■
2												■	■
3													
4											■	■	■
5													

2011	MONTH	1	2	3	4	5	6	7	8	9	10	11	12
TASK 1													
2			■	■	■	■	■	■	■	■	■	■	■
3			■	■	■	■	■	■	■	■	■	■	■
4			■	■	■	■	■	■	■	■	■	■	■
5													

2012	MONTH	1	2	3	4	5	6	7	8	9	10	11	12
TASK 1													
2													
3		■	■										
4		■	■	■									
5		■	■	■	■	■							

Project Management Plan

Responsibilities of Personnel

The Project Leader and Manager (William Horwath) provides project oversight. He is responsible for convening monthly meetings with other PIs, the CalRecycle contract manager and the Project Technicians. The Project Manager and the PIs will consult with the contract manager to make final site selections. The PIs, Project Manager and Project Technicians evaluate data and provide interpretation. The Project Manager is responsible for gradient and flux chamber design, establishing sampling protocols, data quality control, calculating annual N_2O and CH_4 emissions and emission factors, writing quarterly reports, the draft final report and the final report. The project manager will work with K. T. Paw U to design and interpret data from the application of micrometeorological approaches to measure GHG emission at the compost pile level.

The Project Technicians will lead the Sampling Team. The Project Technicians (Travis Wilson and Roxanne Robles) will be responsible for the N_2O and CH4 flux measurements from the composting process. The Project Technicians will be responsible for measuring N_2O flux in the field studies and in the laboratory incubations.

The Sampling Team, which will include student assistants, will be responsible for carrying out the above tasks under the supervision of the Project Technicians, according to protocols established by the Project Manager. Safety decisions will be made by the Project Manager and the Project Technicians.

Management and Coordination

The Project Manager will hold monthly meetings with the PIs and the Project Technicians to plan future activities, discuss results and resolve potential difficulties. The timelines of the tasks will be decided on at the monthly meetings (see attached timelines). Because of the physical distance between sampling locations, some of these meetings may take place via conference call. The Project Manager ensures that the tasks outlined in this work plan are carried out in a timely manner and that the budget is adhered to. The Project Manager will work closely with the Project Technicians, especially in setting up the N fertilization plots and in establishing sampling routines in the field. The Project Manager will confer with the Project Technicians at a minimum on a weekly basis to discuss progress, plans, and difficulties in adhering to establish sampling protocols and timelines.

Curricula vitae

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Education

1993   Ph.D. Soil Science, College of Agriculture, Depart. of Crop and Soil Sciences, Michigan State Univ., E. Lansing, MI.

1993   Ph.D. Forest Ecology, College of Agriculture, Depart. of Forestry, Michigan State Univ., E. Lansing, MI.

1979   BS. Forestry Environmental Impact Assessment, College of Agriculture, Department of Forestry, Southern Illinois University, Carbondale, IL.

Positions Held:

o   Professor of Soil Biogeochemistry, University of California, Davis, CA. 7/04 to present
o   Assoc. Professor of Soil Biogeochemistry, University of California, Davis, CA.7/00 to 6/04
o   Assist. Professor of Soil Biogeochemistry, University of California, Davis, CA.7/96 to 6/00
o   Graduate Faculty, Oregon State University, Corvallis, OR. 1/95 to present
o   Research Soil Microbiologist, USDA ARS, Corvallis, OR.10/94 to 5/96
o   Faculty Research Associate, Oregon State University, Corvallis, OR. 11/92 to 9/94
o   Graduate Research Assistant, Michigan State University, E. Lansing, MI. 9/88 to 10/92
o   Research Specialist, Michigan State University. 11/85 to 9/88
o   Staff Research Associate, University of California at Berkeley, CA 4/83 to 10/85
o   Forestry Apprentice, German Academic Exchange Service, Munich, Germany. 6/79 to 6/80

Awards and Distinctions

o   Soil Science Society of America Fellow, 2009
o   J. G. Boswell Endowed Chair in Soil Science, 2008
o   NSM/MARC Scholar 2002 California State University
o   Outstanding Conduct and Merit 1996, USDA ARS
o   Outstanding Conduct and Merit 1995, USDA ARS

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