

TECHNICAL PROPOSAL

Evaluating Mitigation Options of Nitrous Oxide Emissions in California Cropping Systems

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December 9, 2011_____

Check if applicable:

Animal subjects _____

Human subjects _____

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STATEMENT OF SIGNIFICANCE

Nitrous oxide (N₂O) is an important greenhouse gas produced by agricultural activities. In California, agricultural soils are estimated to contribute 52% of all N₂O (ARB, 2010). Therefore, strategies and the development and implementation of practices that mitigate N₂O emissions from agricultural soil can have a significant impact on California's overall greenhouse gas inventory. Under the statutory authority of AB 32, the California Air Resources Control Board (CARB) has identified research needs on N₂O emissions from agricultural land as one of the early action measures in the plan for the overall reduction of GHG emissions.

Nitrous oxide is produced by soil microorganisms during nitrification and denitrification and is related to the quantity and forms of nitrogen applied (Firestone and Davidson, 1989; Tiedje, 1989; Wrage, 2001). Environmental variables that control microbial activity, such as soil moisture and temperature, soil physical properties, and plant development influence N₂O production (Tiedje, 1989). Hence, N₂O emissions vary to a great degree depending on crop and soil management practices. Current research (funded by CARB, the California Energy Commission [CEC], and the California Department of Food & Agriculture [CDFA]), in eight different types of California cropping systems has shown that the amount and type of fertilizer N inputs, irrigation techniques, and other agronomic practices, such as cover cropping, affect N₂O emissions. The on-going collaborative projects are providing estimates of annual N₂O emissions and have identified management events and critical periods during the year that potentially produce high N₂O emissions. Therefore, it is now an opportune time for starting systematic investigations of management practices having the potential to lower N₂O emissions in California's cropping systems.

We will focus on three intensively managed cropping systems that are expected to have significant N₂O emissions and occupy a large acreage of California's agricultural land, i.e. lettuce (300,000), corn (550,000), and tomato (312,000). We will evaluate alternative management practices that hold the greatest promise of reducing annual N₂O emissions while maintaining productivity, a key criteria of this proposed study, for the selected crops. The proposed strategies to reduce N₂O emissions are targeting fertilizer types and timing of their application, delaying nitrification by using urease and nitrification inhibitors, spatially decreasing the concentration of applied N fertilizer, and modifying irrigation methods. All these proposed practices are expected to maintain yield potentials and could in some cases increase nitrogen fertilizer use efficiency (the ratio of N fertilizer taken up by the crop to N applied). The alternative management practices must have the potential to be adopted by farmers, and therefore, have to be economically and technically feasible. Since some of the approaches put forward in this proposal have not been tried in California, the proposed research will also be a test of these practices' feasibility. Additional approaches may be considered if deemed appropriate in consultation with stakeholders. The outcome of the research will be estimates of annual N₂O emission reduction potential of the implemented alternative management options using the standard practices as a baseline. The data sets generated contribute to the growing database of California N₂O emissions associated with different environmental

conditions, soil types, cropping systems, and farming practices. This database will be a valuable asset for calibrating and validating biogeochemical models.

ABSTRACT

Nitrous oxide (N₂O) emissions from agricultural land comprise 52% of California's total N₂O emissions. Effective strategies to mitigate N₂O from agricultural land could, therefore, help California achieve the goals of the Global Warming Solutions Act of 2006 (AB 32). Nitrous oxide is emitted from soil to the atmosphere as part of the N cycle, and the addition of N in intensively managed cropping systems often increases N₂O emissions. There is, however, potential to reduce N₂O emissions by controlling N inputs, N transformation rates, and placement of N fertilizer. The objectives of the proposed research are to evaluate alternative management practices that potentially reduce annual N₂O emissions in some of California's most important cropping systems, such as corn, lettuce, and tomatoes, and to identify and quantify the most promising N₂O mitigation options.

The proposed alternative practices include management of N inputs by comparing different types of fertilizers, slowing down nitrification rates to reduce N₂O emissions and potentially increase N use efficiency by using nitrification inhibitors, timing and delivery method of fertilizer applications, and by spatially lowering the concentration of N fertilizer in the soil by decreasing the distance between fertilizer bands and reducing rate of N application per band. Some of these practices have the potential to increase fertilizer N use efficiency (the ratio of N fertilizer taken up by the crop to N applied) and to maintain or increase yield per unit of N applied. Nitrous oxide fluxes will be measured for two years in the above cropping systems using static chamber techniques and analysis of air samples by gas chromatography. The annual N₂O emissions will be estimated from intensive measurements of N₂O flux in the field during periods with high N₂O emission potential, and less frequent monitoring of N₂O emissions when fluxes are low. The N₂O emission reduction potential will be calculated from the differences in annual N₂O emissions between the conventionally or alternatively managed treatments. To evaluate the economics of the alternative practices, yields will be measured, and fuel use of alternative management practices will be assessed when necessary. Data of ancillary variables, such as soil moisture, temperature, and soil chemical and physical parameters that are known to affect N₂O emissions will be used to characterize and elucidate patterns of N₂O emissions in each of the systems.

This research will benefit ARB by identifying management practices that lower annual N₂O emissions in five of California's major cropping systems. The data collected in this research can be used to calibrate and validate biogeochemical models for comparisons with previous and future measurements of N₂O associated with environmental variables and management practices and to predict the mitigation potential of each practice on larger scales.

OBJECTIVES

The goal of this project is to evaluate alternative management practices that have the potential to reduce N₂O emissions. The alternative management practices will be assessed in three different types of cropping systems representing large acreages of California's agricultural land. Side-by-side field trials of alternative and standard management practices in each system will provide N₂O emission estimates that will be used to quantify the N₂O reduction potential of the mitigation options. The experiments will also serve as tests of each practice' technical feasibility. In addition, information on costs and agronomic returns of the different practices will be obtained.

The objectives of this project are, based on stakeholders' inputs, to (1) establish standard and alternative management treatments in three different agroecosystems: a) subsurface drip-irrigated tomato fertigated with and without different types of nitrification inhibitors, b) lettuce fertilized with starter and sidedress applications under sprinkler irrigation and fertigated via subsurface drip irrigation, and c) corn fertilized with aqua ammonia, liquid urea ammonium nitrate or calcium nitrate, applied at two spatial concentrations by varying the distance between fertilizer bands and the fertilizer application rate per band under standard tillage, and corn grown under reduced tillage or no-till (2) measure N₂O fluxes in the above cropping systems for two years, (3) estimate annual N₂O emissions and N₂O emission reduction potential for the alternative management practices in each cropping system, (4) measure yields in order to evaluate the economics of each management practice and calculate yield-scaled N₂O emissions (e.g. g N₂O-N g⁻¹ N_{harvested}), (5) characterize the effects of environmental factors on N₂O emissions, and (6) prepare the final report according to ARB guidelines (Exhibit F).

TECHNICAL PLAN

Task 1: *Site Selection and establishment of experimental treatments.*

Representative soils and crop systems in main production areas will be chosen for N₂O monitoring. Soil type, information on soil stratification, soil horizons, and height of water table are critical variables that will be examined before the sites are selected for the studies outlined below. Other variables to be determined are soil C and N content, soil texture, bulk density, and pH. The site selection process will be based on a variety of information, i.e. management practices, site management histories, soil characteristics, and availability/grower collaboration to establish standard and alternative management practices on the same soil type.

Corn: In this system, we propose to study the effects of fertilizer type, spatial distribution of the fertilizer, and tillage practice, as well as the interaction among these factors. Many studies have shown that highly concentrated application of ammonia based fertilizers produce higher N₂O fluxes than applications of N resulting in less concentrated distribution of the fertilizer in the soil e.g. (Venterea *et al.*, 2005; Engel *et al.*, 2010;

Venterea *et al.*, 2010). Banding N fertilizer results in high concentrations of inorganic N in soil, but banding also has the advantage of placing the fertilizer uniformly in the vicinity of a growing crop's roots. In the research proposed here, we will investigate the effect of lowering the concentration of ammonia based N fertilizer by reducing the distance between fertilizer bands, and accordingly, the concentration of N in each band. We hypothesize, that decreasing the distance between bands will reduce N₂O emissions. We will also evaluate the fuel use with each practice because the cost of application is an important consideration in determining whether farmers will adopt a practice. Fuel consumption during the application would also have to be considered in calculating offsets from reduced N₂O emissions.

The type of fertilizer also affects N₂O emissions. Several studies have shown that the most concentrated form of fertilizer N, anhydrous ammonia (82% N) causes the greatest N₂O emissions among the synthetic N fertilizers (Breitenbeck and Bremner, 1986; Thornton *et al.*, 1996; Venterea *et al.*, 2005; Burton *et al.*, 2008; Venterea *et al.*, 2010). Less concentrated fertilizers, such as urea (46% N), also tend to produce more N₂O when they are locally concentrated (Engel *et al.*, 2010). Here, we propose to compare the effects of the following three fertilizers on N₂O emissions: Urea ammonium nitrate (32% N), aqua ammonia (20% N), and calcium nitrate (9% N). The first two are popular choices by California corn growers. Use of calcium nitrate, together with the two spatial distribution treatments, will provide valuable information about processes of N₂O production in these systems. We hypothesize that N₂O emissions will be highest, where the fertilizer is banded at the higher concentration (bands further apart) and among the fertilizer types, N₂O emissions are expected to decrease in the order aqua ammonia > UAN32 > calcium nitrate.

Conservation tillage, including no-till, is growing in popularity in California (Mitchell *et al.*, 2007). Reduced tillage and no-till protect the soil from erosion, reduces production costs, decreases consumption of fossil fuel, and possibly increases carbon sequestration (Baker *et al.*, 2007). According to a meta analysis, the benefits of no-till in reducing global warming potential through carbon sequestration and/or lowering N₂O emissions can only be realized over a longer time period (10-20 years) (Six *et al.*, 2004). Tillage practice and fertilizer placement effects on N₂O emissions have been shown to interact and N₂O emissions, in addition, depend on the type of fertilizer source (Venterea *et al.*, 2005). Therefore, the effect of NT practice on N₂O emissions must be compared to those of standard tillage and different fertilizer types commonly used in California corn production. A factorial experimental design is most appropriate to evaluate the N₂O emission reduction potential of alternative management practices, such as reducing fertilizer concentration, due to application mode or fertilizer choice, and no-till in these systems. The experimental sites will be grower fields in the Sacramento area.

Lettuce: Our previous research in lettuce production systems showed moderate N₂O emissions when the growing crop was fertigated via subsurface drip irrigation (SDI), but we did not conduct formal comparisons of this management practice with other common practices in lettuce production, such as starter and side-dress N fertilizations combined with sprinkler irrigation. Measurements at six commercial farms starting the second crop of the year showed substantial N₂O flux at planting and first irrigation on some commercial fields (Figure 2).

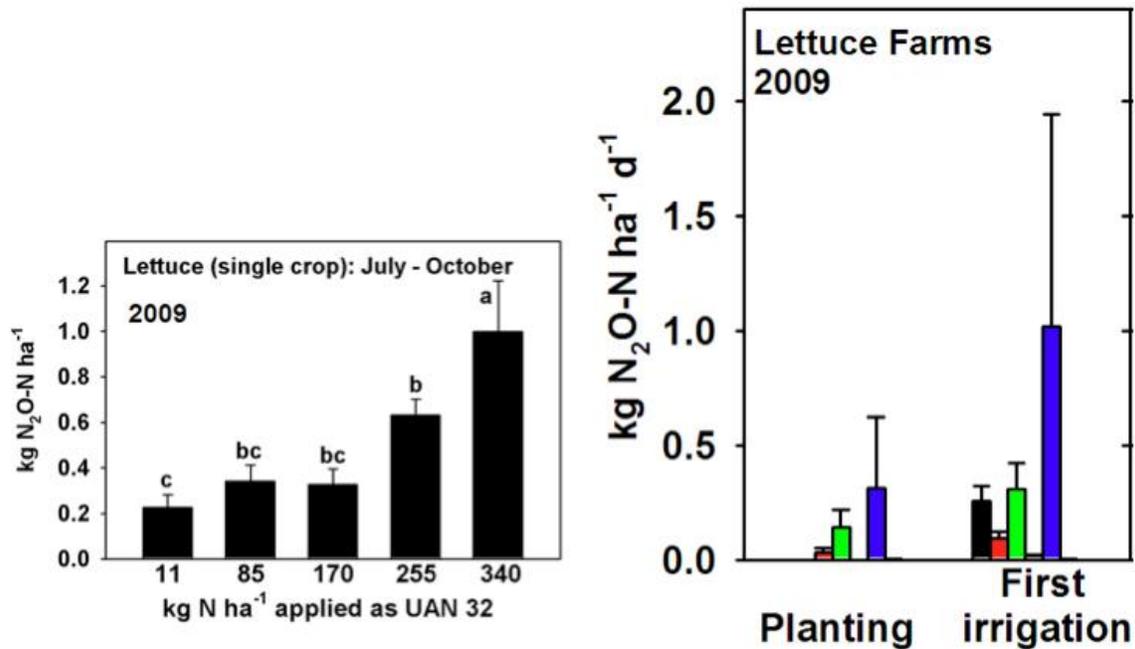


Figure 2. Seasonal N₂O emissions from fertigated lettuce plots with subsurface drip irrigation (left panel) and daily N₂O flux at six commercial lettuce farms at planting and after the first irrigation via sprinklers (right panel).

We will investigate the effect of both the above mentioned practices on annual N₂O emissions on grower fields in Monterey County in order to develop management practices that can be recommended to mitigate N₂O emissions.

Tomatoes: Our two independent studies carried out in grower fields and at the UC Davis Research site Russell Ranch demonstrated that subsurface drip irrigation (SDI) reduces N₂O emissions compared to furrow irrigation (Figure 3). At present, statewide, at

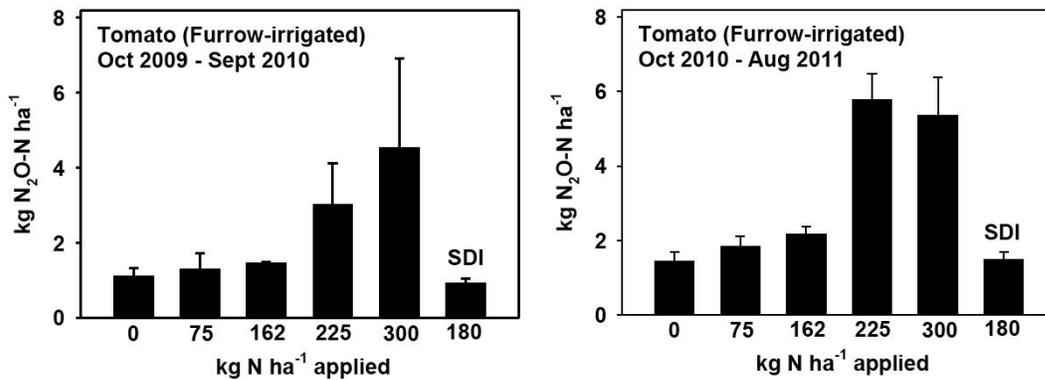


Figure 3. Annual N₂O emissions in processing tomato systems fertilized at several different N rates under furrow and subsurface drip (SDI) irrigation.

least 50% of all processing tomatoes are grown using SDI, and the SDI practice will likely be rapidly adopted (Timothy Hartz, Cooperative Extension Specialist, and Eugene Miyao, UC Farm Advisor, personal communication). Therefore, we will focus on SDI

and investigate how N₂O emissions in processing tomatoes can be further reduced under this management practice.

Nitrification inhibitors, such as nitrapyrin or dicyandiamide (DCD), retard the conversion of ammonium (NH₄⁺) to nitrate (NO₃⁻), and thus, have the potential to reduce N₂O production from both nitrification and denitrification. According to a meta-analysis of 113 data-sets from 35 published studies, nitrification inhibitors, when applied together with N fertilizers, reduced N₂O emissions by 38% (95% confidence interval -45% to -31%) compared with those from soil where only N fertilizer was applied (Akiyama *et al.*, 2010). Thus, nitrification inhibitors are a potentially effective mitigation option for reducing N₂O emissions. In addition, the use of nitrification inhibitors has the potential to increase yields, mainly because more fertilizer N is retained in the soil as NH₄⁺, a form of N less mobile than NO₃⁻, which may be lost from the root zone by leaching. Yield increases due to nitrification inhibitors (generally <10%) have been reported for corn (*Zea mays* L.) and wheat (*Triticum aestivum* L.) (Bhatia *et al.*, 2010; Halvorson *et al.*, 2010; Jiang *et al.*, 2010), and in a flood-irrigated almond orchard (Bill Ulrich, Agrotain International, LLC, personal communication). The additional cost due to an urease and nitrification inhibitor with a 200 lbs (UAN32)-N /acre fertilizer application is \$ 20/acre.

Tomatoes under SDI are typically fertigated with urea ammonium nitrate (UAN32) solution applied in increments during the plants' exponential growth phase. Field data and modeling have shown that during fertigation via SDI urea and NO₃⁻ can move away from the drip tape and the volume of soil with the greatest root length density depending on the fertigation practice and soil texture (Gardenas *et al.*, 2005; Hanson *et al.*, 2006), whereas NH₄⁺ mostly remains near the drip tape where roots are concentrated. To increase the amount of plant NH₄⁺ uptake and decrease N₂O emissions, we will use at least two different types of nitrification inhibitors. We will use a mixture of a reacted type of DCD, which has a positive charge, and a non-reacted DCD, which has no charge. The positively charged DCD is expected to stay near the free NH₄⁺ and slow down its conversion to NO₃⁻. The uncharged DCD will potentially move with the urea and NO₃⁻ in the fertilizer. We will compare the effects of these alternative fertigation treatments on N₂O emissions and yields with those of the standard urea ammonium nitrate fertigation (without nitrification inhibitor) practice.

Additionally, we will measure N₂O emissions and ancillary variables in an organic tomato system at the same location as the other two treatments. Earlier research suggested that N₂O emissions during the tomato growing season may be similar between organically and conventionally managed tomato systems (Burger *et al.*, 2005), although large spikes of N₂O emissions that are sometimes observed after synthetic fertilizer applications would only occur in conventionally systems, and therefore, N₂O emissions may be lower in organic systems. Soils under organic management receive organic N inputs in the form of composts and leguminous cover crops (Cavero *et al.*, 1997). Additional benefits of cover crops are reductions in soil erosion potential, increased water infiltration and soil water retention (Aase and Siddoway, 1976; Battany and Grismer, 2000). Incorporation of a legume cover crop increases the soil available N and potentially N₂O emissions (Kallenbach *et al.*, 2010), but in an organic system the lack of synthetic fertilizer N inputs can be expected to lower N₂O emissions more than the increase due to

the legume input would be since organic N inputs are less concentrated than mineral N additions (see section on corn above).

Annual N₂O emissions based on intensive sampling campaigns have previously not been conducted in organic processing tomato systems. Other factors, such as soil management and resource use, may affect the overall greenhouse gas emissions and economics. Subsurface drip irrigation in organically managed tomatoes is challenging because in these systems the soil alone supplies N to the plants, unless supplemental soluble organic fertilizers, which are costly, are used. If necessary, soluble organic fertilizers will be used in our experiments (Hartz & Johnstone, 2006). The study site will be a grower field in Yolo County or the UC Davis Russell Ranch Sustainable Agriculture research facility, where organically and conventionally managed tomato systems are maintained side-by-side.

Stakeholder input

The stakeholders recommended the following crop selections: Tomatoes, corn, lettuce, celery and leafy green vegetables, wine grapes, almonds, wheat, and cotton. The stakeholders recommended investigations on residue management, which is partially addressed by the proposed study in the organic tomato system. Furthermore, the use of timed-release N fertilizer and nitrification inhibitors was recommended for testing, and this will be conducted in the context of the tomato trials. Some stakeholders proposed improved water management as a mitigation option, which will be addressed in the lettuce experiments. Organic farming, which is currently practiced on <5% of the total agricultural land in California, was advocated as a mitigation option because this practice has the potential to lower overall greenhouse gas emissions compared to conventional farming practice using synthetic fertilizers and pesticides. At the request of stakeholders, we have added organic farming treatment in tomatoes, but cannot cover other crops at present due to lack of sufficient funding. We are actively seeking additional funds to add this component to other crops in the future.

Task 2: *N₂O flux measurements.*

In each system, data will be collected for two years. We will measure N₂O flux intensively when the potential for N₂O emissions is high, but less frequently when N₂O emissions can be expected to be low. Episodes of high N₂O emissions occur after rainfall or irrigation and N fertilizer applications (Bronson and Mosier, 1993; Dobbie *et al.*, 1999; Simojoki and Jaakkola, 2000; Burger *et al.*, 2005) and incorporation of residue especially if followed by soil wetting (Kaiser *et al.*, 1998; Velthof *et al.*, 2002; Baggs *et al.*, 2003; Burger *et al.*, 2005). We will make sure to capture all the spikes in N₂O emissions due to these management events by sampling as frequently as necessary, e.g. following irrigations. Our current research (e.g. Garland *et al.*, 2011) and that of others (Ruser *et al.*, 2001) has shown that over one half of the annual N₂O emissions can occur outside of the cropping period, so N₂O fluxes will also be measured during fall and winter.

Chamber and gas chromatograph (GC) methodology: Nitrous oxide flux will be measured, using a static chamber technique (Hutchinson and Livingston, 1993). Some of the chambers are automated, but these chambers also function as static chambers albeit the air circulates in a closed loop through the chamber and tubing connected to the sampling port. Either round chambers or rectangular chambers will be used, depending on field configurations (bed-and-furrow *vs.* flat). The rectangular stainless chamber bases are 50 x 30 cm and 8 cm deep with a 2 cm-wide horizontal flange at the top end that is inserted into the soil, so that the flange rests on the soil surface. The bases will be left in place unless field operation requires their temporary removal. Thin-wall stainless steel (20 gauge) chamber tops (50 x 30 x 10 cm), with flanges facing down and lined with a rubber gasket, will be placed onto the bases and secured with metal clamps during gas collection. Round, 20 cm-diameter PVC chambers will also be used (see Garland *et al.*, 2011). The chambers will slide snugly over rings that serve as bases. The rings will be pushed 8 cm deep into the soil and left in place in between samplings. The height of the round chambers will also be 10 cm. The chambers will have sampling ports with butyl rubber septa and will be vented (4.8mm dia., 10 cm long tubes), and their outer surfaces will be covered with reflective insulating material.

Chamber gas samples will be collected at equally spaced time intervals (e.g. 0, 30, 60 min) after placing the chamber tops onto the bases. These intervals of sampling collection may be somewhat modified depending on the N₂O fluxes determined in each system during initial analyses. To collect a gas sample from the chamber, headspace air will be removed by inserting the needle of a polypropylene syringe (Monoject) through the septum of the sampling port and by slowly withdrawing 20 mL gas. The gas in the syringes will immediately be transferred into evacuated 12-mL glass vials with grey butyl rubber septa (Exetainer, Labco Ltd., Buckinghamshire, UK). Thus, the air in the glass vial will be pressurized. Having 20-mL gas per sample allows three analyses (see below) of one sample, if necessary. The air temperature inside the chambers will be recorded, along with other environmental variables.

The gas samples will be analyzed by a Shimadzu gas chromatograph (Model GC-2014) with a ⁶³Ni electron capture detector (ECD) linked to a Shimadzu auto sampler (Model AOC-5000). The autosampler uses a gas-tight syringe to remove 5 mL gas from a sample vial and inject it into the GC port. Subsequently, the autosampler's syringe and the GC's sample loop are purged with helium. The GC uses as carrier gas P5 (mixture of 95% argon and 5% methane). The carbon dioxide and N₂O are separated by a Haysep Q column at 80° C. The ECD is at 320° C and the pressure of the carrier gas at the ECD is 60 kPa. The minimum quantity of N₂O detected by this GC system is 0.1 pg s⁻¹. The system will be calibrated daily using analytical grade N₂O standards (Airgas Inc., Sacramento CA). Quality assurance of the N₂O values generated by the GC and its software is obtained by processing N₂O standards in exetainers after taking them to the field and treating them the same way as field samples. The number of daily samples generated at several sites during intensive sampling periods can be processed in a 24-hour period on one of the three gas chromatographs (Dr. Horwath and Dr. Six) available at UCD. Should backlogs occur, samples can be stored for up to two weeks, and their quality assurance is insured by using N₂O standards treated (age and storage conditions) as field samples. Sample collection in the field and analysis of samples by GC will be

according to clearly established protocols developed during the previous projects funded by CARB, CEC, and CDFA.

Task 3: *Annual N₂O emissions, and N₂O emission reduction potential.*

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 to calculate this rate (Hutchinson and Mosier, 1981; Hutchinson and Livingston, 1993; Venterea, 2010). Chamber gas concentrations determined by GC (volumetric parts per million) will be converted to mass per volume units assuming ideal gas relations using the measured air temperature values in the chamber during sampling. The annual N₂O emissions will be calculated by assuming that the measured fluxes represent mean daily fluxes, and that mean daily fluxes change linearly between measurements.

We will calculate the difference in direct N₂O emissions and consider other emissions, such as fuel use in farming operations, to assess the impact of these practices on GHG emissions.

The experimental set-ups will be a randomized complete block or a split plot designs with at least 3 replications. Differences between treatments will be assessed using ANOVA and standard mean separation procedures. Transformation of the N₂O emission data will be carried out for the statistical analysis if the data will not be normally distributed. The N₂O emission reduction potential will be calculated from the difference in annual N₂O emissions between conventionally and alternatively managed plots.

N₂O flux data generated in the proposed research and the ancillary variables measured during gas sampling (see Task 5) can be used to calibrate and validate modeling of N₂O emissions by the DNDC and Daycent models.

Task 4: *Yield and total biomass measurements.*

Yields will be assessed for each treatment in the different cropping systems, and total N removal in the harvested crop will be determined. This will allow calculation of N use efficiency as the ratio of fertilizer N applied to N removed by the harvested crop. Furthermore, N₂O emissions can be calculated as percentage of the N removed by the harvested crop to compare the treatment effects on agronomic based yield-scaled N₂O emissions in each system. We will measure total biomass and its N content in order to calculate total N uptake by the crop. This information will be crucial to develop sensible best management practices for growers.

Task 5: *Effects of environmental variables on N₂O emissions.*

Soil moisture and soil N availability, in addition to carbon availability, largely control the magnitude of N₂O emissions. The highest N₂O fluxes occur at WFPS 60-90% (Linn and Doran, 1984; Davidson, 1992; Dobbie *et al.*, 1999; Simojoki and Jaakkola, 2000). The availability of carbon stimulates microbial activity, thereby decreasing the available O₂ in the soil and increasing NO₃⁻ demand and N₂O production (Weier *et al.*,

1993). 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, and the concentration of NO_3^- , i.e. the N_2O/N_2 ratio decreases with a water content near saturation (WFPS $>90\%$) and increases with increasing NO_3^- concentrations in the soil (Firestone *et al.*, 1982). 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. There is evidence that under O_2 limitation, nitrifiers use NO_2^- as electron acceptor, thereby producing N_2O (Wrage *et al.*, 2001). The main driver of nitrification is NH_4^+ availability.

Soil temperature in addition to air temperature, and soil moisture will be recorded during each gas sampling. Periodically, inorganic N to a depth of 15 cm will be determined in soil extracts, and pH will be measured in soil slurries. 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 recorded 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. Gravimetric soil moisture will be calculated from wet and oven-dry ($105^\circ C$) mass 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 $105^\circ C$. Soil cores to 15 cm depth will be collected in each microplot of each cropping 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). 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 Horwáth, 2003). The pH will be measured in supernatant of soil slurries of deionized H_2O and an equal mass of soil by a pH meter (Model 220, Denver Instrument Co., Arvada, CO).

The ancillary data will be used to characterize the environmental factors that, in addition to N fertilizer application, control N_2O emissions. Measurements of the above variables will contribute to better understanding how environmental factors affect N_2O emissions under California specific conditions, such as the most common irrigation techniques or specific N fertilizer types used in each of the crop systems. These ancillary variables will also be used as inputs for modeling by our collaborators.

Task 6: Reports.

Quarterly progress reports will be submitted to ARB. The draft final report will be submitted 6 months prior to the expiration of the contract according to ARB Research Final Report Format (Exhibit F). Our monitoring plans are determined by logistics tied to the cropping cycles. The final report will be submitted within 45 days of receipt of ARB's comments on the draft Final Report.

2. PROJECT SCHEDULE

- Task 1:** Select sites, establish treatments
- Task 2:** Measure N₂O flux
- Task 3:** Calculate annual N₂O emissions, N₂O emission reductions
- Task 4:** Measure yields
- Task 5:** Measure environmental variables
- Task 6:** Prepare final report

2012	MONTH	1	2	3	4	5	6	7	8	9	10	11	12
TASK													
1													
2													
3													
4													
5													
6													
		i		p	q		p	q		p	q		p

2013	MONTH	1	2	3	4	5	6	7	8	9	10	11	12
TASK													
1													
2													
3													
4													
5													
6													
		q		p	q		p	q		p	q		p

2014	MONTH	1	2	3	4	5	6	7	8	9	10	11	12	
TASK														
1														
2														
3														
4														
5														
6														
		q		p	q		p	dq		p	q	f	q	

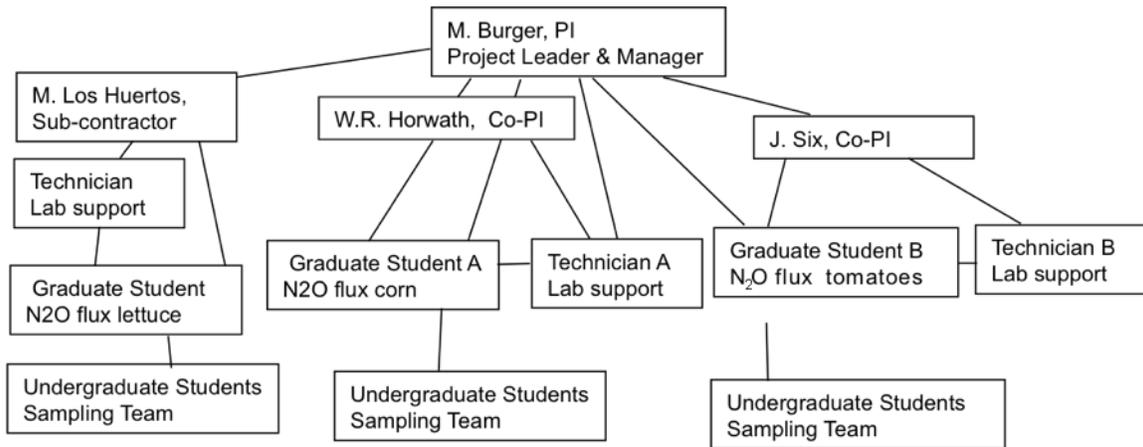
i=initial meeting; p= progress review meeting; q=quarterly progress report; d=draft final report; f=final report

In general, the cropping cycles of each crop system will determine the timeline of the experiments, i.e. timing of N inputs, N₂O flux measurements in response to fertilization and irrigation, and yield measurements.

- Corn: Planting takes place in May, harvest in Sept/Oct depending on variety and purpose (grain vs. silage).
- Tomatoes: Planting takes place in April/May, N fertigation occur during June/July, harvest takes place in August/September.
- Lettuce: In the Salinas valley, lettuce is grown from March through October. On average, 2.4 crops are grown per unit land area.

3. PROJECT MANAGEMENT PLAN

a) Organizational Chart



b) Responsibilities of Personnel

The Project Leader and Manager (Martin Burger) provides project oversight. He is responsible for convening meetings with other PIs, and for communication with the ARB Contract Manager. The Project Manager, PIs, and Contract Manager make the final decision on site selection after considering input by stakeholders. The graduate students are responsible for N₂O flux measurements and collection of soil and plant samples, calculating annual N₂O emissions, and data interpretation under the guidance of the PIs. The undergraduate students assist the graduate students in the field. The technicians assist the graduate students in maintaining laboratory and field instruments and conducting

analytical work in the laboratory. The Project Manager is responsible for establishing sampling protocols, data quality control, writing quarterly reports and the final report. Safety decisions will be made by the Project Manager.

c) Management and Coordination

The Project Manager holds quarterly meetings with the PIs and the graduate students to plan future activities discuss results and resolve potential problems. The timelines of the activities will be decided at the quarterly meetings. 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 Graduate Students, especially in establishing the treatments, experimental designs, and sampling protocols. The Project Manager meets regularly with the graduate students to coordinate research efforts and assist in solving problems. The undergraduate students work under the supervision of the graduate students.

d) Curricula vitae

Martin Burger, Research Manager
Sustainable Agriculture Farming Systems
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EDUCATION

- 2002 Ph.D., Ecology (Area of Emphasis Agroecology); University of California, Davis. Dissertation: Soil Nitrogen Transformations in Response to Farming Practices and the Presence of Roots
- 1996 B.S., International Agricultural Development, Highest Honors; University of California, Davis.

PROFESSIONAL EXPERIENCE

- 2008- Research Manager, Sustainable Agriculture Farming Systems project, University of California, Davis, CA
- 2004-2007 Postdoctoral Scholar
Dept. of Plant Sciences, University of California, Davis, CA
- 2003-2004 Postdoctoral Research Associate
USDA-ARS, Soil and Water Management Unit,
Dept. of Soil, Water and Climate, University of Minnesota, St. Paul, MN
- 1996-2002 Research Assistant
Dept. of Vegetable Crops, University of California, Davis, CA

RESEARCH INTERESTS

Sustainable agricultural management practices that conserve water, reduce discharge of contaminants, and minimize greenhouse gas emissions and energy consumption; carbon and nitrogen cycling in cropping systems; rhizosphere ecology; soil fertility and mineral nutrition of plants; plant nitrogen use under elevated atmospheric carbon dioxide concentrations; nitrous and nitric oxide emissions from agriculture.

PUBLICATIONS

Mailapalli D.R., Horwath W.R., Wallender W.W., Burger M. Infiltration, runoff and export of dissolved organic carbon from furrow-irrigated forage fields under cover crop and no-till management in the arid climate of California. *Journal of Irrigation and Drainage Engineering*. In press.

Burger M. and Venterea R.T. 2011. Effects of Nitrogen Fertilizer Types on Nitrous Oxide Emissions. *In: Guo L., Gunasekara A.S., McConnell L.L. (eds.) Understanding Greenhouse Gas Emissions from Agricultural Management*. American Chemical Society Symposium Book. Washington, DC.

Garland G.M., Suddick E., Burger, M., Horwath, W.R., Six, J. 2011. Direct N₂O emissions following transition from conventional till to no-till in a cover cropped Mediterranean vineyard (*Vitis vinifera*). *Agriculture, Ecosystems & Environment*, 141: 234-239.

- Mailapalli D.R., Wallender W.W., Burger M., Horwath W.R. 2010. Effects of field length and management on dissolved organic carbon export in furrow irrigation. *Agricultural Water Management*, 98(1): 29-37.
- Bloom A.J., Burger M., Rubio Asensio J.S., Cousins A.B. 2010. Carbon dioxide enrichment inhibits nitrate assimilation in wheat and *Arabidopsis*. *Science*, 328: 899-903.
- Burger M. and Matiasek M. 2009. New Approaches to Distinguish between Nitrification and Denitrification as Sources of Nitrous Oxide. *In: Sheldon, A.I. and Barnhart, E.P. (eds.) Nitrous Oxide Emissions Research Progress*. pp. 167-178. Nova Publishers, New York.
- Burger M., Venterea R.T. 2008. Nitrogen immobilization and mineralization kinetics of cattle, hog and turkey manure applied to soil. *Soil Science Society of America Journal*, 72: 1570-1579.
- Jackson L.E., Burger M., Cavagnaro T.R. 2008. Roots, nitrogen transformations and ecosystem services. *Annual Review of Plant Biology*, 59: 341-363.
- Gentile R., Burger M., Pierce D., Smart D.R. 2006. Impacts of Climate Change on Crop and Animal Physiology in California Agriculture. *In Cavagnaro T.R., Jackson L.E., Scow K.M. (eds.) Climate Change: Challenges and Solutions for California Agricultural Landscapes*. California Climate Change Center.
<http://www.energy.ca.gov/2005publications/CEC-500-2005-189/CEC-500-2005-189-SF.PDF>.
- Venterea R.T., Burger M., Spokas K.A. 2005. Nitrogen oxide and methane emissions under varying tillage and fertilizer management. *Journal of Environmental Quality*, 34: 1467-1477.
- Burger M., Jackson L.E., Louie D.T., Lundquist E.J., Miller R.L., Rolston D.E., Scow K.M. 2005. Microbial responses and nitrous oxide emissions during wetting and drying of organically and conventionally managed soil under tomatoes. *Biology and Fertility of Soils*. 42: 109-118.
- Burger M. and Jackson L.E. 2004. Plant and microbial nitrogen use and turnover: Rapid conversion of nitrate to ammonium in soil with roots. *Plant and Soil*, 266:289-301.
- Burger M. and Jackson L.E. 2003. Microbial immobilization of ammonium and nitrate in relation to ammonification and nitrification rates in organic and conventional cropping systems. *Soil Biology and Biochemistry*, 35: 29-37.

PROFESSIONAL AFFILIATIONS

ASA-CSSA-SSSA (Agronomy, Crop Science, and Soil Science Societies of America).

Journal article reviewer for *Global Change Biology*, *Soil Science Society of America Journal*, *Plant and Soil*, *Journal of Agricultural and Food Chemistry*, *Waste Management*, *Journal of Environmental Quality*, *Applied Soil Ecology*, *Soil Science*, *Applied and Environmental Soil Science*.

William Richard Horwath, Professor of Soil Biogeochemistry
Chairman Agriculture and Environmental Chemistry Graduate Group
J. G. Boswell Endowed Chair in Soil Science

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Education

- 1993 Ph.D. Soil Science, College of Agriculture, Department of Crop and Soil Sciences, Michigan State Univ., E. Lansing, MI.
- 1993 Ph.D. Forest Ecology, College of Agriculture, Department 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:

- Chairman Agriculture and Environmental Chemistry Graduate Group 7/10 to present
- J. G. Boswell Endowed Chair in Soil Science, 2008
- Vice Chairman Dept. Land, Air and Water Resources, 10/07 to 10/10
- Professor of Soil Biogeochemistry, University of California, Davis, CA. 7/04 to present
- Assoc. Professor of Soil Biogeochemistry, University of California, Davis, CA. 7/00 to 6/04
- Assist. Professor of Soil Biogeochemistry, University of California, Davis, CA. 7/96 to 6/00
- Graduate Faculty, Oregon State University, Corvallis, OR. 1/95 to present
- Research Soil Microbiologist, USDA ARS, Corvallis, OR. 10/94 to 5/96
- Faculty Research Associate, Oregon State University, Corvallis, OR. 11/92 to 9/94
- Graduate Research Assistant, Michigan State University, E. Lansing, MI. 9/88 to 10/92
- Research Specialist, Michigan State University. 11/85 to 9/88
- Staff Research Associate, University of California at Berkeley, CA 4/83 to 10/85
- Forestry Apprentice, German Academic Exchange Service, Munich, Germany. 6/79 to 6/80

Awards and Distinctions

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

Selected Publications (since 2006)

1. Mitchell, J.P., T.K. Hartz, B.R. Hanson, D.M. May, W.R. Horwath, K.K. Klonsky, E.M. Miyao and W.W. Wallender. 2006. Recent advances in tomato production systems in California. *Acta Hort.* 724:165-175.
2. Veenstra, J. J. W. R. Horwath and J. P. Mitchell. 2006. Conservation Tillage and Cover Cropping Effects on Total Carbon and Aggregate-Protected Carbon in Irrigated Cotton and Tomato Rotations. *Soil Sci. Soc. Am. J.* 171:362–37.
3. Horwath WR. 2007. Carbon Cycling and Formation of Soil Organic Matter. E.A. Paul, Ed. In: *Soil Microbiology, Ecology and Biochemistry*. Academic Press, New York, pp. 303-339.
92. Sivakumar B, Wallender WW, Horwath WR, Mitchell JP. 2007. Nonlinear deterministic analysis of air pollution dynamics in a rural and agricultural setting. *Adv Com Sys* 10: 581-597.
93. Davis JH, SM Griffith, and WR Horwath. 2008. Denitrification and nitrate consumption in an herbaceous riparian area and perennial ryegrass seed cropping system. *Soil Sci. Soc. Am. J.* 72: 1299-1310
94. Mitchell JR, Southard RJ, Madden NM, Klonsky KM, Baker JB, DeMoura RL, Horwath WR, Munk DS, Wroble JF, Hembree KJ, Wallencler WW. 2008. Transition to conservation tillage evaluated in San Joaquin Valley cotton and tomato rotations. *California Ag.* 62: 74-79.
95. Geisseler D, WR Horwath, and TA Doane. 2009. Significance of organic nitrogen uptake from plant residues by soil microorganisms as affected by carbon and nitrogen availability. *Soil Biol. and Biochem.* 41: 1281-1288
96. Doane TA, WR Horwath, JP Mitchell, J Jackson, G Miyao, K Brittan. 2009. Nitrogen supply from fertilizer and legume cover crop in the transition to no-tillage for irrigated row crops. *Nutrient Cycling in Agroecosystems.* 85: 253-262.
97. Geisseler D, WR Horwath. 2009. Relationship between carbon and nitrogen availability and extracellular enzyme activities in soil. *Pedobiologia.* 53: 87-98.
98. Suddick, E. C., K. M. Scow, W. R. Horwath, L. E. Jackson, D. R. Smart, J. Mitchell, and J. Six. 2010. The Potential for California Agricultural Crop Soils to Reduce Greenhouse Gas Emissions: A Holistic Evaluation. In Donald L. Sparks, editor: *Advances in Agronomy*, Vol. 107, Burlington: Academic Press, pp. 123-162.
99. A. Toby O'Geen, A. T., M. J. Singer, and W. R. Horwath. 2010. Soil and Water Conservation for California and the Desert Southwest USA: Past, Present and Future Trends. In: *Soil and Water Conservation Advances in the United States*. SSSA Special Publication 60. T.M. Zobeck and W.F. Schillinger, eds. SSSA, Madison, WI.
113. Kallenbach CM, D E Rolston and W R Horwath. 2010. Cover cropping affects soil N₂O and CO₂ emissions differently depending on type of irrigation. *Agriculture Ecosystems and the Environment.* 137: 251-260.
114. Diaz-Valbuena LR, Leverenz HL, Cappa CD, Tchobanoglous G, Horwath WR, Darby JL. 2011. Methane, Carbon Dioxide, and Nitrous Oxide Emissions from Septic Tank Systems. *Environmental Science and Technology.* 45: 2741-2747.
115. Garland GM, Suddick E, Burger M, Horwath WR, Six J. 2011. Direct N₂O emissions following transition from conventional till to no-till in a cover cropped Mediterranean vineyard (*Vitis vinifera*). *Agriculture Ecosystems & Environment.* 141: 234-239.
116. Roberts, BA.; Fritschi, FB.; Horwath, WR, Scow, KM, Rains, WD and Travis, RL. 2011. Comparisons of Soil Microbial Communities Influenced by Soil Texture, Nitrogen Fertility, and Rotations. *Soil Science.* 176: 487-494.

JOHAN SIX

EDUCATION

- 1998 Ph.D., Soil Science, Colorado State University, Fort Collins, Colorado.
Dissertation: 'Aggregate and Soil Organic Matter Fraction Dynamics in Agroecosystems'
- 1995 M.Sc. Bio-Engineering, Katholieke Universiteit Leuven, Belgium. Major: Soil Science; Minor: Tropical Agriculture. Thesis: 'Soils and Land Use in the Eastern Region of South Vietnam and Lam Dong Province'

RESEARCH EXPERIENCE

- 2006- present *Assistant, Associate, Full Professor*
Department of Plant Sciences, University of California, Davis, CA.
- 2005-2006 *Full Professional Researcher*
Department of Plant Sciences, University of California, Davis, CA.
- 2003-2005 *Associate Professional Researcher*
Department of Plant Sciences, University of California, Davis, CA.
- 2002-2003 *Assistant Professional Researcher*
Department of Agronomy and Range Science, University of California, Davis, CA.
- 2001- present *Research Scientist*
Natural Resource Ecology Laboratory, Colorado State University, Ft. Collins, CO.
- 2000 *Visiting Scientist*
Argonne National Laboratory, Argonne, IL.
- 1999-present *Affiliated Professor*
Department of Soil and Crop Sciences, Colorado State University.
Regular Faculty Member
Graduate Degree Program in Ecology, Colorado State University, Ft. Collins, CO.
- 1999-2001 *Scientist*
Natural Resource Ecology Laboratory, Colorado State University, Ft. Collins, CO.
- 1999 *Research Associate*
Natural Resource Ecology Laboratory, Colorado State University, Ft. Collins, CO.

SELECTED PUBLICATIONS (2008-2011)

- De Gryze, S., J. Lee, S. Ogle, K. Paustian, and J. Six. 2011. Assessing the Potential for Greenhouse Gas Mitigation in Intensively Managed Annual Cropping Systems at the Regional Scale. *Agr. Ecosyst. Environ.* 144:150-158.
- Chivenge, P., B. Vanlauwe, and J. Six. 2011. Does the combined application of organic and mineral nutrient sources influence maize productivity? A meta-analysis. *Plant Soil*, 342:1-30.
- Ayuke, F.O., L. Brussaard, B. Vanlauwe, J. Six, D.K. Lelei, and M.M. Pulleman. 2011. Soil fertility management: impacts on soil macrofauna, soil aggregation and soil organic matter allocation. *Appl. Soil Ecol.*, 48:53-62.
- Garland, G.M., E. Suddick, M. Burger, W.R. Horwath, and J. Six. 2011. Direct N₂O emissions following transition from conventional till to no-till in a cover cropped Mediterranean vineyard (*Vitis vinifera*). *Agr. Ecosyst. Environ.*, 141:234-239.
- Lee, J., C. van Kessel, and J. Six. 2011. Dinitrogen fixation by winter-grown chickpea after waterlogging across scales in a Mediterranean climate. *J. Agron. Crop Sci.*, 197:135-145.

- Chivenge, P., B. Vanlauwe, R. Gentile, and J. Six. 2011. Organic resource quality influences short-term aggregate dynamics and soil organic carbon and nitrogen accumulation. *Soil Biol. Biochem.*, 43:657-666.
- Six, J. 2011. Plant nutrition for sustainable development and global health. *Plant Soil*, 339:1-2.
- Luo, Y., J.M. Melillo, S. Niu, C. Beier, J.S. Clark, A.T. Classen, E. Davidson, J. S. Dukes, R.D. Evans, C. B. Field, C. I. Czimczik, M. Keller, B.A. Kimball, L.M. Kueppers, R.J. Norby, S.L. Pelini, E. Pendall, E. Rastetter, J. Six, M. Smith, M.G. Tjoelker, M.S. Torn. 2011. Coordinated Approaches to Quantify Long-Term Ecosystem Dynamics in Response to Global Change. *Global Change Biol.*, 17:843-854.
- Pereira, E.I.P., H. Chung, K.M. Scow, M.J. Sadowsky, C. van Kessel, and J. Six. 2011. Soil nitrogen transformations under elevated atmospheric CO₂ and O₃ during the soybean growing season. *Environ. Poll.*, 159:401-407.
- Gentile, R., B. Vanlauwe, P. Chivenge, and J. Six. 2011. Trade-offs between the short- and long-term effects of residue quality on soil C and N dynamics. *Plant Soil*, 338:159-169.
- Kong, A.Y.Y., K.M. Scow, A.L. Córdova-Kreylos, W.E. Holmes, and J. Six. 2011. Microbial community composition and carbon cycling within soil microenvironments of conventional, low-input, and organic cropping systems. *Soil Biol. Biochem.*, 43:20-30.
- De Gryze, S., A. Wolf, S.R. Kaffka, J.P. Mitchell, D.E. Rolston, S.R. Temple, J. Lee, and J. Six. 2010. Simulating greenhouse gas budgets of four California cropping systems under conventional and alternative management. *Ecol. Appl.*, 20: 1805-1819.
- Kong, A.Y.Y., K. Hristova, K.M. Scow, and J. Six. 2010. Impacts of different N management regimes on nitrifier and denitrifier communities and N cycling in soil microenvironments. *Soil Biol. Biochem.*, 42: 1523-1533.
- Suddick, E.C., K.M. Scow, W.R. Horwath, L.E. Jackson, D.R. Smart, J.P. Mitchell, and J. Six. 2010. The Potential for California Agricultural Crop Soils to Reduce Greenhouse Gas Emissions: a Holistic Evaluation. *Adv. Agr.*, 107:123-162.
- Kong, A.Y.Y., and J. Six. 2010. Tracing cover crop root versus residue carbon into soils from conventional, low-Input, and organic cropping systems. *Soil Sci. Soc. Am. J.*, 74:1201-1210.
- Gomes, J., C. Bayer, F. Costa, M. Piccolo, J.A. Zanatta, F.C.B. Vieira, and J. Six. 2009. Soil nitrous oxide emissions in long-term cover crops-based rotations under subtropical climate. *Soil Till. Res.*, 106:36-44.
- Hungate, B.A., K.J. van Groenigen, J.Six, J.D. Jastrow, Y.Luo, M.A. de Graaff, C. van Kessel, C. W. Osenberg. 2009. Assessing the effect of elevated carbon dioxide on soil carbon: a comparison of four meta-analyses. *Global Change Biol.*, 15:2020-2034.
- Kong, A.Y.Y., S. J. Fonte, C. van Kessel, and J. Six. 2009. Transitioning from standard to minimum tillage: trade-offs between soil organic matter stabilization, nitrous oxide emissions, and N availability in irrigated cropping systems. *Soil Till. Res.*, 104: 256-262.
- King, A.P., J.K. Evatt, J. Six, R.M. Poch, D.E. Rolston, and J.W. Hopmans. 2009. Annual C and N loadings for a furrow-irrigated field. *Ag Water Management*, 96: 925-930.
- Howitt, R.E., R. Catala-Luque, S. De Gryze, S. Wicks, and J. Six. 2009. Realistic payments could encourage farmers to adopt practices that sequester carbon. *Cal. Ag.*, 63:91-95.
- De Gryze, S., M.V. Albarracin, R. Catala-Luque, R.E. Howitt, and J. Six. 2009. Modeling shows that alternative soil management can decrease greenhouse gases. *Cal. Ag.*, 63:84-90.
- Lee, J., J.W. Hopmans, C. van Kessel, A.P. King, K. J. Evatt, D. Louie, D.E. Rolston, and J. Six. 2009. Tillage and seasonal emissions of CO₂, N₂O and NO across a seed bed and landscape in a Mediterranean climate. *Agr. Ecosys. Environ.*, 129:378-390.
- Buchner, J.S., J. Simunek, J. Lee, D.E. Rolston, J.W. Hopmans, A.P. King and J. Six. 2008. Evaluation of CO₂ fluxes from an agricultural field using a process-based numerical model. *J. Hydr.*, 361:131-143.

- Van Oost, K., J. Six, G. Govers, T. Quine, and S. De Gryze. 2008. Soil Erosion: A carbon sink or source? *Science*, 319:1040-1041.
- De Graaff, M.A., C. van Kessel, and J. Six. 2008. The impact of long-term elevated CO₂ on C and N retention in stable SOM pools. *Plant Soil*, 303:311-321.
- Olchin, G.P., S. Ogle, S.D. Frey, T.R. Filley, K. Paustian, and J. Six. 2008. Residue Carbon Incorporation into Soil Aggregates of No-Tillage and Tillage Dryland Cropping Systems. *Soil Sci. Soc. Am. J.*, 72:507-513.

CV Marc Los Huertos

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Dissertation: Nitrogen Dynamics in Vegetative Buffer Strips Receiving Elevated Nitrogen.

Committee: Steve Gliessman (chair, UC Santa Cruz), Jean Langenheim (UC Santa Cruz), and Pam Matson (Stanford University).

M.A. Ecology and Systematics, San Francisco State University, 1992.

B.A. Biochemistry & Molecular Biology and Environmental Studies, University of California, Santa Cruz, 1987.

Employment

Associate Professor, Division of Science & Environmental Policy, California State University Monterey Bay, August 2011–present.

Assistant Professor, Division of Science & Environmental Policy, California State University Monterey Bay, August 2006–July 2011.

Assistant Research Faculty in Agroecology, Social Sciences Division, University of California, Santa Cruz, January 2001–December 2004.

Research

Selected Peer-Reviewed Articles

Schmidt, CS, AT Fisher, A Racz, BS Lockwood, M Los Huertos. In press. Linking Denitrification and Infiltration Rates during Managed Groundwater Recharge. *Environmental Science and Technology*.

Racz, A., AT Fisher, CS Schmidt, BS Lockwood, M Los Huertos. In press. Spatial and Temporal Infiltration Dynamics during Managed Aquifer Recharge. *Groundwater*.

Schmidt, CS, AT Fisher, A Racz, C Wheat, M Los Huertos, B Lockwood. In press. Rapid nutrient load reduction during infiltration of managed aquifer recharge in an agricultural groundwater basin: Pajaro Valley, California. *Hydrologic Processes*.

Dowd, B, D Press, M Los Huertos. 2008. Policy tools, monitoring, and funding to reduce nutrient pollutants: A case study of nitrate in the Pajaro River, California. *Agriculture, Ecosystems and Environment* 128(3):151-161.

- Lemos, RT, B Sanso, M Los Huertos. 2007. Spatially varying temperature trends in a northern California estuarine reserve. *Journal of Agricultural, Biological, and Environmental Statistics* 12(3):379-396.
- Rein, FA, M Los Huertos, KD Holl, JH Langenheim. 2007. Restoring native grasses as vegetative buffers in a coastal California agricultural landscape. *Madroño* 54(3):249-257.
- Ruehl, C, AT Fisher, M Los Huertos, S Wankel, CG Wheat, C Kendall, C Hatch, C Shennan. 2007. Nitrate dynamics within the Pajaro River, a nutrient-rich, losing stream. *North American Benthological Society Journal*, 26:191-216.
- Ruehl, C, AT Fisher, CE Hatch. M Los Huertos, G Stemler, C Shennan. 2006. Differential gauging and tracer tests resolves seepage fluxes in a strongly-losing stream. *Journal of Hydrology* 330:235-248.
- Wilcox, C, M Los Huertos. 2005. A simple, rapid method for mapping bathymetry of small wetland basins. *Journal of Hydrology* 301:29-36.
- Los Huertos, M, LE Gentry, C Shennan. 2001. Land use and stream nitrogen concentrations in agricultural watersheds along the central coast of California. IN *Optimizing Nitrogen Management in Food and Energy Production and Environmental Protection: Proceedings of the 2nd International Nitrogen Conference on Science and Policy*. Scientific World 1.

Other Publications

- Li, C, W Salas, M Los Huertos. 2004. Quantifying carbon dynamics and greenhouse gas emissions of agricultural soils of California: A Scoping Study. Kearney Foundation/California Energy Commission. California Department of Food and Agriculture.
- Los Huertos, M, C Shennan. 2002. The Soil Resource in Elkhorn Slough. in J. Caffrey and M. Brown, editors. *Changes in a California Estuary: A Profile of Elkhorn Slough*. Monterey Bay Aquarium Press, Monterey.

Active Research Grants and Funding Sources

- USDA-Organic Agriculture Research and Extension Initiative. (Sept. 2011-Aug. 2013). Global Warming Potential of Row Crop Agroecosystems. \$174,199.
- Water Quality Preservation, Inc. (January 2011-Dec 2011). Agricultural Waiver Monitoring. \$91,325.
- CSU-Agricultural Research Initiative (August 2010-July 2012). Global Warming Potential of Contrasting Strawberry Agroecosystems. \$66,531.
- State Water Resources Control Board (March 2007-December 2011). Developing a Periphyton Index of Biotic Integrity for the Central Coast of California. \$660,000
- Community Foundation of Monterey/PG& E Settlement Funds (Jan. 2006-December 2011). Design Tools for Treatment Wetland Design \$42,026.

Regular Course Teaching

- Aquatic Ecology (Bio 448/548), Spring Semester. Environmental Monitoring (ENVS 355), Fall Semester.
- Introduction to Environmental Science (ENVS 201), Spring Semester (usually bought out). Graduate Seminar I (ENVS 500), Fall Semester. Graduate Seminar II (ENVS 502), Spring Semester. Research Methods (ENVS 550), Fall Semester (Co-taught). Advanced Watershed Science & Policy (ENVS 660), Fall Semester (Co-taught).

Professional Activities

American Water Resources Association 2004-present Agronomy Society of America 1999-present Ecological Society of America 1996-present National Association of College Teachers in Agriculture 2010-present

RELATED RESEARCH

- a. Annual N₂O emissions are monitored over two years in vineyard, walnut, almond, tomato, and alfalfa systems under business as usual conditions in the Sacramento Valley by Dr. Six (PI), and Co-PIs Dr. Horwath and Dr. M. Burger, funded by CEC (\$500,000).
- b. Annual N₂O emissions are monitored over two years in conventional and alternative tomato systems in Yolo County by Dr. Six (PI) and Co-PIs Dr. Horwath, Dr. M. Burger, M. Fischer, and Dr. B. Salas, funded by the Packard Foundation (\$350,000).
- c. The effect of biochar additions to soils on greenhouse gas emissions is assessed in vegetable garden, walnut, and vineyard systems in the Sacramento Valley by Dr. Six (PI) and co-PIs Dr. Hernes and Dr. Claassen. Funded by CEC (\$700,000).
- d. Baseline N₂O emissions in California dairy forage systems are being assessed by Dr. Horwath (PI), and Co-PIs Dr. Burger and Dr. Pettygrove. Funded by CARB (\$82,000).
- e. NO_x emissions from soil in California cropping systems to improve ozone modeling are being determined in tomato, alfalfa, silage corn, tomato, and wheat systems by Dr. Horwath (PI) and Dr. Burger. Funded by CARB (\$83,500).
- f. Research to evaluate N₂O emissions from compost in support of AB 32 scoping plan composting measure is conducted by Dr. Horwath (PI). Funded by CAIWMB (\$450,000).

- g. Feasibility of using rice cropping for carbon capture in the Delta is studied by Dr. Horwath (Co-PI). Funded by CA Water Resources Control Board (\$180,000).
- h. Annual N₂O emissions are assessed during two years in tomato rotations with two types of cover crops and winter-fallow under subsurface drip and furrow-irrigation by Dr. Wallender (PI), and Co-PIs Dr. Horwath, Dr. Scow, Dr. Klonsky, E. Miyao, and Dr. Burger. Funded by USDA-CDFR (\$417,000).
- i. Annual N₂O emissions are being assessed over two growing seasons in rice, lettuce, tomato, wheat, and alfalfa in the Sacramento Valley and the Salinas Valley by Dr. Horwath (PI), and Co-PIs M. Burger, J. Six, D. Goorahoo, and T. Hartz, funded by CARB (\$300,000).
- j. Nitrous oxide and CH₄ emissions were monitored at the Rice Experiment Station, Biggs, CA, by Dr. Horwath and technician Yacov Assa. The study includes a comparison of N₂O and CH₄ emissions from a conventional wet-seeded rice system, a wet-seeded rice with early season drainage system, and a drill-seeded rice with early season drainage system. Additionally, each management practice was associated with various N fertilizer levels. This project was funded by California Rice Commission (\$45,000).
- k. Emissions of N₂O were assessed by Dr. Horwath and graduate student C. Kallenbach in processing tomato systems that were either furrow-irrigated or subsurface drip-irrigated at the UC Davis Russell Ranch Sustainable Agriculture Research site from 2005 to 2006. Additional treatments in this project were the presence or absence of a winter legume cover crop and two tillage practices (Kallenbach et al., 2010). The study was funded by the Kearney Foundation of Soil Science (\$90,000).
- l. Emissions of CH₄ and N₂O were assessed by Dr. Horwath and post doctorate Urszula Norton in various chaparral systems with different fire histories from 2005 to 2007. The study was funded by Kearney Foundation of Soil Science (\$90,000).
- m. An integrated assessment of the biophysical and economic potential for greenhouse gas mitigation in California agricultural soils under the lead of Dr. Six, with co-investigators R.E. Howitt, D.E. Rolston, R. Plant, J. Mitchell, C. van Kessel, and J.W. Hopmans, funded by the California Energy Commission/Kearney Foundation (\$334,945), was completed in July 2008. This assessment was accomplished by directly linking an ecosystem model calibrated for California conditions with an economic model that has been extensively used to assess sustainable agricultural practices. The ecosystem model provides greenhouse gas mitigation supply curves based on estimates of changes in soil C, trace gas fluxes, and productivity (yield) based on soil, climate and management data. The ecosystem model outputs serve as input into the economic model. This decision-

- support assessment tool provides an accounting structure for land use and management impacts on C stocks and associated CO₂, N₂O and CH₄ fluxes.
- n. Detailed time series of N₂O emissions after irrigation and after first rainfall after harvest were conducted at the UC Davis Russell Ranch Sustainable Agriculture Research site by Dr. Burger and co-workers in organically and conventionally managed tomato systems (Burger et al., 2005). This research was funded by a LTRAS Seed Grant from the Agronomy Department, UC Davis.
 - o. Flux measurements of N₂O and CH₄ were conducted by Dr. Burger in corn systems with long term tillage treatments and applications of different fertilizer types during 2003 and 2004 in Minnesota (Venterea et al., 2005). Funding for this study was by USDA-ARS.

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