Title: Calibrating, Validating, and Implementing Process Models for California Agriculture Greenhouse Gas Emissions

Project PI

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Table of contents.

Statement of significance

Impact statewide: With the passage of AB 32, The Global Climate Change Solution Act, quantifying N_2O emission from California agricultural land is vital to determining GHG emission budgets. Previously, CARB developed a greenhouse gas inventory for California, using the IPCC worldwide average or default emission factors, which for direct emissions of N_2O have an uncertainty range of -30% to 300%. The CEC sponsored two modeling studies to assess greenhouse gas emission mitigation potentials from California agriculture (Li et al., 2004; Six et al., 2008), both of which suffered from a lack of field data to calibrate and validate the models. One of the goals of the proposed project is to help improve these earlier attempts by leveraging off several companion project collecting N2O data for calibrating and validating models for California specific conditions in addition to providing an independent estimate of N_2O emissions based on California crop specific fertilizer levels. Furthermore, the measurements of N_2O flux and of the physical variables that control N_2O emissions, such as soil moisture, soil inorganic N concentrations, and carbon additions, will serve as basis against which future measurements or the effects of alternative management practices can be used to assess ability of process based models to simulate biogeochemical cycling that controls N_2O production, consumption and emissions. In addition, support from USDA NRCS was used to calibrate and validate the DNDC model for CH_4 emissions from California rice systems. The modeling tools in the proposed research may be validated or revised through future measurements and subsequently used to evaluate alternative management suitable typical California crop rotations impact on net GHG emissions.

Long-term Solution: According to the February 14, 2008 Recommendation of the Economic and Technology Advancement and Advisory Committee (ETAAC) for Technologies and Policies to Consider for reducing greenhouse gas emissions in California report, the following are needed:

> *"A database of event-related and background N2O emissions, crop development and controlling factors (e.g. soil temperature, soil moisture, and soil mineral nitrogen) must be constructed in a range of representative Californian cropping systems, soils, and climates. This database could then be used to calibrate and validate the biogeochemical models"*
>
> *And*
>
> *"A simple, web-based interface, such as the Nutrient and Greenhouse Gas Evaluation Tool or NUGGET (see page 6-15) should be expanded to other California commodities and made readily available to growers and all interested parties to allow the selection and quantification of site-specific management strategies that are sustainable, reduce environmental impacts and are potentially more profitable."*

The group of investigators on this proposal has developed a joint research and proposal effort to directly address the ETAAC recommendations by providing critical data for background and event related N_2O emissions from select cropping systems in the San Joaquin Valley and for validating the DNDC (biogeochemical tool within the NUGGET system) model. This project, coupled with the CDFA, CEC and ARB companion projects (see discussion below), will result in better understanding of California specific N_2O and CH_4 emission profiles and the calibration and validation of a California specific process modeling tool for site and regional level estimates of N_2O and CH_4 emissions. These data and tools are critical for reducing the large uncertainty in N_2O and CH_4 emissions from California agriculture and for developing economically viable mitigation strategies.

Abstract.

Agriculture represents a significant opportunity for greenhouse gas (GHG) mitigation projects through soil carbon sequestration and reductions of methane (CH_4) and nitrous oxide (N_2O) emissions. Recently, significant investments are being made in assessing carbon sequestration projects in agricultural soils, due to the potential for trading carbon credits coupled with significant environmental benefits through improved soil quality, soil fertility, and reduced erosion potential. Changes in farming management practices, such as tillage, fertilization, irrigation, manure amendment, rotation with cover crops, and others are being evaluated for their potential in mitigating GHGs emitted from the agricultural sector. Because the cycles of water, carbon (C) and nitrogen (N) in the agroecosystems are tightly linked, any change in farming management could simultaneously alter crop yields, soil fertility, N leaching, soil C storage, and trace gas emissions. New methodologies linking GIS databases with process-based models are being used to bring complex agroecosystems into a computable framework for assessing the impact of alternative management practices on soil C storage and GHG emissions.

ARB current approach for building the GHG inventory for agriculture relies primarily on using emission factors for estimating emission by activity. While IPCC suggests process modeling (referred to as TIER 3 method) can improve accuracy of emission inventories, it is important to calibrate this method to specific cropping systems, perform model validation to estimate model structural uncertainties and to understand model sensitivity to inputs and overall uncertainty (upper and lower bounds). The goal is to develop, demonstrate and transfer to ARB a framework for collecting GIS and agricultural management data, link these data in a GIS framework with DNDC process models for agricultural N_2O, CO_2 and CH_4 emission inventories, and develop an explicit uncertainty budget due to both structural (derived from model validation) and scaling (unknowns in model input data for inventory, e.g. soils, agricultural management, crops, etc). ***The resulting modeling system will improve ARB agricultural GHG quantification through process modeling and will enable ARB to perform high level assessments of opportunities for GHG mitigation through alternative agricultural practices***. In addition to the modeling results, we propose that this system design is a usable framework that will advance as future field research and process modeling evolves and we have an improved understanding of the science driving GHG emissions from California agriculture.

1.0 Background:

1.1 Introduction.

The California Global Warming Solutions Act of 2006 has legislated GHG emission reductions such that 2020 emission levels are at or below 1990 levels. Mandatory GHG emission reductions are now set in law for the first time in the US. In response to this Act, a Climate Action Team (CAT) was created to identify Discrete Early Actions to reduce emissions and meet the 2020 targets. The 2006 CAT report identified the use of cover crops and conservation tillage as strategies for sequestering soil carbon in California croplands. A challenge with the development of GHG emission reduction policies, particularly market-based policies, is the need to accurately and transparently conduct full GHG accounting to quantify net emission reductions, especially given the strong linkage between soil carbon content and trace gas emissions. In addition, California is now exploring the development of various GHG emission reduction strategies including the potential use of market-based mechanisms to create incentives for producers to adopt voluntary GHG emission practices.

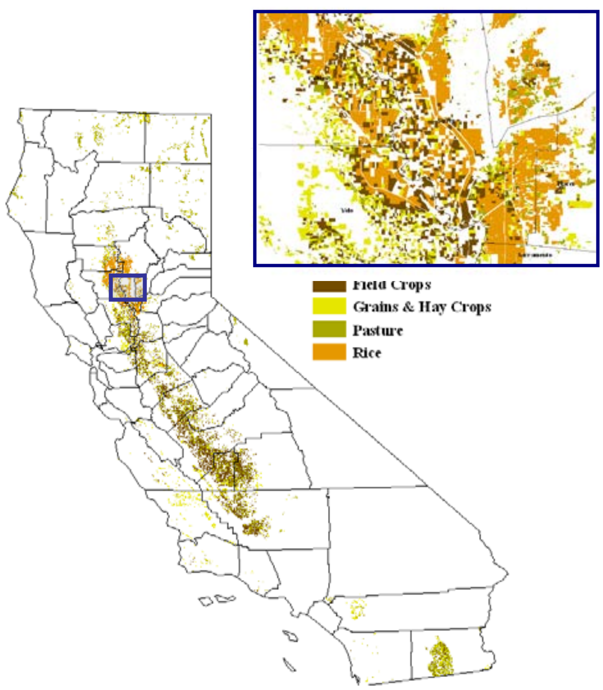

Figure 1. State of California land use map highlighting agricultural areas of interest for this proposal. Zoom area shows details just north of Sacramento. Data are from California Department of Water Resources.

The 1997 California Census of Agriculture reported 43,752 km^2 of cropland in the state, with 34,572 km^2 of it harvested. California agriculture emits CH_4 and N_2O from various agricultural sources, including enteric fermentation, agricultural soil management, rice paddy cultivation, and manure management. In 1999, agriculture in California generated approximately 28.4 million metric tons carbon dioxide equivalent (MMT CO_2 eq.) of GHG emissions, which is approximately 7% of the state's total emissions (California Energy Commission, 2002). Nitrous oxide and methane accounted for 15.57 and 12.85 MMT CO_2 eq., respectively. Agricultural soils were the dominant source of N_2O (95% of total emissions), and enteric fermentation and manure management were the dominant agricultural sources of CH_4 (approximately 96%). Direct emissions of N_2O from agricultural soils accounted for 5.78 MMT CO_2 eq., with indirect emissions accounting for 8.96 MMT CO_2 eq. These emission inventories were developed using emission factor approaches as specified in IPCC guidelines, with some California specific emission factors.

The legislation passed in California creates a clear need for a system that identifies and quantifies agricultural carbon sequestration and greenhouse gas mitigation opportunities. Here, we outline our plan for the design, development, and implementation of such a system. We anticipate that this prototype system will be designed so that it can easily be updated to include new field research for model validation and future improvements in process models.

1.2 Role of Agriculture in Greenhouse Gas Mitigation

Agricultural activities are responsible for approximately 50% of global atmospheric inputs of methane (CH_4) and agricultural soils are responsible for 75% of global nitrous oxide (N_2O) emissions [Scheehle and Kruger, 2005; US EPA, 2005], and thereby represent a significant opportunity for greenhouse gas (GHG) mitigation through reductions of CH_4 and N_2O emissions, as well as through soil carbon sequestration [*Oenema et al*., 2001]. When assessing the impact of food and fiber production systems on the earth's radiation budget, the entire suite of GHGs (i.e., CO_2, CH_4 and N_2O) needs to be considered [*Li*, 1995; *Robertson et al*., 2000; *Smith et al*., 2001, *Li et al*., 2004]. Since each greenhouse gas has its own radiative potential [*Ramaswamy et al*., 2001], a net global warming potential (GWP) of a crop production system can be estimated that accounts for all three gases. Agriculture represents a significant opportunity for greenhouse gas mitigation projects through soil carbon sequestration and reductions of methane (CH_4) and nitrous oxide (N_2O) emissions. Recently, significant investments are being made in assessing carbon (C) sequestration projects in agricultural soils due to the potential for trading carbon credits coupled with significant environmental benefits through improved soil quality, soil fertility, and reduced erosion potential. Changes in farming management practices, such as tillage, fertilization, irrigation, cover cropping, and manure amendment, are currently being evaluated for their potential in mitigating greenhouse gases emitted from the agricultural sector. For example, it has been widely reported that replacing conventional tillage with no-till results in soil organic carbon (SOC) storage (Lal et al. 1999, Smith et al. 2000). The carbon sequestration potential of agricultural lands is being studied with experimental or modeling approaches in a number of recent or on going research projects (e.g. Eve et al. 2002, Falloon et al. 2002, Paustin et al. 2002, Rickman et al. 2002.). Most of the published research focused only on the soil C dynamics with little attention to other greenhouse gases, namely nitrous oxide (N_2O) and methane (CH_4) which may offset gains in greenhouse gas emissions if not managed properly. Few of the reports assessed the impacts of the C sequestration induced by the management alternatives on the coupled N_2O or CH_4 emissions from the same lands.

California rice, for example, is a unique agricultural system due to the use of flooding to meet the plant physiological demands. As a result, the per hectare GHG emissions can be quite high, primarily due to high CH4 emissions since N2O emissions tend to be low due to highly anaerobic soils. In developing their rice emission factor, EPA (2010) summarized field research in the US where measurements of CH_4 ranged from 22 to 1490 kg CH_4/ha/season. This is equivalent to emissions of 0.6 to over 37 tons CO_2e/ha. Shifts in farming management practices such as flooding regimes, rice straw amendment and fertilizer application have been shown to decrease methane emissions significantly (20-80%) (see. Li et al. 2005, 2006 for examples).

1.3 Coupled Carbon and Nitrogen Biogeochemical Processes

In nature, chemical elements typically act in a coupled fashion and represent one of the basic concepts of biogeochemistry. Carbon and nitrogen (N) are one of the best examples of biogeochemical coupling and are both essential elements for most life forms. Photosynthesis is the process initiating the primary production of green plants by synthesizing atmospheric C into biomass C based on the N compounds, chlorophyll. The coupled C and N in plant tissues are incorporated in the soil from litter and exudates and after plants death. In the soil environment, the coupled C and N start the decoupling processes by way of soil microbes as they derive energy from the break down of the organic compounds. The processes result in the separation of C and N by converting the C-N compounds into dissolved organic carbon (DOC) or inorganic C (e.g., CO_2) as well as inorganic N (e.g., ammonium or nitrate). The energy is usually generated during the process by transferring electrons from the C atoms existing in the organic compounds to oxygen. If O_2 is depleted in the soil, certain groups of microbes (e.g., denitrifiers) can use other oxidants as electron acceptors. After oxygen, the most ready-reduced oxidant is nitrate. Nitrate, nitrous oxide (N_2O), and dinitrogen (N_2) are produced when the microbes transfer the electrons from organic C (Firestone 1982). The same is true for CH_4 production although the process occurs under more reductive conditions related to hydrogen production. These processes demonstrate how SOC content and N_2O are related through the coupling and decoupling of C and N in the upland plant-soil systems. In summary, increases in SOC storage, such as those expected to occur under no-till agricultural practices, elevate soil DOC and available N through decomposition, which in turn will stimulate activity of a wide scope of soil microbes including nitrifiers and denitrifiers, which are responsible for N_2O production in the soils.

1.4 Nitrous Oxide Emission and Soil Carbon Content

While nitrous oxide and methane are the major thrust of our proposed system, we contend that decision support systems for assessing GHG emissions in agro-ecosystems should be comprehensive and thus include full greenhouse gas accounting. Since N_2O is the most significant trace gas emission from upland agriculture, we also focus on the link between carbon and nitrous oxide. The correlation of N_2O production with soil C abundance has been observed in a wide scope of field measurements or laboratory experiments conducted over the past five decades. More specifically, *higher N_2O fluxes have been measured from the soils with higher organic matter content*. Many researchers have measured N_2O fluxes from several contiguous plots under similar climate and management conditions, the higher N_2O emissions were mostly observed at the plots with higher SOC contents. Among the observations, organic soils consistently emitted the highest N_2O fluxes (Bremner and Shaw, 1958; Bowman and Focht, 1974; Burford and Bremner, 1975; Stanford et al., 1975; Pluth and Nommik, 1981; Duxbury et al., 1982; Terry et al., 1981; Goodroad and Keeney, 1984; Pang and Cho, 1984; Klingensmith, 1987; Robertson and Tiedje, 1987; Mosier et al.,1991; Vinther, 1992).

1.5 Process-based Models and Agricultural Mitigation of Greenhouse Gases

Based on the experimental observations as well as biogeochemical analysis, DOC and available N have been recognized to be two dominant factors affecting soil N_2O emissions, although not exclusively. Soil temperature, moisture, pH, redox potential, and other substrate concentrations can also affect N_2O production. These soil environmental factors are driven by a group of primary drivers (e.g., climate, topography, soil properties, vegetation, and anthropogenic activity) on the one hand, and drive a series of biochemical or geochemical reactions, which determine N_2O production and consumption, on the other hand. It is the complex interactions among the primary drivers, soil environmental factors, and the biogeochemical reactions that result in the observed, highly variable N_2O fluxes. For example, conversion from conventional tillage to no-till could simultaneously alter soil temperature, moisture, redox potential and soil DOC and available N content. These affected factors will simultaneously and collectively alter the direction and rates of decomposition, nitrification, denitrification, and substrate diffusion, which in turn collectively determine N_2O emission. Process-based modeling is the only solution to bring the complex system into a calculable framework. During the last decade, many process models (e.g., CASA, CENTURY, Roth-C, N-EXPERT, etc.) were developed focusing on soil C dynamics and N_2O emissions. The Denitrification-Decomposition (DNDC) model is one of the process-based modeling efforts. DNDC was constructed based on four basic concepts, i.e., biogeochemical abundance, field, coupling, and cycling. DNDC consists of six sub-models for soil climate, crop growth, decomposition, nitrification, denitrification, and fermentation. The six interacting sub-models include fundamental factors and reactions, which integrate C and N cycles into a computing system (Li et al., 1992, 1994; Li 2000). DNDC has been validated against numerous datasets observed worldwide (Figure 2). During the last several years, DNDC has been independently tested by researchers in many countries and applied for their national C sequestration and N_2O inventory studies. By tracking crop biomass production and decomposition rates, DNDC simulated long-term SOC dynamics. DNDC predicts N_2O emissions by tracking the reaction kinetics of nitrification and denitrification across climatic zones, soil types, and management regimes (Figure 2). With its prediction capacity of both SOC and N_2O, DNDC is ready to serve offset analyses between C sequestration and N_2O emissions for agro-ecosystems.

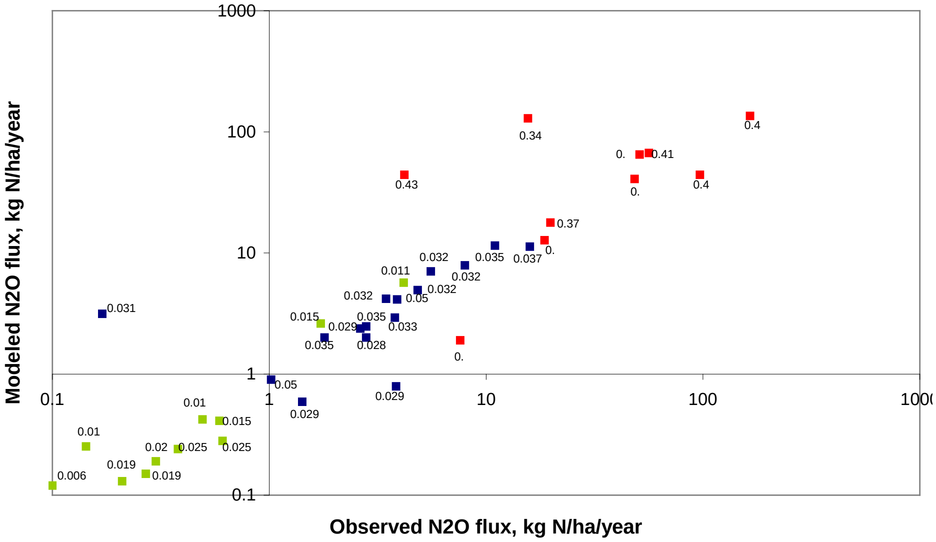

Figure 2. Comparison of observed with DNDC-modeled N_2O fluxes from agricultural sites in the U.S., NZ, Canada, the U.K., Germany, Costa Rica, and China. The red dots are the sites with SOC contents higher than 10%, the blue dots 2%-10%, and the green dots <= 2%. The field data from Mosier et al., 1996, Ryden and Lund 1980, Terry et al. 1981, Crill 2000, Zheng et al. 1999, Smith et al. 2002, Brown et al. 2002, and Flessa et al. 1996.

Several reports released recently discussed potentials of the alternative management practices in sequestering atmospheric C. Unfortunately, most of the research reports or proposals have not addressed non-CO_2 greenhouse gases, especially N_2O. Actually, N_2O is an important greenhouse gas due to its high radiative efficiency (298 times higher than CO_2) and relation with a series of farming practices (Li, 1995; Robertson et al., 2000; Li et al., 2002). The net offset between reductions in atmospheric CO_2 and increases in atmospheric N_2O can be significant, and in some cases can result in a net increase in atmospheric CO_2 equivalents (Robertson et al., 2000). Aulakh et al. (1984) and Robertson et al. (2000) observed emissions from cultivated soils with conventional tillage and no-till in the U.S., and found N_2O emissions were higher from the no-till cropland.

Since C sequestration and N_2O emission are both affected by many environmental factors but in different ways, shifting from one location to another will inherently alter the effects of any management alternatives on the net GWP. DNDC, with its fundamental biogeochemical processes and access to GIS data for regional assessments, can quantify the net GWP effects of alternative management practices across climatic zones, soil types, and management regimes.

2.0 Project Objectives:

A scoping study (Li et al. 2004) funded by California Energy Commission assessed using the DNDC (DeNitrification-DeCompostion) model to estimate recent SOC dynamics and N_2O emissions at the county scale for all of the counties in California and to make recommendations for more detailed field studies on carbon sequestration and N_2O emissions under a wide scope of alternative management scenarios and studies to calibrate and improve process models for California agricultural systems. The recommendations of this scoping study were the following:

- Establish a program to collect data on agricultural management practices, to improve the spatial representation of management practices and account for regional and cropping system differences. Critical data should also include information on residue and manure management.

- For future study, use the updated Natural Resources Conservation Service's Soil Survey Geographic (SSURGO) database. The improved spatial and thematic resolution of these data will result in improved model estimates of carbon dynamics and GHG emissions.
- Further validate the DNDC model, to better quantify the model's performance in simulating carbon dynamics, N_2O, and CH_4 over a range of California agroecosystems. This validation should consist of: (1) performing model validations using existing carbon dynamics, CH_4 and N_2O field data, and (2) developing a field measurement program to cover critical gaps in field data across a range of major crops and management systems..
- Evaluate alternative mitigation scenarios for: no-till, conservation tillage, and conventional tillage; optimized fertilizer application rates; shifts in irrigation and water management and the use of cover crops.

Since the Li et al. (2004) recommendations, there have been several field studies (ARB, CEC, Packard Foundation and CDFA N2O projects) to collect data for a range of California cropping systems and projects to extend DNDC biogeochemical process modeling to animal agricultural systems in California.

This proposal intends to build and leverage off these efforts to work with ARB to develop a process modeling system for improving the inventory and for assessing opportunities to mitigation GHG emissions. Thus, we propose the following objectives:

Objective 1: develop GIS databases for statewide GHG modeling,
Objective 2: compile agricultural management databases,
Objective 3: assess model uncertainties (both structural and scaling) through model validation,
Objective 4: perform comparison of DNDC and DAYCENT models at select sites,
Objective 5: compile GHG emission estimate for California agriculture, and
Objective 6: work with ARB inventory staff on use and updates to the modeling system.

3.0 Technical plan.

Background on DNDC Model

Process-based models have been developed to examine the complex interactions of agricultural management practices, soil C dynamics, and N_2O emissions. An agroecosystem biogeochemistry model—Denitrification-Decomposition (DNDC)— was originally developed for quantifying C sequestration and trace gas emissions for the U.S. agroecosystems (Li et al., 1992; Li et al., 1994; Li et al., 1996; Li, 2000). DNDC is a plot-scale model that consists of two components: (1) three sub-models for soil climate, plant growth and decomposition which predict the dynamics of soil temperature, moisture, pH, Eh and substrate concentration profiles based on primary drivers (e.g., daily weather, soil properties, and crop management scenario); and (2) three sub-models for nitrification, denitrification, and fermentation which track production, consumption and emission of N_2O, NO, N_2, ammonia (NH_3) and methane, based on soil environmental factors (Figure 3).

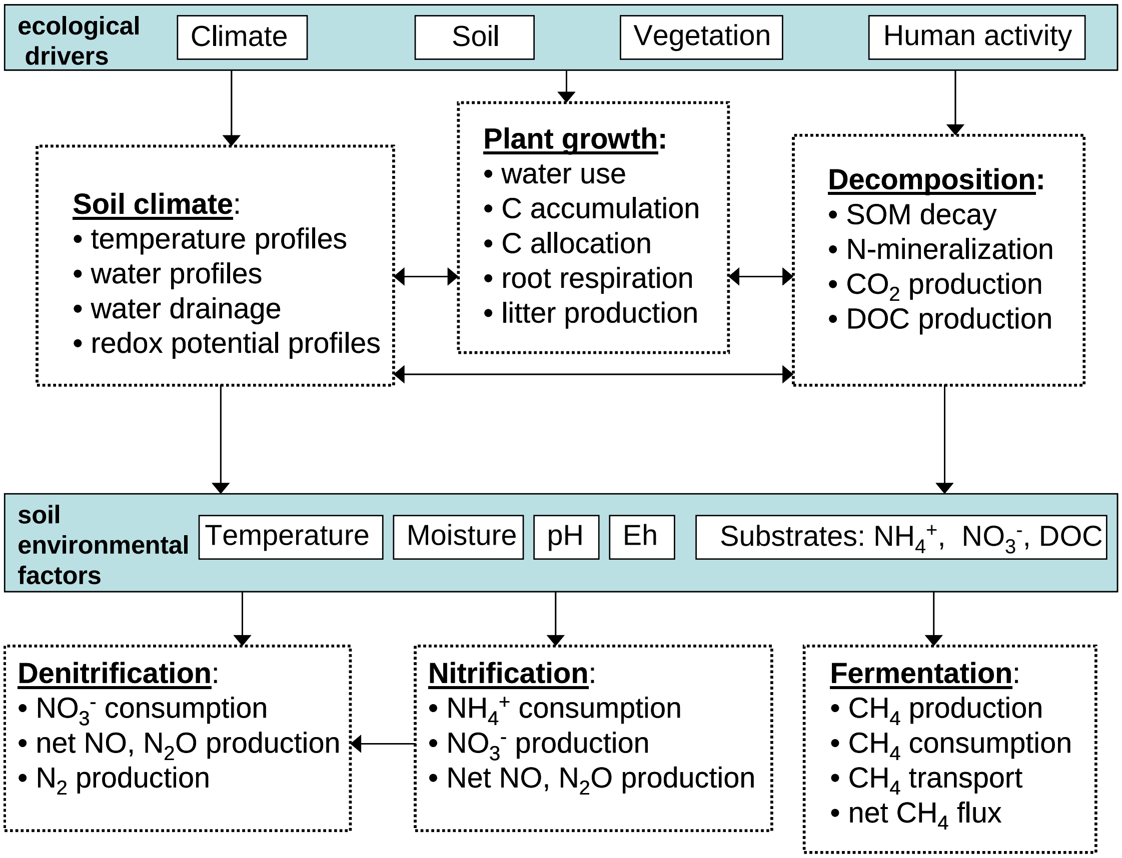

Figure 3. Structure of the DNDC Model.

DNDC simulates SOC dynamics by tracking SOC gains through crop litter incorporation and SOC losses through decomposition. About fifty major crops, including cover crops, in the U.S. have been parameterized in DNDC. The dominant cropping practices, such as crop rotation, tillage, fertilization, manure amendment, irrigation, flooding, weeding, grazing, and grass cutting, have also been parameterized in DNDC. Driven by climate, soil and management conditions, DNDC quantifies crop litter production by precisely tracking crop development, growth and yield at a daily time step. Crop root deposition and aboveground residue incorporation are the major SOC sources for the row crops while manure application amends SOC for organic farms or pastures. During the modeling processes, the N coupled with the C in the litter or manure incorporated in the soil is quantified and partitioned into the corresponding soil organic matter (SOM) pools. In DNDC, SOM consists of four sub-pools, namely litter, living microbes, humads and humus. Each of the sub-pools contains labile and resistant components. Each component possesses a specific decomposition rate subject to temperature, moisture and N availability. The living microbial pool plays a central role in regulating the bulk decomposition rate of SOM. The microbial activity is determined by the quantity and quality of SOM. Higher SOM usually supports higher population of the microbes. But only the litter with lower C/N ratio can sustain the microbial activity by providing adequate free N during the decomposition. DNDC also simulates N losses from the soil by precisely tracking nitrification, denitrification, ammonia volatilization, nitrate leaching, and N uptake by plant. N_2O production, consumption and emission are calculated with the nitrification and denitrification functions, which are subject to a series of soil physical and chemical conditions. For example, conversion of conventional tillage to no-tillage would alter not only the SOM profile but also the soil temperature, moisture and redox potential that will collectively affect both nitrification and denitrification and non-linearly change N_2O emissions. Equipped with the detailed C and N turnover processes embedded in the model, DNDC predicts impacts of agricultural management practices on SOC and N_2O fluxes simultaneously.

Field observations, such as crop biomass and yield, soil climate, SOC storage dynamics, soil ammonium and nitrate contents, and emissions of CO_2, N_2O and other gases, will be utilized to calibrate and validate DNDC. Decomposition, nitrification, denitrification and other processes related to soil C and N transformations will be simulated by DNDC, and the modeled dynamics of the processes will be compared with field results to interpreting the observations. Thus, the understanding gained from the field measurements regarding the interactions among climate/soil conditions, management practices, SOC dynamics and N_2O emissions will be synthesized in DNDC.

The new version of DNDC calibrated and validated against the field observations will be used to predict impacts of crop production on N_2O emissions at the field scale. Given one goal of this proposal is to validate DNDC using field data collected by other companion projects, it is important to validate the models at the precise site scale, where detailed soil and management parameters are available and at the field scale, which is the scale at which management decisions are made. Biogeochemical processes are highly variable in space and time and are non-linearly coupled with ecological drivers that are also varied over space and time (Bouwmann, 1995; Li, 2000). Therefore, for biogeochemical process models to be useful for understanding impacts of various management alternatives for agricultural mitigation of greenhouse gases, estimates of model uncertainty and sensitivities are needed. The scientific community is somewhat split on the current state of knowledge on estimating emissions of N_2O from agricultural soils. Many scientists now feel that the biogeochemical processes that control N_2O emissions are well known and availability of sufficient data on soils and management practices limits our ability to accurately estimate N_2O emissions at site and regional scales. Conversely, some scientists still believe that we do not have a sufficient understanding of these biogeochemical processes to estimate N_2O emissions. Clearly the efficacy of estimating site, watershed, county, and regional scale trace gas emissions is currently limited to a certain extent by availability of spatially explicit and accurate management, climate and soils data. Due to recent advances in gridding climate station data (Thornton et al., 1997; Thornton and Running, 1999), spatially explicit, daily climate data are being produced (e.g. see DAYMET model). Therefore, soil heterogeneity is becoming the major source of uncertainty for upscaling. For this project we will focus our uncertainty and sensitivity analyses on an assessment of how uncertainties in our estimates of soil factors (e.g. soil texture, SOC, pH) impact our ability to estimate nitrous oxide emissions.

DAYCENT Process Model

The DAYCENT model is another widely used process model for quantification of soil carbon dynamics and N_2O emissions from cropland soils. It is a daily time-step version of the (monthly time step) CENTURY model (Parton et al. 1987). Like DNDC, the model is composed of a series of sub-models that predict biochemical and energy transfer processes. The submodels in DAYCENT include: decomposition, plant production, water movement, and temperature dynamics, all running at daily time steps. The soil and decomposition (SOM) sub model and the nutrient sub-model collectively simulate the movement of C, N, P and S throughout various above and belowground pools. The plant production submodel simulates plant growth and thus the distribution of above and below ground nutrients. The water flow sub-model simulates the movement of water through the plant canopy, litter, and soil (Parton et al. 1998). The soil temperature sub model estimates daily minimum and maximum temperatures at specified depths based on daily minimum and maximum temperatures in combination with several other factors (e.g. soil texture) (Parton et al. 1998). Del Grosso et al. (2005) using DAYCENT at the regional level in the US found that nationwide adoption of no-till could potentially mitigate 20% of emissions from US agriculture.

Empirical models can developed based on numerical correlation between the primary drivers (e.g., climate, soil properties, vegetation and management) and the measured gas fluxes ignoring the processes. Daycent simulates N2O flux as a fraction of total soil N mineralization rate subject to soil moisture. Since there is no direct mechanical relationship between N2O production and soil moisture, the correlation can be set up based on the correlation coefficients empirically obtained from observations. The empirical approach works well for the soils where the coefficients were produced.

Why DNDC and California Applications?

We have selected the DNDC process model for this project because of its flexibility to model the wide range of cropping and animal production systems in California and its ability to be directly linked with geospatial databases of croplands and biophysical drivers of N2O emissions, namely soils, climate and atmospheric N deposition. DNDC is the only process model currently able to predict N2O and CH4 emissions from aerobic and anaerobic cropping systems, manure management (both aerobic and anaerobic) and direct emissions from livestock (e.g. enteric fermentation). The model is currently being used by a wide array of stakeholders, including NGOs (EDF and TNC), state agencies (ARB), federal agencies (USGS), agricultural groups (California Rice Commission, CA Sustainable Winegrowing Alliance, CA Almond Board) and universities (UC Davis and California State University Fresno) in the State for GHG studies. Our team consists of DNDC model developers (Drs. Changsheng Li and William Salas) and leading field researchers and modelers in California (Dr.s Johan Six and Will Horwath).

Tasks:

Task 1: Build GIS databases

This task will build GIS databases on crop land areas (derived from DWR) on soils (NRCS SSURGO), climate (CIMIS stations) and crops (DWR and NASS CDL). For each crop field, probability distribution functions (PDFs) for SOC, bulk density, pH, and texture will be calculated from the soil surveys. Daily precipitation, temperature, wind speed, and solar radiation will be compiled for each field using CIMIS with cokriging. Automated remote sensing algorithms will be used to map rice production areas including spatially explicit maps of rice hydroperiods for DNDC modeling.

Task 1.1 Building GIS Cropland Databases for Process Modeling:

The crop acreages will be derived from GIS databases developed by the California Department of Water Resources (DWR) analyses of aerial photos and field surveys. The photos and surveys were taken starting in the mid 1990s and have continued through to 2006. The DWR databases contained data for only 41 out of 58 counties in California. Based on the 1997 National Agricultural Statistics Service (NASS) statistics, the missing 17 counties contain less than 1.4% of total crop area in the state and thus were omitted from this analysis, because we do not have other sources of consistent data that include maps of the crop type. Some crop polygons in the DWR database are broadly classified as field crop (field-99) grain crops (grain-99) and pasture (pasture-99). These are areas where DWR did not provide specific crop information, just broad crop type. We will allocate these areas based on the proportions of the observed subclasses within each county. For example, if a county has 100 ha of alfalfa, 50 ha of non-legume hay, and 60 ha of pasture-99, then alfalfa and non-legume hay subclasses represent 66.67% and 33.33% proportions of observed subclasses. So, we would then allocate the 60 ha of pasture-99 as 40 ha of alfalfa and 20 ha of non-legume hay.

California has a wide variety of specialty crops (the DWR Truck crop class includes, for example, artichokes, lettuce, berries, and tomatoes), with large annual variability in cropping area. Farmers often change specialty crops from one year to the next. The DWR database was derived from aerial photos acquired over several years. Therefore, since our objective of this study is to build a general modeling system for the state inventory, we will assume that the total area of truck crops was evenly split into crops based on recent county ag commissioners reports.

We propose to use the DWR GIS databases for mapping location of annual, perennial, rice (with remote sensing, see task 1.4) and grasslands. However since DWR databases are not up to date and cover a decade between aerial imagery acquisitions, we will assign county level crop areas based on the annual county commissioner's reports. The DWR databases provide good spatial representation of general cropping systems but are not annual. For our process modeling we want good area estimates linked with spatial information on biophysical drivers (soils and daily climate). Our baseline assumption is that the location of specific perennial crops will not change, unless there is large discrepancy between the area in the county agricultural statistics and the DWR databases and there has been a significant time lag between the DWR mapping and the current reporting.

In California, most crops are grown in complex rotations. The DWR land-use GIS survey will be used to determine the spatial distribution of crops coupled with a probability approach to generate crop rotations through time. The DWR GIS product contains detailed maps of field locations and cultivated crops derived from analyses of aerial photos and field surveys. For example, the Solano and Placer Counties were surveyed in 1994; Yuba in 1995; Yolo in 1997; Colusa, Glenn, and Sutter in 1998; Butte in 1999; Fresno and Sacramento in 2000; and Kings in 2003. In addition, more than 1000 empirical 5-year sequences of crops were also gathered by DeGryze et al. (2010) from farmer surveys and pesticide use reports obtained by agricultural commissioners. We will use these data to develop crop rotation information. Theses data suggest that a farmer's decision on which crop to plant in the current year is dependent on which crops were grown in the previous years. The probabilistic model developed by DeGryze et al (2010) will be used to simulate realistic crop rotations. This probabilistic model was calibrated by calculating the following (conditional) probabilities:

$$\Pr(Cr_t = A) \quad \text{[Equation 1]}$$

$$\Pr\,(Cr_t = A|Cr_{t-1}) \quad \text{[Equation 2]}$$

$$\Pr\,(Cr_t = A|Cr_{t-1}, Cr_{t-2}) \quad \text{[Equation 3]}$$

where $\Pr(Cr_t = A)$ is the probability to have crop A in the current year (time t), $\Pr\,(Cr_t = A|Cr_{t-1})$ is the probability to have crop A in the current year contingent on previous-year's crop Cr_{t-1}; and $\Pr\,(Cr_t = A|Cr_{t-1}, Cr_{t-2})$ is the probability to have crop A in the current year contingent on previous-year's crop Cr_{t-1}, and the crop from two years before Cr_{t-2}. The data indicated that a farmer's decision to plant a crop was only dependent on the crops that were planted two years before, except for alfalfa-hay, which was grown in four- or five-year rotations. These conditional probabilities will be applied as follows: For each individual field in each in the DWR data, the crop grown in X (since DWR survey are collected in different year we designate the year as X), the first year of the simulations, was selected based on the DWR data. The crop grown in the following year, X+1, was selected based on the probabilities from Equation 2 and conditioned by the crop grown in X for that individual field. In all subsequent years until 2010, the crop planted was selected randomly based on the probabilities from Equation 3, and conditioned on the crops grown over the two years before.

Task 1.2 Building GIS Soil Databases for Process Modeling:

Biogeochemical process modeling requires information on soil conditions. Soil characteristics will be obtained from both the Natural Resources Conservation Service (NRCS) STATSGO (1:250,000) and SSURGO (1:18,000) databases. SSURGO provides detailed information that was designed for analyses at the landowner, farm, or county level. At the present time, SSURGO data is available for the bulk of California. For the areas that lack SSURGO availability, the regional-level STATSGO data will be utilized. Both soil datasets contain the same soil parameters and thus are easily merged. DNDC uses four soil properties: soil bulk density, clay fraction, pH, and organic carbon content. The minimum, maximum and area weighted values of these properties will be derived for each DWR cropland polygon based on SSURGO and STATSGO databases.

For the purpose of incorporating soil parameters into biogeochemical modeling and remote sensing applications, hawse have developed an open-source Python data extraction algorithm specific for the SSURGO database. By design, SSURGO soil parameters come arranged by depth according to horizon, component within horizon, and by spatial mapunit, and as a result, data are multi-dimensional in terms of depth and space for one polygon location. Therefore, our algorithm reformats this information through a series of operations (including data extraction and weighted averaging) such that soil parameters are rearranged and uniquely linked by depth and space. The algorithm works with the main tabular files of the database; the horizon, component, and mapunit files. Example soil parameters include, but are not limited to organic matter, PH, bulk density, and soil content (clay, sand, and silt).

Task 1.3 Build Climate Database System:

Climate inputs to DNDC include daily values of minimum and maximum air temperature, precipitation, and solar radiation. *CIMIS Station Data:* We have developed data extraction scripts to automatically request and retrieve hourly CIMIS weather station data both for historical records as well as real-time data using daily scheduled crontabs. CIMIS provides data access to their database via a free access ftp site or a membership access page requiring registration and login. Although the ftp site allows for free non-registered access, scripting of data retrieval from this site is greatly hampered due to inconsistent data formats, complex data organization, and limited available data ranges (i.e., ftp site provides access to partial data covering only last few years). Since the membership login provides access to the full dataset, we developed a set of tools that allow complete, automated data retrieval from CIMIS. Included is a universal code for manual or automatic scheduled data downloads and daily updates of CIMIS hourly and daily data for one or multiple stations. The extraction program stores the downloaded data in a local file depository in DNDC input format. In addition, supporting code is provided to locate the nearest CIMIS stations given LON/LAT coordinates. The code gives distance and azimuth to those stations so that a user can choose which station is most appropriate. The code has been tested to run successfully on both Linux/Unix and MS Windows family of operating systems.

Task 1.4 Build Automated Rice Mapping System:

Rice production systems are an important source of methane in California. After the rice traw burning phase down act of 1991 most rice farmers incorporate the rice straw residue following harvest and then flood the field again in the winter to enhance straw decomposition. This anaerobic decomposition of rice straw leads to additional winter fluxes of methane (Fitzgerald et al. 2000). Based on support from EDF and California Rice Commission through an NRCS Conservation Innovation Grant a rice mapping and GHG emission modeling system based on DNDC has been developed. This task will demonstrate and deliver a system for automated rice mapping, including mapping the use of winter flooding for rice straw decomposition and migratory waterfowl habitat. We will identify flooded rice paddies using a multistep process based on MODIS spectral data (See Torbick et al 2010). An operational image processing system has been developed and applied to high frequency MODIS indices. The filter used a relationship between the Land Surface Water Index (LSWI) (eq.4) and the Enhanced Vegetation Index (EVI) (eq. 5).

- $LSWI = \frac{\rho nir - \rho swir}{\rho nir + \rho swir}$ (eq.4)
- $EVI = 2.5\ X \frac{\rho_{nir} - \rho_{red}}{\rho_{nir} + 6\ X\ \rho_{red} - 7.5\ \rho_{blue} + 1}$ (eq. 5)
- MODIS Flood = LSWI + 0.05 > EVI (eq. 6)

EVI builds on previous indices that measure vegetative surface conditions by incorporating information from the blue (MODIS blue band = 459-479nm) band's sensitivity to atmosphere and coefficients adjusting for soil and background effects. LSWI utilizes shortwave infrared's (SWIR) sensitivity to moisture and has been used to assess ecological conditions and flood dynamics previously. The algorithm focuses on the period from flooding/transplanting through rapid plant growth in the early part of the growing season to the point where a full canopy exists. A temporary inversion of the vegetation indices, where LSWI either approaches or is higher than EVI values, signals flooding in paddy rice fields. To slightly relax the simple threshold assumption an adjustment factor is included. In this study flood characterization was determined using the relationship between LSWI and EVI (eq. 6). This algorithm has been successfully implemented in China and South and Southeast Asia to map rice paddies.

The outcome of this task will be maps of rice extent from 2007 through 2010 and maps of winter flooding for 2007/08, 2008/09 and 2009/10 winters. These data will augment the DWR cropping databases and include spatial maps of planting/harvest dates of rice and winter flooding hydroperiod that will be used to drive DNDC simulations of GHG emissions from rice.

Task 2: Collect crop growth, yield and management data for DNDC

We will collect and compile regional-specific crop growth/yield (calibrate growth model) and management data (tillage, irrigation, fertilizer, crop residue management, cover crops, etc). Data sources include UCCE Cost/Return Studies, UC Extension, and commodity groups. GIS data will be used to characterize growing regions by soil, climate and cropping systems (e.g. truck crops, grains, etc). Application of remote sensing for mapping and monitoring rice area and water management will be demonstrated.

Task 2.1 Collect region specific crop growth data:

Crop growth directly affects soil C and N dynamics as well as moisture regime, which directly control GHG emissions from the soils. DNDC models crop growth/yield based on a group of parameters such as maximum yield, biomass partitioning, C/N ratio, water requirement, accumulative temperature for maturity, N fixation etc. Collecting regional specific crop data will assist the model simulation of soil C sequestration and CH_4 and N_2O emissions.

We are leveraging this project off several companion project collecting N_2O field data where crop growth data is being collected. See Task 3 for a description of the crops being studies. In addition to these field data, we will compile existing data on crop growth and yields from the literature (e.g. Lobel et al.) and county scale crop yield reports. These data will be used to develop crop models for DNDC and to calibrate individual crop parameters (see Task 4).

Task 2.2 Collect regional and crop specific management data:

To run DNDC we will need to collect general information on crop cultural practices. Information on typical plant and harvest dates, tillage, fertilizer use, crop residue management, crop rotations and irrigation practices will be collected by crop and growing region. We will use extensive data collected by UC Extension (e.g. Cost and Return studies) and talk with a range of commodity groups to collect much of this information on a region and crop basis. UCCE has developed reports for the vast majority of crops in the state and have disaggregated the typical management practices into nine major growing regions. These reports provide important information on typical tillage, irrigation, fertilizer use, and timing of planting and harvest. These data will form the basis of our agricultural management databases. Additional expert opinion will be sought for crops and areas where we do not have sufficient information.

Task 3: Compile existing field data on GHG emissions.

This will entail collecting data from ARB, Waste Board and CSU ARI funded projects that are collecting N2O emission data from croplands receiving chemical fertilizer and dairy effluent.
This project is part of a larger effort by three research groups (Horwath at UCD, Six at UCD, D. Goorahoo CSU Fresno) measuring N_2O emissions in 10 different cropping systems located in the Sacramento Valley, San Joaquin Valley and Central Coast region. The state agencies involved in funding these efforts include Air Resources Board, California Energy Commission, and California Department of Food and Agriculture. In addition, the David and Lucile Packard Foundation is providing support. The combined efforts of these separate projects will provide scientifically sound results to develop best management practices (See details in Section 10 Related Research and table 1 below). The N_2O emission data collected in these projects will serve as a data set to validate modeling efforts and produce the products proposed in this project.

Table 1 Cropping systems for N2O measurements and modeling. Table provides acreage, fertilizer rates, region for measurements (SV – Sacramento Valley, SJV – San Joaquin Valley, Coastal California), and project (FREP – Dr. Goorahoo PI proposal, CEC – Dr. Six PI, ARB – Dr. Horwath PI). These projects are using similar set of field methods with the goal of covering major cropping systems and regions in a systematic and consistent fashion. In addition, previous work by Co-I Six and others have collected data on tomato, corn, wheat, sunflower, safflower, alfalfa, mellon and cotton. These data will also be used in testing and model crop calibration.

Crop systems selected for N2O monitoring

	statewide acreage	**Fertilizer range kg N/ac**	**Region**	**Project**
corn	520,000	0-140	SJV, SV	FREP, ARB
wheat	520,000	0-90	SV	CEC
cotton	560,000	30-120	SJV	FREP
tomatoes	280,000	50-120	SV	CEC, ARB
rice	526,000	0-200	SV	ARB
alfalfa	1,050,000	0 or 25	SV	CEC
Lettuce	210,000	50-150	Coastal	ARB
grapes	790,000	0-50	SJV, SV	CEC
almonds	585,000	20-160	SJV, SV	CEC

Task 4*:* Calibrate and validate the DNDC crop growth model.

Since accurate crop growth modeling is critical for process modeling, we will calibrate/test crop growth (physiology/phenology) submodels in DNDC based on data collected in task 3. The modeled spatial and temporal variations in crop yields will be compared with observed crop yield data across the entire geographic domain as well as time span (30-50 years).

Proper parameterization of soil physical conditions (which drive soil moisture dynamics) and crop simulation plays a crucial role in modeling C and N biogeochemistry and N_2O emissions. Through transpiration and N uptake as well as depositing litter into soil, plant growth regulates soil water, C and N regimes, which in turn determine a series of biogeochemical reactions impacting N_2O emissions. We will calibrate the DNDC crop model for cropping systems to be included in the project. We will calibrate the following crop parameters:

- ***Maximum biomass (kg C/ha)***: The maximum biomass productions for grain, leaves+stems (non-harvest above ground biomass), and roots under optimum growing conditions (namely, maximum biomass assuming no N, water or growing degree day limitations). The unit is kg C/ha (1 kg dry matter contains 0.4 kg C). If local data are not available, then literature values and county statistics will be used.
- ***Biomass fraction***: The grain, leaves+stem, and root fractions of total biomass at maturity.
- ***Biomass C/N ratio***: Ratio of C/N for grain, leaves+stems, and roots at maturity.
- ***Total N demand (kg N/ha)***: Amount of the total N demanded by the crop to reach the maximum production.
- ***Thermal degree days (°C)***:Cumulative air temperature from seeding till maturity of the crop.

- ***Water demand (g water/g dry matter***): Amount of water needed for the crop to produce a unit of dry matter of biomass.
- ***N fixation index***: The default number is 1 for non-legume crops. For legume crops, the N fixation index is equal to the ratio (total N content in the plant)/(plant N taken from soil).

DNDC currently has default values for these parameters but we seek to refine these paramters for California crops, especially the wide variety of specialty crops.

Task 5: Compare DNDC and Daycent Process Models

DNDC and DAYCENT are two widely used models for quantifying N_2O emissions from crop land soils. Their approach for estimating N_2O emissions differs. DAYCENT employs the "leaky pipe theoretical approach (Davidson 1991) for quantifying emissions and utilizes a more empirical approach to calibrate the model to observed emissions. This task will validate DNDC and Daycent using a subset of data from Task 3 and from other projects collecting N2O emissions from land application of Manure (e.g. ARB- and Waste Board- funded project with Dr. Will Horwath, Dr. Goorahoo ARI funded project).

The estimation of agricultural GHG emissions is problematic mainly due to scaling issues from point to regional scales (Davidson 2001). This limitation has resulted on relying on estimates of GHG emissions from process-based models. The two most commonly used process based models for estimating greenhouse gas emissions are DNDC (Li et al. 1992) and DAYCENT (Parton et al. 1998).

The DNDC model estimates GHG emissions through a combination of three sub-models: a thermal-hydraulic model, a decomposition model, and a denitrification model (Li et al. 1992). The thermal-hydraulic submodel estimates heat flux and moisture in the surface soil profile, the decomposition submodel predicts decomposition and other reactions such as nitrification, and denitrification is represented on the basis of water filled pore space (Li et al. 1992).

The DNDC model addresses spatial heterogeneity as the key factor controlling GHG emissions. Li et al. (2004) conclude that even with a known set of management practices are implemented over a wide geographic area, spatial variation in soil properties are responsible for the largest source of uncertainty in the model prediction. The DNDC model addresses this limitation by using the most sensitive factor approach to constrain the uncertainty running twice for each defined spatial unit the maximum and minimum values of the most sensitive soil factors to produce an emissions range given the variation in soil properties (Li et al. 2004). Li et al. (1996) used DNDC to compile a nationwide US agricultural emissions inventory using the US states as spatial unit and found: 1) at the national scale, tillage and fertilizer inputs were the most significant factors affecting N_2O emissions, 2) spatial variability in N_2O emissions were driven largely by soil C and climate, and 3) three crops (corn, winter wheat, and soybean) accounted for 54-60% of total emissions.

The DAYCENT model is a daily time-step version of the (monthly time step) CENTURY model (Parton et al. 1987). Like DNDC, the model is composed of a series of sub-models that predict biochemical and energy transfer processes. The submodels in DAYCENT include: decomposition, plant production, water movement, and temperature dynamics, all running at daily time steps. The soil and decomposition (SOM) sub model and the nutrient sub-model collectively simulate the movement of C, N, P and S throughout various above and belowground pools. The plant production submodel simulates plant growth and thus the distribution of above and below ground nutrients. The water flow sub-model simulates the movement of water through the plant canopy, litter, and soil (Parton et al. 1998). The soil temperature sub model estimates daily minimum and maximum temperatures at specified depths based on daily minimum and maximum temperatures in combination with several other factors (e.g. soil texture) (Parton et al. 1998). Del Grosso et al. (2005) using DAYCENT at the regional level in the US found that nationwide adoption of no-till could potentially mitigate 20% of emissions from US agriculture.

Validation of emissions estimates from process bases models such as DNDC and DAYCENT through direct measurement is extremely challenging because of the high soil spatial variability and event-based nature of trace gas emissions (e.g. N_2O) and the prohibitive cost of sampling at sufficiently expansive scales to match the modeling.

While DNDC has been validated across a wide range of agroecosystems, including California, continued testing is being conducted with a focus on the cropping systems in the Central Valley of California. The model tests cover a relatively complete spectrum of management alternatives, which include tillage intensity (moldboard plow, chisel-disk, sweep plow, and no-tillage), N rate and source (synthetic N fertilizer, manure, legumes), crop types (sweet corn, silage corn, rice, etc.), and rotation systems (crops, fallow, cover crops). The model test will cover a range of soil types (clay content) and climate characteristics which are bracketed by the available field sites. The tests focus on how DNDC can capture the effects of the alternative management practices on both soil C sequestration and trace gas emissions in comparison with the field observations. Discrepancies between observations and modeled results will be analyzed from the mechanical view based on theoretical analysis and experimental results. Based on the analysis, questions or suggestions will be raised to modify the existing processes embedded in DNDC. The experience generated from this model validation/testing procedure will benefit not only model development but also future field experiment design.

This model validation comparison of DNDC and Daycent will provide insight into relative model uncertainties. Both models are extensively used for estimating GHGs emissions, and a quantitative evaluation of the differences will provide a common base for comparing the inventories and uncertainties.

Products:

- Validated site-level model estimates of carbon sequestration and trace gas emissions (field data on carbon sequestration and trace gas emissions are available through existing collaborations, thus funding for data collection is not requested for this project).
- Both model and field-based sensitivities of C sequestration and N_2O emissions to the commonly practiced farming management alternatives at site scale for the California pasture, grain, rice, and field crop regions.

***Task 6*: Run validated DNDC models to compile Statewide GHG emission estimate**

Once we have built the GIS databases (Task 1), developed the DNDC crop models for California crops (Task 4), built regional databases on crop and dairy management practices (Task 2) and validated DNDC

(Task 5), we will run the modeling system to estimate agricultural GHG emissions at the state level. The target year for this simulation will be set based on discussions with ARB.

There are over 400 commodities in California. We will discuss with ARB which crops to include and which will not be a focus of this initial project. Our initial thought is to include those crops that had over 60,000 acres harvested in 2008. Based on the California Agricultural Statistics for 2008 this would include the following:

Vegetable crops: broccoli, carrots, leaf lettuce, romaine lettuce, head lettuce and processing tomatoes. For these 6 vegetable crops, just under 700,000 acres were harvested in 2008 representing approximately 70% of the total harvested area of vegetables.

Fruit and Nut Crops: Almonds, Avocados, Grapes (raison, table and wine), Oranges, Pistachios and Walnuts. Approximately 1,500,000 acres were harvested in 2008, representing over 75% of the total acreage harvested in 2008.

Field and Seed Crops: Barley, Cotton, Grain Corn, Hay/Alfalfa, Rice and Wheat. In 2008, approximately 3,170,000 acres of these crops were harvest, representing over 95% of the total for all field and seed crops grown in California in 2008.

We propose to work with ARB to:

- refine this list of crops for the DNDC modeling
- select an appropriate quantification methodology to include those crops and crop areas not included in this list.

***Task 7*: Quantify sensitivities and uncertainties in inventory estimate**

We will quantify sensitivities and uncertainties in inventory estimate due to both model precision (structural uncertainty) and scaling up using GIS data. Uncertainties will be quantified using a series of statistical approaches. DNDC model structural uncertainty will be derived from field validation analyses (see discussion in previous work and Co-funding sections). Scaling uncertainty will be derived using Monte Carlo analyses and the PDFs from Task 1. Model sensitivity will identify critical input data needed to minimize uncertainties and guide future data collection efforts.

Biogeochemical processes are highly variable in space and time and are non-linearly coupled with ecological drivers that are also varied over space and time (Bouwmann 1995, Li 2000). Therefore, for decision support systems to be useful for understanding impacts of various management alternatives for agricultural mitigation of greenhouse gases, estimates of model uncertainty and sensitivities are needed. Clearly, the efficacy of estimating county to regional scale carbon sequestration and trace gas emissions is currently limited to a certain extent by availability of spatially explicit and accurate management, climate, and soils data. Through our remote sensing algorithm development, we plan to address the lack of spatially explicit management data. In addition, due to recent advances in gridding climate station data (Thornton et al. 1997, Thornton and Running 1999), spatially explicit, daily climate data are being produced (e.g. see DAYMET model). Therefore, for this project we will focus our uncertainty and sensitivity analyses on the assessment of how uncertainties in our estimates of soil factors (e.g. soil texture, SOC, pH) and remote sensing derived management affect our ability to estimate carbon sequestration and trace gas emissions. We propose to develop tools for identifying specific sensitivities of management alternatives and to quantify the uncertainties generated from the process of scaling up across the range of expected biophysical and environmental conditions. Our uncertainty task will include a three step assessment of uncertainty using variable ranges with Latin Hypercube Sampling (LHS).

To meet this objective, we will implement the following 3-step process:

- ***Step 1*:** Select the set of major biophysical conditions, crops, and management practices found in the Central Valley region. Dominant management practices will come from survey data from CTIC and our remote sensing analyses. Our selection of the range of biophysical conditions will be stratified by crop type. Using our GIS data layers obtained as part of objective 3, we will sample the distribution of expected variables to characterize of range of expected soil conditions based on STATSGO and SSURGO databases, which provide upper and lower estimates of SOC, bulk density, clay fraction, and pH (parameters required for DNDC).
- ***Step 2*:** Individual variables will be changed across their range of expected values or conditions while all other variables are held constant to indicate single parameter sensitivities. DNDC will be run to examine the magnitude and direction of changes in trace gas emissions and C sequestration. Based on this sensitivity analysis, we will select those variables that cause the majority of variance in modeled trace gas emissions and C sequestration.
- ***Step 3*:** To examine the interaction between variables we will use LHS (McKay et al. 1979). LHS is similar in concept to Monte Carlo sensitivity analysis, but does not require as many sample runs. Since Monte Carlo analysis is based on purely random sampling, it requires a large number of samples to provide statistically valid results. LHS is based on a stratified sampling approach that can create statistically significant results with significantly fewer model runs. The LHS technique ensures that the entire range of each variable is sampled. A statistical summary of the model results will produce indices of sensitivity and uncertainty that relate the effects of heterogeneity of input variables to model predictions.

We propose to work with ARB to:

- Discuss sources of uncertainty in scaling due to inputs and model structural uncertainties.
- Discuss long term approach for updating model structural uncertainty Identifying largest sources of uncertainty in input/activity data – guide future data collection efforts

Products:

- Tool for deriving uncertainty estimates from DNDC modeled estimates of trace gas emissions and carbon sequestration.
- Maps of uncertainty in modeled carbon sequestration and N_2O emissions due to range in soil conditions across conventional, conservation, and no-till systems.

Task 8: Technology transfer to ARB staff in using modeling system

This task will focus on technology transfer to ARB of project algorithms, databases, model validation, software and guidelines for updating the modeling system for future inventories. We foresee the modeling system will a living system that will improve over time as new research is completed, improved spatial data are available and future improvements in the model derived from additional validation. We propose to meet with ARB research staff twice a year during the project to review our methods and provide any technical train necessary on the use of the modeling system and databases. A draft final report will be submitted to ARB for review six months prior to the end of the project.

4.0 Data Management Plan:

The project will follow GIS metadata standards develop by the OGC Technical Committee. We will also work with ARB to follow any internal data standards. For the modeling component, we will use well accepted statistical measures for estimating and quantifying model uncertainties.

The project will record original analytical data in worksheets and in Excel spreadsheets. All paperwork, , analytical data and the final report will be scanned as PDF files. All files will be backed up on an additional hard drive daily, and to a CD periodically. Backup CDs will be retained for 10 years. Additionally, an incremental offsite backup of all data will be performed weekly. Offsite backups will be retained for three months. Paper records will be retained three years.

5.0 Facilities

The ***Complex Systems Research Cente***r (CSRC) Science Computing Facility (SCF) at University of New Hampshire has a wide range of servers, printing and plotting devices, and archiving systems that are integrated using several internal networks. Overall SCF support is provided by UNH's Research Computing Center. Our existing computer infrastructure will meet our anticipated computational needs. The main CSRC servers consist primarily of high-end, multi-processor computing systems manufactured by Dell, SGI, and SUN Microsystems. The Dell systems run Linux and are used for CPU intensive jobs, parallel modeling, and storage. They include an 18 CPU Beowulf cluster with 1.35 Terabytes (TB) of RAID5 disk space, nine dual-CPU servers with a combined capacity in excess of 21 TB of RAID5 storage, and several other application and web servers. Backups and archives are done using the Networker product from Legato. Most of the main servers share a gigabit (Gb) switch with the archive/backup system for high-speed communications. Nearline storage is done on two tape library units, a 30 slot unit with 1.5 TB, and 120 slot unit with 12.0 TB of native storage.

Applied GeoSolutions, LLC has two offices with approximately 2100 square feet. AGS computing infrastructure includes multiple Linux workstations, PC workstations, and 4 windows-based PCs. A high-speed internal network that provides access to printers and on-line and near-time file systems links the AGS computers. AGS software includes GIS, database and image processing licensed software, including ArcGIS, ENVI, IDL, MySQL, ACCESS, etc, as well as open source software for Web-GIS production (Postgres/POST GIS, University of Minnesota Mapserver, etc).

UC Davis Facilities:

Horwath's Soil Biochemistry laboratory conducts research on soil organic matter and plant ecology in terrestrial systems. The lab is out fitted with computers and standard lab equipment such as centrifuges, balances, computers, water baths etc.

Analytical equipment available for this project includes the following :
- GC equipped with FID, ECD and TCD detectors for CO_2 N_2O and CH_4 determination
- Soil inorganic, extractable N (NH_4^+ and NO_3^-) analyzer (Lachat Autoanalyzer)

- low temperature freezers, refrigerators, water baths, vacuum pumps, grinders, ball mills, drying ovens, high speed centrifuges, laminar flow hood, low speed centrifuges, incubators, and total C and N analyzers (COSTEC).
- LiCor 6400 Field CO_2 analyzer (with soil CO_2 flux chamber) (LiCor, Inc. Lincoln, NE)
- LiCor 5000 leaf area instrument.

Instrumentation available in the Six laboratory include Shimadzu gas chromatographs for CO_2, N_2O, and CH_4 analyses, a shimadzu TOC/TN analyzer, a spectrophotometer for mineral N analyses, reaction vessels for high pressure digestion for BPCA isolation, rotary evaporator, automatic flux chambers, various centrifuges and Sartorius analytical balances. Other instrumentation in use or with access to include: an Agilent 6890 gas chromatography coupled to a 5973 mass selective detector containing both electron impact and chemical ionization sources, total C and N analyzers (Leco and Carla Erba), -80°C freezers, refrigerators, water baths, vacuum pumps, grinders, ball mills, soil and plant dryers, and chemostats. In the new Plant and Environmental Sciences building, a special laboratory is designated for natural abundance isotope research whereas another laboratory is designated for enriched isotope work. With funding from the University and NSF, a new Stable Isotope Facility was established in the new Plant and Environmental Sciences. The facility encompasses 12 Stable Isotope Ratio Mass Spectrometer (SIRMS) (Europa 20-20) and a variety of equipment for preparation of samples to be analyzed for enriched and natural abundance ^{13}C, ^{15}N and ^{18}O. Two SIRMS are designated to analyze solid ^{15}N-enriched samples. Four SIRMS (Europa 20-20; HYDRA) are dedicated for solid ^{15}N, ^{13}C, and ^{18}O natural abundance samples. One Europa 20-20 is also equipped with a gas analyzer interfaced with the Europa 20-20 for isotopic analysis of CO_2 and N gases. It has also the capability to determine H/D ratios. A IO-analyzer is interfaced with an SIRMS to measure dissolved ^{13}C. Another SIRMS is equipped with a 10 port inlet manifold and a dual inlet for precise isotopic measurements. A GC is also interfaced with this SIRMS for the isotopic analysis of volatile C and N compounds. Samples can be introduced into the mass spectrometer for isotopic analysis following combustion or pyrolysis.

6.0 References

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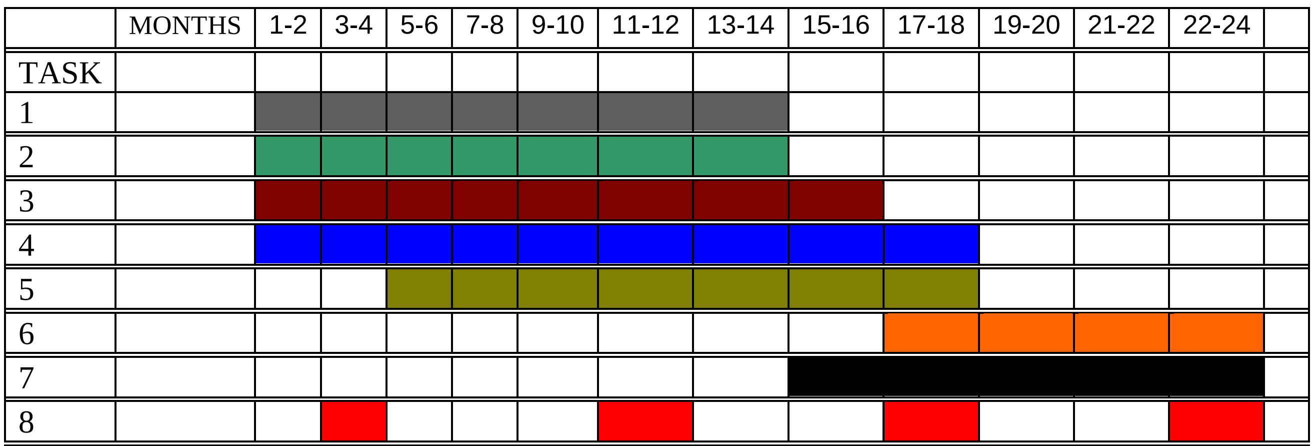
7.0 Work plan

	Month:	1-2	3-4	5-6	7-8	9-10	11-12	13-14	15-16	17-18	19-20	21-22	22-24			
Personnel	Task No.															Total hrs by task
C. Li	4	40	32	28	24	16	16	8	8							172
Principal	5			40	40	40	40	9								169
Investigator	6									35	35	35	35			140
	7								32	32	26	25	25			140
	8		16				16			16			24			72
Subtotal		40	48	68	64	56	72	17	40	83	61	60	84			693
UNH Res. Tech	1	160	160	140	58											518
	2	80	80	60	39											259
	3	16	16	40	80	60	47									259
Subtotal		256	256	240	177	60	47									1036
W. Salas	1	8	8	8	4											28
Consultant	2	16	8	8	8	8	8									56
	3		8	4	4	4	4	4								28
	4		4	4	4	4	4	4	4							28
	8		8				8			56	12		56			140
Subtotal		24	36	24	20	16	24	8	4	56	12	0	56			280
UC Davis	2	80	80	80	80	60	60	80								520
Post-docs	5				60	60	60	120	120	96						516
Subtotal		80	80	80	140	120	120	200	120	96	0	0	0			1036
TOTAL																3045

8.0 Project schedule

PROJECT SCHEDULE

Task 1: Build GIS Databases
Task 2: Collect crop yield and management data
Task 3: Compile and collect field N2O data
Task 4: Validate DNDC crop growth models
Task 5: Validate DNDC and Daycent
Task 6: Run model for statewide emissions estimation
Task 7: Quantify uncertainties
Task 8: Technology Transfer with ARB



m p m p m,d m F

p = Quarterly Progress report
d = Deliver draft final report
f = Deliver final report
m = Meeting with ARB staff

9.0 Project management plan.

Changsheng Li (PI) will coordinate the project and lead the modeling work. He has been the lead developer of DNDC for nearly 20 years, and over that time has conducted model evaluations and regional model applications with scientists from around the world. *Johan Six and Will Horwath* (Co-Is) will lead the collection of agricultural management data, crop yield data for model calibration and assist in the Daycent and DNDC model comparisons. *William Salas* (Consultant) will lead the rice mapping and training with ARB and will assist the Dr. Li and the UNH research scientist in GIS data collection, model validation and regional DNDC analyses. Dr. Salas has worked with Li on DNDC applications for the past 15 years, and has worked on SAR and optical remote sensing for almost 20 years.

CVs:

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PROFESSIONAL PREPARATION

University of Science and Technology of China, Beijing; Geochemistry; B.S.; 1964
Chinese Academy of Sciences, Beijing; Environmental Chemistry; M.S.; 1981
University of Wisconsin and Chinese Academy of Sciences; Biogeochemistry; Ph.D.; 1988

PROFESSIONAL EXPERIENCE

1. **Research Professor** (September 1992 - Present), Complex Systems Research Center, Institute for the Study of Earth, Oceans, and Space, University of New Hampshire. Develop biogeochemical models for terrestrial ecosystems. Study on impacts of climate change and alternative management on sustainability of agricultural, grassland and forest ecosystems by integrating biogeochemical models, GIS databases and remote sensing analysis. Principal Investigator (PI or Leading Scientist) of projects

- "Developing Biogeochemical Model for Predicting N2O emissions from the US Agricultural Land" sponsored by EPA in 1989-1991;

- "Development of Biogeochemical Model of Carbon and Nitrogen Cycles in Agro-Ecosystems" sponsored by NSF in 1992-1994;

- "Quantifying Atmospheric Impacts of Rice Agriculture in China" sponsored by NASA in 1995-1997;

- "Assessing the Influence of Asian Rice Paddies on the Growth Rate of Atmospheric Methane 1980-2020" sponsored by NASA in 1998-2000;

- "Development of a Soil Carbon Model (Forest-DNDC) for Wetland and Upland Forests" sponsored by USDA Forest Service in 2000-2008;

- "Developing a Desktop DNDC Tool for Evaluating Best Management Practices for Reducing Nutrient Loading to Elkhorn Slough NERR" sponsored by NOAA in 2002-2004;

- "Disseminating a GIS Based Nutrient Management Training Tool for Coastal Managers" sponsored by NOAA in 2004-2006;

- "Quantifying CO2 Fluxes from Boreal Forests in Northern Eurasia (Russia): An Integrated Analysis of Flux Tower Data, Remote Sensing Data and Biogeochemical Modeling" sponsored by NASA in 2005-2007;

- “Predicting Impacts of Alternative Farming Management Practices on Crop Yield, Soil Carbon Sequestration and Trace Gas Emissions from Chinese Rice Agriculture” sponsored by EPA in 2005-2006;

- “Developing Manure-DNDC: Quantifying Ammonia and Methane Emissions from California Dairies” sponsored by USDA in 2006-2008;

- “Nitrogen Management for Reducing N2O Emission and Nitrate Leaching in No-Till Systems in Upper Mississippi Watershed: Measurement and Modeling” sponsored by USDA in 2006-2008.

2. **Senior Scientist** (August 1989 - October 1992), The Bruce Company, Washington, D.C., consulting U.S. Environmental Protection Agency with Global Climate Change programs. Studied on greenhouse gas emissions from agroecosystems.

3. **Senior Administrator** (April 1988 - August 1989), National Environmental Protection Agency of China, Beijing. Managed pollution-related environmental projects in China.

4. **Deputy Director** (October 1985 - April 1988), Chinese Academy of Sciences, Research Center for Eco-Environmental Sciences, Beijing. Managed interdisciplinary research projects of carbon, nitrogen, sulfur and phosphorus biogeochemical cycles in China.

5. **Assistant Research Professor** (September 1981 - April 1983), Chinese Academy of Sciences, Institute of Environmental Chemistry, Laboratory of Regional Environment Studies, Beijing. Studied on river pollution in China.

6. **Chief of Laboratory** (January 1968 - September 1978), Chinese Academy of Sciences, Institute of Geochemistry, Laboratory of Environmental Geology, Guiyang, China. Studied on endemic diseases related to biogeochemical cycling of trace elements in the rural areas in China.

SYNERGISTIC ACTIVITIES

1**. Conducted research on biogeochemical theories and methodologies** with a focus on human-involved ecosystems since 1968. These studies have enhanced scientific understanding of impacts of chemical elements on human health, urban pollution control, forest conservation, greenhouse gas emissions, and agricultural sustainability. The studies on the endemic cardiovascular disease (Keshan Disease, caused by selenium deficiency in soils), and on pollution control in Beijing were each awarded the National First Class Prize in China in 1977. The latest efforts focused on impacts of anthropogenic activities on land resources and climate change through modeling impacts of agricultural management on crop yield, soil fertility, nitrogen leaching, and greenhouse gas emissions.

2. **Distributed basic knowledge of biogeochemistry** to the public through training undergraduate and graduate students, writing textbooks, presenting lectures, and publishing papers.

3. **Served government agencies** - the National Environmental Protection Agency of China (1988-89) and the US EPA (1989-92)- working on scientific aspects of policies related to natural resource conservation, pollution control, and global climate change.

4. **Established strong, collaborative, academic ties** between the environmental research communities of the U.S., China, Germany, the U.K., Belgium, Finland, Russia, Canada, Australia, New Zealand,

India, Japan and other countries through various international or US research projects. Participated in EU nitrogen biogeochemistry projects NOFRETETE and NitroEurope; training a wide range of international researchers, graduate students and policy makers for DNDC applications

PUBLICATIONS (selected out of 96 total)

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Li C, Zhuang YH, Cao MQ, Crill1 PM, Dai ZH, Frolking S, Moore B, Salas W, Song WZ, Wang XK, 2001, Comparing a national inventory of N2O emissions from arable lands in China developed with a process-based agro-ecosystem model to the IPCC methodology. *Nutr. Cycl. Agroecosystems 60:159-175*.

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Li, C., S. Frolking, and T.A. Frolking, 1992a, A model of nitrous oxide evolution from soil driven by rainfall events: 1. Model structure and sensitivity, *Journal of Geophysical Research*, 97:9759-9776.

Li, C., S. Frolking, and T.A. Frolking, 1992b, A model of nitrous oxide evolution from soil driven by rainfall events: 2. Applications, *Journal of Geophysical Research*, 97:9777-9783.

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EDUCATION
1993 Ph.D.s Soil Science, College of Agriculture, Depart. of Crop and Soil Sciences & Forest Ecology, 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:
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

Publications (Selected since 2003)

1. Dahlgren, R.A., W.R. Horwath, K.W. Tate, and T.J. Camping. 2003. Blue oak enhance soil quality in California oak woodlands. California Agriculture 57(2):42-47. 714 p.
2. Yu, Z., T.E.C. Kraus, R.A. Dahlgren, W.R. Horwath, and R.J. Zasoski. 2003. Mineral and dissolved organic nitrogen dynamics along a soil acidity-fertility gradient. Soil Sci. Soc. Am. J. 67:878-888.
3. van Groenigen, J.W., C.S. Mutters, W.R.Horwath, and C. van Kessel. 2003. NIR and DRAFT-MIR spectrometry of soils for predicting soil and crop parameters in a flooded field. Plant and Soil 250:155-165.
4. Bird, J.A., C. van Kessel, and W.R. Horwath. 2003. Stabilization and ^{13}C-Carbon and immobilization of 15N-Nitrogen from rice straw in humic fractions. Soil Sci. Soc. Am. J. 67:806-816.
5. van Groenigen J.W., Burns E.G., Eadie J.M., Horwath W.R., van Kessel C. 2003. Effects of foraging waterfowl in winter flooded rice fields on weed stress and residue decomposition. Agriculture, Ecosystems and Environment 95: 289-296.
6. Doane, T.A., O.C. Devêvre, and W.R. Horwáth. 2003. Short-term soil carbon dynamics of humic fractions in low-input and organic cropping systems. Geoderma 114:319-331.
7. Horwath, W.R. 2003. Microbial Biomass in Soils. In: Encyclopedia of Agrochemicals. Academic Press, New York. In Press.
8. Doane, T.A. and W. R. Horwath. 2003. Spectrophotometric Determination of Nitrate with a Single

Reagent. Analytical Letters: ANALYTICAL LETTERS 36,: 2713–2722.
9. Koivunen, M. E., C. Morisseau, J. W. Newman, W. R. Horwath and B. D. Hammock. 2003. Purification and characterization of a methylene urea-hydrolyzing enzyme from *Rhizobium radiobacter* (*Agrobacterium tumefaciens*). Soil Biol. And Biochem.: In Press.
10. Kraus T. E. C., R. J. Zasoski, R.A. Dahlgren, W.R. Horwath and C.M. Preston. 2004. Carbon and nitrogen dynamics in a forest soil amended with purified tannins from different plant species. Soil Biology and Biochemistry 36 (2): 309-321.
11. Koivunen M. E. and W. R. Horwath. 2004. Effect of management history and temperature on the mineralization of methylene urea in soil. Nutrient Cycling in Agroecosystems 68: 25-35.
12. Doane T.A. and W. R. Horwath. 2004. Annual dynamics of soil organic matter in the context of long-term trends. Global Biogeochemical Cycles: 18: 1-11.
13. Garcia-G. R., Gomez A., Lopez-U. J., Vargas-H. J., W.R. Horwath. 2004. Tree growth and delta C-13 among populations of Pinus greggii Engelm. at two contrasting sites in central Mexico. Forest Ecology and Management 198: 237-247.
14. Koivunen M. E. and W. R. Horwath. 2005. Methylene urea as a slow-release nitrogen source for processing tomatoes. NUTRIENT CYCLING IN AGROECOSYSTEMS 71 (2): 177-190.
15. Onsoy YS, Harter T, Ginn TR, Horwath WR. 2005. Spatial variability and transport of nitrate in a deep alluvial vadose zone. VADOSE ZONE JOURNAL 4 (1): 41-54.
16. Doane TA, Horwath WR 2004. Annual dynamics of soil organic matter in the context of long-term trends. GLOBAL BIOGEOCHEMICAL CYCLES 18 (3): Art. No. GB3008 AUG 6 2004
17. Seiter, S. and W.R. Horwath. 2004. Strategies for Managing Soil Organic Matter to Supply Plant Nutrients. In: Magdoff, F. and R.R. Weil, editors. Chp. 9, pp. 269-293. Soil Organic Matter in Sustainable Agriculture. CRC Press.
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19. Mitchell, J.P., R.J. Southard, W.R. Horwath, J.B. Baker, K.Klonsky, D.S. Munk and K.J. Hembree. 2005. Reduced tillage production system alternatives for processing tomatoes and cotton in California's San Joaquin Valley. Acta Horticulturae. 638:95-99.
20. Koivunen, M.E. and W.R. Horwath. 2005. Methylene urea as a slow-release nitrogen sources for processing tomatoes. Nutrient Cycling in Agroecosystems 71:177-190.
21. Rasmussen, C., Southard, R.J., and W.R. Horwath. 2005. Modeling energy inputs to predict pedogenic environments using regional environmental databases. Soil Science Society of America Journal 69:1266-1274.
22. Southworth, D., He, X.H., Swenson, W., Bledsoe, C.S., and W.R. Horwath. 2005. Application of network theory to potential mycorrhizal networks. Mycorrhiza 15 (8): 589-595
23. Moran, K.K., Six, J., Horwath, W.R., and C. van Kessel. 2005. Role of mineral-nitrogen in residue decomposition and stable soil organic matter formation. Soil Science Society of America Journal.
24. Horwath, W.R. 2005. Carbon cycling and formation of soil organic matter. *In*, Encyclopedia of Soil Science and Technology. W. Chesworth (Ed.), Kluwer Academic Publishers, the Netherlands.
25. Sivakumar, B., Wallender, W.W., Horwath, W.R., Mitchell, J.P., Prentice, S.E. and B. A. Joyce. 2005. Nonlinear analysis of rainfall dynamics in California's Sacramento Valley. Hydrological Processes 20 (8): 1723-1736
26. Chavez-Aguilar G., Fenn M.E., Gomez-Guerrero A., Vargas-Hernandez J. and W.R. Horwath. 2006. Foliar nitrogen uptake from simulated wet deposition in current-year foliage of Abies religiosa. Agrocencia 40: 373-381.
27. Davis J.H., Griffith S.M., W.R. Horwath, Steiner J.J. and Myrold D.D. 2006. Fate of nitrogen-15 in a perennial ryegrass seed field and herbaceous riparian area. Soil Sci. Soc. Am. J. 70: 909-919.

28. Rasmussen C., Southard R.J. and W.R. Horwath. 2006. Mineral control of organic carbon mineralization in a range of temperate conifer forest soils. Global Change Biol. 12: 834-847.
29. He X.H., Bledsoe C.S., Zasoski R.J., Southworth D. and W.R. Horwath. 2006. Rapid nitrogen transfer from ectomycorrhizal pines to adjacent ectomycorrhizal and arbuscular mycorrhizal plants in a California oak woodland. New Phytologist 170: 143-151.
30. Southworth D., He X.H., Swenson W., Bledsoe C.S. and W.R. Horwath. Application of network theory to potential mycorrhizal networks. Mycorrhiza 15: 589-595.
31. Harter, T., Y. Onsoy, K. Heeren, M. A. Denton, G. Weissmann, J. W. Hopmans, and W. R. Horwath, 2005. Deep Vadose Zone Hydrology demonstrates fate of nitrate in eastern San Joaquin Valley. California Agriculture 59(2):124-132.
32. 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. I71:362–37.
33. Winsome T., Epstein L., Hendrix P.F., and W.R. Horwath. 2006. Competitive interactions between native and exotic earthworm species as influenced by habitat quality in a California grassland. Applied Soil Ecology 32: 38-53.
34. Davis JH, Griffith SM, Horwath WR, Steiner JJ, Myrold DD. 2006. Fate of nitrogen-15 in a perennial ryegrass seed field and herbaceous riparian area. Soil Science Society of America Journal. 70: 909-919.
35. Rasmussen C, Southard RJ, Horwath WR. 2007. Soil mineralogy affects conifer forest soil carbon source utilization and microbial priming. Soil Science Society of America Journal 71: 1141-1150.
36. Davis JH, Griffith SM, Horwath WR, Steiner JJ, Myrold DD. 2007. Mitigation of shallow groundwater nitrate in a poorly drained riparian area and adjacent cropland. Journal of Environemtal Quality 36: 628-637.
37. Kallenbach CM, DE Rolston, WR Horwath. 2010. Cover cropping affects soil N2O and CO2 emissions differently depending on type of irrigation. Agr. Ecos. & Env. 137: 251-260.
38. 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.

Curriculum Vitae
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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

2009-2010	*Full Professor in Agroecology* Department of Plant Sciences, University of California, Davis, CA
2008-2009	*Associate Professor in Agroecology* Department of Plant Sciences, University of California, Davis, CA.
2006-2008	*Assistant Professor in Agroecology* Department of Plant Sciences, University of California, Davis, CA.
2002-2006	*Assistant, Associate and Full 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.

EDITORIAL BOARDS

2010-present	Subject Matter Editor Ecospheres
2008-present	Section Editor for Plant and Soil
2005-present	Associate Editor for European Journal of Soil Science
2005	Guest Editor for Special Issue of Nutrient Cycling in Agroecosystems
2003-2010	Subject Editor for Soil Biology & Biochemistry
2003-2008	Consulting Editor for Plant and Soil

AWARDS

2002 Excellence In Presentation Award-Division S-7 Forest & Range Soils, Soil Science Society of America.

1998 Outstanding Graduate Student Award-Division S6 Soil & Water Management & Conservation, Soil Science Society of America.

1997 Travel award for the symposium “Soil Respiration: Implications for Climate change” held at the 1997 Annual Soil Science Society of America Meeting.

REVIEWER

Proposals: Agence National de La Recherche, CAMS Mini-Grant Proposal Program, Canadian Agri-Food Research Council, The Chilean Research Fund Council (FONDECYT), Czech Science Foundation (GACR), Deutsche Forschungsgemeinschaft, Israel Science Foundation; Kansas NSF EPSCoR, National Aeronautics and Space Administration, North Central Region Sustainable Agriculture Research and Education (NCR-SARE) Program, The Rockefeller Foundation, United States National Science Foundation (Ecosystems Science Cluster; Geobiology

& Low Temperature Geochemistry Program; Geosciences Program; OISE - Americas Program; Long-term Research in Environmental Research), United States Department of Agriculture/National Research Initiative, and United States Department of Energy.

Manuscripts: Advances in Environmental Research; Agricultural and Food Science; Agriculture, Ecosystems & Environment; Agronomie: Agriculture & Environment; Applied Soil Ecology; Arid Land Research and Management; Australian Journal of Soil Research; Bioenergy Research; Biogeochemistry; Biogeosciences; Biology and Fertility of Soils; Bioresource Technology; Bioscience; Canadian Biosystems Engineering; Canadian Journal of Soil Science; Catena; Computers and Electronics in Agriculture; Ecological Applications; Ecological Complexity; Ecological Engineering; Ecology; Ecosystems; Environmental Management; European Journal of Soil Biology; European Journal of Soil Science; Forest Ecology and Management; Forest Science; Frontiers in Ecology and the Environment; Gayana Botanica; Geoderma; Global Biogeochemical cycles; Global Change Biology; Journal of Plant Nutrition and Soil Science; Journal of Agronomy; Journal of Environmental Quality; Journal of Geophysical Research; Journal of Hydrology; Journal of Tropical Ecology; Nature; Nature Geosciences; New Zealand Journal of Agricultural Research; Microbial Ecology; New Phytologist; Nutrient Cycling in Agroecosystems; Oecologia; Organic Geochemistry; Pedobiologia; Pedosphere; Plant and Soil; Proceedings of the National Academy of Sciences; Soil and Tillage Research; Soil Biology and Biochemistry; Soil Science; Soil Science Society of American Journal; Trends in Microbiology; Vadose Zone Journal; Water Resources Research.

Synergetic Activities

* *Representative* for Colorado State University at Task 1 – Basic processes and Mechanisms – of the Consortium for Agricultural Soils Mitigation of Greenhouse Gases (CASMGS).
* *Keynote Speaker* at the 11th International Nitrogen Workshop, 2001. Reims, France,at the Advances in Soil Structure Research Workshop, 2002, Prince Edward Island, Canada, and at the COST 627 Action on C sequestration in grasslands, 2004, Gent, Belgium.
* *Editorial Board* of Soil Biology & Biochemistry and Plant and Soil.
* *Manuscript Reviewer* for Advances in Environmental Research, Agronomie: Agriculture & Environment, Biogeochemistry, Canadian Biosystems Engineering, Canadian Journal of Soil Science, Ecological Applications, European Journal of Soil Science, Geoderma, Global Change Biology, Journal of Environmental Quality, Journal of Tropical Ecology, Oecologia, Plant and Soil, Soil and Tillage Research, Soil Biology and Biochemistry and Soil Science Society of American Journal.
* *Proposal Reviewer* for CAMS Mini-Grant Proposal Program, Canadian Agri-Food Research Council, Kansas NSF EPSCoR, The Rockefeller Foundation, and US National Science Foundation.
* *Organizer.* Symposium: "Nitrous Oxide Emissions from Soils: From Controls to Multi-Gas Approach." Soil Sci. Soc. Am. meeting, 2003, Denver, Colorado. Workshop: "The Role of Light Fraction and Particulate Organic Matter in Intensively Managed Systems." LTER All Scientists Meeting, Snow Bird, Utah

PUBLICATIONS (2006-2010)*:*

In press

Lee, J., C. van Kessel, and J. Six. Dinitrogen fixation by winter-grown chickpea after waterlogging across scales in a Mediterranean climate. J. Agron. Crop Sci.

Kong, A.Y.Y., K.M. Scow, A.L. Córdova-Kreylos, W.E. Holmes, and J. Six. Microbial community composition and carbon cycling within soil microenvironments of conventional, low-input, and organic cropping systems. Soil Biol. Biochem.

Haddix, M.L., A.F. Plante, R.T. Conant, J. Six, J.M. Steinweg, K. Magrini-Bair, R.A. Drijber, S.J. Morris, and E.A. Paul. The role of soil characteristics on temperature sensitivity of soil organic matter. Soil Sci. Soc. Am. J.

Bach, E.M., S.G. Baer, C.K. Meyer, and J. Six. Soil microbial recovery during grassland restoration on contrasting soil texture. Soil Biol. Biochem.

Gentile, R., B. Vanlauwe, and J. Six. Litter quality impacts short- but not long-term soil carbon dynamics. Ecol. Appl.

Pedroso, G., C. De Ben, R. Hutmacher, S. Orloff, D. Putnam, J. Six, C. van Kessel, S. Wright, and B. Linquist. Establishment and Productivity of Irrigated Switchgrass across Ecozones in California. Cal. Ag.

Vanlauwe, B., J. Kihara, P. Chivenge, P. Pypers, R. Coe, and J. Six. Agronomic use efficiency of N fertilizer in maize-based systems in Sub-Saharan Africa within the context of Integrated Soil Fertility Management. Plant Soil

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. Coordinated Approaches to Quantify Long-Term Ecosystem Dynamics in Response to Global Change. Global Change Biol.
Gentile, R., B. Vanlauwe, P. Chivenge, and J. Six. Trade-offs between the short- and long-term effects of residue quality on soil C and N dynamics. Plant Soil

2010
De Gryze, S., A. Wolf, S.R. Kaffka, J.P. Mitchell, D.E. Rolston, S.R. Temple, J. Lee, and J. Six. Simulating greenhouse gas budgets of four California cropping systems under conventional and alternative management. Ecol. Appl. 20: 1805-1819.
Gillabel, J., B. Cebrian-Lopez, J. Six, R. Merckx. 2010. Experimental evidence for the attenuating effect of SOM protection on temperature sensitivity of SOM decomposition. Glob. Change Biol. 16:2789-2798.
Gentile, R., B. Vanlauwe, A. Kavoo, P. Chivenge and J. Six. 2010. Residue quality and N fertilizer do not influence aggregate stabilization of C and N in two tropical soils with contrasting texture. Nutr. Cycl. Agroecosys. 88:121-131.
Baer, S.G., C.K. Meyer, E.M. Bach, R.P. Klopf, and J. Six. 2010. Contrasting ecosystem recovery on two soil textures during grassland restoration: implications for conservation and mitigation. Ecosphere, 1: article5 p 1-22.
Spencer, R.G.M., P.J. Hernes, R. Ruf, A. Baker, R.Y. Dyda, A. Stubbins, and J. Six. 2010. Temporal controls on dissolved organic matter and lignin biogeochemistry in a pristine tropical river, Democratic Republic of Congo. J. Geophys. Res. 115: G03013, doi:10.1029/2009JG001180
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.
Fonte, S.J., E. Barrios, and J. Six. 2010. Earthworm impacts on soil organic matter and fertilizer dynamics in tropical hillside agroecosystems of Honduras. Pedobiologia 53:327-335.
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.
Lei, B., M. Fan, Q. Chen, J. Six, and F. Zhang. 2010. Changes in soil organic matter characteristics following the conversion of wheat-maize to vegetable cropping systems. Soil Sci. Soc. Am. J. 74:1320-1326.
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Ruark, M.D., B.A. Linquist, J. Six, C. van Kessel, C.A. Greer, R.G. Mutters, and J.E. Hill. 2010. Seasonal losses of dissolved organic carbon and total dissolved solids from rice production systems in northern California. J. Environ. Qual. 39:304-313.

2009
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.
Lee, J., E.A. Laca, C. van Kessel, J. Hopmans, D.E. Rolston, and J. Six. 2009. Tillage Effects on Spatiotemporal Variability of Particulate Organic Matter . Appl. Environ. Soil Sci. doi:10.1155/2009/219379.
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Chivenge, P., B. Vanlauwe, R. Gentile, H. Wangechi, D. Mugendi, C. van Kessel, and J. Six. 2009. Organic and mineral input management to enhance crop productivity in Central Kenya. Agron. J. 101: 1266-1275.

Spencer, R.G.M., A. Stubbins, P.J. Hernes, A. Baker, K. Mopper, A.K. Aufdenkampe, R.Y. Dyda, V.L. Mwamba, A.M. Mazedi, J.N. Wabakanghanzi, and J. Six. 2009. Photochemical degradation of dissolved organic matter and dissolved lignin phenols from the Congo River. J. Geophys. Res. 114: G03010.

Vieira, F.C.B., C. Bayer, J.A. Zanatta, J. Mielniczuk, and J. Six. 2009. Organic matter in no-till subtropical soil subjected to legume cover crop-based maize systems. Soil Sci. Soc. Am. J. 73: 1699–1706.

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.

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Plante, A.F, A. Kougentakis, A. Sen, C. Slominski, J. Six, E.A. Paul, and R.T. Conant. 2009. Does physical protection of soil organic matter attenuate temperature sensitivity? Soil Sci. Soc. Am. J. 73:1168-1172.

De Graaff, M.A., C. van Kessel, J. Six. 2009. Rhizodeposition-induced decomposition increases N availability to wild and cultivated wheat genotypes under elevated CO2. Soil Biol. Biochem. 41:1094-1103.

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.

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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.

Gentile, R., B. Vanlauwe, C. van Kessel, and J. Six. 2009. Managing N availability and losses by combining fertilizer-N with different quality residues in Kenya. Ag. Ecosys. Envir. 131:308-314.

Decock, C., K. Denef, S. Bode, J. Six, and P. Boeckx. 2009. Critical assessment of the applicability of gas chromatography-combustion-IRMS to determine amino sugar dynamics in soil. Rapid Comm. Mass Spec. 23:1201-1211.

Stewart, C.E., K. Paustian, R.T. Conant, A.F. Plante, and J. Six. 2009. Soil carbon saturation: implications for measurable carbon pool dynamics in long-term incubations. Soil Biol. Biochem. 41:357-366.

Fonte, S.J., T. Winsome, and J. Six. 2009. Earthworm populations in relation to soil organic matter dynamics and management in California tomato cropping systems. Appl. Soil Ecol. 41:206-214.

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.

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KEY QUALIFICATIONS:

- Technical management, planning and supervisory responsibilities in the areas of information systems, remote sensing, geographic information systems, and modeling with an emphasis on natural resource applications, greenhouse gases inventory and mitigation, nutrient management and human-environment interaction.
- Extensive experience in technology transfer and training in geographic information systems, remote sensing and modeling for land use and land cover change studies, national and international data and metadata standards, and linking scientific data to policy needs.

EDUCATION:

Ph.D., Natural Resources, 2001, University of New Hampshire
M.S., Forestry, 1993, University of New Hampshire
B.S., Mathematics, minor in Physics, 1984, University of Vermont

COUNTRIES of WORK EXPERIENCE:

Brazil, China, India, Indonesia, Laos, Malaysia, Philippines, Thailand, and Venezuela.

PROFESSIONAL EXPERIENCE:

President & Chief Scientist, Applied Geosolutions, LLC, 87 Packers Falls Road, Durham, NH, 2000 - present

Applied GeoSolutions, LLC (AGS) was formed in 2000 to provide consulting services in training and applications of geo-spatial technologies for environmental applications. AGS mission is to promote, support and provide scientifically sound cutting-edge geo-spatial technologies and integrated spatial information services for enhanced environmental stewardship. AGS research, education and technology transfer activities focuses on the use of well validated and accepted geospatial decision support tools for improved understanding of the air and water quality impacts of land use and development of site specific mitigation analyses.

AGS provides and uses well accepted and peer reviewed remote sensing, GIS, and modeling tools and a network of scientists that collectively provide a complete solution for your environmental impact assessments, land use analyses and geo-spatial technology needs.

Salas' expertise includes use of biogeochemical models for assessing environmental impacts of agricultural land use, remote sensing and GIS tools for environmental applications, GIS and remote sensing technical support, applications of transportation, land use, urban sprawl, GHG emission inventories, and training and technology transfer in the use of geo-spatial technologies. Principals of the company have a long history of successful contracts and grants with government, academia and private industry. Given rapid developments in the field of geo-spatial technologies, we ensure access to the most up-to-date technologies by utilizing a network of scientists that are active in academic research and technology development. Recently, his research has focused on using process based biogeochemical models to assess releases of carbon and nitrogen from manure management. He has conducted research, technology transfer, training and outreach projects worldwide (e.g. Brazil, China, Laos, India, Indonesia, Malaysia, Thailand, Venezuela, Vietnam).

Dr. Salas' work experience at AGS includes:

- ***AGS Project Manager and Co-Investigator: Global Emissions from Land Use Change Project***. A World Bank funded project with the primary objective to develop improved, spatially-explicit estimates of greenhouse gas emissions from land cover change for global tropics and subtropics in Africa and South America. Applied Geosolutions, LLC was responsible for compiling and processing remote sensing products related to forest mapping and cover change mapping across the study region. All new remote sensing data layers (circa 2000-2005) for the study region were compiled at a spatial resolution of 500 meters. Due to scope of the project, the primary data set used for mapping forested area in 2000, as well as forest cover loss between 2000 and 2005 was MODIS Vegetation Continuous Fields (VCF- MOD44B). Landsat pairs were acquired, processed, and analyzed to provide validation information across the study area.
- ***AGS Project Manager and Principal Investigator:*** **Creating and quantifying carbon credits from voluntary practices on rice farms in the Sacramento Valley** A NRCS funded project to develop, refine, and test voluntary greenhouse gas (GHG) emission reduction and sequestration practices on rice farms in California's Sacramento Valley, to assess their economic and operational feasibility, and test GHG accounting protocols all in an effort to facilitate agriculture sector participation in potential future GHG emission reduction programs anticipated from an new aggressive state mandate to achieve substantial GHG emission reductions by 2020. Our project deliverables include: 1) assessment of innovative new practices that provide net GHG emissions reductions on rice farms; 2) A detailed yet practical accounting of economic costs and benefits associated with the implementation of these practices; 3) an assessment of recently developed GHG accounting protocols for the agriculture sector; 4) a web-based GIS system for accessing DNDC modeling and GHG offset opportunities at the field scale.
- ***AGS Project Manager and Co-Investigator*** Development of Kenya and Ghana's R‐Plan for REDD. These projects supported the Governments of Ghana and Kenya in preparing the technical and policy components of the REDD R‐Plan. Applied Geosolutions, LLC is part of a team led by Winrock International to assist in developing a Readiness Plan that compiles the state of knowledge on various components, identifies necessary steps in framework Terms of Reference in alignment with international best practices and consistent with Kenyan and Ghanaian priorities, possibilities and practices. The consultants assembled for this work are proven international leaders in providing technical and advisory services to clients on a variety of issues related to climate change mitigation and land use change including methodological development, carbon accounting, legal dimensions of REDD international policy, carbon markets and forestry, and forest policy.
- ***AGS Project Manager and Co-Investigator*** for Integrating Technologies to Monitor and Predict Patterns of Urban Growth for NOAA/CICEET, September 2002 to August 2005. Developed algorithms for mapping urban growth and geospatial models for forecasting the amount and location of future development based on local economic, social conditions, natural resources and transportation infrastructure. Provided series of seminar presentation on the theory and application of these geospatial models.
- ***AGS Project Manager and Co-Investigator*** for "Integrating Geospatial and Web-Based Technologies to Improve Land Use Planning in Coastal New Hampshire" for NOAA, September 2007 to September 2009. Refinement and training with the AGS proprietary SUBNET model, web tools for display of GIS datasets of urban growth, and overall project support.
- ***AGS Project Manager and Lead Investigator*** for Regional Integrated Program for Irrigation and Fertilization Management Assistance Program, funded by California State Water Control Board, June 2005 – October 2006.
- ***AGS Project Manager and Principal Investigator*** for NASA SBIR Phase II Program, Prototyping a Rangeland Decision Support System, March 2006 – February 2008, Project Budget: $600,000
- ***Remote Sensing Advisor*** to a large privately owned US-based firm. Provided technical advice on the uses of remotely sensed imagery and GIS technologies for evaluation of BMPs for water quality/TMDL analyses and assessment of natural gas seepage, May 2005 to January 2006.
- ***AGS Project Manager and Principal Investigator*** for "Developing and Applying Process-based Models for Estimating GHG and Air Emissions from California Dairies", *California Energy Commission,* March 2005 – February 2008
- ***Modeling Advisor*** to LCA Consultants in Denmark for an assessment of production technologies and environmental impacts of pig production in U.S., Brazil and Europe, November 2003 to July 2004.
- ***AGS Project Manager and Lead Investigator*** for "Assessing Potential Impacts of Forest Management on GHG Emissions", Jan 2005 – March 2006, *Winrock International.* Identified and evaluated appropriate use of existing land use and land cover data, especially remotely sensed and GIS data, with biogeochemical modeling for conducting assessments of greenhouse gas emission from forest management and rangeland management alternatives.

- ***AGS Project Manager and Lead Investigator*** for "Land Use and Land Cover Dynamics of China in Support of NEESPI Science" funded under the *NASA Carbon Cycle Science Program*, NRA-04-OES-01, Jan 2005 – Jan 2008. Project role to identify, obtain, and evaluate GIS databases on agricultural land use, soils and climate data in Heilinjiang Province of China. Perform geospatial modeling of historic, current and future agricultural management impact on soil fertility, greenhouse gas emissions and crop yields.
- ***Technology Transfer Specialist*** for SIVAM Technology Transfer Series, Raytheon, Michigan State University, and Brazilian SIVAM Office, August 2000 – June 2001. Provided training and technology transfer seminars on state of the art applications of remote sensing, GIS, and geo-spatial modeling for environmental applications. Led training and technology transfer activities for in four cities in Brazil which included short courses and seminars on the eight separate remote sensing and GIS topics related to environmental monitoring and natural resource management.
- ***Modeling Specialist*** for SAIC to develop normalization data for the eutrophication TRACI impact stud, January 2001 – April 2001. Led a team of 3 scientists. Performed a literature review of nutrient loading to water bodies across the U.S. Performed a modeling analysis of N2O emissions from U.S. agricultural production in 1990.
- ***AGS Project Manager and Co-Investigator*** for USDA NRI Program, "Developing Manure DNDC: A process based model for ammonia and methane emissions from California dairies", January 2005 – December 2006.
- ***AGS Project Manager and Lead Investigator*** for NASA SBIR Phase I Program, Building a Rangeland Decision Support System, January 2005 – July 2005
- ***AGS Project Manager and Modeling Specialist*** *for California Energy Commission and Kearney Foundation of Soil Science*, "California Carbon Scoping Project: Modeling potential county level carbon sequestration in agricultural soils of California", September 2003 – February 2004.
- ***AGS Project Manager and Co-Investigator*** for "Disseminating a GIS based nutrient management tool for coastal managers" *NOAA/CICEET*, October 2004 – September 2006. Compiled GIS databases of land use, soils, climate and agricultural management practices. Led training workshops on using the DNDC watershed tool for assessing nutrient loading.
- ***AGS Project Manager and Co-Investigator*** for Developing a desktop DNDC tool for evaluating best management practices for reducing nutrient loading to Elkhorn Slough NERR, *NOAA/CICEET*, September 2002 to August 2004. Compiled GIS databases of land use, soils, climate and agricultural management practices. Worked with local stakeholders on nutrient management issues. Led two training workshops (15-25 participants) on using the DNDC watershed tool for assessing nutrient loading.
- ***AGS Project Manager and Co-Investigator*** for Assessing the Influence of Asian Rice Paddies on the Growth Rate of Atmospheric Methane 1980-2020, *NASA*, February 2003 – January 2006.

Research Scientist, Complex Systems Research Center, Institute for the Study of Earth, Oceans, and Space, University of New Hampshire, 1991 - 2002.

Dr. Salas' research focused on developing decision support tools with the goal of transferring advances in remote sensing research, geo-spatial analyses, and spatial databases to meet the information needs of the natural resource community. His research has focused on the use of visible, infra-red, and microwave remote sensing data with geographical information systems for monitoring and modeling tropical deforestation, land cover and land use change, and agricultural land use at the site to regional scales. Central to these research activities has been the development of spatially explicit databases on land cover, land use, and other biophysical attributes and socio-economic census data for biogeochemical and land use and land cover change modeling. His active research projects include: development of remote sensing approaches for quantifying vegetation recovery and changes in biomass following disturbance, determination of the optimal scale for these approaches, and testing of disturbance-specific parameters that may influence rates of forest regrowth in the tropics; developing databases on land use, soil properties, agricultural management practice, and climate as inputs for regional biogeochemical analyses.

He has worked extensively with many remote sensing data from any platforms, including Landsat, Spot, SIR-C, JERS-1, ERS-1, Radarsat, AVHRR, and SSM/I. He has worked and been a co-investigator on the NASA Landsat Pathfinder Humid Tropical Forest Project to develop and map wall-to-wall deforestation and forest re-growth across Amazonia and Southeast Asia with Landsat data over the past 20 years. Pathfinder tasks included developing hybrid methodology for operational analysis of Landsat MSS, TM, and ETM data for mapping deforestation, development of a series of validation sites throughout Southeast Asia, and assisting in development of project information management system for tracking project image and GIS databases including over 3000 Landsat images and derived projects.

Dr. Salas' work experience at Complex Systems Research Center includes:

- ***Remote Sensing and GIS Specialist*** for Land Cover Change Analysis, Aceh Province, Indonesia, for Conservation International, January 1999 – August 1999. Performed a land cover change analysis for Weh, Breueh, and Nasi Islands in Aceh Provice using multi-temporal Landsat data, GIS databases and field data.
- ***Remote Sensing and GIS Specialist*** for Mapping Land Cover Change in the Ca River Watershed, Vietnam for the World Resources Institute, August 1998 – May 1999. Performed a land cover change analysis for Ca River watershed using multi-temporal Landsat data, GIS databases and field data. Lead field reconnaissance and ground validation data collection. Performed training workshops and meetings in Hanoi and Hue, Vietnam.
- ***Remote Sensing and GIS Specialist*** for World Bank Inspection Panel study in Rondönia, Brazil, January 1998 to October 1998. Performed land cover change analysis to assess the impact of road infrastructure development in Rondönia on protected reserves.
- ***Co-Investigator and Remote Sensing and GIS Specialist*** for Spatial Models of Environmental Processes: A Study of Deforestation in Thailand for the World Bank, January 1997-October 1998. Performed remote sensing analysis, GIS modeling, technology transfer, and field data collection to examine patterns of land use change in upland of Northeast Thailand.
- ***Remote Sensing and GIS Technology Transfer Specialist*** for UNDP and IGBP START programs in Indonesia, Laos, Philippines, Malaysia, and Thailand, 1996 – 1999. Held training workshops, performed needs assessments, developed research networks and performed analyses of socio-economic drivers of land use change in Southeast Asia.
- ***Co-Investigator and Remote Sensing and GIS Specialist*** for Human Dimensions of Deforestation and Regrowth in the Brazilian Amazon, for NASA, May 1997 – May 1999
- ***Remote Sensing Specialist for*** Landsat Pathfinder Humid Tropical Forest Project for NASA, January 1994 – October 1998. Developed and supervised all remote sensing and image processing tasks for the Remote Sensing and Geographic Information Systems Laboratory for NASA Landsat Pathfinder Project, overseeing of data issues (selection, formats, and ordering) and all Southeast Asian science and field activities for the NASA's Landsat Pathfinder Humid Tropical Forestry project.
- ***Remote Sensing Specialist for*** Quantifying the atmospheric impacts of paddy rice agriculture in China. 7/98-6/01 NASA, July 1998 – June 2001. Developed and supervised all radar remote sensing and image processing tasks for mapping the extent of rice paddies in China and estimation of methane emissions.
- ***Co-Investigator and Remote Sensing and GIS Specialist*** for Use of SAR for Monitoring Deforestation and Secondary Growth in the Tropics for NASA, October 1995 – September 1998. Lead the radar remote sensing, image processing and ground data collection tasks for mapping the extent and structure of secondary forests in Amazonia.
- ***Co-Investigator and Remote Sensing and Modeling Specialist*** Case Studies and Diagnostic Models of Inter-Annual Dynamics of Deforestation in Southeast Asia, NASA, January 1997 – October 1999.
- ***Project Director and Remote Sensing Specialist*** for Pattern to Process in Amazonia: Measurement and Modeling of the Inter-Annual Dynamics of Deforestation and Regrowth, NASA, October 1998 - September 2000.

Member Technical Staff, Terrestrial Planets Mission Analysis Group, Mission Design Section, Jet Propulsion Laboratory, NASA, 1985 - 1990.

Worked with Mission Design and Radar Science Groups on the Tropical Rainforest Ecology Experiment. Developed satellite orbit models and Synthetic Aperture Radar (SAR) acquisition models for the Magellan Mission to Venus and NASA Alaska SAR Facility projects.

NATIONAL and INTERNATIONAL COMMITTEES and PANELS

Dr. Salas has served on the Science Advisory Panel, NIST Biobased Advisory Group. This panel was convened to assess the environmental impacts of biobased products. Salas' role was to evaluate the impact of agricultural practices on releases of nutrient to air and water. He also serve4d on a Peer Review Group for Evaluating Environmental Benefits of Dairy Waste Anaerobic Digester Project, in support of CEC PIER funded Commonwealth Energy Biogas program. He is a member of the Scientific Advisory Panel for the ALOS Kyoto and Carbon initiative under the auspices of the Japanese Space Agency NASDA. The goal of this initiative is to plan, acquire, and archive ALOS PALSAR data and develop algorithms for implementation of analysis strategies in support of the Kyoto Protocol. He has also served on the Global Observation of

Forest Cover (GOFC) High Resolution Design Team and co-authored the final design document on the role of high resolution optical and radar systems for operational monitoring of global forests. He has been a technical advisor on the use of remote sensing for land use and land cover change for the Southeast Asia LUCC Network. He is also been a member of the NASDA's JERS-1 SAR Research Program on Global Forest Monitoring and ALOS PALSAR Research Team focusing on use of SAR for forest monitoring in the Amazon and Southeast Asia and rice monitoring in Asia using SAR data with GIS and Biogeochemical models. Panels and committees include:

- Science Advisory Panel, Technical Working Group on Agricultural Greenhouse Gases (T-AGG)
- Expert Reviewer, California Climate Action Registry, Manure management protocol development.
- Expert Reviewer, EPA 2005 Greenhouse Gas Emission Inventory, Forestry and Agricultural Emissions Chapters.
- Expert Reviewer, US Climate Change Science Program, SAP 4.3, The Effects of Climate Change on Agriculture, Land Resources, Water Resources, and Biodiversity.
- Expert Panel, US EPA, Meeting on Land Cover and Land Use Indicators Relevant to EPA's *Report on the Environment.*
- Science Advisory Panel, JAXA ALOS Kyoto & Carbon Initiative
- Advisory Panel, NIST Biobased Advisory Group
- Peer Review Group for Evaluating Environmental Benefits of Dairy Waste Anaerobic Digester Project, in support of CEC PIER funded Commonwealth Energy Biogas program.
- Member, Fine Resolution Design Team, Committee on Earth Observation Satellite Global Observation of Forest Cover Pilot Project.
- Member, Science Team for NASDA JERS-1 SAR.
- Member, Science Team for NASDA ALOS PALSAR
- Member, Science Team for POSAR ESSP proposal for P-band Orbiting SAR.
- Member, Landsat Pathfinder Program Science Working Group, National Aeronautics and Space Administration.
- Member, High Resolution Satellite Data Working Group, International Geosphere Biosphere Project-Data and Information System (IGPB-DIS) and Committee on Earth Observation Satellites (CEOS), participant in Land Cover Working Group, International Geosphere Biosphere Project-Data and Information System (IGPB-DIS).
- Review Panel, Cooperative Institute for Coastal and Estuarine Environmental Technology.
- Reviewer, USDA NRI program
- Reviewer, Kearney Foundation Soil Science, University of California
- Review Panel, Terrestrial Ecology Program, NASA
- Review Panel, Earth System Science Fellowship Program, NASA
- Review Panel, Space Science Student Involvement Program, NASA.
- Review Panel, NASA Landsat Pathfinder: North American Landscape Characterization (NALC) Product Refinement Workshop, Las Vegas, NV.

SELECTED RECENT PEER REVIEWED PUBLICATIONS AND REPORTS (out of more than 50 total)

1. **Salas, W** and Torbick, N., 2010, Developing Rice Decision Support Tools, in The ALOS Kyoto and Carbon Initiative, JAXA, JAXA EORC, NDX-100003.
2. Torbick, N., **Salas, W**, Hagen, S. and X. Xiao 2010. Integrating SAR and optical imagery for regional mapping of agro-ecological paddy attributes in the Poyang Lake Watershed, China. Canadian Journal of Remote Sensing. (accepted)
3. Torbick, N., **Salas, W**, Hagen, S. and X. Xiao, 2010, Mapping rice agriculture in the Sacramento Valley, USA with multitemporal PALSAR and MODIS imagery. IEEE J. Selected Topics in Applied Earth Observations and Remote Sensing. (accepted).
4. Wang, C, Wu, J, Zhang, Y., Pan, G., Qi, J., and **W. Salas**, 2009, Characterizing L-band scattering of paddy rice in southeast China with radiative transfer model and multi-temporal ALOS/PALSAR imagery, *IEEE Transactions on Geoscience and Remote Sensing*, 47(4): 988-998.
5. Zhang, Y., Wang, C., Wu, J., Qi, J., and **W. Salas**, 2009, Mapping Paddy Rice with Multi-temporal ALOS PALSAR Imagery in Southeast China, International Journal of Remote Sensing, 30(23):6301-6315.
6. **Salas, W**, Li, C., Mitloehner, F., and J. Pisano. 2008. Developing and Applying Proces-Based Models for Estimating Greenhouse Gas and Air Emission From California Dairies. *California Energy Commission, PIER Energy-Related Environmental Research. CEC-500-2008-093*
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10.0 Related research.

This proposal builds off of significant federal, state and stakeholder investment in field research on GHG emissions from California and development and testing of the DNDC model. The following is a list of the most relevant projects:

1. CEC project for the scoping effort. In 2003 a CEC funded project ($40,000) titled "Carbon Scoping Project for Kearney Foundation: Assessing the Opportunity for Greenhouse Gas Mitigation in California Agriculture" used DNDC to perform an initial scoping study of agricultural greenhouse gas emissions in California. PI: Dr. Marc LosHuertos.

2. Funding from the California State University Agricultural Research Initiative (CSU-ARI) ($200,000), PI: Dr. Goorahoo, titled *"Nitrous oxide emissions from California Orchard and Vegetable Cropping Systems"*, will be collecting N_2O data which would be useful in validating the DNDC model. In addition to the CSU-ARI project, an CDFA ($150,000) supported project titled "Measuring and Modeling Nitrous Oxide Emissions from California Cotton, Corn and Vegetable Cropping Systems" will also be collecting nitrous oxide (N_2O) data for silage corn and cotton crops and calibrating DNDC for these cropping systems.

3. Manure-DNDC project funded by CEC ($296,000) and National Milk Producers Federation ($900,000) project for developing Manure-DNDC model for estimating Greenhouse Gas, Ammonia and VOC emissions from dairies. PI: Dr. William Salas. The National Pork Board has just contracted with a team led by Dr. Salas to extend Manure-DNDC for swine production systems. Emission data collected by Dr. Frank Mitloehner at UC Davis for a swine facility in California will be used to validate Manure-DNDC. NCBA has tentatively agreed to fund an LCA project that will utilize Manure-DNDC to quantify GHG emissions from archetype cattle productions systems in the US, including California.

4. NRCS- CIG grant for California rice ($450,000), PI; Eric Holst (EDF). Titled "Creating and quantifying carbon credits from voluntary practices on rice farms in the Sacramento Valley: Accounting for multiple benefits for producers and the environment". Project calibrated and tested DNDC for quantifying GHG (CH_4 and N_2O) emissions from rice production system.

5. Recently funded CDFA SCBG projects. One project ($300,000) is led by the Almond Board of California (PI: G. Ludwig) as it titled "Carbon dynamics of orchard floor applied chipped almond prunings as influenced by irrigation methods, soil type, cover crop management and farm practices". One focus of this project is the development and calibrating of an almond submodel for DNDC. The second project ($450,000) is led by California Sustainable Winegrape Alliance (PI: Allison Jordan), titled "Field Testing a Carbon Offset and Greenhouse Gas Emissions Model for California Wine Grape Growers to Drive Climate Protection and Innovation". This project

will refine the calibration of the winegrape crop model in DNDC and will test the model based on data collected by Dr. Dave Smart at UC Davis and Dr. Kerrie Stenwerth at USDA ARS.

6. This proposed study will complement the project entitled "Assessment of Baseline N_2O Emissions in California Cropping Systems," funded by CARB ($ 300,000), PI Dr. Horwath. In this project, which will last from 2009 to 2012, N_2O emissions in response to various levels of nitrogen fertilization will be monitored in tomato, wheat, lettuce, rice and alfalfa systems during two years. Annual N_2O emissions and the fraction of N fertilizer emitted as N_2O will be calculated. Best management practices based on the N_2O emission results will be developed.
7. A complementary N_2O monitoring project, which has been approved by CARB at the Concept Proposal stage ($ 82,000 requested), is entitled "Assessment of Baseline Nitrous Oxide Emissions in California's Dairy Systems," PI Dr. Horwath. In that study, N_2O emissions in three forage cropping systems receiving dairy waste lagoon water will be assessed during one year. This proposed NOx emission study will be incorporated into the dairy N_2O study to leverage the efforts.
8. The proposed study will also complement a project entitled "N_2O Emissions from the Application of Fertilizers in Agricultural Soils," funded by CEC ($ 500,000) for the duration of three years (2009-2012), PI Dr. Six, Co-PI Dr. Horwath. The N_2O emissions in response to fertilizer additions will be monitored in a range of cropping systems and spatial variability of N_2O fluxes will be assessed. This project also has a modeling component.
9. A project entitled "Determining nitric oxide emissions from soil in California cropping systems to improve ozone modeling," PI Dr. Horwath, has been approved for funding by CARB at the Concept Proposal stage ($ 83,500 requested). Nitric oxide (NO) fluxes will be assessed at multiple events relating to fertilization and irrigation during one year in tomato, wheat, alfalfa, and almond systems, as well as in the silage corn system selected for this proposed study. It is expected that both studies' interpretation of the results will benefit from each other. Some leverage is also gained from shared logistics and experimental site management.

10. A project entitled "Developing BMPs for applying dairy lagoon water to forage crops in Stanislaus County using the RZWQM model to minimize nitrate leaching to groundwater and optimize crop uptake," funded by the State Water Resources Control Board ($512,000 UC Davis portion of $974,000 State Water Resources Control Board contract with the East Stanislaus Resource Conservation District), grant number 06-113-555-0, is currently conducted (2007-2009). The UC Davis investigators are W.R. Horwath and G.S. Pettygrove. This project will assess and develop BMPs for applying dairy lagoon water to forage crops to minimize nitrate losses to groundwater and to optimize crop uptake. RZWQM allows rapid site-specific irrigation and nutrient management practice evaluation. Funding originates from state Proposition 50 bonds. Data have been collected over two cropping seasons on three dairy forage fields. Modeling is especially focused on turnover rates of organic nitrogen and leaching of nitrate.

11. Another project entitled "Triple-cropping dairy forage production systems through conservation tillage in California's San Joaquin Valley," is funded by USDA/CSREES ($ 65,9200), 2009-2011. UC Davis investigators are Jeff Mitchell and William Horwath.

12. Currently, N_2O and methane (CH_4) emissions are being monitored at the Rice Experiment Station, Biggs, CA, by Dr. Horwath and technician Jakov Assa. The study includes a comparison

of N_2O and CH_4 emissions from a conventional wet-seeded rice systems, a wet-seeded rice with early season drainage system, and a drill-seeded rice with early season drainage system. Additionally, each management practice is associated with various N fertilizer levels. This project, entitled "Evaluation of best management practices for irrigation and nitrogen fertilizer application to mitigate greenhouse gas emissions from rice cropping," is funded by California Rice Commission ($45,000).