A. COVER PAGE

Measuring and Modeling Nitrous Oxide Emissions from California Cotton, Corn and Vegetable Cropping Systems

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C. Justification

C.1 Problem: The effects of the anthropogenic increase in atmospheric greenhouse gas (GHG) concentrations on climate change are beyond dispute (IPCC, 2007), and agriculture does play a key role in this issue, both as a source and a potential sink for GHG (Cole *et al.,* 1993). Of the three biogenic GHGs (i.e., CO_2, CH_4, and N_2O) contributing to radiative forcing in agriculture, N_2O is the most important GHG to be considered, researched, and eventually controlled within intensive and alternative cropping systems. It is estimated that in California, agricultural soils account for 64% of the total N_2O emissions, and N_2O may contribute as much as 50% to the total net agricultural greenhouse gas emissions (CEC, 2005). However, the reliability of these estimates is highly uncertain, which stems, in part, from a lack field measurements in California (Li and Salas, 2004), and in part, from the inherently high temporal variability of N_2O flux from soils. In a statistical analysis of 1125 N_2O studies from all over the world, the average 95% confidence interval was -51% to +107% (Stehfest and Bouwman, 2006). Among California's statewide greenhouse gas emissions, the magnitude of N_2O emissions is the most uncertain (CEC 2005).

Episodes of high N_2O fluxes are often related to soil management events like N fertilization, irrigation, or incorporation of crop residue, but the magnitude of the responses to such field operations also depends on soil physical and chemical factors, climate and crop system. Meta-analyses based on over 1000 studies found that fertilizer N application rates have significant effects on N_2O emissions, in addition to other factors like fertilizer type, crop type, or soil texture (Bouwman et al., 2002; Stehfest and Bouwman, 2006). Many of California's high-value crops are intensively managed in terms of N fertilizer use and irrigation, which are factors that have the potential to contribute to substantial N_2O emissions. Furthermore, California's mild winter temperatures and erratic rainfall patterns may be conducive to sporadic high N_2O emissions in the winter. The intensive management of cropland and the dependence on irrigation might also present opportunities to optimize management practices in order to mitigate N_2O emissions. However, the establishment of an improved estimate of N_2O emissions based on field measurements that capture both the temporal variability of N_2O emissions and a range of environmental conditions representative for California's main crop systems must precede any mitigation strategies.

C.2 CDFA/FREP Goals: This proposal addresses the following FREP program goals:

- Fertilization practices — research will examine fertilization application rates impact on crop yields and total N_2O emissions.
- Site-specific fertilizer technologies & Diagnostic tools for improved fertilizer recommendations — project will calibrate and validate a process modeling tool for assessing site specific fertilizer impacts on crop yields and nitrous oxide emissions.

strategies that are sustainable, reduce environmental impacts and are potentially more profitable."

The group of investigators on this proposal have 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 CEC and ARB companion projects (see discussion below), will result in better understanding of California specific N_2O emission profiles and the calibration and validation of a California specific process modeling tool for site and regional level estimates of N_2O emissions. These data and tools are critical for reducing the large uncertainty in N_2O emissions from California agriculture and for developing economically viable mitigation strategies.

ETAAC report suggested a coordinated research effort to address N_2O emissions from California agriculture would require $2 to $3 million dollars. The group of investigators involved in this project is currently involved in securing funds from two other sources for N_2O measurements. One complementary project proposal (Titled: N_2O Emissions from the Application of Fertilizers in Agricultural Soils; PI is Dr. Johan Six, 3-year project for $400,000) has been submitted to the California Energy Commission PIER rfp for Research Projects on Climate Change of Relevance to California, Research Topic 2. A second project will be submitted to the Air Resource Board and California Department of Food and Agriculture to be co-funded for $300,000 and is titled: "*Establish Baseline N_2O Emissions from Nitrogen Fertilizer use Based on Field-Derived California Specific N_2O Emission Factors*". Both projects have a similar methodology for N_2O emission assessment and will be able to partially leverage costs associated with the labor intensive collection of N_2O flux data. Furthermore, the three combined projects will enable us to develop a rich database for future model calibration and validation.

Additional matching fund will be sought for through the California State University - Agricultural Research Initiative. This initiative is a system wide program through the Chancellor's Office to support agricultural research by matching externally funded grants to CSU researchers and their cooperators. ARI has been in place since 2000 with a budget of $5,000,000 per year. External grants can be matched up to $150,000 per year for up to 3 years. Matches can be 1:1 for funded external support and 1:2 for in-kind external support. A significant portion of the external funding must be administered through a CSU campus foundation. ARI grants may be extended for an additional year or more if the budget has not been expended and objectives are not yet completed.

The air quality research group under the lead of co-PI Dr. C. Krauter at CSU Fresno has matched 7 external grants with equivalent ARI support since 2001. It should be noted that ARI matching funding was approved for every air quality external grant awarded to the research group at CSU Fresno to date. Should this proposed CEC project be funded, ARI match will be sought for 2009-11.

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

Modeling N2O emissions: The DNDC (DeNitrification-DeComposition) model 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 1).

DNDC simulates SOC dynamics by tracking SOC gain through crop litter incorporation and SOC loss 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 in the U.S. 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 for estimating SOC and N_2O fluxes across climatic zones, soil types and management regimes for agroecosystems.

C.6 Contribution to Knowledge Base California's agriculture is characterized by input intensive management in a diversity of cropping systems. In these systems, the intensive use of fertilizer N and the frequent wetting and drying cycles induced by irrigation likely lead to great N losses through denitrification. Moreover, N_2O losses are probably maintained at relatively high levels throughout the year due in part to the mild winter characteristic of California's Central Valley (Ryden and Lund, 1980). However, quantification of these high losses has not been conducted for many of the cropping systems in California. About 330 different crops are grown in the state, many of which exclusively in California. A very substantial area is occupied by 'non-conventional' crops, such as orchards, vineyards, and intensely cropped vegetables (See Table 1).

Table 1: California's 10 most important crops area wise, and their economical value (California Department of Food and Agriculture)

area rank	crop	area (1000 acres)	economical value ($million)	economical rank
1	hay (mainly alfalfa)	1550	1141	6
2	nuts (almonds, walnuts and pistachios)	900	3454	1
3	grapes	800	3166	2
4	cotton	657	625	11
5	rice	526	408	13
6	intensely cropped vegetables (lettuce, broccoli, carrots, celery and peppers)	496	2920	3
7	wheat	369	104	>15
8	fruit trees (oranges, plums, lemon, peaches)	359	1292	5
9	tomatoes	307	942	9
10	corn	520	52	>15

There has been significant research to (a) develop a processes level understanding of N_2O production and emissions, (b) measure emissions from cropland systems, and (c) develop process models. However, there is a paucity of data for California. This project will address this lack of data in California. In particular, this project will collect specific baseline and event related N_2O emissions for corn and cotton in San Joaquin Valley and calibrate and validated the DNDC model for these important crops. Table 2 summarizes the cropping systems for our coordinated research (see section C.4) on N_2O emissions for California agriculture.

Work Plan and Methods

The following set of tasks was designed to incrementally achieve the proposal objectives.

Task 1: Select cropping systems for N_2O field measurements.
At the onset of the project we will convene an oversight committee for a meeting to discuss the selection of crops, define industry standard cultivation practices for each crop and design of our field trials. Our current plan for field crops includes two crops that have large cultivation areas in the San Joaquin valley (corn with 120-240 lbs N/acre and cotton with 100-200 lbs N/acre). Corn field trials will include organic amendments (dairy lagoon water and compost). We will perform preliminary model simulations as part of the site selection process. Based on GIS databases of soils, climate and agricultural systems we will explore the range of soil and climate conditions under which the selected cropping systems are occurring. These conditions will then be modeled to generate the range of expected emission profiles. These emission profiles will then be used for selection of field measurement sites (e.g. expected relatively high and low emission sites). We have already built GIS databases of land-use with individual polygons of crop type (based on DWR legend), soils (STATSGO, SUSRGO) and daily climate (derived from nearest CIMIS station). Final selection of crops and industry standard irrigation/fertilizer treatments will be made after consultation with oversight committee.
In each corn and cotton system, we will set up five fertilizer N treatments, consisting of a pre-plant N-P-K and an urea/UAN side dress addition, will be applied at a rate of 25%, 50%, 75%, 100% and 125% of the nominal application rates in the five microplots per one-acre plot. Five microplots (4.5 m x 6 m) will be set up in each of treatment plots of the corn/cotton systems.

Task 2: Measure and calculate N_2O emissions
Two replicate plots of each treatment will be sampled in each of the two growing seasons in corn and cotton. Given the episodic nature of N_2O emissions, we propose to implement a variable sampling schedule, with most intensive measurement occurring during periods with expected high N_2O emission rates (following nitrogen fertilizer applications with irrigation or rain events). The N_2O flux will be measured daily in each microplot following fertilizer applications and irrigation or rainfall events. However, flux measurements will be taken less frequently (weekly) when elevated N_2O flux has subsided and soils are relatively dry. We will collect at a minimum weekly emission data during periods without fertilizer applications. During winter, the frequency of flux measurements will be dictated by rainfall and may be intensive for extended periods. During at least two irrigation events, N_2O flux will be measured every 6 h to obtain an estimate of diurnal fluctuations. In addition, if we have sufficient funds to support the manufacture of automated flux chambers, then we will enhance our measurement frequency to daily.

Two polyvinyl chloride (PVC) rings (30-cm diameter by 10 cm) will be installed in each plot to a depth of approximately 5 cm. In each plot one ring will be placed directly in the fertilizer band where appropriate. The other ring will placed between plant rows (furrow

Once the live biomass is simulated correctly, we can double check the sizes of the dead biomass and litter layer. If necessary, parameters controlling root or shoot death can be adjusted. Second, we will verify soil C dynamics, and adjust decomposition factors if necessary. Only in third and last step, we will compare modeled and measured N_2O fluxes, and again adjust the relevant parameters.

Using the validation time series, we will be able to independently quantify the performance of the models by comparing modeled and measured data at individual time points and weekly periods during the year. Once the models are calibrated and validated, annual budgets can be calculated. Performance of the model will be assessed to examine the cumulative fluxes, temporal variability in fluxes and the ability to capture effects of different management practices (fertilizer application rates, timing, use of organic amendments).

<u>*Task 4: Run NUGGET-DNDC to examine regional N_2O emissions across soils and climate conditions.*</u>
We will compile GIS databases of San Joaquin Valley of the actual climate (derived from CIMIS station data), range in soil conditions (NRCS SSURGO database of organic carbon, pH, texture and bulk density), and location of crops (use DWR land use surveys as general guide). We will use GIS data for regional simulation of NUGGET-DNDC to examine spatial and temporal variability in emissions for the two crops of choice (cotton and corn). Our model results will be compared to the ARB emission estimates.

<u>*Task 5: Reporting and dissemination of results.*</u> Project results will be presented at annual FREP conference, CEC climate change conference and with annual briefings to CDFA, Fertilizer Industry groups (e.g. WPHA) and to ARB. Periodic project updates will be provided to the San Joaquin Valley AG Technical Group (group contains representatives from CA State Agencies, Academic Researchers and Industry Groups).

Task Timeline and Milestones:

	2009				2010				2011			
	Mar-Apr	May to Nov		Dec	Jan to Nov			Dec	Jan to Mar	Apr to Jul	Aug to Oct	Nov & Dec
Task 1: Select Sites/treatments												
Convene oversight committee												
Model simulation/site selection												
Task 2: N2O Measurements												
Task 3: Model Validation												
Task 4: Regional Modeling												
Task 5: Reporting and Dissemination												

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