CDFA- Nitrous Oxide Emission Final Report

Reporting Period: July 01st 2009 to December 31st, 2013

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(A) Project Information

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Project Title: Measuring and modeling nitrous oxide emissions from California cotton, and vegetable cropping systems
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Have expenditures exceeded the amount allocated for the reporting period: NO
If "Yes", then explain any Modifications to Project/Budget: Not Applicable

(B) Project Objectives

The overall goals of this project were to: (1) determine detailed time series of nitrous oxide (N_2O) fluxes and underlying factors at crucial management events (irrigation, fertilization, etc.) in representative agro-ecosystems in Central Valley of California; and

(2) compile intensive data on N_2O fluxes for use in calibrating and validating the processed based biogeochemical De-Nitrification - De-Composition (DNDC) model. Specific objective of this phase of the research funded by CDFA was to determine N_2O flux measurements for cotton and tomatoes grown on sandy loam soils and fertilized with Urea Ammonium Nitrate (UAN-32).

(C) Abstract

The effects of the anthropogenic increase in atmospheric greenhouse gases (GHGs) concentration on climate change are beyond dispute. Of the three biogenic GHGs (i.e., carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O)), N_2O is considered to be the most potent. The overall goal of this study was to determine detailed time series of N_2O fluxes at crucial management events, for cotton and a fresh market tomato crop in the Central Valley of California. For the cotton Site A, the objective was to determine N_2O fluxes for cotton from beds and furrows and for Site B, the objective was to determine N_2O emissions for cotton fertilized with different rates Urea Ammonium Nitrate combined with an N inhibitor- Nutrisphere-N (NSN). For the tomato experiment, the objective was to determine the effect of a deficit subsurface drip irrigation (SDI) regime and multiple fertilizer application rates on soil N_2O emissions. Flux chamber measurements were conducted using an EPA approved methodology to collect air samples which were ultimately analyzed using a Gas Chromatograph. For the cotton crop, the N_2O fluxes were highest when irrigation was applied after fertilizer application. Overall, the total N_2O fluxes from furrows were 64% to 70% lower than that from the beds, on which the fertilizers were applied, and the emission factor (EF) for beds ranged from 0.69% to 1.94 %. The emission factors (EFs) for 50, 100 and 150 lbs N/acre applied with NSN was 0.01, 0.29 and 0.38% respectively, whereas for the same treatments without application of inhibitor was 0.34, and 0.20% respectively. In 2013, for plots receiving 50, 100 and 150 lbs N/ac, the NSN reduced the total N_2O emissions by 19%, 54% and 52%, respectively. The N_2O EFs determined in this study using the time series integration approach were considerably lower than the IPCC default values (1+0.0125% N fertilizer applied). The high degree of variability of N_2O fluxes implies that the snap-shot approach for calculation of EF can be misleading. In the tomato experiment, any significant differences in the N_2O fluxes due to the irrigation and/or fertilizer treatments, generally peaked within two hours after fertilizer application. Overall, there was a moderate positive correlation between the amount of N_2O-N emitted and the fertilizer applied (r= 0.64) and with the volume of water applied (r= 0.74). The amount of N_2O-N in kg per ha emitted during tomato cropping season ranged from 0.162 to 0.291 in 2012 and from 0.203 to 0.444 in 2013. More importantly, these emission rates were relatively constant in both years at 0.002 kg N_2O-N per ha per lb

of N fertilizer and would imply that the incremental addition of both fertilizer and water through SDI could be highly efficient management practices to minimize the N_2O emissions in tomato cropping systems.

Introduction

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 (California Energy Commission, CEC, 2005). 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 measurement in California (CEC, 2005; EPA 2010), 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 a and b; 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.

In 2011, 80,500 farms were operated in California which contributed about 3.7% of the total farms in the US (CDFA, 2012). In Mediterranean climates, such as in California, intensive irrigation and N fertilizer application can lead to conditions that promote elevated CO_2 and N_2O emissions). In 2004, California Environmental Protection Agency Air Resource Boards (CA EPA ARB) GHG inventories estimated that in California the largest source of N_2O is agriculture which contributes about 50% of the state's total N_2O emissions (ARB CA 2011). Therefore, in order to achieve the mandatory reduction in GHG emissions by California Global Warming Solutions Act of 2006 (AB 32), quantification of N_2O emissions from California's agricultural land is essential. Most of the studies conducted on N_2O emissions in California which used flux chamber method, such as Burger et al. (2005), estimated N_2O emissions after irrigation and drying of organically and conventionally managed tomatoes in California. Lee et al. (2009), quantified N_2O emissions from a field with standard tillage and from a field recently converted to minimum tillage system using flux chamber method. Kallenbach et al. (2010) compared effects of sub surface drip irrigation versus flood irrigation and winter cover crop system versus no cover crop system in tomato on N_2O emissions using flux chamber method and Garland et al. (2011) used Vented-closed-flux chamber method to quantify N_2O emissions from a cover cropped Mediterranean Vineyard under Conventional tillage system and No- till system. However, it is practically impossible to continuously monitor GHG fluxes across all possible combinations of crops rotations, management practices, soils and microclimates within the Central Valley. This can be achieved by developing emission factors (EFs) for each crop grown under different management practices. In addition, there is a need to evaluate the various management practices to mitigate these emissions.

The main objectives of the current research were to: (1) determine detailed time series of N_2O fluxes and underlying factors at crucial management events (irrigation, fertilization, etc.) in representative agroecosystems in Central Valley of California; and (2) compile an intensive dataset on N_2O fluxes for use in the calibration and validation of the processed based biogeochemical DNDC model.

At the time of the CDFA award, the project was funded to measure and model *Nitrous Oxide Emissions from California Cotton, Corn and Vegetable Cropping Systems.* However, upon review of the budgetary and labor requirements for a detailed study, it was recommended by the stakeholders, that the CDFA funded project focus primarily on cotton and at least one other vegetable crop grown in the central San Joaquin Valley (SJV). Subsequently, additional matching funds were obtained through the California State University - Agricultural Research Initiative (CSU-ARI). 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.

Currently, there are no estimates of N_2O emissions for cotton grown in California agricultural soils. Hence, the primary focus of this CDFA funded research was to determine the baseline N_2O emissions from cotton, grown on sandy loam soils and fertilized with UAN-32. Secondary objectives were to calculate the total N_2O emissions throughout the entire crop season, and to determine the N_2O EFs for cotton with different fertilizer treatments. In addition, the efficacy of using N inhibitor as an approach to mitigate N_2O emissions was also investigated.

Fresh market tomatoes was selected as the second crop. The objective was to determine the N_2O fluxes from *Quali T-47* cultivar of tomato with three irrigation rates (100, 80 and 60 % of total Evapotranspiration (ET)) and three N fertilizer rates of Urea Ammonium Nitrate (UAN-32 at 100, 150 and 200 lbs N/acre). The irrigation method was sub-surface drip irrigation (SDI) and the crop was grown a sandy loam soil. The data collected from the current research would supplement that collected for processing tomatoes from a related study funded by the California Energy Commission (CEC) and conducted by researchers at University of California, Davis. Ultimately, the information from both studies will contribute to the ongoing efforts to quantify N_2O emissions from fertilizer applications in California's agricultural soils.

Based on the above, the focus of this final report will be on the research aimed at determining N_2O flux measurements for cotton and tomatoes grown on sandy loam soils and fertilized with UAN-32.

(D) Work Description

I. Cotton Experiment

The specific objectives of the cotton research were:

a) Comparison of the N_2O fluxes from beds and furrows at various management events in cotton cropping system;
b) Determination of the effect of three rates of N fertilizer, applied with and without Nutrisphere-N® (NSN) inhibitor on N_2O fluxes in cotton cropping system; and,
c) Determination of EFs for the cotton grown on sandy loam soils and fertilized with UAN-32 applied with and without Nutrisphere-N; and,

The study was conducted during 2011, 2012 and 2013 growing seasons at two locations: site A in Kings County, near Hanford, CA and the site B at California State University (CSU), Fresno, CA.

Site A

The first site was located at the South-East corner of the Graingeville Boulevard and 5th avenue intersection, Hanford, California with GPS location; 36°34'26.88" N and 119° 54'61.43" W. The soil at this location is characterized as a Youd Fine Sandy Loam soil. At this site, Phytogen 725 RF, an Acala variety of cotton was grown with furrow irrigation. This variety of cotton is Round Up tolerant and was planted on 30 inch beds in early April with John Deere Maxi Merge Vacuum six row planter at the rate of 15 pounds of seed per acre. Inter-row cultivation was done 35 days after planting (DAP) to control the weeds in the field. Approximately 50 DAP, 136 lbs N/acre of UAN-32 fertilizer was applied with knife injectors in the beds on either side of the cotton plants. During the previous Fall, approximately 10 pounds per acre (2 tons) of turkey manure was applied to winter wheat planted for silage. All other agronomic practices for the pest control were typical of those used by the grower over the years of cotton production. In the first week of October Cotton Quick at the rate of 3 quarts and Gin Star at the rate of 4 ounces per acre were applied as defoliant. The crop was harvested in the last week of October using a John Deere six row picker. Similar planting and agronomic practices were conducted over the three years of the study.

Site B

The second field study was conducted during the 2011- 2013 growing seasons on Fresno State's University Agricultural Laboratory (UAL), commonly referred to as the Fresno State farm having GPS coordinates as latitude 36°49'54.954" N and longitude 119° 44'83.26" W.

The field having Ramona Sandy Loam type of soil was planted with Phytogen 725 RF cotton variety. This Acala type, Round up tolerant cotton was planted in mid-April using a John Deere Maxi Merge six row planter. The previous crop for 2011 was cotton followed by winter wheat for silage.

Approximately 61 DAP, four different rates of UAN-32 i.e., 0, 50, 100 and 150 lbs N/acre were applied to 4 plots consisting of 6 rows (30-inch x 1250 ft.) and other 3 plots received 3 different rates of UAN-32 (50, 100 and 150 lbs N/acre) with Nutrisphere- N (NSN). The NSN was applied at a rate of 0.05%per unit volume of UAN-32. The UAN-32 was applied with a knife injector in bands on both sides of the beds. The field was cultivated twice and sprayed once with Roundup for early weed control. At 81 DAP, Potassium nitrate and urea were applied at a rate of 5 lbs/ acre as a foliar spray combined with Carbine and Surfactant. Diamond and Pix were sprayed 84 DAP. In 2013 an additional treatment in which plots with no fertilizer and just NSN was included in the field experiment.

Harvest was performed using a John Deere 9900 four row picker. Four rows were machine harvested and the seed-cotton weighted using a portable boll buggy scales. The seed-cotton was moduled for transport to the gin. A gin turnout of 0.36 was used to convert seed-cotton harvest weights to lint yields.

<u>Nitrous Oxide Gas Samples</u>

Rectangular stainless-steel chamber bases (50 x 30 x 8 cm) were installed in each plot to a depth of approximately 5 cm. These chambers were left in place throughout the growing season. Flux measurements were performed, following the USDA-ARS GRACEnet project protocols (Parkin and Venterea, 2010), by placing stainless steel chamber tops lined with a rubber gasket on the chamber bases and collecting gas samples after 0, 20 and 40 minutes. Air samples were collected from the chamber's headspace with a needle and a 20 ml syringe and were stored at room temperature (20^{o}) in 12 ml Labco glass vials until analyzed with a Gas Chromatograph. Chamber and air temperatures were measured during each gas sampling time.

N_2O fluxes were calculated from the rate of change of the concentration of N_2O in the chamber headspace and for this GRACEnet protocol was followed. According to this protocol, if the rate of change of trace gas concentration in the headspace was constant then linear regression was used to calculate the slope of concentration vs time data otherwise curvi-linear concentration data with time was used (Parkin and Venterea, 2010).

The Gas Chromatograph data compiled by UC Davis group managed by Dr. Martin Burger, provided results as N_2O concentration per 12 ml vials. The gas standards (0, 0.4 and 1 ppm) were used to apply standard curve relationship to calculate the gas concentration of samples in ppm units. Further, ppm data was adjusted for the chamber temperature variation and converted to flux data by following the same protocol used by the other researchers for N_2O projects funded by CDFA, CEC and the California Air Resources Board (CARB). For calculation of total N_2O–N emissions for different treatments throughout the crop season, flux rates over the entire crop season were interpolated linearly and integrated to determine the cumulative N emissions calculated in the units g N/ha. The final flux data from both the sites (A and B) was subjected to analysis of variance (ANOVA) at a probability of 0.05 using Microsoft Excel 2010 software. The separation of means was conducted using Tukey's HSD (α =0.05).

Emission Factors (EFs) Calculations

To determine the EF for cotton with different treatments, the first step was to subtract the baseline N_2O emissions from the total N_2O fluxes throughout the entire crop season and then these were converted into kg N/ha by dividing with 1000. Further, the kg N/ha was converted into lbs N /acre emitted by multiplying with 0.89. Finally, the N_2O emissions factor for each treatment was calculated by the following equation;
EF (%) = lbs N per acre emitted x 100 / total lbs N per acre applied

For comparison, the EF was also determined using the following IPCC equation derived by Bouwman (1996) for direct N_2O emissions from agricultural soils:

E= 1+0.0125. F
where, E is the emission rate (Kg N_2O-N/ha/year), the value of 1 Kg N/ha is the background emission rate and F is the fertilizer application rate.

II. Tomato Experiment

The tomato study was conducted on Center for Irrigation Technology (CIT) research plots at California State University, Fresno located at GPS co-ordinates latitude 36 ^{o} 81' 51.63" N, longitude -119 ^{o} 73'21.38" W. After review of the limited data collected in 2011, a decision was made to repeat the tomato trials in 2012 and 2013. The primary objective was to determine the effect of a deficit sub-surface drip irrigation (SDI) regime and multiple fertilizer application rates on soil N_2O emissions in a fresh market tomato cropping system grown on a sandy loam soil.

Soils for the tomato experiment were characterized as Hanford Fine sandy loam soil. The beds were 5 feet wide and 75 feet long. Fresh market tomato cultivar Quali T 47, which is a beefsteak, determinate and late maturity type was hand transplanted in late May in 2012 and in mid-June in 2013. Plant spacing was 12 inches. The crop was harvested in August 2012 and in September 2013, equivalent to 100 days after transplanting (DAT) by hand picking the fruits. The fruits were separated into green, breaker and red fruits. The total yield, marketable and non-marketable yields were recorded. In addition, the Brix values, a measure of the total soluble sugars (TSS), of red fruits were recorded.

The experimental layout was a split plot design with SDI rates (I) being the major factor and fertilizer rates (F) being the sub plot factor. The irrigation rates comprised of one standard rate and two deficit irrigation rates where the I1 treatment was equivalent to 100% of the daily evapotranspiration rate (ET), I2 was 80% ET and I3 was 60% ET.

The ET was calculated using the California Irrigation Management Information System (CIMIS) station number 80 located on the CSU, Fresno campus as a reference ET, which was then converted to use with a tomato cropping system using published crop coefficients (Amayreh and Al-Abed, 2005). A manifold with three irrigation lines for the three irrigation rates controlled by electronic valves in connection with automated data logger system. An electronic meter was used to calculate the amount of water added to each irrigation treatment. Irrigation was performed using a sub-surface drip irrigation system, with drip lines buried at six inches.

Urea Ammonium Nitrate (UAN 32) was used at three different rates 100 lbs/acre (F1), 150 lbs/acre (F2) and 200 lbs/acre (F3) as fertilizer rate treatments. In 2012, the fertilizer was applied by splitting net application rate into 10, 15, 20, 20, 20 and 15% of at 9, 21, 27, 45, 56 and 65 days after transplanting (DAT). In 2013, a basal rate of 15lbs N/ac was applied to all plots. Then, the remainder of the fertilizer for the three treatment rates were applied at rates equivalent to 10, 10, 20, 25 and 20% of the total N rate at 13, 27, 40, 47 and 54 DAT. Liquid fertilizer was measured for each plot and hand applied by mixing with water using plastic squeeze bottles for uniform application. Typical nitrogen application rate in California used by growers is 125-250 lbs/acre.

<u>Sampling Schedule</u>

A similar N_2O sampling approach as that described above for the cotton experiment was adopted. Briefly, rectangular stainless-steel chamber bases (50 x 30 x 8 cm) were installed in each plot to a depth of approximately 5 cm. These chambers were left in place throughout the growing season. Flux measurements were performed, following the USDA- ARS GRACEnet project protocols (Parkin and Venterea, 2010), by placing stainless steel chamber tops lined with a rubber gasket on the chamber bases and collecting gas samples after 0, 20 and 40 minutes. Air samples were collected from the chamber’s headspace with a needle and a 20 ml syringe and were stored at room temperature (20^{o}) in 12 ml Labco glass vials until analyzed with a Gas Chromatograph. Chamber and air temperatures were measured during each gas sampling time.

A total of 10 sampling events occurred over the 2012 season. Of these 10 events, 9 were centered around fertilizer applications with sampling events at DAT 27, 43 and 64 occurring a day prior to fertilizer application, events at DAT 28, 45 and 65 occurring the same day as fertilizer application and events at DAT 29, 46 and 66 occurring one day after fertilizer application. The final sampling event occurred at harvest and corresponded to DAT 100.

In 2013, there was a total of 22 sampling events. Generally, flux measurements were conducted a day before the fertilizer application, and then at 2 hours, 24 hours and 48 hours after the fertilizer application during drip irrigation. Sampling events were centered around fertilizer applications on the following DAT: 12, 26, 40, 47, 54, and 64. The final sampling event occurred prior to harvest and corresponded to DAT 83.

(E) Results & Discussion

I. Cotton Experiment

N_2O Fluxes at Various Management Practices in 2011

At Site A, from measurements taken at the fertilization and two irrigation events, the N_2O fluxes from beds averaged 201 (±46) µg $N/m^2/d$ which was approximately 127% more than that detected from the furrows. After fertilizer application early in the season, there was a high degree of variability in the N_2O fluxes, and hence there was no significant difference between the N_2O fluxes from the beds and those from the furrows (Figure 1). After irrigation events during the season with no further addition of fertilizers, fluxes from the beds tended to decrease from the beds. When the first irrigation was applied after the fertilizer addition, N_2O fluxes from the furrows were 63% lower than that from the beds (Figure 2). After the last irrigation, N_2O fluxes from the beds were reduced to 126 µg $N/m^2/d$, whereas those from the furrows remained similar as during early in the season i.e., 100 µg $N/m^2/day$ (Figure 3). After the harvest of the crop, when crop residue was ploughed back into the field, N_2O fluxes from the beds further reduced to approximately, 20 µg $N/m^2/d$ but the fluxes from the furrows remained 100 µg $N/m^2/d$ as measured during the previous event (Figure 4).

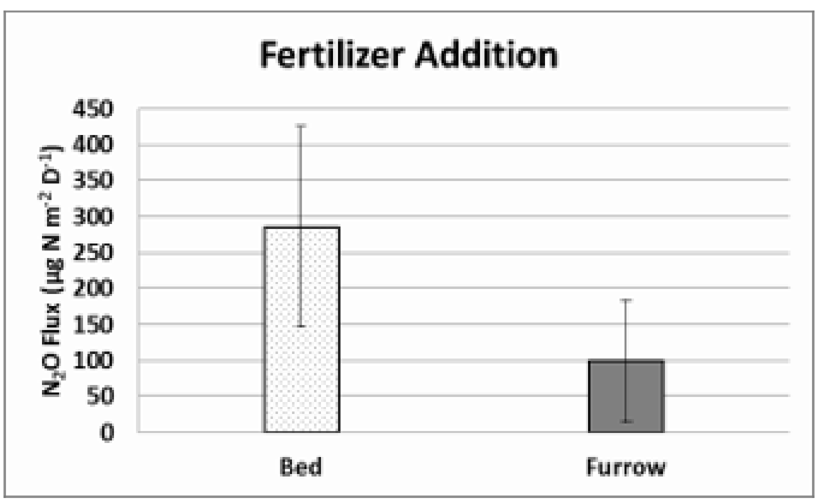


Figure 1. Mean nitrous oxide emissions (µg $N/m^2/d$) from beds and furrows for cotton after fertilizer application in 2011, at Site A.

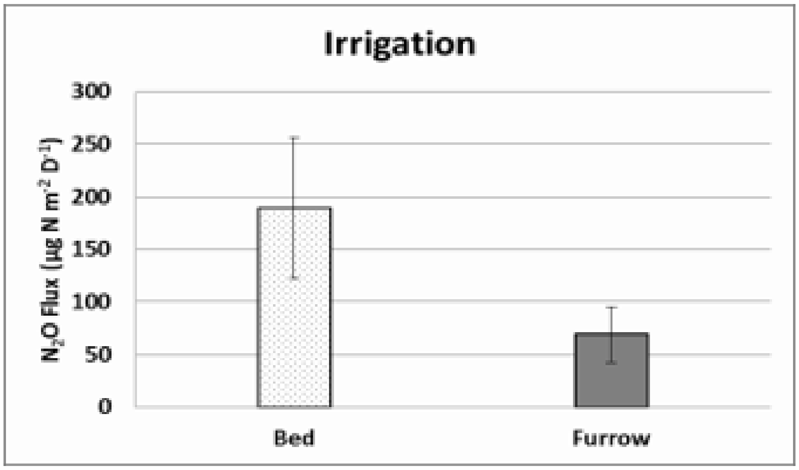


Figure 2. Mean nitrous oxide emissions (µg N/m^2/d) from beds and furrows for cotton after irrigation in 2011, at Site A.

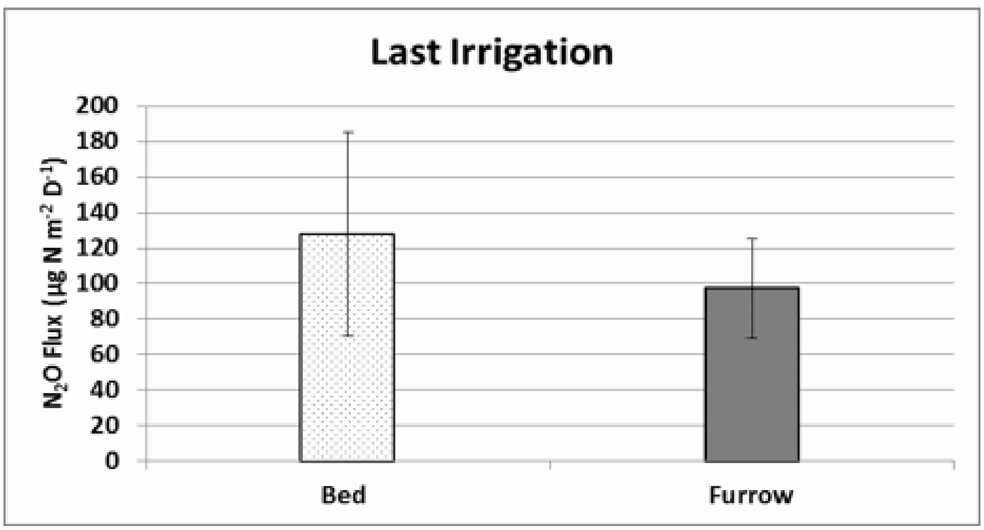


Figure 3. Mean nitrous oxide emissions (µg N/m^2/d) from beds and furrows for cotton after last irrigation event in 2011 at Site A.

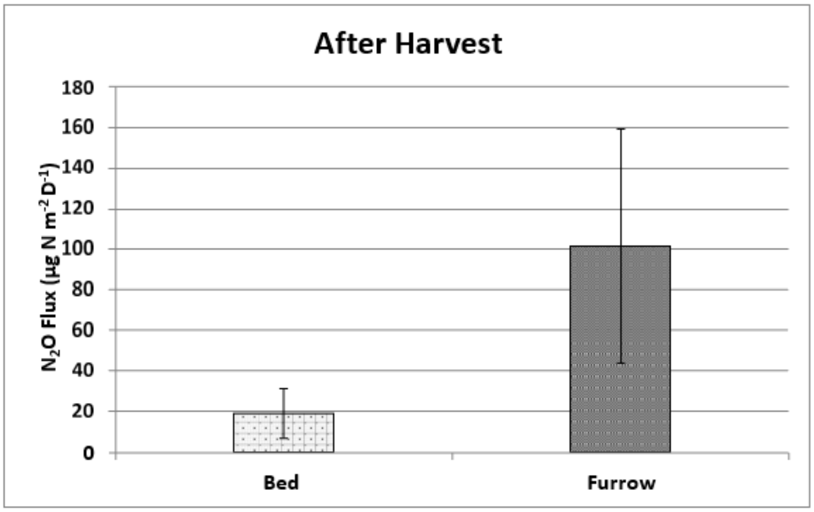


Figure 4. Mean nitrous oxide emissions (µg N/m^2/d) from beds and furrows for cotton after harvest and disking of the field in 2011 at Site A.

At Site B, after fertilizer application the N_2O fluxes ranged from less than 240 to 960 µg N/m^2/d for the plots receiving 50 to 100 lbs N/acre respectively. The N_2O fluxes from the treatment with 100 lbs N/acre were observed to be the highest as compared to other treatments, whereas the inhibitor reduced these fluxes by as much as 59% (Figure 5).

After the first irrigation, which was followed fertilizer application, the N_2O fluxes were observed to be the highest of the entire season; ranging from 480 to 1920 µg N/m^2/d. The N_2O fluxes from the treatments with inhibitor remained almost similar to those as recorded before irrigation whereas the fluxes from the treatments without inhibitor were double the fluxes as observed after fertilizer addition. The N_2O fluxes for 50 and 100 lbs N/acre were 515 and 1900 µg N/m2/d respectively, where inhibitors reduced these fluxes by 66% for both the treatments. The N_2O fluxes for the treatment with 150 lbs N/acre were 1933 µg N/m2/d and from the same treatment applied with inhibitor fluxes were 46% lower (1044 µg N/m2/d) (Figure 6).

After the fourth irrigation, there was no significant difference in the fluxes due to inhibitor whereas fluxes observed to be highest from the 150 lbs n/acre treatment as compared to 50 and 100 lbs N/acre. The average N_2O fluxes were 203 µg N/m2/d with a high degree of variability (Figure 7). After the final irrigation, N_2O fluxes were much lower compared to that measured after the first irrigation. Furthermore, there was no correlation between the N_2O fluxes, and the fertilizer applied early in the season (Figure 8). Following the harvest of the crop and ploughing of the crop residue into field, there was no significant difference between different fertilizer rate and inhibitor treatments. In addition, during this event a high degree of variability was observed for N_2O fluxes (Figure 9).

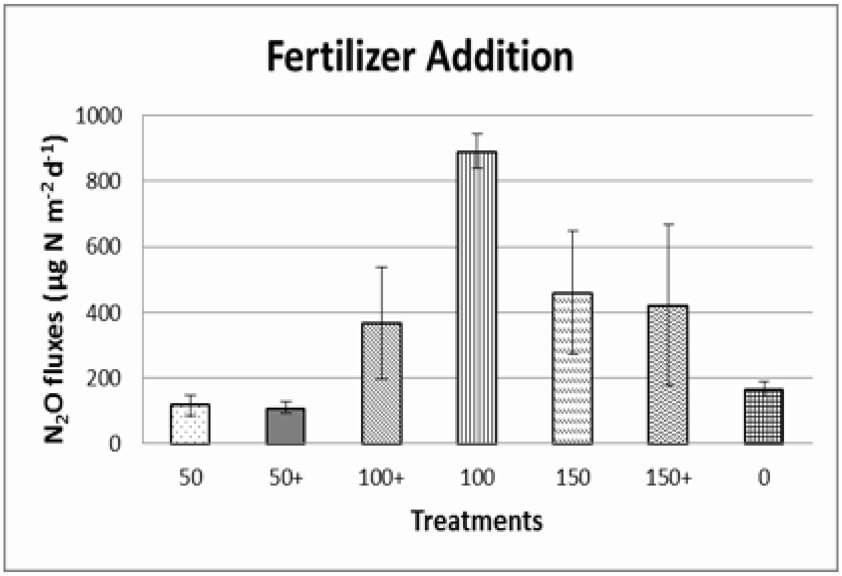


Figure 5. Mean nitrous oxide emissions (µg N/m^2/d) in 2011 from different fertilizer and inhibitor treatments for cotton after fertilizer application at Site B.

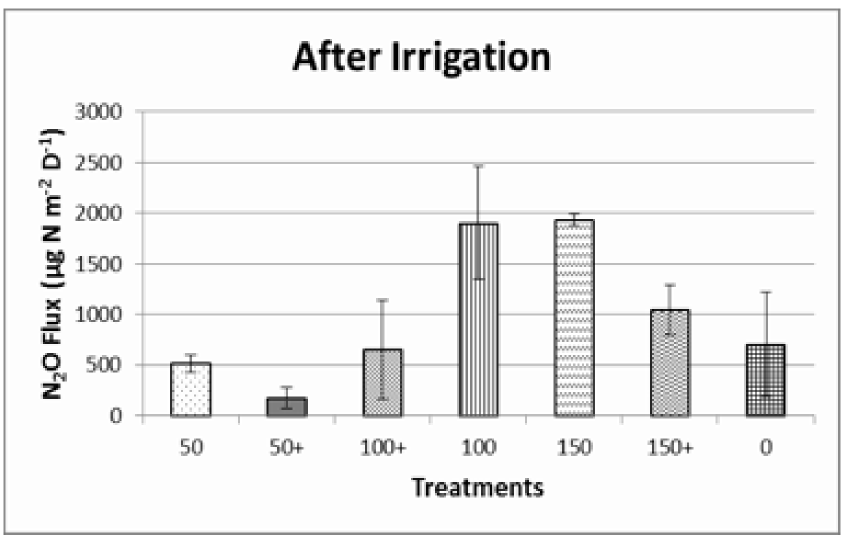


Figure 6. Mean nitrous oxide emissions (µg N/m^2/d) from different fertilizer and inhibitor treatments for cotton after first irrigation in 2011 at Site B.

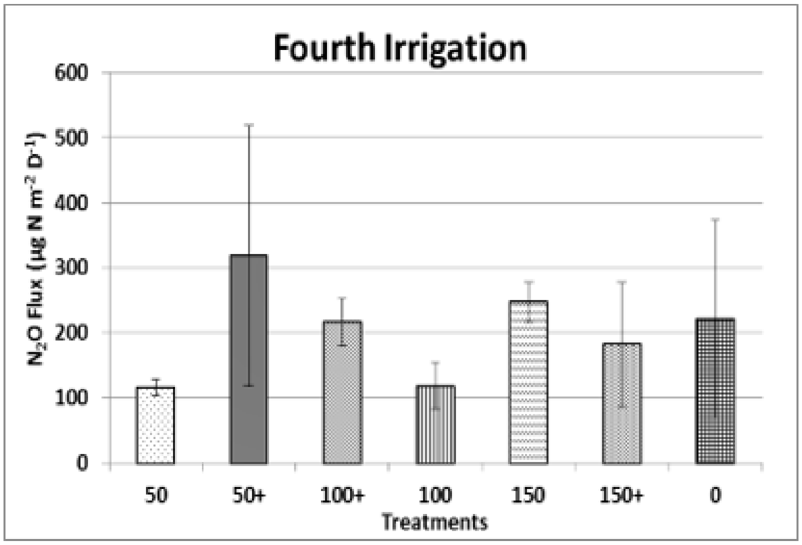


Figure 7. Mean nitrous oxide emissions (μg N/m^2/d) from different fertilizer and inhibitor treatments for cotton after fourth irrigation in 2011at Site B.

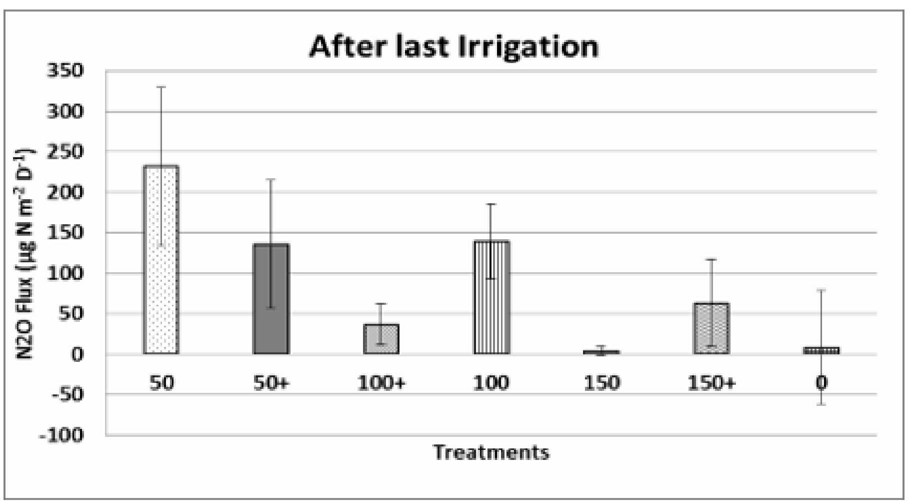


Figure 8. Mean nitrous oxide emissions (μg N/m^2/d) from different fertilizer and inhibitor treatments for cotton after last irrigation in 2011 at Site B.

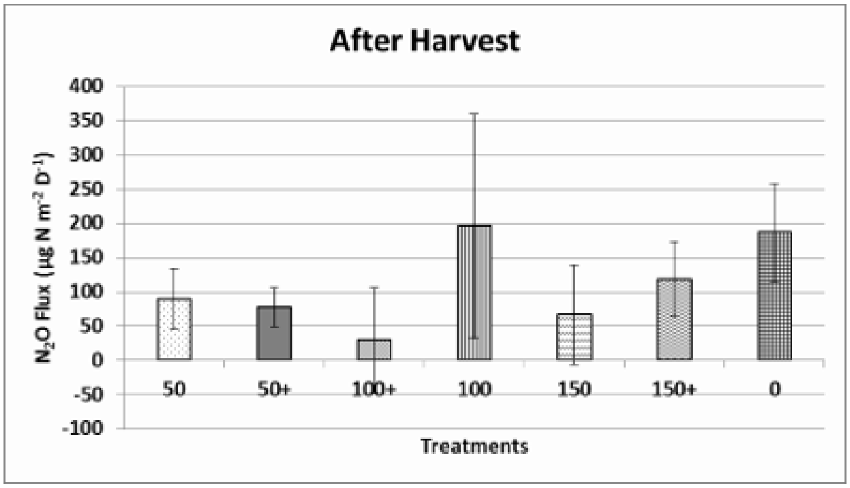


Figure 9. Mean nitrous oxide emissions (µg N/m^2/d) from different fertilizer and inhibitor treatments for cotton after harvest in 2011 at Site B.

Overall in 2011, the N_2O fluxes were observed to be influenced by the UAN-32 fertilizer rates and irrigation events at Site B. In addition, the Nutrisphere-N reduced the N_2O fluxes by as much as 50%. A major limitation during this year was that due to sampling being conducted at only four events, it was not possible to get detailed time series N_2O flux trends. Hence, the findings for the 2011 season can best be described as "snapshots" of the N_2O fluxes following episodic events such as fertilization, irrigation and incorporation of residue, which have been documented to significantly affect N_2O emissions. A further disadvantage with this method of snapshot sampling was that any linear interpolation of flux patterns between these events may not be accurate, due to uncertainties associated with fluxes occurring during the relatively long period between sampling events. Therefore, in 2012 and 2013 it was decided to conduct more frequent samplings and generate a time series pattern of N_2O fluxes throughout the crop period.

N_2O Fluxes Throughout the Cotton Crop Season in 2012 & 2013

Site A- Hanford-2012

During 2012, the N_2O fluxes from the beds and furrows at Site A followed similar patterns throughout the crop growth period. Highest N_2O fluxes (23063 µg N/m^2/d) were observed to occur after first irrigation which was applied 24 days after fertilizer application (Figure10), which was equivalent to between 81 and 96 days after planting (DAP). In addition, there were instances when the furrows acted as a sink for N_2O, for example, at 40 and 61 DAP (Figure 11 and 12). These negative fluxes were observed early in the season after planting and later after the crop harvest and ploughing of the crop residue.

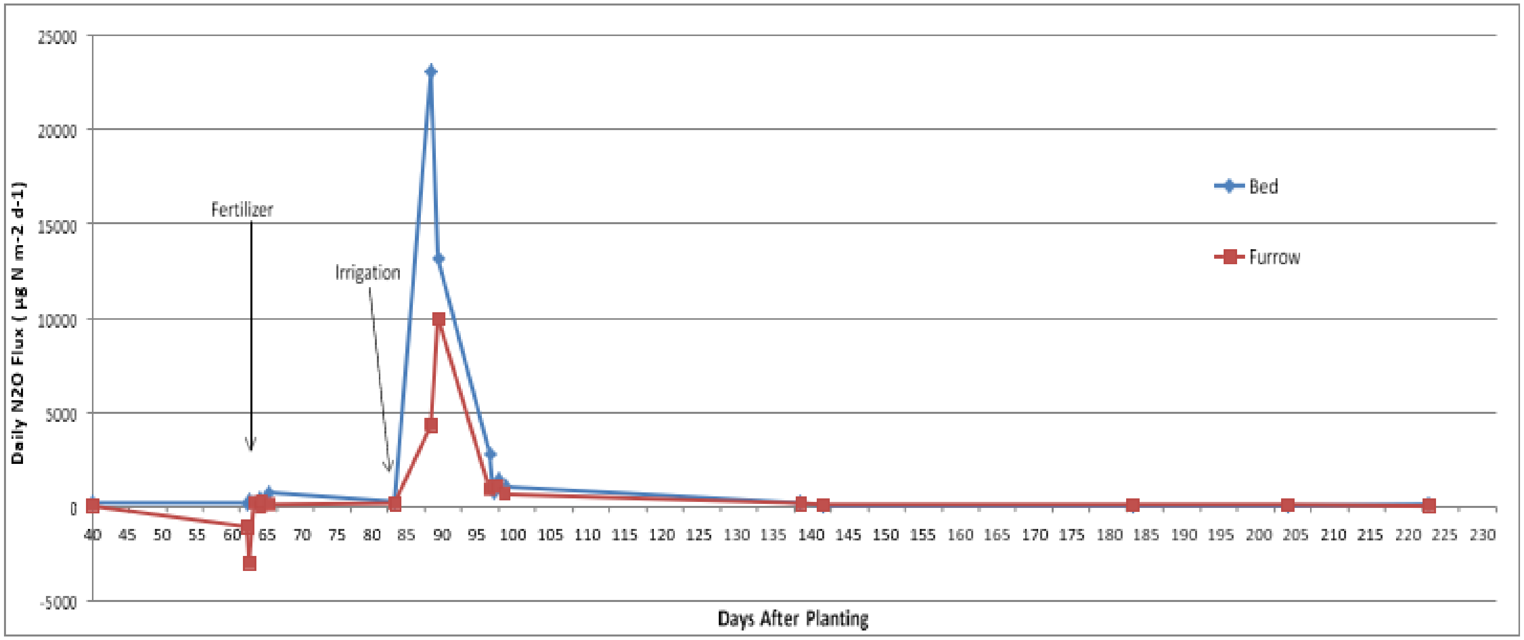
Generally, conditions that interfere with N_2O diffusion results in the consumption of N_2O by the soil (Chapius-Lardy et al., 2007). The intermediate denitrification process stage which involves the reduction of N oxides during respiration of hetereotrophic bacteria is normally associated with the soil acting as a sink for N_2O. In addition, nitrifiers may also play a part in soils acting as N_2O sinks via the pathway known as nitrifier-denitrification. Basically, the process involves the transformation of NO_2^- to NO to N_2O and finally to N_2 (Cascitti and Ward, 2001; Schmidt et al., 2004). In the current study, no attempt was made to identify the microbial populations, so it is not clear which of the nitrifying or denitrifying processes would have resulted in the negative fluxes observed during 2012.

When various events were observed thoughout the crop season, at 40 DAP N_2O fluxes from beds were significantly (P = 0.03) higher than that observed from the furrows. During this event, significant amount of N_2O fluxes were emitted from the beds i.e., 116 µg N/m^2/d whereas furrows acted as sinks i.e., -20 µgN/m^2/d (Figure 11). For measurements taken at 2 hrs before fertilizer application at 61 DAP, there was no significant difference between the N_2O fluxes from beds and furrows (P = 0.43) (Figure 12). Similarly, at 2, 16, 24, 48 and 72 hours after fertilizer application, there were no significant differences in the N_2O fluxes from beds and furrows (P = 0.48, 0.21, 0.41, 0.51 and 0.43 respectively) (Table 1).

Before the first irrigation i.e., 81 DAP, there was no significant difference between the N_2O fluxes from beds and furrow (P = 0.23). Two days after irrigation i.e., 86 DAP, even though the N_2O fluxes were observed to be the highest fluxes of the season but due to high degree of variability there was no significant difference between the fluxes from beds and furrows (P = 0.29). Similarly, at 3 days after the irrigation event, N_2O fluxes from the beds were comparable to those from the furrows (P = 0.56). In addition, at 94 DAP i.e., before the cultivation of field for weed control there was no significant difference between the fluxes from the beds and furrows (P = 0.21). At 2, 24 and 48 hours after cultivation there was no significant difference between the treatments for N_2O fluxes (P = 0.64, 0.64 and 0.48 respectively) (Table 2).

Mean N_2O fluxes for the beds and furrows measured at the following events in 2012, for which there were no significant differences, are summarized in Table 3: a) before and after the last irrigation (136 and 139 DAP); b) before defoliation (181 DAP); and, c) after defoliation (202 DAP). After the harvest of the crop and ploughing of crop residue into the field (221 DAP), the N_2O fluxes from the beds were significantly higher at P=0.18 than that of the furrows which acted as a sink for N_2O.

Figure 10. Nitrous oxide emissions from beds and furrows throughout the 2012 growing season for cotton at Site A.



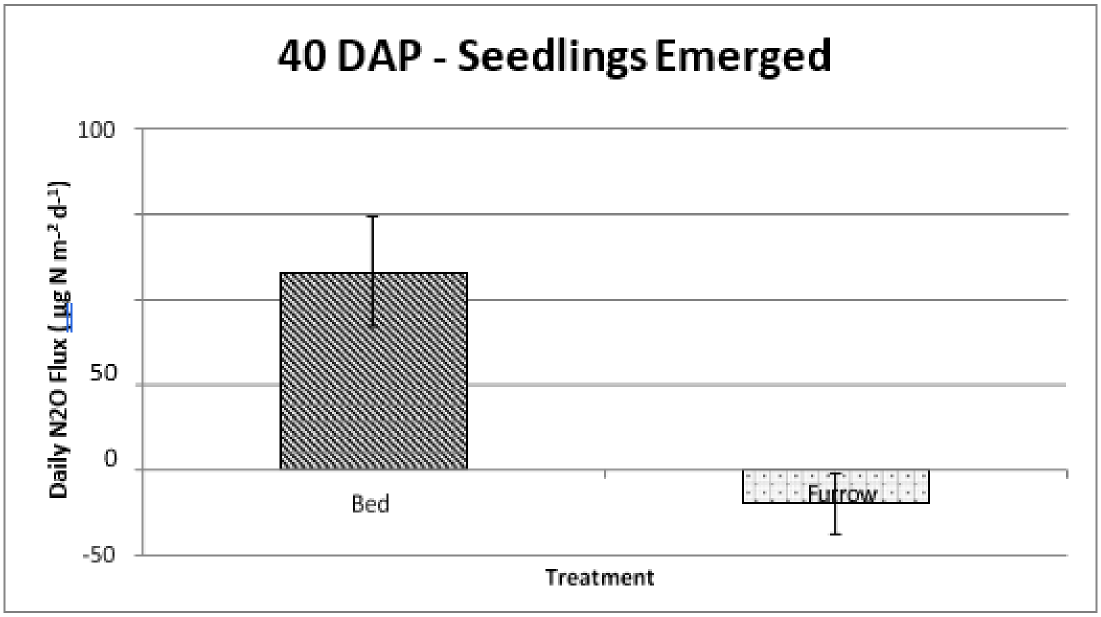


Figure 11. Mean nitrous oxide emissions (µg N/m^2/d) from the beds and furrows at 40 DAP in 2012 for cotton crop at Site A.

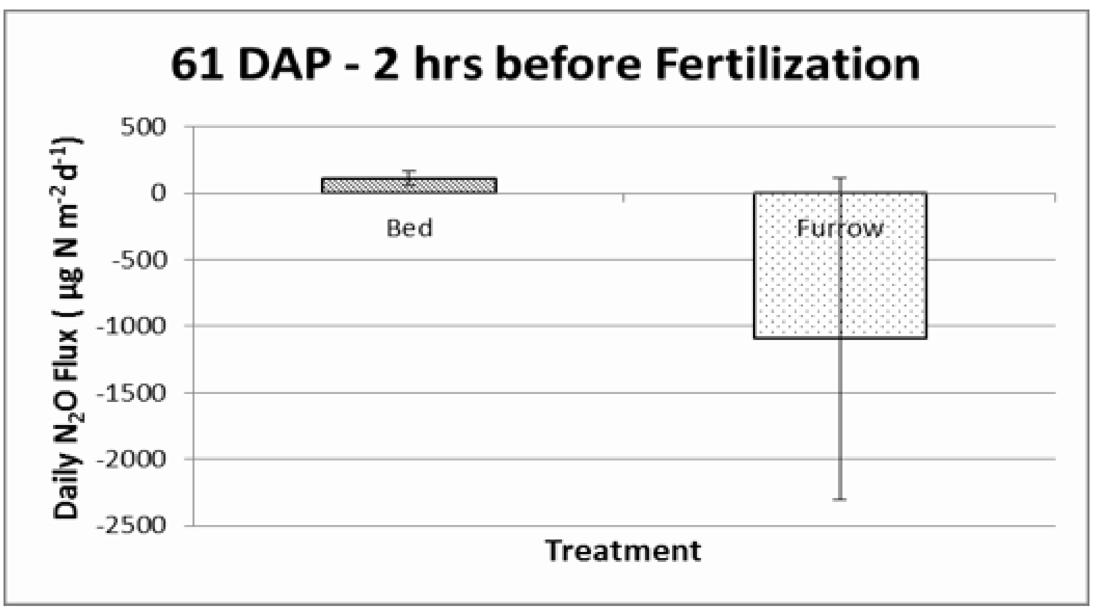


Figure 12. Mean nitrous oxide emissions (µg N/m^2/d) from the beds and furrows at 61 DAP in 2012 for cotton crop at Site A.

Table 1. Mean nitrous oxide emissions ±SE (µg N/m²/d) for cotton crop at Site A after planting and during fertilizer application events in 2012 from beds and furrows.

	40	61	61.4	62	62.8	63	64
Bed	115.9(±32.07)a	110.9(±53.7)a	276.7 (±141.6) a	153.6(±17.0) a	352.6(±402.5) a	310.9 (±168.0) a	694.6(±631.2)a
Furrow	-19.8(±17.7) b	-1093.2(1211.2) a	-3053.6(±3828.1) a	108.2(±24.9) a	-77.3(±88.9) a	163.5 (±101.9)a	65.6 (±47.47) a
P-value	0.03	0.43	0.48	0.21	0.41	0.51	0.43

Table 2. Mean nitrous oxide emissions ±SE (µg N/m²/d) for cotton crop at Site A during irrigation and cultivation events in 2012 from beds and furrows.

	81	86	87	94	94.4	95	96
Bed	227.7 (±76.5) a	23062.4(±12934.4)a	13062.8 (±333.8) a	2761.8 (±1170.0) a	687.2 (±70.9) a	1367.2 (±653.6) a	969.4 (±405.4) a
Furrow	85.7 (±64.1) a	4249.8 (±3265.1)a	9905.6 (3737.9) a	805.6 (±417.7) a	970.2 (±519.3) a	977.2 (±372.0) a	607.4 (±206.0) a
P-value	0.23	0.29	0.56	0.21	0.64	0.64	0.48

Table 3. Mean nitrous oxide emissions ±SE (µgN/m²/d) for cotton crop at Site A during irrigation, defoliation and harvest events in 2012 from beds and furrows.

	136	139	181	202	221
Bed	117.2 (±30.5) a	-71.9 (±127.6) a	-2.5 (±14.8) a	3.5 (±5.5) a	6.42 (±16.19) a
Furrow	89.4 (±20.1) a	7.4 (±111.9) a	19.7 (±5.07) a	18.1 (±36.7) a	-26.8 (±10.38) a
P-value	0.50	0.66	0.29	0.73	0.18

Site A- Hanford-2013

In 2013, the N_2O fluxes at Site A corresponding to the various sampling events outlined in Table 4 are shown in Figure 13. Based on the ANOVA presented in Table 5, the significant differences in the N_2O fluxes between the beds and the furrows occurred primarily during the irrigation events after the fertilizer application, which was equivalent to between 73 and 99 DAP. This peak in N_2O emissions corresponded to that observed in 2012 as shown in Figure 10. During the period from 125 DAP to 146 DAP, the mean N_2O emissions from the beds and furrows were similar (Table 5), even though there were three irrigation events. This would imply that the N_2O emissions from the fertilizer was no longer occurring as the N fertilizer would have either been taken up by the plants, transformed into another N form, stored in the soil, or lost to atmosphere as other reactive N forms.

Table 4. Sampling schedule for measurement of N_2O emissions at Site A during 2013.

No.	Date	DAP	Sampling events
1	6/4/2013	64	first sampling (before irrigation)
2	6/11/2013	71	before fertilizer application (after irrigation)
3	6/11/2013	71.5	2hrs after fertilizer application
4	6/12/2013	72	24 hrs after fertilizer application
5	6/13/2013	73	48 hrs after fertilizer application
6	6/24/2013	84	3 days after irrigation
7	6/25/2013	85	4 days after irrigation
8	6/26/2013	86	5 days after irrigation
9	7/8/2013	98	3 days after irrigation
10	7/9/2013	99	4 days after irrigation
11	7/10/2013	100	5 days after irrigation
12	7/25/2013	125	10 days sampling event
13	8/5/2013	131	after irrigation
14	8/6/2013	132	2nd sampling after irrigation
15	8/19/2013	133	after irrigation
16	8/20/2013	145	2nd sampling after irrigation
17	8/21/2013	146	3rd sampling after irrigation

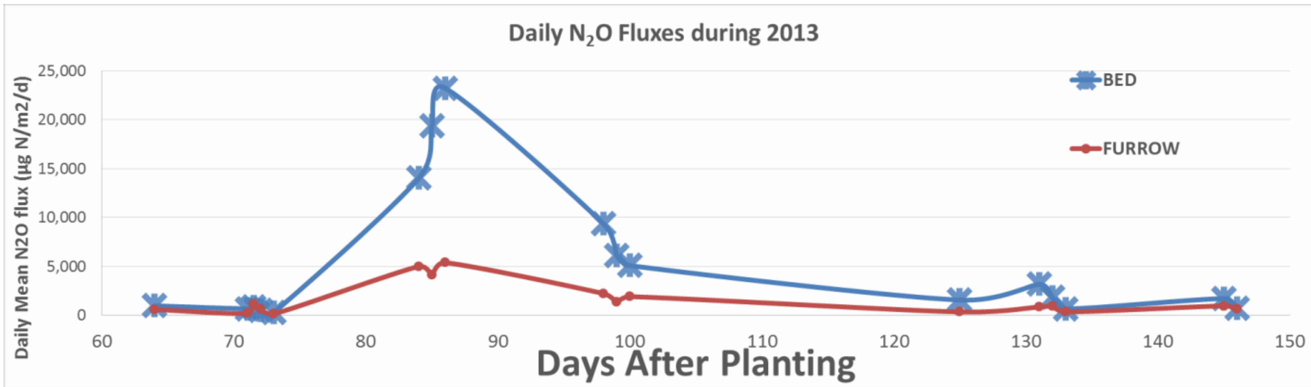


Figure 17. Nitrous oxide emissions from beds and furrows throughout the 2013 growing season for cotton at Site A.

Table 4. Mean nitrous oxide emissions ±SE ($\mu gN/m^2/d$) from beds and furrows, along with ANOVA, for the cotton crop at Site A during the various sampling events in 2013.

Date	**4-Mar**	**11-Jun**	**11-Jun**	**12-Jun**	**13-Jun**	**24-Jun**
DAP	**64**	**71**	**72**	**72**	**73**	**84**
Bed	968.99(±284.01) a	669.17 (±123.91) a	842.38 (±341.27) a	504.49(±153.46) a	277.51 (±30.74) a	14029.3 (±672.69) a
Furrow	593.86(±184.40) a	188.57(±83.86) b	1137.50 (±133.98) a	677.7 (±281.19) a	136.91(±20.04) b	5001.74 (±1146.64) b
P-value	0.330	**0.033**	0.466	0.617	**0.019**	**0.002**

Date	**25-Jun**	**26-Jun**	**8-Jul**	**9-Jul**	**10-Jul**	**25-Jul**
DAP	**85**	**86**	**98**	**99**	**100**	**125**
Bed	19372.17 (±3981.84) a	23239.51 (±545.00) a	9349.07 (±1069.85) a	6110.36(±1399.94) a	5083.38(±1407.28) a	1562.76(±606.84) a
Furrow	4158.05 (±1443.33) b	5386.97 (±1178.18) b	2220.70 (±186.59) b	1337.01(±291.49) b	1911.30 (±269.31) a	346.80 (±156.61) a
P-value	**0.023**	**0.000**	**0.003**	**0.029**	0.091	0.124

Date	**5-Aug**	**6-Aug**	**7-Aug**	**19-Aug**	**20-Aug**
DAP	**131**	**132**	**133**	**145**	**146**
Bed	3173.23 (±2392.78) a	1845.15(±540.83) a	663.79 (±223.06) a	1707.37(±225.94) a	734.19(±264.52) a
Furrow	857.85 (±619.62) a	930.35(±181.28) a	345.37(±85.34) a	959.66(±682.23) a	657.21(±252.65) a
P-value	0.402	0.184	0.253	0.357	0.844

Site B- Fresno- 2012

At the Fresno location (Site B), the N_2O fluxes in 2012 followed the similar temporal trends for all the fertilizer rates and inhibitor treatments throughout the crop season (Figure 18). The N_2O fluxes were observed to be highest when irrigation was applied after fertilizer application ranging up to 10,000 µg N/m^2/d and it decreased with time (Figure 18). The highest fluxes were observed between 67 and 104 DAP.

In 2012, the first sampling event was 16 DAP as a measure of background N_2O fluxes. During these measurements, the beds had just been prepared and shaped for the seeding of cotton. The daily N_2O flux was observed to be high ranging from 300 to 1800 µg N m^{-2}d^{-1} which might be due to the relatively high degree of soil disturbance involved in the preparation practice. There was no significant difference in N_2O fluxes among any of the plots. One day after planting (1 DAP) the cotton which was followed by one rain event, there was no significant difference in N_2O emissions among the treatments. At 62 DAP, which represented the cultivation of the field prior to irrigation, there were no significant differences in daily N_2O fluxes with the average N_2O flux ranging from 40 to 500 µg N m^{-2}d^{-1}. Fertilizer was applied at 67 DAP and after 2 hrs of fertilization there was no significant difference between the treatments. Similarly, one day after fertilizer application, there was no significant difference among any of the treatments of different fertilizer rates and inhibitor (Table 5).

Seventy DAP the field was cultivated for weed control and the first irrigation was applied on the same day. At 73 DAP, the highest daily N_2O fluxes of the season were detected. However, there was no significant difference in N_2O fluxes among the 7 treatments. The N_2O fluxes at the fertilization event ranged from 1200 to 6620 µg N m^{-2}d^{-1} compared to the pre fertilization ranges of 76 to 435 µg N m^{-2}d^{-1}. Similarly, after 4 days of irrigation, there was no significant difference among the plots receiving 50, 100 and 150 lbs N/acre with and without NSN inhibitor. At 103 DAP i.e., 3 days after the 2nd irrigation, N_2O fluxes from the 50 lbs N/acre treatment were significantly higher than that from other treatments. The NSN reduced these emissions by 91% (Figure 19), whereas 4 days after 2nd irrigation there was no significant difference among the treatments (Table 6).

At 150 DAP, which represented measurements taken prior to the last irrigation event, N_2O fluxes from 100 lbs N/acre treatment were significantly higher than from the other treatments and the inhibitor reduced these emissions by more than 50% (Figure 19). After the last irrigation (162 and 163 DAP) and before defoliation (185 DAP), N_2O fluxes from all the treatments were similar. However, after defoliation and rain event (211 DAP), N_2O fluxes from the 100 lbs N/acre treatment were significantly higher than from other treatments (Figure 20). During this event, the inhibitor reduced these emissions by as much as 60% (Figure 20) (Table 7).

After harvest, following a rain event and disking (226 DAP), the fluxes were negative from treatments with Nutrisphere-N inhibitor (Figure 21). As discussed before, these negative fluxes may be due to processes such as the nitrifier-denitrifier pathway which would have resulted in the soil acting as a sink for the N_2O.

Figure 18. Nitrous oxide emissions throughout the 2012 crop season from cotton applied with three rates of fertilizer treatments with and without Nutrisphere-N inhibitor at Site B.

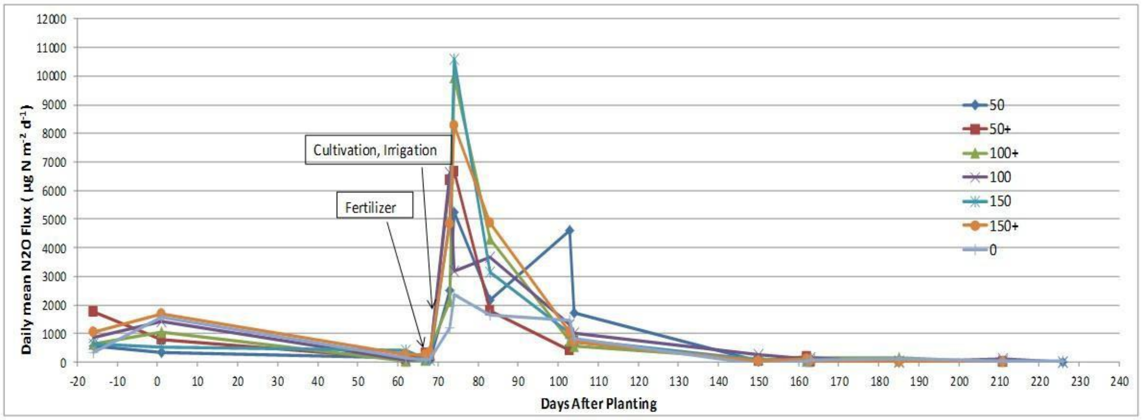


Table 5. Mean Nitrous oxide emissions ±SE (µg N/m^2/d) for cotton crop before planting, after planting, cultivation and fertilizer application events in 2012 from different treatments at Site B.

Treatment	16_DBP	1_DAP	62_DAP	67_DAP	68_DAP
50	545.5 (±377.92) a	347.5 (±171.49) a	141.7 (±81.36) a	123.1 (±61.16) a	76.4 (±103.76) a
50+	1755.4(±1339.2) a	806.9 (±644.02) a	113.8 (±65.01) a	295.6(±217.25) a	196.9 (±162.3) a
100+	621.5 (±253.09) a	1047.4 (±475.7) a	39.0 (±39.71) a	75.8 (±87.83) a	434.9 (±199.14) a
100	875.6 (±215.81) a	1441.9 (±416.5) a	93.4 (±60.99) a	125.4 (±43.72) a	265.4 (±54.98) a
150	649.8 (± 154.82)a	519.0 (±473.5) a	424.8 (±401.9) a	96.9 (±23.34) a	90.2 (±181.71) a
150+	1056.6(±450.66) a	1702.8 (±563.9) a	282.8 (±232.63) a	260.6 (±148.19)a	324.2 (±64.01) a
ANOVA P-values					
F Rate	0.80	0.37	0.34	0.65	0.33
NSN	0.38	0.31	0.65	0.34	0.15
F-rate*NSN	0.51	0.30	0.96	0.58	0.92

Table 6. Mean nitrous oxide emissions ±SE (µg N/m^2/d) for cotton crop during two irrigation events from different fertilizer and inhibitor treatments at Site B.

Treatment	73_DAP	74_DAP	83_DAP	103_DAP	104_DAP
50	2504.0 (±435.5)a	5229.0 (±187.54) a	2184.5(±1600.7)a	4608.4 (±847.8)a	1712.5(±596.4) a
50+	6369.0(±4946.27)a	6680.8 (±3737.8) a	1807.1 (±526.1) a	407.6 (±116.2)b	715.9 (±310.5) a
100+	2144.8 (±456.43)a	9966.5(±1872.7) a	4295.4 (±234) a	759.2(±104.9)b	567.0(±203.5) a
100	6617.5(±1363.41)a	3176.4 (±1334) a	3667.2(±1592.5)a	1311.7(±863.4) b	1027.9(±249.2) a
150	4996.2(±1288.38)a	10609.3(±2682.1)a	3151.1(±1520.2)a	1011.9(±337.1)b	784.9 (±343.8) a
150+	4832.3(±1812.71)a	8256.9 (±3361.0) a	4877.2(±2080.5)a	1067.5 (±265.5)b	697.2(±338.13) a
ANOVA P-values					
F Rate	0.97	0.37	0.3	0.024	0.39
NSN	0.89	0.36	0.58	0.003	0.11
F-rate*NSN	0.23	0.23	0.76	0.003	0.47

Table 7. Mean nitrous oxide emissions ±SE (μg $N/m^2/d$) for cotton crop during last irrigation, defoliation and harvest events in 2012 from different fertilizer and inhibitor treatments at Site B.

Treatment	150_DAP	162_DAP	163_DAP	185_DAP	211_DAP	226_DAP
50	31.5(±11.7) d	137.1 (±62.0) a	44.9 (±44.3) a	16.6 (±13.1) a	-15.0 (±9.3)d	8.3 (±5.3)b
50+	35.8 (±35.1) cd	171.8(169.0) a	8.2 (±36.4)a	-22.4(±10.6)a	5.1 (±10.9) bcd	-10.5(±21.5)b
100+	108.3(±11.4)a	32.0 (±20.0) a	166.7(±122.2) a	161.1 (±96.0) a	-1.3(±2.8)c	-46.0(±23.7)c
100	270.2 (±71.4)b	106.9 (±22.5) a	136.3 (78.8) a	11.3 (±75.4) a	128.7 (±56.6)a	20.8 (±4.7)a
150	67.1 (±18.08)c	38.5 (±12.7) a	79.2 (36.2) a	25.0 (±23.3) a	29.3 (±23.4)b	2.2 (±11.8)a
150+	37.8 (±76.2)bcd	133.4 (±59.8) a	45.1 (±22.5) a	4.7 (±4.9) a	10.6 (±20.5)bc	-33.2(±14.3)c
ANOVA P-values						
F Rate	0.01	0.54	0.19	0.23	0.07	0.62
NSN	0.12	0.78	0.81	0.49	0.08	0.007
F-rate*NSN	0.2	0.57	0.85	0.17	0.04	0.32

Figure 19. Mean nitrous oxide emissions (μg $N/m^2/d$) obtained from cotton with different fertilizer rate and inhibitor treatments before last irrigation event in 2012 at Site B.

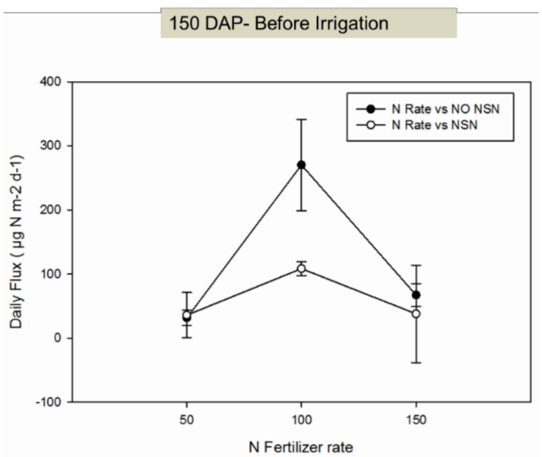


Figure 20. Mean nitrous oxide emissions (μg $N/m^2/d$) obtained from cotton with different fertilizer rate and inhibitor treatments after rain event, before defoliation and before harvest of the crop in 2012 at Site B.

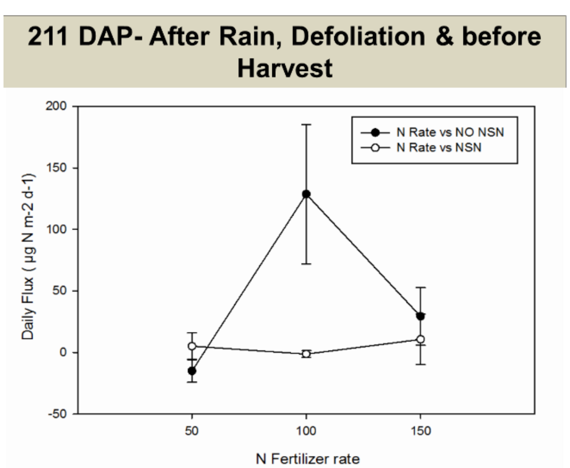
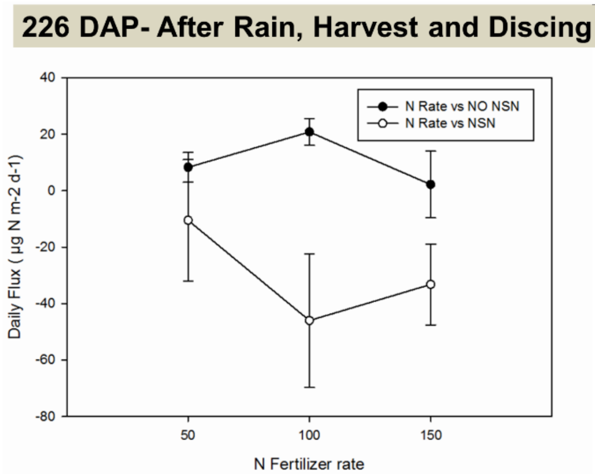


Figure 21. Mean nitrous oxide emissions (µg N/m^2/d) obtained from cotton with different fertilizer rate and inhibitor treatments after harvest of the crop followed by discing the crop residue into the field in 2012 at Site B.



Site B- Fresno- 2013

In 2013, the N_2O fluxes at Site B corresponding to the various sampling events outlined in Table 8 are shown in Figure 22. Based on the ANOVA presented in Table 9, fertilizer rates resulted in significant differences N_2O fluxes for measurements taken at 74 and 102 DAP, which corresponded to 24 hours after fertilizer application and three days after an irrigation event (Table 8), respectively. At 91, 102 and 104 DAP, which represented sampling after irrigation events, the NSN addition significantly reduced the amount of N_2O emissions. There was no significant interaction between N rates and NSN on the amount of N_2O emissions.

Total nitrous oxide emissions over the 2013 crop season from the cotton at Site B, receiving three rates of fertilizer treatments with and without Nutrisphere-N inhibitor are shown in Figure 23. For the unfertilized plots, the application of NSN resulted in a 38% reduction in total N_2O emissions. For plots receiving 50, 100 and 150 lbs N/ac, the NSN reduced the total N_2O emissions by 19%, 54% and 52%, respectively (Figure 23).

Table 8. Sampling schedule for measurement of N_2O emissions at Site B during 2013.

NO.	DAP	Date	Event
1	70 DAP	6/10/2013	Baseline sampling
2	73 DAP	6/13/2013	2 hrs after fertilizer application
3	74 DAP	6/14/2013	24 hrs after fertilizer application
4	77 DAP	6/17/2013	Prior to irrigation
5	91 DAP	7/1/2013	3 days after Irrigation
6	102 DAP	7/12/2013	3 days after Irrigation
7	103 DAP	7/13/2013	2nd sampling after irrigation
8	104 DAP	7/14/2013	3rd sampling after irrigation
9	116 DAP	7/26/2013	10 days after last sampling event
10	123 DAP	8/2/2013	3 days after irrigation
11	124 DAP	8/3/2013	4 days after irrigation
12	125 DAP	8/4/2013	5 days after irrigation
13	136 DAP	8/15/2013	10 days after last sampling event
14	143 DAP	8/22/2013	3 days after irrigation
15	144 DAP	8/23/2013	4 days after irrigation

Figure 22. Nitrous oxide emissions throughout the 2013 crop season from cotton applied with three rates of fertilizer treatments with and without Nutrisphere-N inhibitor at Site B.

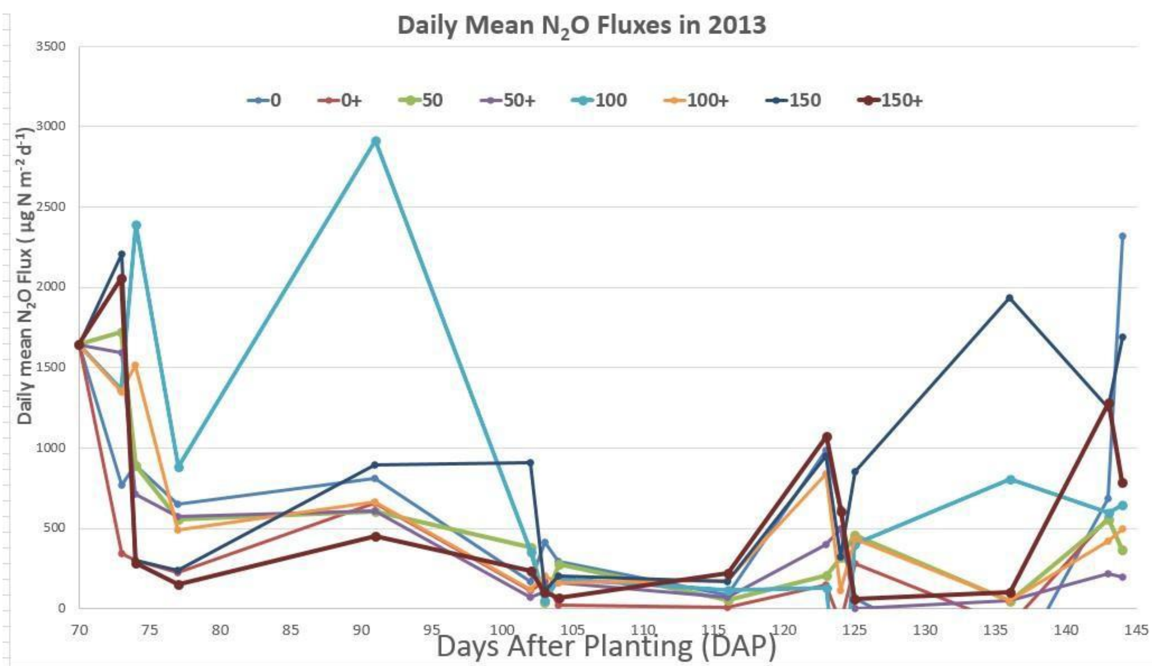
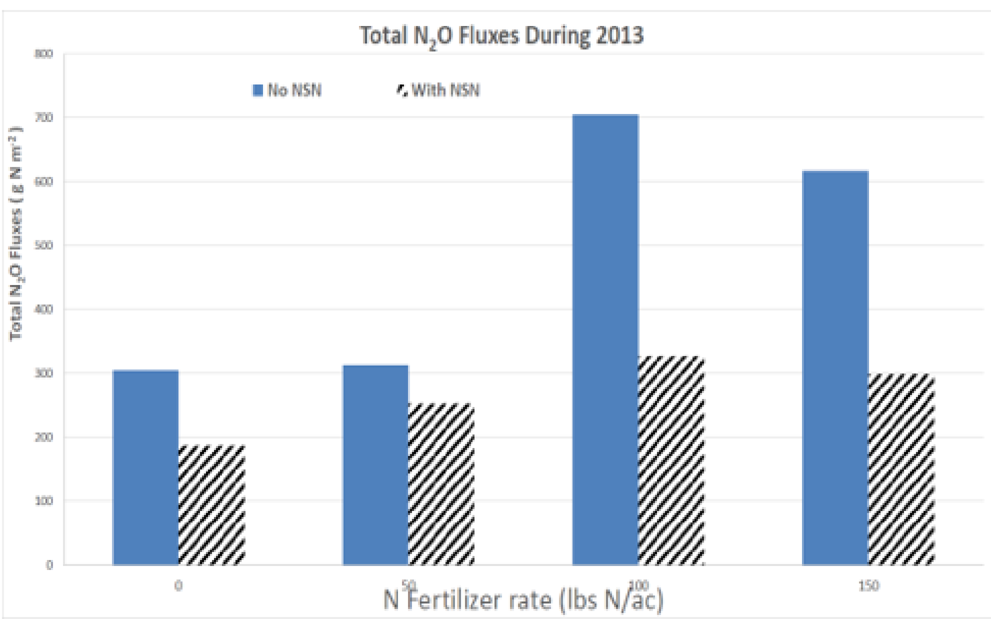


Table 9. Mean Nitrous oxide emissions ±SE (µg N/m2/d) from the different treatments for cotton crop at Site B around fertilizer application and irrigation events in 2013.

NRate	73 DAP	74 DAP	77 DAP	91 DAP	102 DAP	103 DAP	104 DAP
0	556.18(200.44) a	597.98(212.39) ab	437.64(196.26) a	733.40(219.13) a	139.34(44.90) b	294.45(130.17) a	159.65(70.50) a
50	1657.43(520.01) a	803.97(181.65) ab	565.51(149.81) a	605.84(66.59) a	224.37(136.63) ab	75.69(25.40) a	217.38(98.51) a
100	1357.55(147.19) a	1955.55(581.21) a	684.55(357.50) a	1788.77(756.11) a	238.36(92.34) ab	130.28(49.67) a	172.76(34.19) a
150	2131.93(920.49) a	292.89(65.32) b	198.18(37.48) a	672.79(151.66) a	572.07(184.12) a	106.41(29.77) a	135.40(58.64) a
NSN							
0	1516.58(355.69) a	1119.59(331.81) a	583.85(196.31) a	1306.00(401.21) a	452.94 (116.39) a	156.39(72.08) a	239.96(55.10) a
I	1334.96(446.95) a	705.61(222.58) a	359.08(91.10) a	594.40(77.98) b	134.13 (33.74) b	147.04(29.38) a	102.63(25.51) b
P-value							
N Rate	0.342	0.016	0.51	0.085	0.038	0.18	0.845
NSN	0.768	0.237	0.348	0.056	0.006	0.898	0.054
Nrate* NSN	0.996	0.798	0.879	0.117	0.212	0.282	0.627

Figure 23. Total nitrous oxide emissions over the 2013 crop season from cotton applied with three rates of fertilizer treatments with and without Nutrisphere-N inhibitor at Site B.



N_2O Emission Factors for Cotton in 2012 & 2013

At Site A- Hanford

The total N_2O fluxes throughout the 2012 crop season were observed to be 64% lower from furrows as compared to that from the beds. Throughout the whole crop period, 1657 g N/ha was emitted from the beds and 601 g N/ha was lost from the furrows. Assuming that the emissions from the furrows were representative of soils which did not receive any UAN 32, then the N_2O emission factors (EFs) from the beds was calculated to be 0.69% for 137 lbs N/acre. This is considerably less than the 2.71 determined using the IPCC equation derived by Bouwman (1996).

During the 2013 monitoring period, the total N_2O fluxes were observed to be 70% lower from furrows as compared to that from the beds. Throughout the whole crop period, 4489 g N/ha was emitted from the beds and 1326 g N/ha was lost from the furrows. Overall, 2013 emissions were more than twice that observed in 2012. For just an 8lbs N/ac increase in fertilizer application in 2013, the N_2O emissions from the beds increased by a factor of

2.5. For the furrows, the total N_2O emissions was 2.2 times that observed in 2012. Assuming that the emissions from the furrows were representative of soils which did not receive any UAN 32, then the N_2O EF from the beds was calculated to be 1.94% for 145 lbs N/acre. This value is higher than that calculated for the 2012 growing season, but still less than the 2.71 determined using the IPCC equation derived by Bouwman (1996).

At Site A the total N_2O emissions from beds were higher as compared to that from the furrows and these results were opposite to those observed by McTaggart and Smith (1996) in a potato study in Scotland and by Russer et al., (1996) in Germany. However, the N losses observed for cotton in this study were similar to as those observed by Burger and Horwarth (2013) for corn grown in California. In a field study, these researchers observed that the total N_2O emissions were higher from the beds followed by shoulder as compared to those from the furrows for different fertilizer rate treatments ranging from 0 to 337 lbs N/acre in corn cropping system. In contrast to Burger and Horwarth (2013) and Cai et al. (2014) in their field and incubation studies respectively, who observed increases in N_2O fluxes with the increase in rate of fertilizer application, there was a decrease in the total N_2O fluxes as the cotton was fertilized with relatively higher amount of N fertilizer.

At Site B- Fresno

The EFs for cotton treated with different rates of UAN-32 ranged between 0.20% and 0.34% (Table 10). Application of NSN with the fertilizer at the rate used in this study further reduced the N_2O emissions over the season with the EFs being reduced to between 0.01 to 0.38%. The total N lost from 50, 100 and 150 lbs N/acre treatments were 0.37, 0.51 and 0.42 lbs N/acre respectively, whereas the total N losses from the same treatments applied with inhibitor was 0.01, 0.47 and 0.79 lbs N/acre respectively. There was a net decrease in N loss per acre for the 50 and 100 lbs N/acre treatments applied with inhibitor as compared to N_2O emissions in plots without the inhibitor treatments. However, for the 150 lbs N/acre treatment, there was a 90% increase in N emissions. This reduction in efficacy of the NSN to mitigate N_2O emission at the highest fertilizer rate would imply that the mechanisms involved in reducing N_2O emissions may be overwhelmed at N rates above 100 lbs N/ac. Hence, further studies involving NSN should focus on measuring N_2O emissions for (a) application rates above the 0.05% v/v of fertilizer used in the current study, and (b) plots subjected to multiple applications of the NSN throughout the growing season.

Table 10. Emission factors (EFs) for cotton treated with different rates of UAN-32 applied with and without Nutrisphere-N inhibitor at Site B.

Treatment	N rate (lbs/acre)	2012 EF%	2013 EF%
1.	50	0.34	0.01
2.	50+N	0.01	0.12
3.	100	0.32	0.36
4.	100+N	0.29	0.13
5.	150	0.20	0.19
6.	150+N	0.38	0.07

In summary, the N_2O emission factors (EFs) for cotton grown on sandy loam soils and treated with different rates of UAN-32 ranged between 0.20% and 0.36%. These EFs which were obtained by integrating the net N_2O emissions over the crop season were considerably less than the 1.625, 2.25 and 2.875% calculated using the IPCC equation. In addition, these EFs for cotton are lower than those reported by Burger and Horwarth (2012) for other major crops grown in California such as tomato (1.3-1.77%) and alfalfa (4.15- 12.06%). In 2013, the application of Nutrisphere-N (NSN) at a rate of 0.05% v/v with the fertilizer further reduced the N_2O emissions over the season for the N rates of 100 and 150 lbs N/ac, which resulted in a decrease in EFs to 0.13 and 0.07%, respectively (Table 10). To the best of our knowledge, the EFs determined in the current study are the first set of EFs obtained for a cotton crop grown on sandy loams in the

SJV. The values obtained in this study are slightly lower than the 0.95% and 1.48% observed for cotton grown in China (Liu et. al., 2010) and in Uzbekistan (Scheer et al., 2008), respectively. In the study by Liu et al. (2010), it was observed that soil temperature, moisture and mineral N content also affected the N_2O emissions. As part of the next phase of this research, we are also investigating the relationships between the N_2O fluxes and the various soil, crop and climatic parameters.

II. <u>Tomato Experiment</u>

<u>Tomato Yield</u>**:** In 2012, there was no significant effect of either fertilizer rate or the interaction between irrigation and fertilizer rates on total fruit yield, non- marketable yield, marketable yield, Green tomato weight, red tomato weight, breaker tomato weight and Brix indices of fruits (Table 11). However, irrigation rates affected total weight, marketable, green tomato and breaker tomato yields with the highest values from the irrigation treatment with 100% ET as compared to those from 80 and 60% ET (Table 12). The Brix values of tomato fruits were highest from the treatment with 60%ET compared to plants that received 80 and 100% of daily ET. In 2013, fertilizer and/or irrigation had no significant effects on any of the tomato yields (Table 13).

Table 11: Level of Significance from ANOVA for tomato yields obtained in 2012.

Treatment	Total Weight	Non-marketable Weight	arketable Weight	Green Weight	Breaker Weight	Red Weight	Brix
Irrigation	0.003*	0.126	0.004*	0.021*	0.015*	0.117	0.025*
Fertilizer	0.627	0.797	0.713	0.784	0.737	0.825	0.366
Irrigation x fertilizer	0.666	0.451	0.848	0.412	0.475	0.594	0.489

Table 12: Mean weights (lbs per subplot) for tomatoes subjected to the various irrigation rates. *Values followed by the same letters are not significantly different at the α= 0.05 level.*

ET Rate (%)	Total Wt.	Non-marketable Weight	Marketable Weight	Green Weight	Breaker Weight	Red Weight	Brix
100	21.93 a	1.74 a	20.183 a	14.86 a	2.5 a	2.82 a	3.68 b
80	14.67 b	1.75 a	12.92 b	9.98 b	1.43 b	1.5 a	3.95 b
60	11.9 b	0.98 a	10.92 b	7.47 c	1.07 b	2.37 a	4.56 a

Table 13: Level of Significance from ANOVA for tomato yields obtained in 2013.

Treatment	Total Weight	Green Weight	Breaker Weight	Red Weight
Irrigation	0.456	0.248	0.502	0.094
Fertilizer	0.210	0.520	0.252	0.855
Irrigation x fertilizer	0.733	0.826	0.834	0.565

<u>N_2O fluxes at various sampling events in 2012</u>

In 2012, there was no significant interaction between irrigation and fertilizer application rates for any sampling event (Table 14). Also, with the exception at 66 DAT, there was no significant effect of irrigation rate at any sampling event. At 66 DAT the N_2O fluxes were observed to be the highest from the irrigation treatment with 100% ET compared to those from the 80 and 60% ET treatments (Figure 24). Nitrogen fertilizer application rate of 200 lbs N/acre was observed to have highest amount of N_2O fluxes as compared to those from 100 and 150 lbs N/acre treatments at 27DAT (Figure 25) which represented measurements between first and second fertilizer application. There was no significant effect of fertilizer rate on the N_2O fluxes during any other sampling event.

Table 14: Mean daily N_2O fluxes (µg N m^{-2} d^{-1}) and ANOVA from the tomato crop in 2012 as a function of irrigation and fertilizer rates.

DAT	27	28	29	43	45	46	64	65	66	100
Irrigation										
100	619.8 a	641.9 a	532.8 a	418.4 a	188.0 a	1860.4a	1046.5a	564.7 a	323.5 a	19.4 a
80	698.6 a	1132.0 a	373.2 a	248.4 a	208.5 a	173.2 a	496.8 a	402.1 a	65.1 ab	14.3 a
60	346.6 a	487.8 a	618.0 a	245.2 a	186.3 a	37.3 a	142.1 a	298.2 a	15.6 b	19.7 a
P-Value	0.591	.652	.774	.461	.995	.062	.285	.490	.011*	.978
Fertilizer										
100	149.7 b	310.3 a	533.9 a	203.7 a	121.4 a	167.4 a	756.0 a	295.0 a	41.8 a	9.8 a
150	196.4 b	952.7 a	677.9 a	471.9 a	285.7 a	1120.5a	333.6 a	386.1 a	248.8 a	14.1 a
200	1318.9 a	998.7 a	312.2 a	236.5 a	175.7 a	783.1 a	595.8 a	583.8 a	113.7 a	29.6 a
P-Value	.001*	.547	.560	.063	.636	.195	.229	.452	.210	.835
Irrigation X Fertilizer										
P-Value	.272	.663	.626	.225	.273	.195	.350	.662	.665	.858

Figure 24: Effect of irrigation rates on N_2O emissions (μg N m^{-2} d^{-1}) at 66 DAT in 2012.

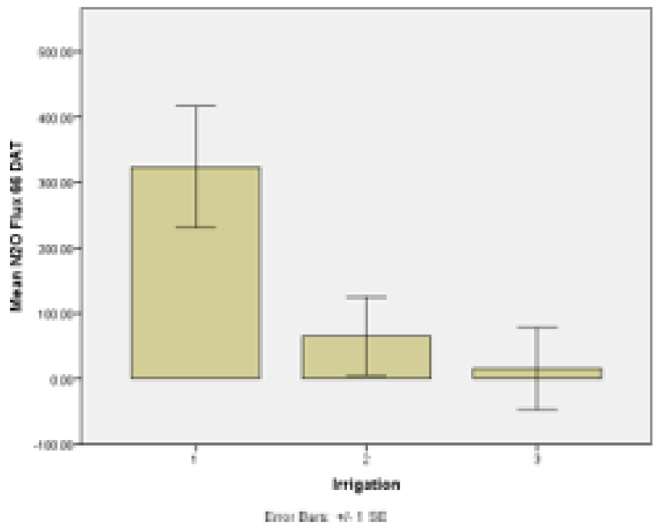
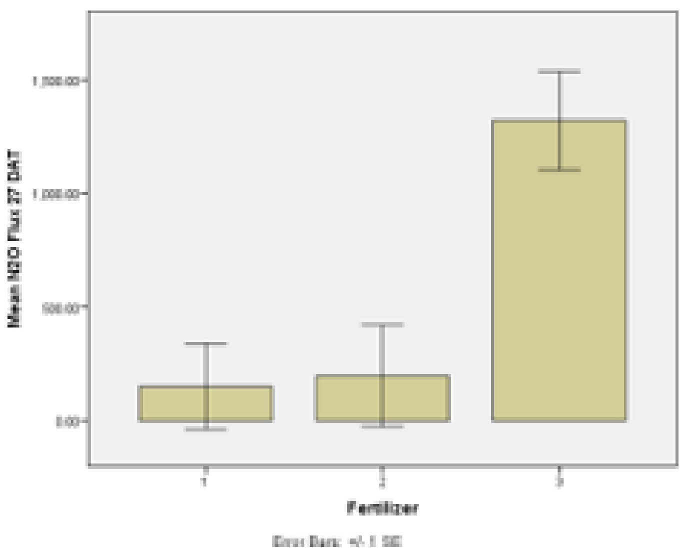


Figure 25: Effect of fertilizer rates on N_2O emissions (μg N m^{-2} d^{-1}) at 27 DAT in 2012.



N_2O fluxes at various sampling events in 2013

Of the 22 sampling events conducted in 2013 (Table 15), there were only following four events when there was a significant effect of either irrigation (I) or fertilizer (F) rates, or interaction effect (F x I), on the mean daily N_2O fluxes (Table 16):

a. DAT 27: Sampling conducted 2 hours after fertilizer application;
b. DAT 28: Sampling conducted 24 hours after fertilizer application;
c. DAT 47: Sampling conducted 2 hours after fertilizer application;
d. DAT 55: Sampling conducted 2 hours after fertilizer application;

It should be noted that the subsurface method of irrigation utilized in the current study meant that the irrigation system was in operation on a daily basis.

Table 15. Sampling schedule for measurement of N_2O emissions for tomatoes in 2013.

No.	Date	DAT	Event
1	7/1/2013	12	before fertilizer application
2	7/2/2013	13	2 hrs after fertilizer application
3	7/3/2013	14	24 hrs after fertilizer application
4	7/4/2013	15	48 hrs after fertilizer application
5	7/15/2013	26	before fertilizer application
6	7/16/2013	27	2 hrs after fertilizer application
7	7/17/2013	28	24 hrs after fertilizer application
8	7/18/2013	29	48 hrs after fertilizer application
9	7/26/2013	37	before fertilizer application
10	7/29/2013	40	2 hrs after fertilizer application
11	7/30/2013	41	24 hrs after fertilizer application
12	7/31/2013	42	48 hrs after fertilizer application
13	8/2/2013	44	before fertilizer application
14	8/5/2013	47	2 hrs after fertilizer application
15	8/6/2013	48	24 hrs after fertilizer application
16	8/7/2013	49	48 hrs after fertilizer application
17	8/9/2013	51	before fertilizer application
18	8/12/2013	54	2 hrs after fertilizer application
19	8/13/2013	55	24 hrs after fertilizer application
20	8/14/2013	56	48 hrs after fertilizer application
21	8/22/2013	64	8 days since last sampling event
22	9/10/213	83	19 days since last sampling event
			Total number of samples: 2376

Table 16: Mean daily N_2O fluxes (μg N m^{-2} d^{-1}) and ANOVA from the tomato crop in 2013 as a function of irrigation and fertilizer rates.

DAT	27	28	47	54
Irrigation (I)				
100 (I1)	753.9 a	369.0 a	817.6 a	1427.4 b
80 (I2)	928.9 a	308.2 a	1135.6 a	303.1 a
60 (I3)	787.0 a	176.4 a	1062.1 a	512.7 b
P-Value	0.880	0.230	0.111	0.069*
Fertilizer (F)				
100 (F1)	577.4 a	255.5 a	672.0 a	969.0 a
150 (F2)	713.9 a	409.3 a	719.6 a	749.2 a
200 (F3)	1178.4 b	188.8 a	1712.3 b	566.2 a
P-Value	0.007*	0.637	0.081*	0.604
Irrigation X Fertilizer				
P-Value	0.758	0.021*	0.012*	0.342

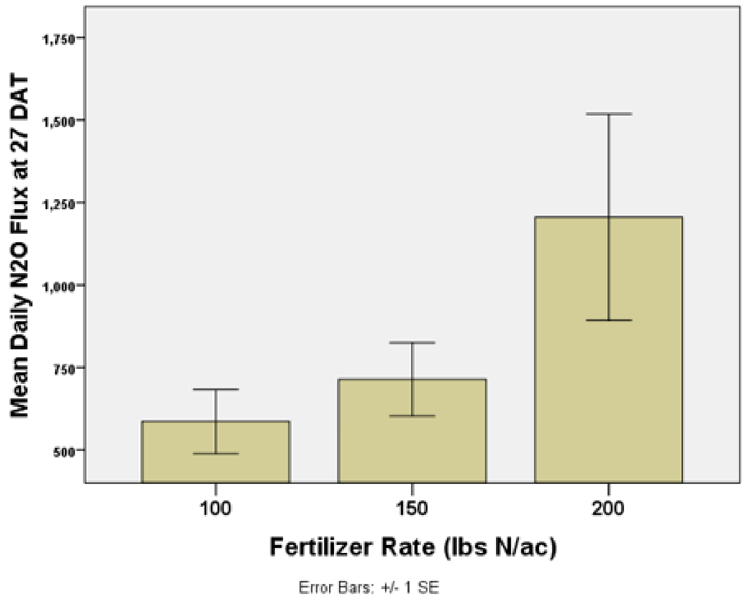


Figure 26: Effect of fertilizer rates on N_2O emissions (μg N m^{-2} d^{-1}) at 27 DAT in 2013.

At 27 DAT, for the sampling event corresponding to 2 hours after fertilizer application, the N_2O fluxes from the plots receiving the highest fertilizer application were almost twice that from the plots that received the relatively lower N rates (Figure 26). During this sampling event, the N_2O fluxes were not significantly affected by the irrigation rates or any fertilizer x irrigation (F x I) interaction (Table 16). However, at the 28 and 47 DAT sampling events which represented 24 and 2 hours after fertilizer applications, respectively, there was a significant ($P< 0.05$) fertilizer x irrigation interaction effect on the N_2O fluxes (Table 16, Figures 27 and 28). During the 28 DAT sampling event, the highest N_2O fluxes with the 150lb N/ac (F2) (Figure 27a) and the 100 lb N/ac (F1) (Figure 27b) treatments were associated with 100 % ET (I1) and 80% ET (I2) irrigation regimes, respectively. For the plots receiving the 60% deficit ET (I3), the N_2O fluxes from the mid and high fertilizer rates were significantly greater than the emissions from the plots fertilized with 100lbs N/ac (Figure 27c). At 47 DAT, there were no significant differences in the N_2O emissions amongst the plots fertilized at different rates and subjected to 100% ET irrigation (Figure 28a). However, the N_2O fluxes from the plots fertilized with 200lb N/ac were approximately 2.7 times those that received the 100 and 150 lbs N/ac (Figure 28b,c). In addition to the F x I interaction effect at 47 DAT, fertilizer rate also had a significant ($P =0.08$) on the mean daily N_2O flux with the emissions from the plots fertilized at the highest rate (F3 = 200lsb N/ac) being about 2.5 times that observed for the two lower rates (Figure 29). At 54 DAT, only irrigation rate had any significant ($P=0.069$, Table 16) on daily N_2O fluxes, with the 100%ET (I1) irrigated plots exceeding the fluxes from the plots irrigated at 80%ET (I2) and 60%ET (I3) by a factor of 3.5 (Figure 30).

Of the four sampling events for which there were significant differences in the N_2O fluxes due to the irrigation and/or fertilizer treatments, three occurred when the sampling events were at two hours after fertilizer application (27, 47 and 54 DAT). With the exception of the sampling event at 28DAT, by 24 hours after fertilizer application it appears the effects of the fertilizer and irrigation treatments on the N_2O fluxes were similar. Ideally, it would have been worthwhile conducting continuous flux measurements throughout the entire 24 hours after the fertilizer application in an effort to detect exactly when the N_2O fluxes peaked. Realistically, with the sampling protocol utilized in the current study along with budgetary and labor constraints, continuous N_2O flux monitoring was not an option. Overall, the N_2O daily flux data compiled in the current study concurred with other researchers such as those reported by Moiser (1994), Kennedy et al., (2013) and Kallenbach et al. (2010). Other researchers have found that the use of sub-surface irrigation could play a significant role in reducing N_2O emissions from agricultural crops. For example, Kennedy et al. (2013) found that using sub-surface irrigation and fertigation practices significantly reduced daily fluxes of N_2O. That finding is pertinent to the current study because of the use in both cases of sub-surface drip irrigation systems and while the method of fertilizer application was different, hand applied for this study versus fertigation for Kennedy et al. (2013), there is evidence that the method of irrigation, and not just the fertilizer application rate, can be a significant determining factor in N_2O emissions.

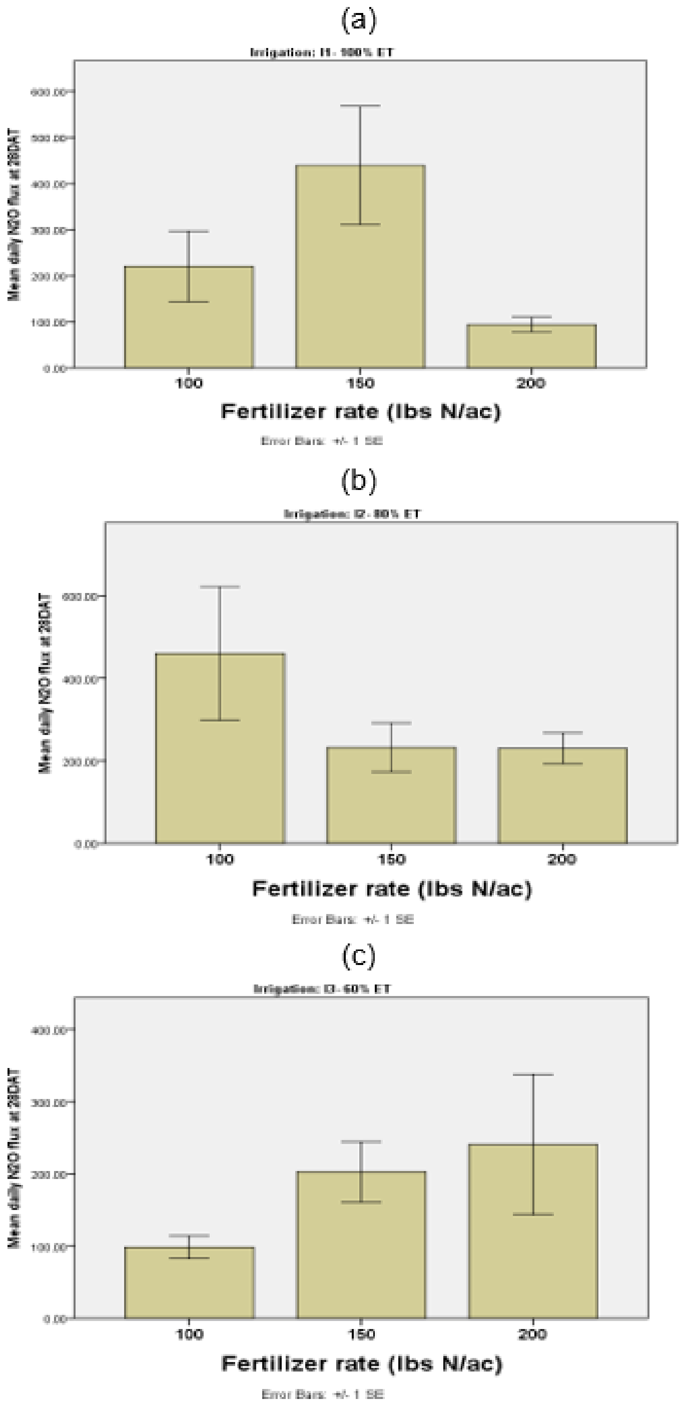
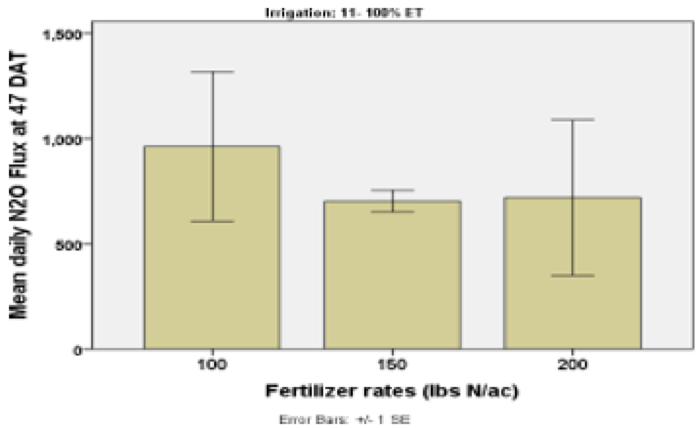
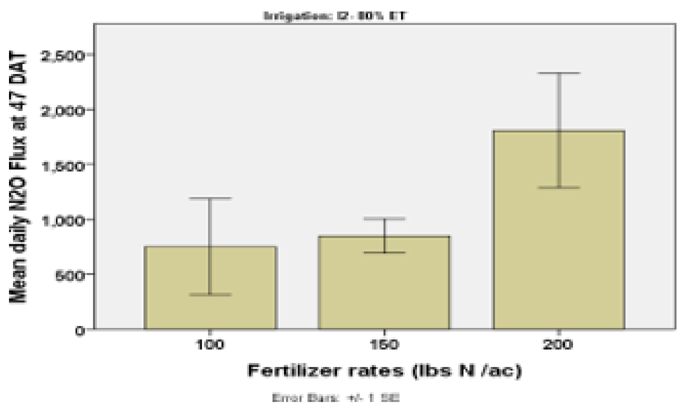


Figure 27: Effect of fertilizer rates on N_2O emissions (μg N m^{-2} d^{-1}) as a function of irrigation rates of (a) 100% (b) 80% and (c) 60% ET measured at 28 DAT in 2013.

(a)



(b)



(c)

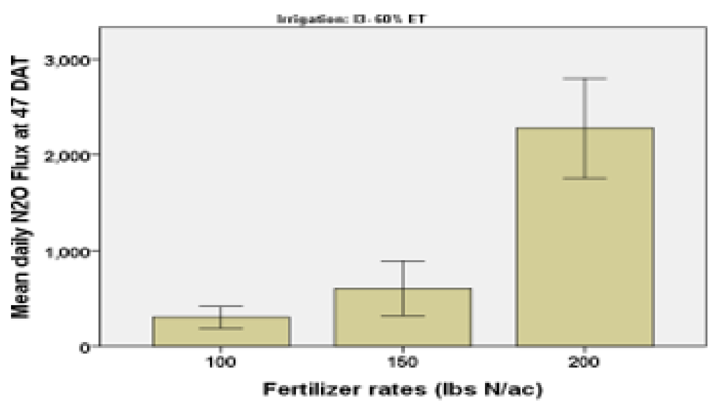


Figure 28: Effect of fertilizer rates on N_2O emissions (μg N m^{-2} d^{-1}) as a function of irrigation rates of (a) 100% (b) 80% and (c) 60% ET measured at 47 DAT in 2013.

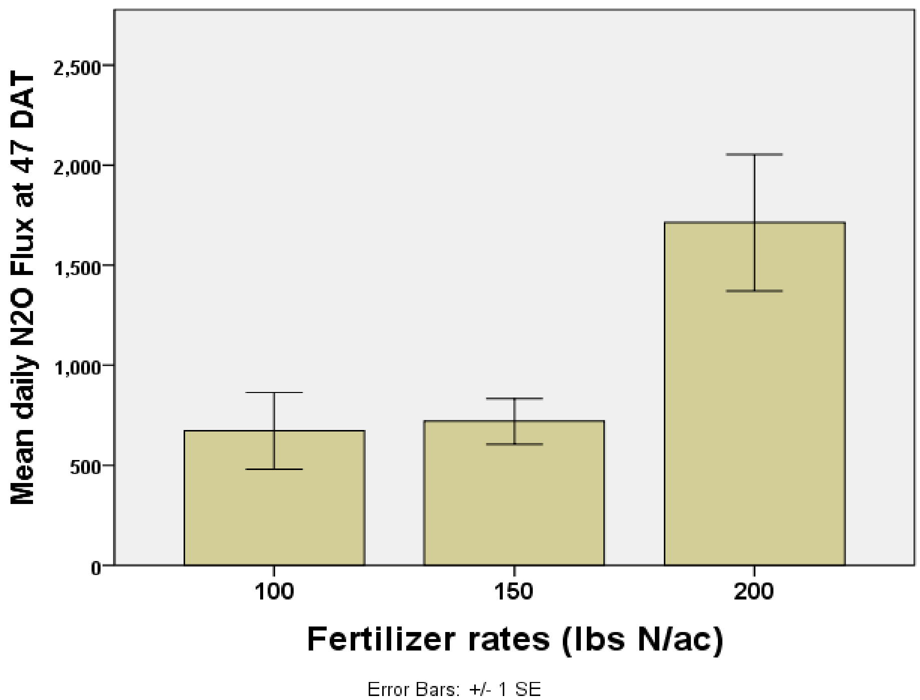


Figure 29: Effect of fertilizer rates on N_2O emissions (μg N m^{-2} d^{-1}) at 47 DAT in 2013.

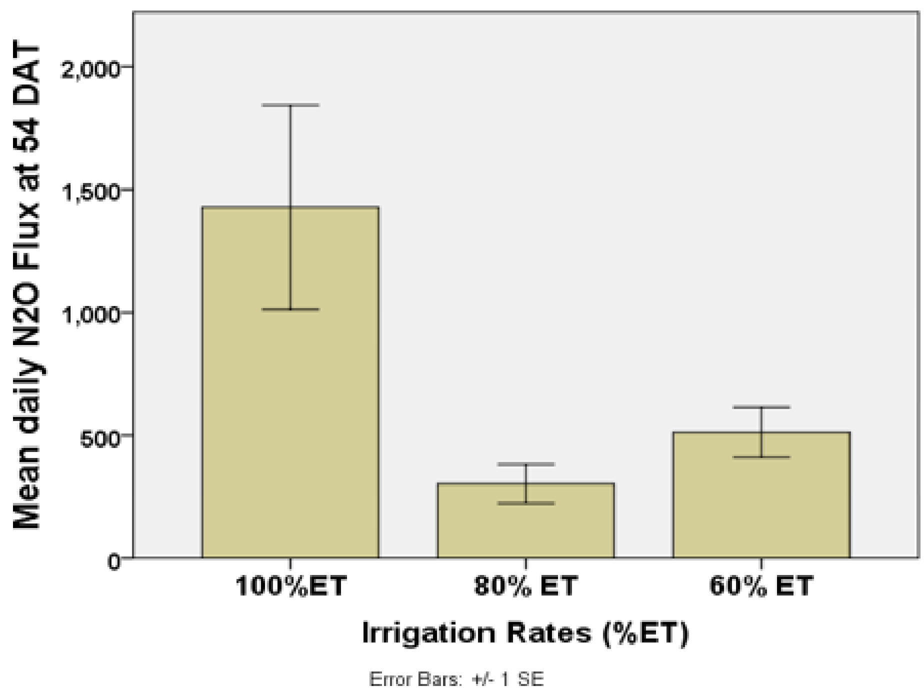


Figure 30: Effect of irrigation rates on N_2O emissions (μg N m^{-2} d^{-1}) at 54 DAT in 2013.

Total N_2O Emissions from Tomato Crops in 2012 & 2013

In addition to comparing the N_2O fluxes for the various irrigation and fertilizer treatments at the individual sampling events, the total fluxes and amount of N_2O-N emitted on a kg per ha (or lbs/ac) basis were determined by integrating the area under the time series graphs generated for each growing season. Figures 31 and 32 show the nitrous oxide emissions as a function of (a) irrigation (I) and (b) fertilizer (F) rates throughout the 2012 and 2013 tomato seasons, respectively. A summary of total N_2O emissions from the tomato crops in 2012 and 2013 as a function of fertilizer and irrigation rates is provided in Table 17. As indicated earlier, a sampling protocol which included continuous monitoring, or at least more frequent sampling events, would provide a better depiction of N_2O fluxes during the season. For example, the graphs generated for the 2013 season (Figure 32) which comprised of 22 sampling evens versus that generated for the 2012 season (Figure 31) with 10 sampling events, would allow for a more accurate interpolation of the total fluxes between sampling events.

Based on the summary provided in Table 17, the amount of N_2O-N in kg per ha emitted during tomato cropping season ranged from 0.162 to 0.291 in 2012 and from 0.203 to 0.444 in 2013. More importantly, when these emissions were expressed on the basis of the amount of fertilizer applied throughout the season, the emission rates were relatively constant in both years at 0.002 kg N_2O-N per ha per lb of N fertilizer. Overall, there was a moderate positive correlation (r= 0.64) between the amount of N_2O-N emitted and the fertilizer applied, with the correlation being relatively stronger in 2013 (r = 0.99) than in 2012 (r = 0.48).

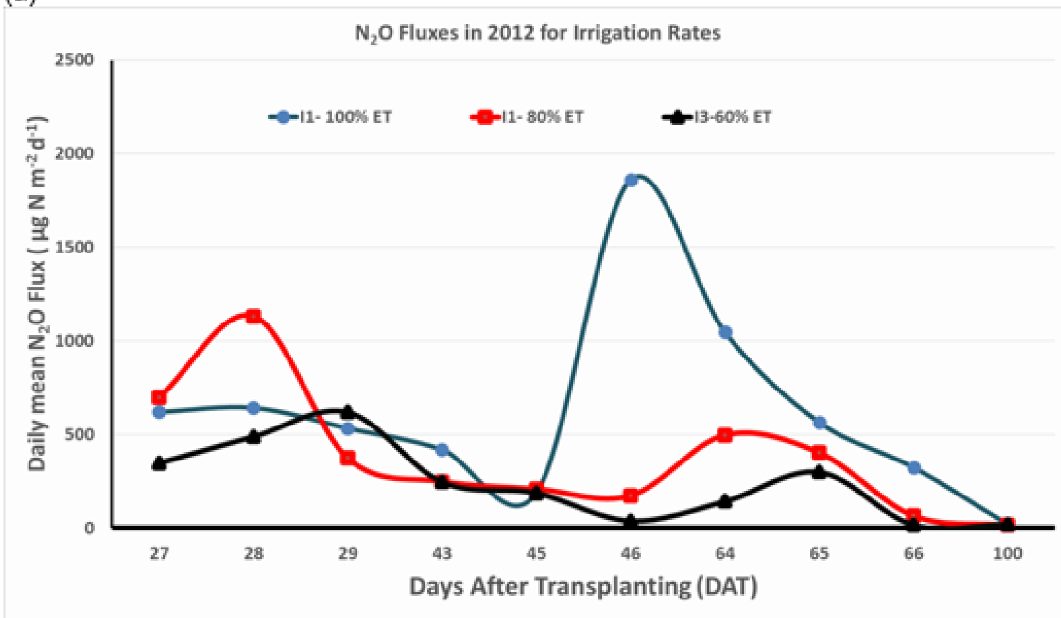
With respect to the volume of water applied during the 2012 season, the amount of N_2O-N emitted increased from 0.102 kg N_2O-N per ha per mm water for plots receiving 60%ET (I3) to 0.428 kg N_2O-N per ha per mm water for the 100%ET irrigated plots. In 2013, the amount of N_2O-N emitted from the 80%ET (I2) and 100%ET (I1) irrigated plots were approximately 1.7 times greater than the emissions from the plots irrigated at 60%ET (I3). Overall, there was a positive correlation (r= 0.74) between the amount of N_2O-N emitted and the volume of water applied, with the correlation being relatively stronger in 2013 (r = 0.92) than in 2012 (r = 0.82).

Ancillary data collection for DNDC modeling & Future Work

In addition to the nitrous oxide emissions work in this report, a number of soil and crop samples were also collected at each sampling event for subsequent inclusion in the DNDC modeling phase of the research. The parameters analyzed included the following: Soil moisture percent; Soil carbon (C) to nitrogen (N) ratio; Soil nitrate and ammonium content; Soil pH and electrical conductivity (ECe); Soil bulk density (Db); Water filled Pore Space (WFPS %); Leaf Area Index (LAI); Plant height; Root and shoot biomass; Plant tissue C:N ratio; and, Cotton lint and tomato yields. The projected work for the remainder of 2015 will constitute part of the final year of CSU-ARI matching funds, and the findings from these investigations will be shared with CDFA upon completion.

Figure 31. Nitrous oxide emissions as a function of (a) irrigation (I) and (b) fertilizer (F) rates throughout the 2012 tomato season.

(a)



(b)

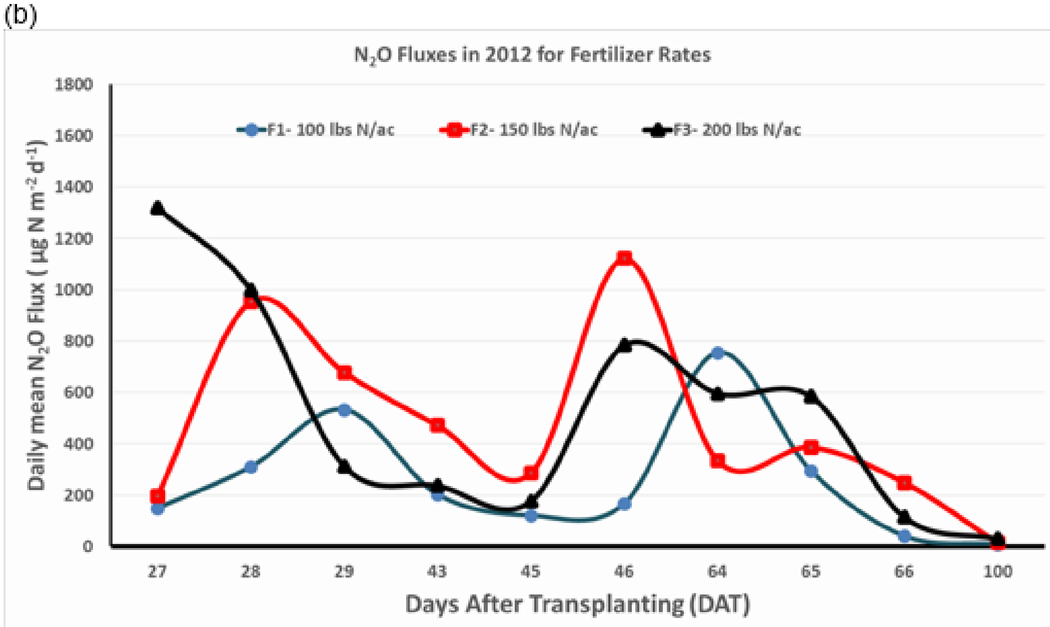
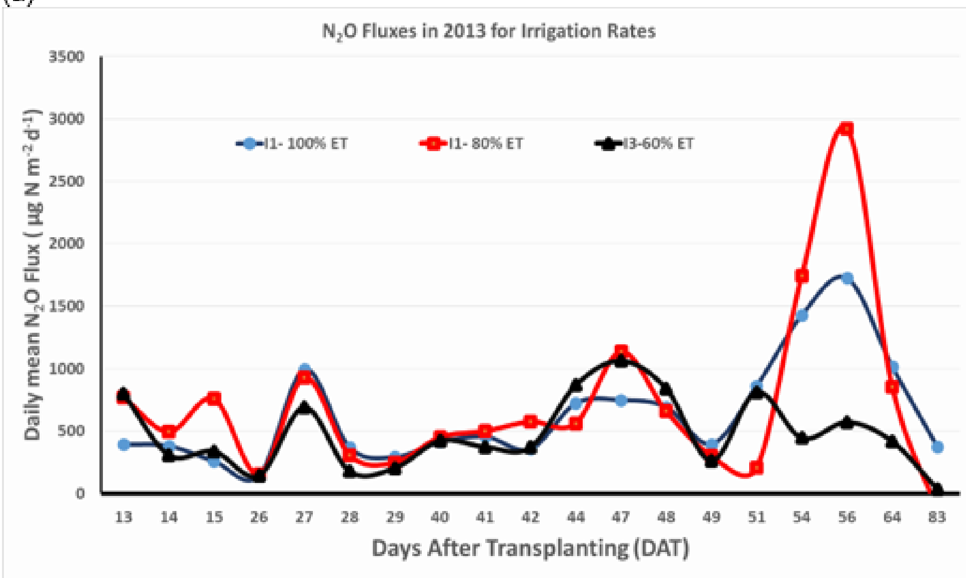


Figure 32. Nitrous oxide emissions as a function of (a) irrigation (I) and (b) fertilizer (F) rates throughout the 2013 tomato season.

(a)



(b)

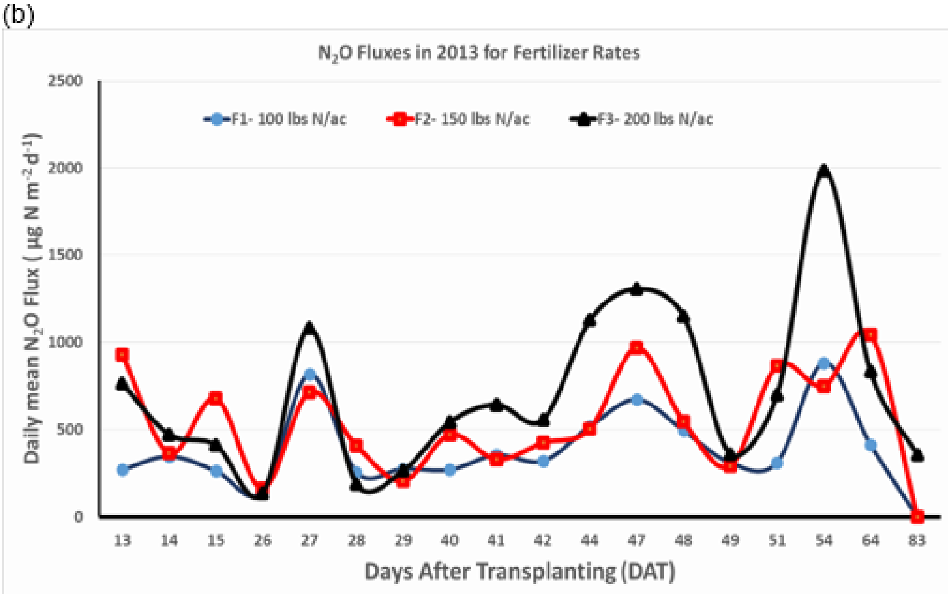


Table 17: Summary of total N_2O emissions from the tomato crops in 2012 and 2013 as a function of fertilizer and irrigation rates.

	2012				2013		
Fertilizer	**F1**	**F2**	**F3**		**F1**	**F2**	**F3**
TOTAL N2O emitted (ug/m2)	16167.60	29134.14	22333.74		20306.75	35489.15	44350.71
N2O-N emitted in kg N/ha	0.162	0.291	0.223		0.203	0.355	0.444
N2O-N emitted in lbs N/ac	0.144	0.259	0.199		0.181	0.316	0.395
Total N applied per acre (lbs N/ac)	100	150	200		100	150	200
N2O-N emitted in kgN/ha/ lb fertilzer	0.0016	0.0019	0.0011		0.002	0.002	0.002
N2O-N emitted in lbs N/ac/lb fertilizer	0.0014	0.0017	0.0010		0.0018	0.0021	0.0020
Relative Change in emissions	NA	0.06%	-0.15%		NA	0.06%	-0.03%
Irrigation	**I1-100%ET**	**I2-80%ET**	**I2-60%ET**		**I1-100%ET**	**I2-80%ET**	**I2-60%ET**
TOTAL N2O emitted (ug/m2)	42753.17	14731.38	10150.93		45751.86	47634.75	26616.82
N2O-N emitted in kg N/ha	0.428	0.147	0.102		0.458	0.476	0.266
N2O-N emitted in lbs N/ac	0.381	0.131	0.090		0.407	0.424	0.237
Total water applied (mm)	432	346	259		444	355	266
N2O-N emitted in kgN/ha/ mm water	0.0010	0.0004	0.0004		0.0010	0.0013	0.0010
N2O-N emitted in lbs N/ac/ mm water	0.0009	0.0004	0.0003		0.0009	0.0012	0.0009
Relative Change in emissions	NA	0.06%	0.003%		NA	-0.03%	0.03%

Concluding Remarks:

Cotton Experiment: For cotton grown on sandy loam soils and fertilized with UAN-32, the major findings from the current study are:

- The total N_2O emissions from the beds were generally 30-36% higher than those from the furrows throughout the cropping season. In addition, at post-harvest incorporation of the cotton residue, the furrows acted as a N_2O sink.
- The emission factor (EF) from the cotton beds and fertilized with 137 - 145lbs N/ac as UAN-32 ranged from 0.69% to 1.94 %, which is less than the 2.71% calculated using the IPCC equation.
- The EFs for cotton treated with different rates of UAN-32 ranged between 0.20% and 0.34%. Application of Nutrisphere-N (NSN) with the fertilizer at the rate 0.05% v/v of further reduced the N_2O emissions over the season with the EFs being reduced to between 0.01 to 0.38%.
- In 2012, at the application rate of 0.05% v/v, the NSN appears to be most effective for mitigating the N_2O emissions, when the fertilizer rate was less than 100 lbs N/acre.
- In 2013, for the unfertilized plots, the application of NSN resulted in a 38% reduction in total N_2O emissions. For plots receiving 50, 100 and 150 lbs N/ac, the NSN reduced the total N_2O emissions by 19%, 54% and 52%, respectively.
- The reduction in efficacy of the NSN to mitigate N_2O emission at the highest fertilizer rate would imply that the mechanisms involved in reducing N_2O emissions may be overwhelmed at N rates above 100 lbs N/ac. Hence, further studies involving NSN should focus on measuring N_2O emissions for (a) application rates above the 0.05% v/v of fertilizer used in the current study, and (b) plots subjected to multiple applications of the NSN throughout the growing season.
- The N_2O EFs determined in this study using the time series integration approach were considerably lower than the IPCC default values (1+0.0125% N fertilizer applied).
- The high degree of variability of N_2O fluxes implies that the snap-shot approach for calculation of EF can be misleading. Hence, an approach involving either continuous monitoring of the N_2O fluxes, or more frequent sampling around fertilizer application and irrigation events is strongly recommended.

Tomato Experiment: For fresh market tomatoes grown on sandy loam soils, fertilized with UAN-32, and irrigated with subsurface drip irrigation (SDI) the major findings from the current study are:

- Fertilizer and irrigation rates appeared to significantly influence the N_2O emission within 2 hours of fertilizer application.
- The amount of N_2O-N in kg per ha emitted during tomato cropping season ranged from 0.162 to 0.291 in 2012 and from 0.203 to 0.444 in 2013. More importantly, when these emissions were expressed on the basis of the amount of fertilizer applied throughout the season, the emission rates were relatively constant in both years at 0.002 kg N_2O-N per ha per lb of N fertilizer.
- Overall, there was a moderate positive correlation (r= 0.64) between the amount of N_2O-N emitted and the fertilizer applied, with the correlation being relatively stronger in 2013 (r = 0.99) than in 2012 (r = 0.48).
- With respect to the volume of water applied during the 2012 season, the amount of N_2O-

N emitted increased from 0.102 kg N_2O-N per ha per mm water for plots receiving 60%ET (I3) to 0.428 kg N_2O-N per ha per mm water for the 100%ET irrigated plots. In 2013, the amount of N_2O-N emitted from the 80%ET (I2) and 100%ET (I1) irrigated plots were approximately 1.7 times greater than the emissions from the plots irrigated at 60%ET (I3).

- Overall, there was a positive correlation (r= 0.74) between the amount of N_2O-N emitted and the volume of water applied, with the correlation being relatively stronger in 2013 (r = 0.92) than in 2012 (r = 0.82).
- The relatively constant emission rates of 0.002 kg N2O-N per ha per lb of N fertilizer determined for the fertilizer and deficit irrigation regimes, would imply that the incremental addition of both fertilizer and water through SDI could be highly efficient management practices to minimize the N_2O emissions in tomato cropping systems.

DNDC Modeling: This phase of the research is the primary focus of the work for the final year of the matching CSU-ARI funded project. In addition, the ancillary data from the cotton and the tomato trials are also being analyzed as part of the CSU-ARI matching project and will be provided to CDFA upon completion.

Acknowledgements:

We would like to acknowledge Dr. Martin Burger and the rest of the research group at UC-Davis for their assistance with the analysis of the gas sample. Also a special thank you to the “Grad Lab Team” for the long hours in the field during the collection of data over the past three years.

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(F) Project impacts

This project addressed the following FREP program goals:

- Fertilization practices — research examined fertilization application rates impact on total N_2O emissions.
- Site-specific fertilizer technologies such as subsurface drip irrigation, Nitrogenase inhibitors and split application of Nitrogen fertilizers- tools for improved fertilizer recommendations were evaluated for their impact on nitrous oxide emissions.
- Additional areas that support FREP's mission, such as air quality — project will improve our understanding of N_2O emission profiles for two important San Joaquin Valley crops.

The project was directed towards CDFA's and FREP's mission to advance the agronomically sound and environmentally safe use of fertilizers. 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 needed to address the mandated reduction in GHG emissions by 2020. 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 compared. The N_2O emission data collected in the current research will be useful for validating or revising future measurements, as management practices are adjusted, and typical California crop rotations change.

The group of investigators on this project have developed a joint research in an effort to directly address recommendations for 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 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.

(G) Outreach Activities Summary

1. **Scientific and Technical Presentations**: (Seminars, lectures, and posters)

   On November 17th, 2009, a PowerPoint presentation was delivered at the 17th Annual CDFA-FREP conference held in Visalia.

   In November 2010, a PowerPoint presentation was delivered by Dave Goorahoo at the 2010 International Annual Meeting of the ASA, CSSA and SSSAtri-societies. Copies of the slides used in this presentation which focused on the significance and overview of the research project are attached in section (**K)** of this report.

   In November 2010, a Poster was presented by Natalio Mendez at the 2010

International Annual Meeting of the ASA, CSSA and SSSA tri-societies. A copy of this poster which focused on use of the INNOVA for measuring N_2O and CO_2 concentrations in a tomato crop is attached in section (**K**) of this report.

In February 2011, the graduate student also presented the poster at the annual Plant and Soil conference of California Chapter of the American Society of Agronomy.

Mahal N.K., Goorahoo D., Roberts B. & C. Sharma F., 2013. Estimation of nitrous oxide emissions from cotton treated with Nutrisphere - N. ASA, CSSA, and SSSA Annual Meetings, Tampa, FL.

Mahal N.K., Goorahoo D., Sharma F., Robles J., 2013. Nitrous Oxide Emissions from cotton treated with Nurisphere-N. Jordan College of Agricultural Science and Technology Seminar Series, Fresno, CA.

Mahal N.K., Goorahoo D., Sharma F., Robles J., 2013. Validation of DNDC model for estimation of nitrous oxide emissions from agricultural soils. Soil Water Conservation Society International Annual conference, Reno, Nevada.

Mahal N.K., Goorahoo D., Roberts B. & C. Sharma F., 2014. N_2O Emissions from Cotton treated with Inhibitors. 28th Annual California State Research Symposium, CSU East Bay, CA.

Mahal N.K., Goorahoo D., Roberts B. & C. Sharma F., 2014. Nitrous Oxide Emission factors for cotton fertilized with Urea Ammonium Nitrate and treated with Nutrisphere-N. American Society of Agronomy California Chapter – 2014 Plant and Soil Conference, Fresno, CA.

2. Industry Contacts/Interactions:

Throughout the course of the study, visits to the Hanford site and collaboration with the grower were maintained on a regular basis.

(I) Factsheet/Database Template

1. Project Title: Measuring and modeling nitrous oxide emissions from California cotton, and vegetable cropping systems

2. Grant Agreement Number: 09-0001

3. Project Leaders

Dave Goorahoo
Associate Professor- Vegetable Crops Production-Plant Science Department California State University, Fresno. email: dgooraho@csufresno.edu

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Florence Cassel S.
Assistant Professor Irrigation and Water Management Plant Science Department, California State University, Fresno email: fcasselss@csufresno.edu

4. Start Year/End Year: July 1, 2009 to December 31, 2013

5. Location: Fresno and Hanford, CA.

6. County: Fresno and Kings

7. Highlights:

   The total N_2O emissions from cotton beds were generally 30-36% higher than those from the furrows throughout the cropping season. The emission factors (EFs) for cotton treated with different rates of UAN-32 ranged between 0.20% and 0.34%. Application of Nutrisphere-N (NSN) with the fertilizer at the rate 0.05% v/v of further reduced the N_2O emissions over the season with the EFs being reduced to between 0.01 to 0.38%.

The N_2O EF determined for cotton using the time series integration approach were considerably lower than the IPCC default values (1+0.0125% N fertilizer applied).

For fresh market tomatoes the N_2O fluxes due to the irrigation and/or fertilizer treatments, generally peaked within two hours after fertilizer application. T

There was a moderate positive correlations between the amount of N_2O-N emitted and the fertilizer applied (r= 0.64) and with the volume of water applied (r= 0.74).

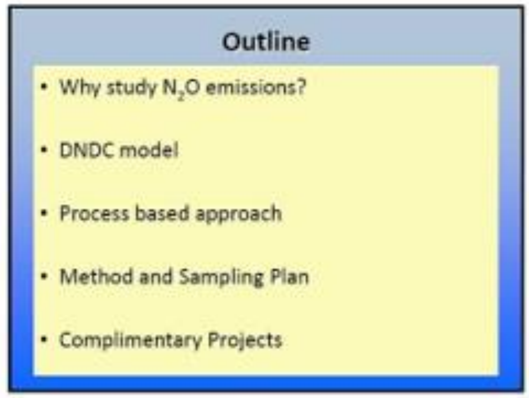
8. Introduction: The effects of the anthropogenic increase in atmospheric greenhouse gases (GHGs) concentration on climate change are beyond dispute. Of the three biogenic GHGs (i.e., carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O)), N_2O is considered to be the most potent. The overall goal of this study was to determine detailed time series of N_2O fluxes at crucial management events, for cotton and a fresh market crop in the Central Valley of California.

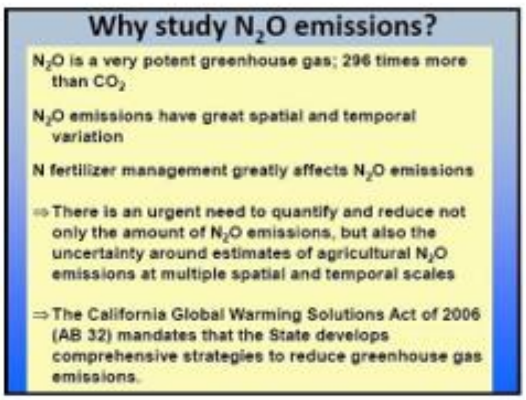
9. Methods/Management :The overall goals of this project were to: (1) determine detailed time series of nitrous oxide (N_2O) fluxes and underlying factors at crucial management events (irrigation, fertilization, etc.) in representative agro-ecosystems in Central Valley of California; and (2) use the intensive data on N_2O fluxes to calibrate and validate processed based biogeochemical De-Nitrification - De-Composition model (DNDC). Specific objective of this phase of the research funded by CDFA was to determine N_2O flux measurements for cotton and tomatoes grown on sandy loam soils and fertilized with Urea Ammonium Nitrate (UAN-32).Flux chamber measurements were conducted using an EPA approved methodology to collect air samples which were ultimately analyzed using a Gas Chromatograph.

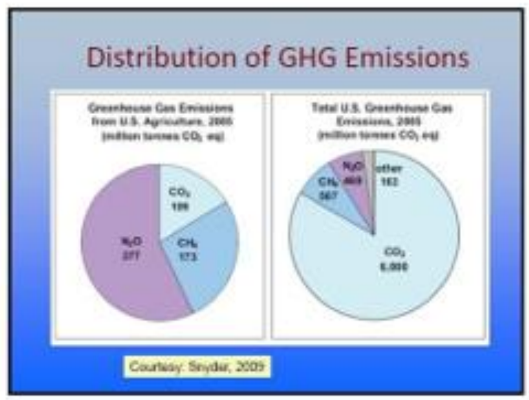
10. Findings: For the cotton crop, the N_2O fluxes were highest when irrigation was applied after fertilizer application. Overall, the total N_2O fluxes from furrows were 64% to 70% lower than that from the beds, on which the fertilizers were applied, and the emission factor (EF) for beds ranged from 0.69% to 1.94 %. The emission factors (EFs) for 50, 100 and 150 lbs N/acre applied with NSN was 0.01, 0.29 and 0.38% respectively, whereas for the same treatments without application of inhibitor was 0.34, 0.32 and 0.20% respectively. In 2013, for plots receiving 50, 100 and 150 lbs N/ac, the NSN reduced the total N_2O emissions by 19%, 54% and 52%, respectively. The N_2O EFs determined in this study using the time series integration approach were considerably lower than the IPCC default values (1+0.0125% N fertilizer applied). The high degree of variability of N_2O fluxes implies that the snap-shot approach for calculation of EF can be misleading. In the tomato experiment, any significant differences in the N_2O fluxes due to the irrigation and/or fertilizer treatments, generally peaked within two hours after fertilizer application. Overall, there was a

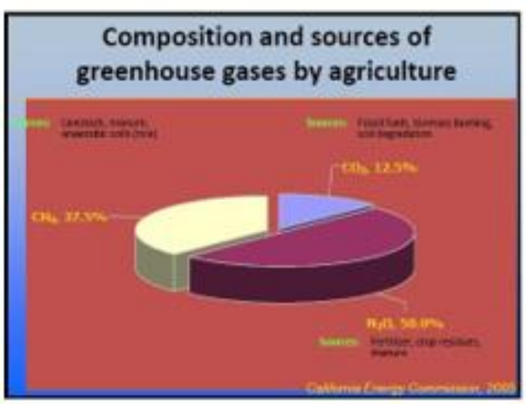
moderate positive correlations between the amount of N_2O-N emitted and the fertilizer applied (r= 0.64) and with the volume of water applied (r= 0.74). The amount of N_2O-N in kg per ha emitted during tomato cropping season ranged from 0.162 to 0.291 in 2012 and from 0.203 to 0.444 in 2013. More importantly, these emission rates were relatively constant in both years at 0.002 kg N_2O-N per ha per lb of N fertilizer and would imply that the incremental addition of both fertilizer and water through SDI could be highly efficient management practices to minimize the N_2O emissions in tomato cropping systems.

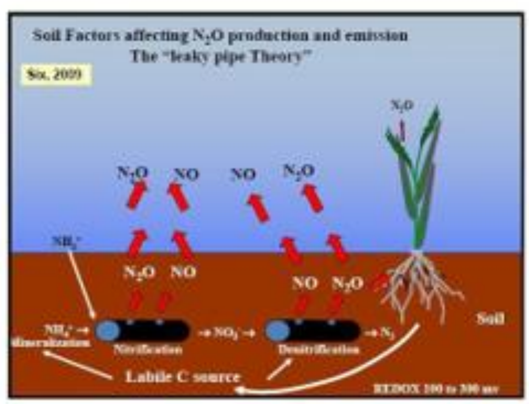
(J) Copy of the Product/Result PowerPoint presentation by Dr. Goorahoo at 2010 International Annual Meeting of the ASA, CSSA and SSSA tri-societies





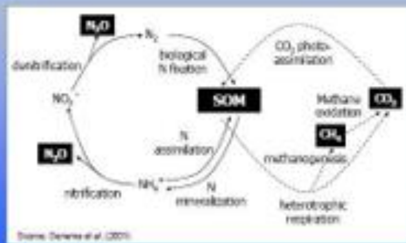






Nitrogen and carbon cycles

Six, 2009



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

1.CA Department of Food and Agriculture (CDFA)- Fertilizer Research and Education Program (FREP)

2. CA State University (CSU)- Agricultural Research Institute (ARI)

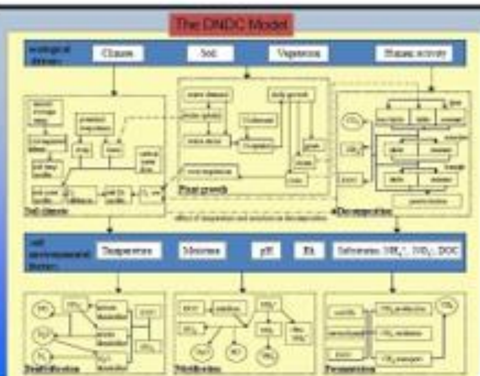
Funding for three years (2010 to 2013)

Project Objectives

- ✓(1) Determine detailed time series of N_2O fluxes and underlying factors at crucial management events (irrigation, fertilization, etc.) in representative agroecosystems in Central Valley of California; and
- ✓(2) use the intensive data on N_2O fluxes to calibrate and validate processed based biogeochemical model (**DNDC**)

DNDC Model

DNDC stands for Denitrification and Decomposition, two processes dominating losses of N and C from soil into the atmosphere, respectively.

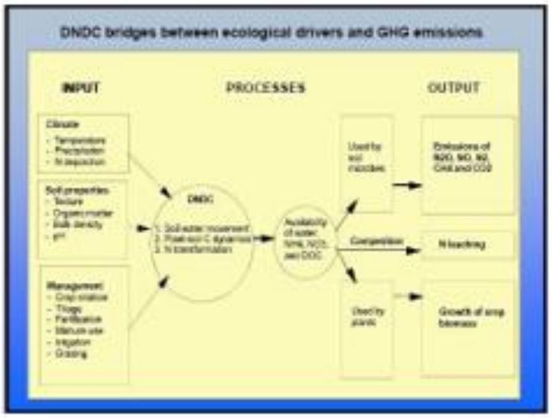


Model Validation…

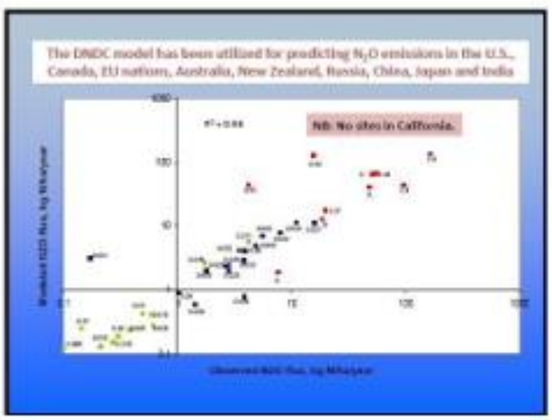
- Rigorous model validation is key for acceptance (scientific and market)
- Lack of appropriate field data for process-model validation
- DNDC has been validated extensively for agroecosystems worldwide (over 100 peer review papers)
- Additional validation efforts underway (e.g. CA).

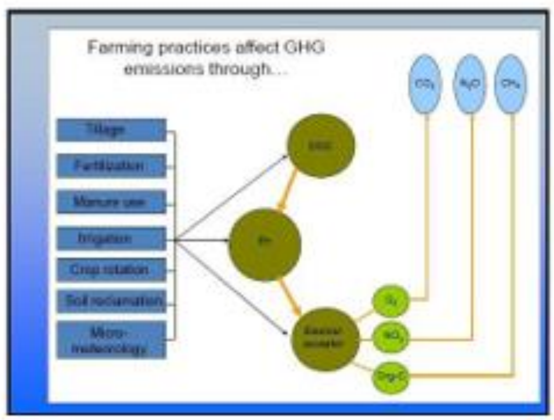
What are Process-based Models?

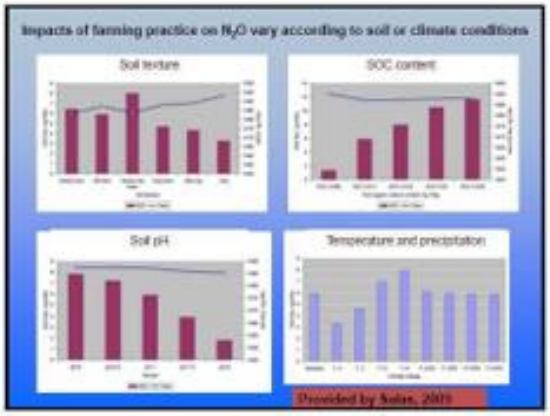
- Process-based modeling refers to biochemical and geochemical reactions or processes
  - Process modeling, in this case, does **not** refer to fertilizer practices or components per se, but
- **Biogeochemical processes**… like decomposition, hydrolysis, nitrification, denitrification, etc…
- True process-based models **do not rely on constant emission factors**. They simulate and track the impact on emissions of varying conditions within the management system (e.g., tillage, fertilization, irrigation, harvesting, residue management).



DNDC resulted from a 20-year international effort with researchers from the U.S., China, Germany, the U.K., Canada, Australia, New Zealand, the Netherlands, Belgium, Finland, Japan and India.



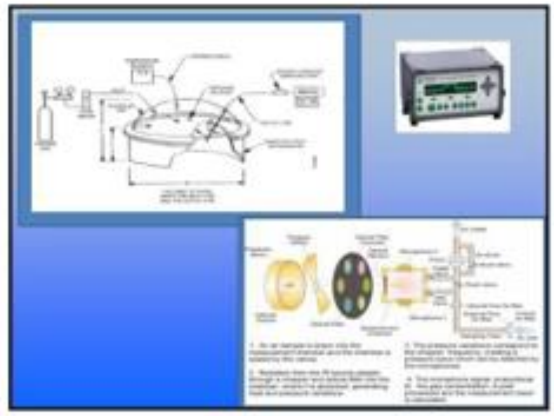




Proposed Tasks

Measure and calculate N_2O emissions

- ✓ Replicate plots
- ✓ N_2O flux in microplot following fertilizer applications and irrigation or rainfall events.
- ✓ measurements will be taken less frequently (weekly) when elevated N_2O flux has subsided and soils are relatively dry.
- ✓ Flux chambers will be used with fixed PVC rings.
- ✓ Chamber headspace gas samples will be sampled and analyzed by a Photoacoustic Field Gas-Monitor 1412 (INNOVA AirTech Instruments)



Flux Chamber Method with INNOVA

Proposed Tasks cont'd

Ancillary measurements.

- ✓ Soil and air temperature
- ✓ Periodically (every 3 weeks) inorganic N and pH
- ✓ Crop yields
- ✓ Total N application rates
- ✓ Biomass, N tissue analysis for root, stalk, leaves, and after harvest, C:N ratio of root and leaves
- ✓ Agronomic Practices: Tillage operations (date and frequency); Fertilizer application rates and frequency

Proposed Task cont'd

3. Validate DNDC model in three stages:

- ✓ **1) test the model with no calibration (i.e., not new data collected in this project is used to calibrate the model,**
- ✓ **2) test the model with moderate calibration (i.e., 50% of the new data is used for calibration and the other 50% is left for validation) and**
- ✓ **3) test the model with extensive calibration (i.e., 75% of the new data is used for calibration and the other 25% is left for validation).**

Proposed Task cont'd.

Run DNDC across range of corn systems

- ✓ **GIS data (NRCS) on soils will be used to capture range of soil conditions**
- ✓ **CIMIS data will be used for daily climate**
- ✓ **DWR land use maps**

Complementary Project Proposals

- *"N2O Emissions from the Application of Fertilizers in Agricultural Soils"*; PI is Dr. Johan Six, 3-year project by CEC PIER program
- *"Establish Baseline N_2O Emissions from Nitrogen Fertilizer use Based on Field-Derived California Specific N_2O Emission Factors"*; PI is Dr. Will Horwath, project funded by CARB
- California State University - Agricultural Research Institute. Funds will be used for expanding field measurements and model validation efforts.

THANK YOU !

☺

Any Questions?

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Nitrous Oxide Emissions From Drip Irrigated Tomatoes Subjected to Elevated Carbon Dioxide Levels

Natalio Mendez, Dave Goorahoo, Florence Cassel S., & Gerardo Orozco

Department of Plant Science & Center for Irrigation Technology, California State University, Fresno

Background

•The effects of the anthropogenic increase in atmospheric greenhouse gas (GHG) concentrations on climate change are beyond dispute, and agriculture can play a key role in this issue.

• Nitrous oxide (N_2O) is emitted from soil to the atmosphere as part of the nitrogen (N) cycle, but the addition of reactive nitrogen (N) in the form of fertilizer in intensive crop systems increases N_2O emissions.

• In 2004, the California Energy Commission reported that agricultural soil was estimated to account for 68% of the total U.S. N_2O emissions, equivalent to 386.7 Tg CO_2. In CA, 55 % of all N_2O emissions have been estimated to come from agricultural soil.

• The California Global Warming Solutions Act of 2006 (AB 32) mandates that the State develops comprehensive strategies to reduce greenhouse gas emissions.

•Increase in GHG concentrations, including those stemming from N_20 and carbon dioxide (CO_2) has been partly attributed to agriculture.

•CO_2 enters the atmosphere as the result of fossil fuel, solid waste, wood burning and other industrial production processes. However, CO_2 can also be sequestered by plants as part of the biological carbon cycle.

• Sustainable agricultural practices are necessary to minimize GHG emissions while maintaining optimal crop production. Particularly it is important to quantify N_2O emissions in fields fertilized with N sources and subjected to elevated atmospheric CO_2 levels.

Objective

- **Overall Goal:** Determine detailed time series of N_2O fluxes and underlying factors at crucial management events (irrigation, fertilization, etc.) in representative agro-ecosystems in California.
- **This Phase:** **To assess the use of the INNOVA for comparing N_2O concentrations in tomatoes subjected to open field CO_2 canopy enhancement.**

Materials and Methods

Fig 1: Flux chamber

Fig 2: N free air for purging chamber

Fig 3: INNOVA 1412

Fig 4. INNOVA and Flux Chamber Assembly

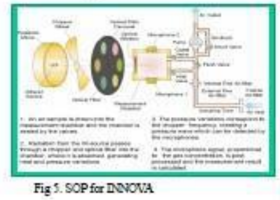

Fig 5. SOP for INNOVA

•Location: CSUF Center for Irrigation Technology; Fresno, Ca.

•Soil Texture: Sandy loam (Avg. pH= 7.2, Avg. EC = 1.2 dS/m

•Crop Planted: Tomatoes, Cultivar: Bobcat

• Irrigated with a subsurface drip system.

• In elevated CO_2 plots CO_2 was applied through surface drip lines.

• The Photoacoustic Field Gas-Monitor INNOVA 14124 was used for N_2O and CO_2 concentrations at three locations in the ambient and CO_2 enhanced plots (Fig. 6).

•Measurements : Sep. 22[nd]; oct .15[th] & 22[nd] 2010.

•Avg Temp: Inside Chamber: 31.4 C, Inside chamber Soil: 32.6 C, Outside Chamber: 27.3 C, Outside Chamber Soil: 28.5 C.

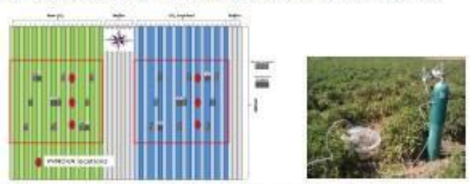

Fig 6. Plot Layout showing N_2O sampling locations (*left*) and gas & chamber assembly (*right*).

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Preliminary Results & Future Work

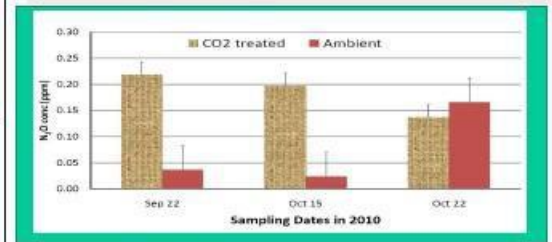

Fig 7. N_2O concentrations during the course of the study.

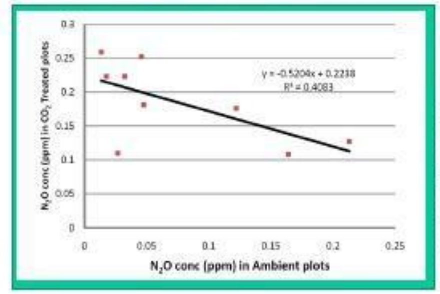

Fig 8: (*left*) N_2O concentrations obtained in the CO2 enhanced plots versus concentrations obtained for the tomatoes grown in ambient conditions.

•For the CO_2 <u>enriched plots</u>, mean daily CO_2 levels within the crop canopy ranged from 580ppm to 400 ppm during the 7 hours of application. <u>Ambient</u> CO_2 concentration was 358 ppm (*Data not shown*).

• For the CO_2 <u>enriched</u> plots, mean N_2O concentration decreased from 0.22 (±0.02) ppm on September 22[nd] to 0.14 (±0.02) ppm on October 22[nd] 2010. In contrast, there was an increase in the N_2O levels from 0.04 (±0.01) to 0.17 (±0.03) ppm from the plots where tomatoes were exposed to ambient conditions (*Fig. 7*)

•Generally, there was a moderate (r = 0.64) negative correlation between the N_2O levels measured in the CO_2 enriched plot versus those measured in the ambient plots (*Fig. 8*).

• Future work will focus on the collection of additional parameters (e.g. soil moisture and SOM) to calibrate and validate processed based biogeochemical <u>De</u>-<u>N</u>itrification - <u>De</u>-<u>C</u>omposition model (DNDC) in our efforts to characterize N_2O dynamics within vegetable cropping systems.

•Data obtained with this INNOVA device will be compared with the data collected with our 2[nd] method using static flux chambers

With funding from this CDFA project and the CSU-ARI, it was possible to fully support a graduate student- Navreet Mahal- to conduct the work related to the cotton research. This student has successfully completed her master's degree and is now pursuing her Ph.D. studies at Iowa State University. The material for the cotton experiment for 2011 and 2012 presented in this report is taken from the final thesis submitted by Mahal (2014). For additional details the reader can download as PDF from: http://cdmweb.lib.csufresno.edu/cdm/ref/collection/thes/id/109463.

With funding from this CDFA project and the CSU-ARI, it was possible to partially support another graduate student- Michael DeWall- to conduct the work related to the tomato research. This student has successfully completed his master's degree and is now employed as a research associate with CIT. The material for the tomato experiment for 2011 and 2012 presented in this report is taken from the final senior project submitted by DeWall (2014). For additional details the reader is directed to complete report on file at Biology Department at Fresno State, or can request a PDF copy from Dr. Dave Goorahoo (dgooraho@csufresno.edu).

The matching CSU-ARI project will end in October 2015. At the completion of additional analyses of the various datasets, and modeling efforts with the DNDC model, along with any manuscripts submitted for peer review and publication in scientific Journals will also be forwarded to CDFA.

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