Section A

Final Report for the period 1/1/2013 – 6/30/2015

Project Title: Assessment of Baseline Nitrous Oxide Emissions in Response to a Range of Nitrogen Fertilizer Application Rates in Corn Systems

FREP Grant # 12-0453-SA

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Section B
Objectives:

(1) Determine the annual nitrous oxide (N_2O) emissions in response to a range of nitrogen (N) fertilization rates in a corn cropping system;

(2) calculate yield-scaled N_2O emissions (e.g. g N_2O-N g^{-1} $N_{harvested}$) and N_2O emission factors (EF) for each fertilizer level;

(3) determine the nitrogen use efficiency (defined as the ratio of N yield of the corn crop to applied N) and optimum N rate (economic N yield) of the corn crop;

(4) identify key environmental conditions affecting N_2O flux.

Section C
Abstract

Corn has the largest acreage of California's field crops, but to-date there are no data on the effects of fertilizer nitrogen (N) rates on the emissions of the greenhouse gas nitrous oxide (N_2O) in irrigated corn systems in the State. Furthermore, there is a lack of field data that can be used to provide N fertilization guidelines to California corn producers. In this study, N_2O emissions in a furrow-irrigated corn system fertilized at five different N rates and crop N uptake were measured during two years in commercial fields of Stockton clay soil. In the first year (2013), the N rates varied between 8 and 337 kg N ha^{-1} and N_2O emissions ranged from 0.2 (±0.04) – 1.9 (±0.5) kg N_2O-N ha^{-1}. In the second growing season (2014), N_2O emissions ranged from 1.1 (±0.2) - 6.1 (±0.4) kg N_2O-N ha^{-1} at N fertilizer rates from 75 -344 kg N ha^{-1}. The percentage of fertilizer N emitted as N_2O (emission factor, EF) ranged from 0.3 – 0.6% in 2013 and from 1.4% -

to 2.1% in 2014. The apparent N use efficiencies taking into account both N fertilizer and pre-plant nitrate as crop N inputs ranged from 0.66 – 0.98 in 2013 and from 0.86 – 1.39 in 2014. In both years, yields did not differ between the highest and lowest N fertilizer treatments, suggesting that N was not limiting yields, but N uptake by the corn crop varied significantly from 207 – 288 kg N ha^{-1} in 2013 and from 233 – 377 kg N ha^{-1} in 2014. Assessing plant available N and adjusting N fertilizer rates accordingly is essential to keep N_2O emissions as low as possible while maintaining yield potential.

Section D
Introduction

Nitrous oxide (N_2O) contributes 3% to California's (CA) total GHG emissions or about 24% of the total greenhouse gas (GHG) emissions from CA's agriculture sector (California Air Resources Board 2015). With the passage of the Global Warming Solutions Act (Assembly Bill 32), quantifying N_2O emission from different cropping systems is a prerequisite to address the mandated reduction in GHG emissions by 2020 and develop effective mitigation practices and strategies. To date, N_2O emissions in California cropping systems have been assessed in multi-year studies in tomato, wheat, lettuce, alfalfa, almond, and vineyards (Garland et al. 2011, 2014; Kennedy et al. 2013; Schellenberg et al. 2012; Verhoeven and Six 2014; Burger et al. 2013; Burger and Horwath 2012). Among California's field crops, corn has the largest acreage (610,000 acres). However, missing is a systematic, controlled investigation on the effect of N fertilizer levels on N_2O emissions in irrigated corn production in California.

Nitrous oxide (N_2O) is produced in soil by microorganisms that use inorganic forms of nitrogen (N). Nitrous oxide is generated mainly under oxygen limitation as by-product of nitrification [conversion of ammonium (NH_4^+) to nitrate (NO_3^-)] and denitrification [conversion of NO_3^- to atmospheric nitrogen (N_2)] and through chemodenitrification (Firestone and Davidson 1989; Robertson and Groffman 2015; Van Cleemput and Baert 1984; Zhu et al. 2013). In addition to the availability and form of N in inorganic form, the production of N_2O is controlled by biophysical factors, such as soil carbon, moisture, temperature and oxygen concentration, microbial activity and plant development (Tiedje 1994; Venterea et al. 2012). Meta-analyses based on over 1000 studies found that fertilizer nitrogen (N) application rates have significant effects on N_2O emissions (Eichner 1990; Bouwman et al. 2002; Stehfest and Bouwman 2006). Moreover, N_2O emissions increase sharply in response to N additions that exceed crop N needs (Edis et al. 2008; McSwiney and Robertson 2005; Van Groenigen et al. 2010). Presently, there are few N fertilization guidelines for corn production in California. Thus, data on both N fertilizer use by the crop and N_2O emissions are needed. The present study takes a systems approach evaluating N_2O emissions, crop performance, N use efficiency, and potential environmental impacts with various levels of N fertilizer applications. The over-arching goal is to develop best management practices that minimize N_2O emissions without sacrificing corn yield potential.

Section E
Work description:

Task 1. Site selection. Suitable sites for the study were located in 2013 in the vicinity of Stockton. The soil is Stockton clay, classified as fine, montmorillonitic, thermic Typic Pelloxererts (National Cooperative Soil Survey). The soil properties are shown in Table 1. Corn was grown at the site in the season prior to the first study-year (2013), and wheat preceded corn at the site of year 2 (2014). Corn was grown for grain in the 2013 season and for silage in the 2014 season. The fields were furrow-irrigated with furrows spaced 152 cm and beds approximately 1 m wide.

Table 1. Soil properties in the two fields used for the experiments.

Year	Sand	Clay	Bulk density	Total carbon	Total nitrogen	pH
	%	%	g cm^{-3}	%	%	
2013-14	30.4	35.0	1.30	1.04	0.1	7.0
2014-15	18.8	43.4	1.20	1.12	0.1	6.8

Task 2. Experimental design. In both years, each treatment was imposed on three beds for the full length of the field (184 m in 2013 and 170 m in 2014). Static chamber techniques were used to take N_2O flux measurements (Hutchinson and Livingston 1993; Parkin and Venterea 2010). Chamber bases were installed at three locations varying in distance from the head of the field (irrigation channel) within each treatment. At each replicate location three chamber bases were installed, i.e. a furrow and a shoulder chamber base (both 15x15x6 cm depth), and a bed chamber base (30x50x8 cm depth) that covered exactly one half of the bed.

Nitrogen, phosphorus, and potassium (NPK) starter fertilizer (3-10-10 plus 0.5 gallon zinc per acre in 2013, and as 8-24-6 with plus 0.5 gallon zinc per acre in 2014) was applied at planting on April 17, 2013 and April 18, 2014. In 2013, the N fertilizer treatments in the form of urea ammonium nitrate (UAN) were randomly imposed 17 days after planting when the corn was about 13 cm tall, and in 2014, the side dress N treatments were applied 27 days after planting when the corn was in the V4 stage (about 30 cm tall) (Table 2). The N fertilizer in the form of urea ammonium-nitrate (UAN32) was injected at a depth of 15 cm, in two bands about 15 cm from the plant line (2 fertilizer bands per plant row). Furrow irrigation occurred at a frequency of 7-10 days (d) with the first irrigation on May 19, 2013 and May 26, 2014.

Table 2. Nitrogen fertilizer treatments in 2013 and 2014.

2013		2014	
NPK starter	Side dress UAN	NPK starter	Side dress UAN
Apr. 17	May 4	Apr. 18	May 15
kg N ha^{-1}		kg N ha^{-1}	
8	0	13	n.d.
8	139	13	73
8	226	13	162
8	270	13	254
8	342	13	344

n.d. = no data; due to an error, fertilizer was applied in the zero-N side dress treatment.

Task 3. N_2O flux measurements. During the growing season, N_2O flux measurements were taken frequently (daily or every other day) following irrigation events until the elevated N_2O fluxes occurring in some of the treatments receded to background levels about three months after planting. Afterwards, gas emission samples were taken twice a week. Following the harvest 2013, gas samples were collected bi-weekly through March 2014. After the harvest 2014, gas sampling was irregular due to field operations. Unexpectedly, the field was fertilized in November 2014. We subsequently stopped measuring N_2O flux in this field. However, we continued monitoring emissions in a nearby field where corn had been grown under drip irrigation during the growing season 2014. Those data should at least give some indication of the winter fluxes in this soil type.

During N_2O flux measurements, chambers (height 10 cm) were fitted onto the bases and 20 mL headspace air was removed from a sampling port with butyl rubber septa via syringe and needle after 0, 20 and 40 min and stored in evacuated 13 mL glass vials with grey butyl rubber septa. Air temperatures were recorded at each time interval. The headspace air samples were analyzed by a Shimadzu gas chromatograph (Model GC-2014) linked to a Shimadzu auto sampler (Model AOC-5000). The gas chromatograph was calibrated daily using analytical grade N_2O standards (Airgas Inc., Sacramento CA).

Task 4. Ancillary data & yield measurements. Soil cores from 0-30 cm and 30-60 cm depth were taken (5 composite samples each consisting of 10 individual cores) before planting to assess pre-plant nitrate (NO_3^-) levels. During the growing season, inorganic N to a depth of 15 cm was measured weekly. Soil and ambient air temperature, and soil moisture were recorded during each gas sampling. In 2014, soil moisture was measured at 7 cm depth underneath each chamber by Decagon 5-TE moisture sensors (Decagon Inc., Pullman, WA). Bulk density in the 0-15 cm layer was determined twice during the growing season. Crop biomass was measured at harvest by weighing all the plants in a 4 m long section of the bed per replicate. The cobs were removed, the grain stripped from the cobs, dried at 60°C and then weighed. Biomass N and grain N were determined by dry combustion (Costech Analytical Technologies, Valencia, CA).

5. Calculations & deliverables. Gas fluxes were calculated from the rate of change in chamber concentration, chamber volume, and soil surface area (Hutchinson and Livingston 1993; Parkin and Venterea 2010). Chamber gas concentrations determined by GC (volumetric parts per million) were converted to mass per volume units assuming ideal gas relations and using the air temperature values during sampling. The growing season N_2O emissions were calculated by trapezoidal integration under the assumption that the measured fluxes represent mean daily fluxes. The emission factors were calculated as the amount of N_2O-N divided by the amount of fertilizer N applied (per unit area). The N uptake-scaled N_2O emissions were calculated by dividing the growing season N_2O emissions by the amount of N in the corn biomass at harvest. The yield-scaled N_2O emissions were calculated by dividing the total N_2O emissions by the mass of grain in year 2, the mass of grain was separately measured), and then the mass of N_2O was converted to carbon dioxide equivalents, using a conversion factor of 398, to allow a comparison of the results with meta-analysis data (Linquist et al. 2012). The apparent N use efficiency (NUE) was calculated as the amount of N in corn biomass divided by the sum of pre-plant NO_3^--N and fertilizer N. For 2013, N fertilizer use efficiency (FUE) was calculated by subtracting the mean biomass N in the control treatment from the biomass N in each fertilized treatment and expressing the result as a percentage of the applied fertilizer N (Bock 1984).

Differences between N fertilization treatments were assessed using one-way ANOVA and standard mean separation procedures. The two seasons were analyzed separately as completely randomized design since the initial ANOVA did not show a significant block (distance from irrigation canal) effect. To meet the assumptions of homogeneity of variance, normal distribution of residuals, and additivity, the cumulative N_2O emission data were natural log transformed for the 2013-14 season and power transformed for 2014. The yield-scaled N_2O emission data were natural log transformed. A Tukey means separation procedure was performed to detect differences between treatment means. The statistical analyses were conducted with SAS software (SAS Institute Inc., version 9.4, Cary, NC).

Section F
Results

Mean total seasonal N_2O emissions in the N fertilized treatments across both years ranged from 0.73 (±0.33) – 6.14 (±0.68) kg N_2O-N ha^{-1} (Table 3). In 2013-14, the N_2O emissions did not differ among the fertilized treatments. Mean daily N_2O fluxes and mean cumulative N_2O emissions are shown in Figures 1 &2. In 2014, the N_2O emissions were significantly higher in the 344 kg N ha^{-1} than in the 164 and 75 kg N ha^{-1} treatments, while emissions in the 75 kg N ha^{-1} treatment were lower than in any of the other treatments. Mean daily N_2O fluxes and mean cumulative N_2O emissions are shown in Figures 3 & 4. The post-harvest N_2O emissions (September 2013 – March 2014) ranged from 11.6 - 43.5 g N_2O-N ha^{-1} in the first year. The post-harvest season emissions in the second year (August 2014 – February 2015) in an adjacent (subsurface drip irrigated) field were 99.6 (±51.1) g N_2O-N ha^{-1} (previous season 174 ±46.5 g N_2O-N ha^{-1}).

Table 3. Pre-plant nitrate levels, mean annual nitrous oxide (N_2O) emissions and standard errors (±), emission factors (EF), and yield-scaled N_2O emissions in 2014 and 2013. Mean N_2O emissions designated with the same letters are not significantly different ($P<0.05$). n = 3.

Fertilizer N treatments	Pre-plant NO_3^-	N_2O-N	EF	N uptake-scaled N_2O	Yield-scaled N_2O*
kg N ha^{-1}			%	g N_2O-N kg^{-1} N	kg CO_2 equiv. Mg^{-1}
2013					
11	72	0.25 ±0.03 a			
139	72	0.82 ±0.32 b	0.6	4.06 ±1.74 a	40 ±17 a
226	72	0.73 ±0.33 b	0.3	3.49 ±1.36 a	40 ±14 a
270	72	1.52 ±0.67 b	0.5	5.87 ±2.04 a	71 ±28 a
342	72	1.94 ±0.30 b	0.6	6.95 ±1.61 a	77 ±19 a
2014					
75	94	1.08 ±0.18 a	1.4 ±0.2	4.61 ±0.41 a	40 ±7 a
164	94	3.41 ±1.26 b	2.1 ±0.4	12.24 ±3.21 ab	113 ±24ab
254	94	4.23 ±1.04 bc	1.7 ±0.4	14.38 ±4.25 b	151 ±37 b
344	94	6.14 ±0.68 c	1.8 ±0.1	16.50 ±1.57 b	205 ±13 b

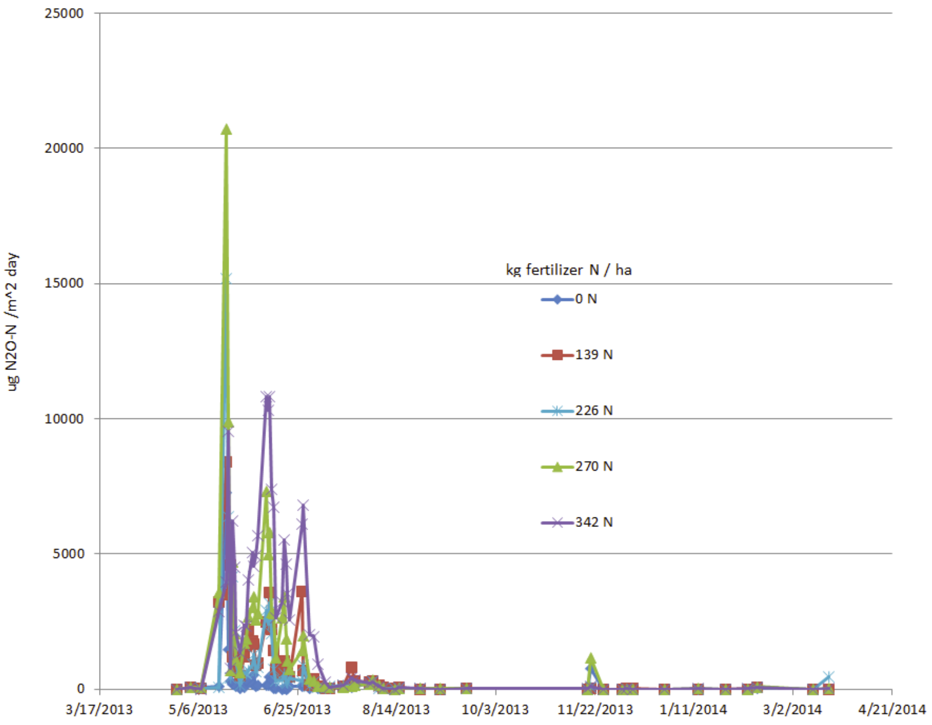


Figure 1. Mean daily N_2O fluxes in 2013-14. n = 3.

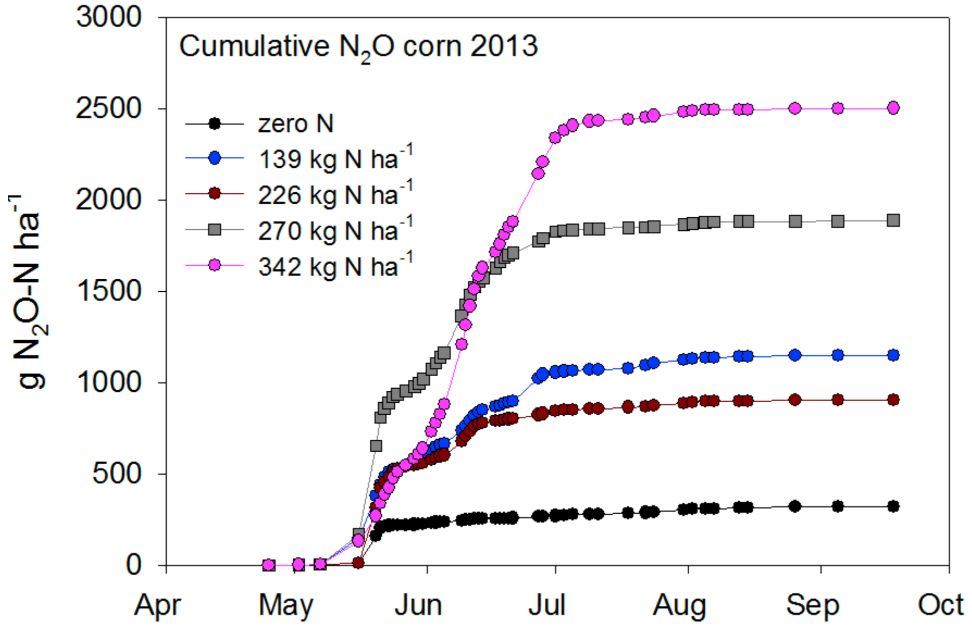


Figure 2. Average cumulative N_2O emissions in the different treatments in 2013.

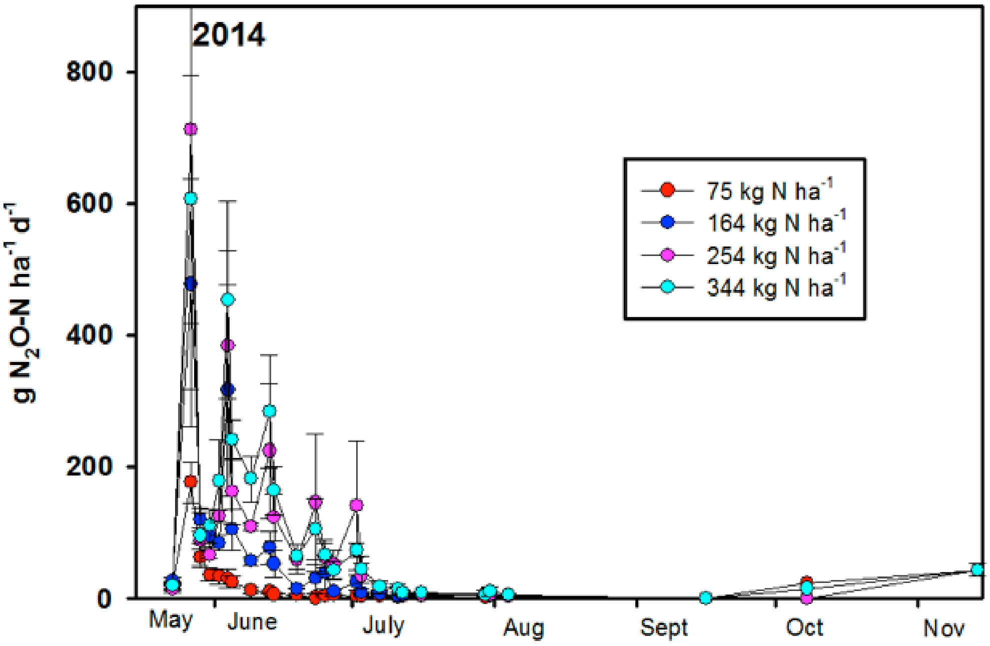


Figure 3. Mean daily N_2O fluxes in 2014. n = 3.

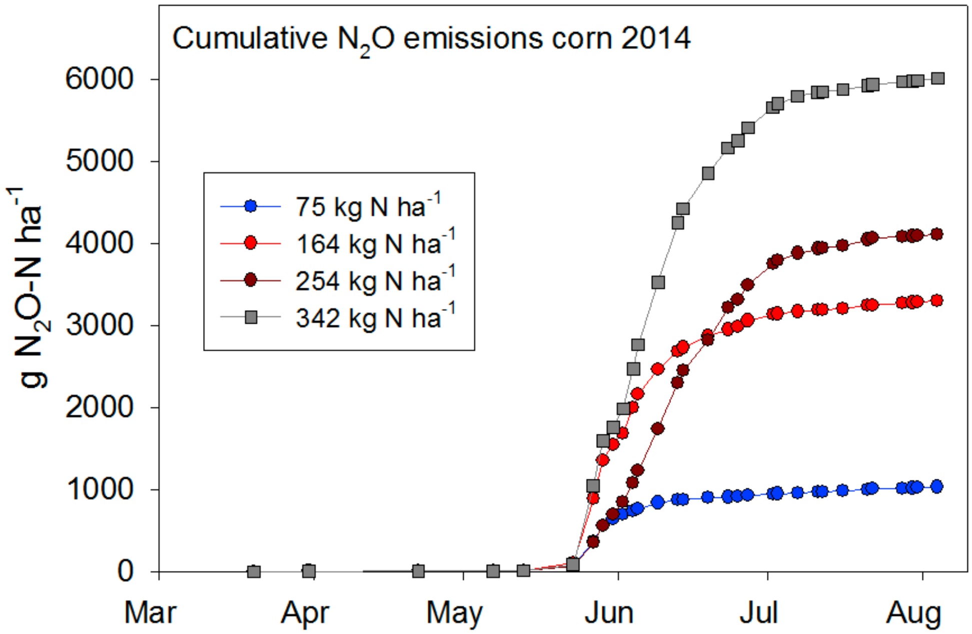


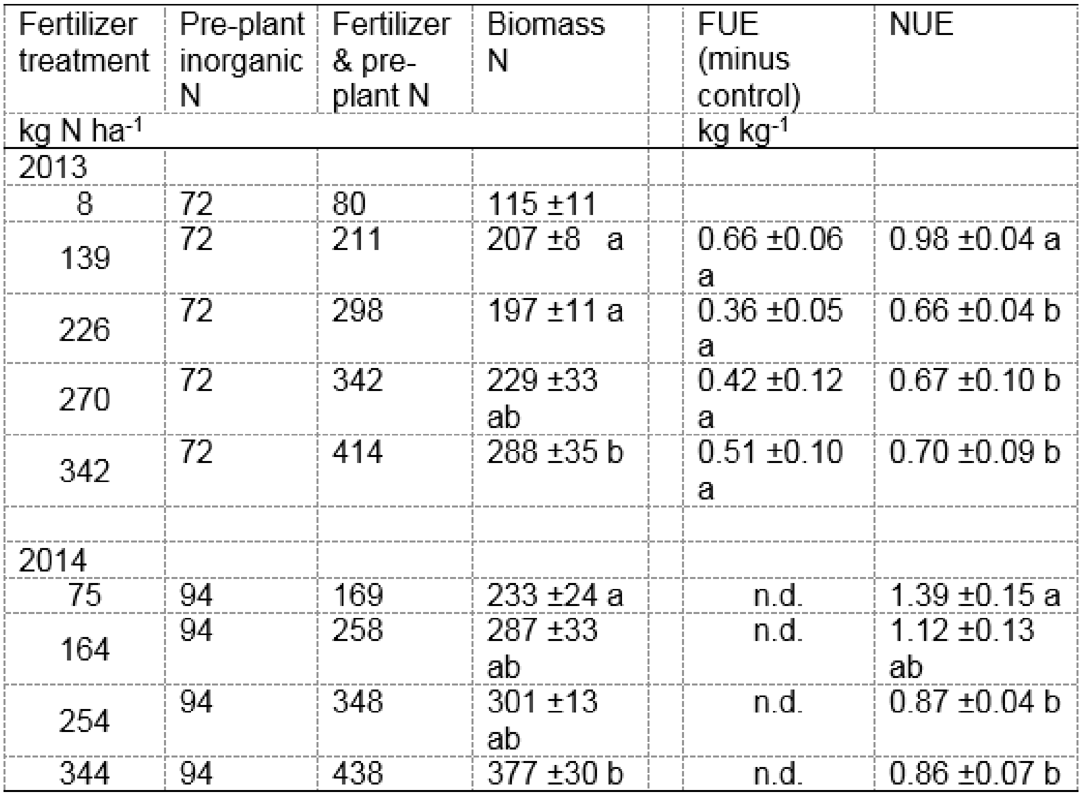
Figure 4. Average cumulative N_2O emissions in the N fertilizer treatments in 2014. n = 3.

The N_2O emissions tended to be higher in year 2 (2014) than in year 1 (2013). The yield-scaled N_2O emissions did not differ among fertilized treatments in 2013, but in 2014, yield-scaled N_2O emissions were significantly lower in the 75 than in the 254 and 344 kg N ha^{-1} treatments and similar among 164, 254, and 344 kg N ha^{-1} treatments.

Table 4. Mean corn yields and standard errors (SE). in 2014 corn was harvested for silage, but grain yields were also determined. Values designated by the same letters are not significantly different (P>.05). n= 3.

Treatment kg N ha^{-1}	Mg grain ha^{-1} (SE)	Silage yield Mg dry wt. ha^{-1}	kg grain N ha^{-1}
2013			
8	4.2 (1.2) c		64 ±15 a
139	10.8 (0.4) ab		157 ±4 b
226	9.6 (0.5) b		147 ±5 ab
270	10.2 (0.8) b		167 ±25 b
342	13.8 (1.7) a		226 ±5 b
2014			
75	12.5 ±0.3 a	30.8 ±2.6 a	
164	14.1 ±0.6 a	31.1 ±3.1 a	
254	13.1 ±0.2 a	29.0 ±1.9 a	
344	14.0 ±0.5 a	32.9 ±2.8 a	

Table 5. Mean corn biomass N and apparent N fertilizer use (FUE) and N use efficiencies (NUE) and standard errors (±) in 2014 and 2013. Means designated with the same letters within each column and year are not significantly different ($P<0.05$). n = 3.



Fertilizer treatment	Pre-plant inorganic N	Fertilizer & pre-plant N	Biomass N		FUE (minus control)	NUE
kg N ha^{-1}					kg kg^{-1}	
2013						
8	72	80	115 ±11			
139	72	211	207 ±8 a		0.66 ±0.06 a	0.98 ±0.04 a
226	72	298	197 ±11 a		0.36 ±0.05 a	0.66 ±0.04 b
270	72	342	229 ±33 ab		0.42 ±0.12 a	0.67 ±0.10 b
342	72	414	288 ±35 b		0.51 ±0.10 a	0.70 ±0.09 b
2014						
75	94	169	233 ±24 a		n.d.	1.39 ±0.15 a
164	94	258	287 ±33 ab		n.d.	1.12 ±0.13 ab
254	94	348	301 ±13 ab		n.d.	0.87 ±0.04 b
344	94	438	377 ±30 b		n.d.	0.86 ±0.07 b

The emission factors (EF, percentage of N of the applied fertilizer emitted as N_2O) ranged from 0.3 – 0.6% in 2013 and from 1.4% (75 kg N ha^{-1} treatment) – 2.1% (164 kg N ha^{-1} treatment) in 2014.

In 2013, corn grain yields were greater in the 342 than in 270 and 226 kg N ha^{-1} treatments, but yields did not differ between the 342 and 139 kg N ha^{-1} treatments (Table 4). In 2014, silage corn yields did not differ among the N fertilization treatments (data not shown). Corn biomass N uptake and the apparent N fertilizer use (FUE) and N use efficiencies (NUE) are shown in Table 5.

Section G

Discussion and Conclusions

Objective 1: In both years, the N_2O emissions increased with increasing fertilizer N application rates, albeit the differences in emissions among the fertilized treatments in the first year of the study were not statistically significant. According to a recent meta-analysis of 548 observations of seasonal/annual N_2O emissions in the U.S. corn belt, where the average N applied fluctuates between 138 and 157 kg N ha^{-1} (USDA ERS 2012), the average N_2O emissions were 3.8 (standard deviation 5.16) kg N_2O-N ha^{-1} per growing season (Decock 2014). In dairy forage production systems in California, Burger, Lazcano, and Horwath (2013) reported corn growing season N_2O emissions ranging from 2.2 -16.2 kg N_2O-N ha^{-1} in systems receiving N inputs in the form of synthetic fertilizer and liquid dairy manure of 400 – 500 kg N ha^{-1} per corn growing season. The results of the present study are therefore in general in agreement with those of other studies. The results were analyzed separately for each year because the emissions were measured in different fields (although the same soil type and same farm). The N_2O emissions tended to be higher in the second year. The most likely explanation for the higher emissions may be the higher clay content of the field used in year 2 compared to that of the first year (Table 1). Soil texture influences N_2O emissions, with finer texture soils emitting more N_2O than coarse-textured soils (Bouwman et al. 2002). The N_2O emissions could therefore be expected to be inherently higher from the soil with the higher clay content. The pre-plant nitrate levels were higher in the second year and might have contributed to the higher emissions in that year. Other factors that might indicate different conditions from year to year did not vary much. For example, CO_2 emissions resulting from microbial activity and root respiration were similar in both years (results not shown), and in both years, surface water with relatively low levels of NO_3^- (1 mg NO_3^--N L^{-1}) was used for irrigation.

Objective 2: The N uptake-scaled N_2O emissions were calculated to explore the relationship between N_2O emissions and crop N uptake, with increasing values potentially indicating excess inorganic N not taken up by the crop as the source of N_2O. In 2014, the N uptake- and yield-scaled N_2O emissions (Table 3) in the 75 kg N ha^{-1} treatment were significantly lower than in the two treatments that received the highest N applications, supporting the hypothesis that N_2O emissions increase non-linearly when fertilizer N is applied in excess of crops' need (McSwiney and Robertson 2005; Van Groenigen et al. 2010). Whether the increase in N_2O emissions was indeed 'non-linear' could not be formally evaluated for lack of sufficient (five) N fertilizer levels in 2014. In 2013, N uptake- and yield-scaled N_2O emissions did not differ among the treatments. In 2014, the EFs were 1.4 – 2.1%, but in 2013 the EFs in all the treatments were lower than 0.7%. In a meta-analysis of 122 observations of seasonal N_2O emissions in corn systems at 19 different sites from all over the world, the mean EF was 1.06% (Linquist et al. 2012). The same study reported average corn yields of 8.0 Mg ha^{-1} and yield-scaled N_2O emissions of 185 kg CO_2 Mg^{-1} (Linquist et al. 2012). Yields in the present study were higher (9.6 -14.1 Mg ha^{-1}) and yield-scaled N_2O emissions lower in all but one treatment (Tables 3 & 4).

Objective 3: The apparent N use efficiencies, for which both the applied N and the pre-plant NO_3^- levels were considered as N inputs, were relatively high, ranging from 66 – 98% in 2013 and from 86 – 139% in 2014. The N fertilizer use efficiency in 2013 ranged from 36 - 66% (Table 5). Greater N uptake than inputs indicated the presence of N sources other than those measured in the study (Table 5). Since inorganic N in the irrigation water was low, the in-season soil mineralized N was likely the main source of N besides fertilizer and residual inorganic N. The biomass N uptake of the control provides an estimate (35 kg N ha^{-1}) of the soil N supplying capacity or in-season N mineralization.

In both years, yields did not differ between the highest and lowest N application treatments. This seems to indicate that N was not limiting in any of the fertilized treatments and that adding 75 and 139 kg N ha^{-1} as fertilizer N would have been sufficient in 2013 and 2014, respectively. However, these results alone may not suffice to develop corn N fertilization guidelines. According to recommendations from other areas in the U.S., corn needs about 18 – 22 kg N Mg^{-1} (36 – 45 lbs N / U.S. ton) grain (Alley et al. 2009; Beegle and Durst 2003). Assuming a yield potential of 14 Mg ha^{-1} at this site, the corn N requirement based on these recommendations would be 248 – 304 kg N ha^{-1}, which corresponds approximately to the 226 kg N ha^{-1} treatment (fertilizer + pre-plant N 298 kg N ha^{-1}). In 2013, the N removal by the harvested crop in this treatment was 147 kg N ha^{-1}, leaving approximately the same amount as surplus. In 2014, an N rate of 164 kg N ha^{-1} (+94 kg residual NO_3^--N ha^{-1}), which resulted in a yield of 14.1 Mg grain ha^{-1}, would have been an appropriate recommendation. In 2014, crop N removal as silage in this treatment was 287 kg N ha^{-1}, an amount slightly higher than the combined N application and pre-plant NO_3^--N.

Objective 4: The NUE data mirrored N uptake- and yield-scaled N_2O results (Table 3), i.e. in 2014, the lowest N fertilizer rate (75 kg N ha^{-1}) resulted in a significantly higher NUE than the application of 254 and 344 kg N ha^{-1} and the lowest N fertilizer N rate showed the lowest N_2O emissions. These data suggest a relationship between N_2O emissions and crop N uptake, as discussed under objective 2. The 2014 data suggest that adjusting recommended fertilizer N rates downward could possibly reduce N_2O emissions. However, the yield-scaled N_2O emissions in 2014 did not differ between the two lowest N application treatments, and in 2013, N_2O emissions did not differ among all the treatments.

Section H

Project Impacts

The data generated in this project will be made available for calibration and validation of a mechanistic model (DeNitrification–DeComposition, DNDC) to model N_2O emissions at other locations in California. No recommendations for corn fertilization in California exist. This is one of very few N rate studies conducted in the State. Growers' awareness of the relationships among N rates, yields, N use efficiency, and N_2O emissions will be raised at several up-coming outreach events, where the results of this study will be presented. The importance of pre-plant N sampling, the value of N management budgets and adjustments of N fertilizer application rates will be highlighted at these events. Thus, the project should impact grower fertilizer N management and stewardship of natural resources.

Section I

Outreach Activities Summary

An interpretive summary was published in the annual CDFA FREP proceedings. A grower workshop for corn growers will take place on August 28, 2015, at the R.J. Cabral Ag. Extension Center in Stockton. Additional outreach events will take place next winter (November – March). A manuscript for a peer-reviewed journal is in preparation.

Section J
Factsheet/Database Template

Project Title: Assessment of Baseline Nitrous Oxide Emissions in Response to a Range of Nitrogen Fertilizer Application Rates in Corn Systems

FREP Grant # 12-0453-SA

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Start Year/End Year: 2013 - 2015
Location: Stockton area
County: San Joaquin
Highlights:

- Annual N_2O emissions in furrow-irrigated corn systems ranged from 0.82 – 1.9 kg N_2O-N ha^{-1} at N fertilizer rates varying between 139 and 342 kg N ha^{-1} in 2013-14 and from 1.1 – 6.1 kg N_2O-N ha^{-1} in 2014-15 at N rates of 75 – 344 kg N ha^{-1}.
- The N_2O emissions increased with increasing N rates, but corn yields did not differ between the highest and lowest N fertilizer application rates.
- Assessing pre-plant mineral N and adjusting N fertilizer rates accordingly is recommended to keep N_2O emissions and nitrate leaching potential as low as possible.

Introduction:

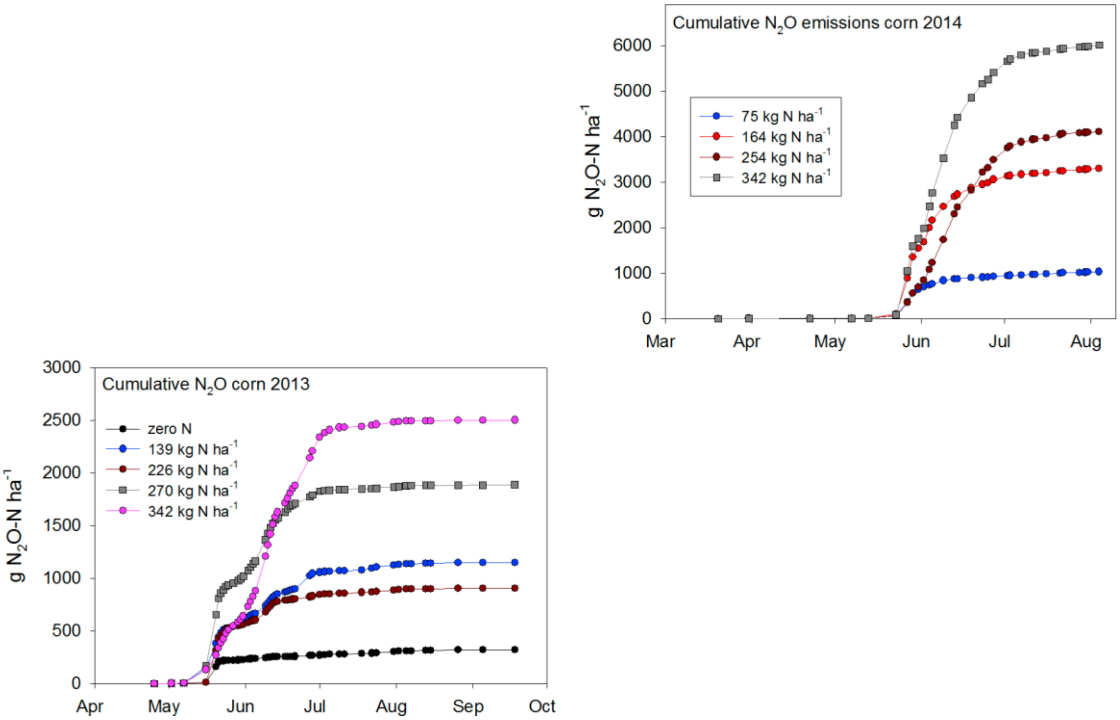
Nitrous oxide is a potent greenhouse gas produced in soil as a result of N fertilizer additions and naturally occurring N transformations. Presently, there are no estimates of N_2O emissions in response to varying N fertilizer rates and no guidelines on N fertilization of corn crops in California although more than 600,000 acres of corn (both silage and grain) are grown in the State. Excess mineral N (nitrate) in agricultural soil poses a risk to groundwater due to nitrate leaching during the irrigation season and winter rains, and N_2O emissions have been shown to be related to N fertilizer additions. This study was designed to identify N fertilizer rates that keep N_2O emissions as low as possible while maintaining yield potential in furrow irrigated corn production.

Methods/Management:

The study was conducted over two years in fields with a clay content of 35% and 43% in the vicinity of Stockton, CA. The treatments were established in 3 beds wide and 184 and 170 m long sectors of furrow irrigated fields. The N rates were 8, 143, 221, 265, and 337 kg N ha^{-1} in 2013 and 75, 164, 254, and 344 kg N ha^{-1} in 2014. The N_2O fluxes were measured by removing air samples at regular intervals from the headspace of covers placed on the soil for one hour. The air samples were analyzed by gas chromatography. The fluxes were calculated by the increase in concentration of N_2O in the chamber headspace by taking into account the volume of the chamber, the area covered by the chamber, and the temperature of the chamber head space. Measurements were taken frequently following irrigation events because N_2O emissions typically increase sharply at high soil water content, and approximately weekly during times when the soils were relatively dry. Annual N_2O emissions were calculated by assuming that measured fluxes represented daily fluxes and changed linearly between measurements. Yields were measured by weighing all the plants in a 4 m long section of the bed per replicate. The cobs were removed, the grain stripped from the cobs, dried at 60°C and then weighed. Biomass N and grain N were determined by dry combustion. The apparent N use efficiency (NUE) was calculated as the amount of N in corn biomass divided by the sum of pre-plant NO_3^--N and fertilizer N.

Findings:

In both years, substantial amounts of nitrate (72 and 94 kg N ha^{-1} in 2013 and 2014, respectively) were measured at planting. In the first year, there were no significant differences in N_2O emissions among the fertilized treatments, but in the second year the N_2O emissions increased significantly with increasing N fertilizer rates from about 1 kg N ha^{-1} in the 75 kg N ha^{-1} treatment to about 6 kg N_2O-N in the 344 kg N ha^{-1} treatment. In both years, yields did not differ between the highest and lowest N rate treatments, but N uptake was greater in the high than low N treatments, ranging from 207 – 288 in 2013 and from 233 – 377 in 2014. The apparent N use efficiencies ranged from 0.66 – 0.98 in 2013 and from 0.86 – 1.39 in 2014. The relatively high apparent N use efficiencies indicate the presence sources other then fertilizer and residual mineral N, most likely in-season mineralizable N. Assuming a yield potential of 14 Mg grain ha^{-1} at this site, a N fertilizer recommendation (fertilizer plus pre-plant nitrate N) based on guidelines from other regions of the U.S. would be 248 - 304 kg N ha^{-1}. In the first year of the study, such a rate would have resulted in a surplus of about 150 kg N ha^{-1} after accounting for N removal in the harvested grain, and in the second year, this rate matched crop N removal, in part because the corn was harvested as silage. Assessing pre-plant mineral N and adjusting N fertilizer rates accordingly is highly recommended because N_2O emissions are clearly related to N fertilizer rates.



Figures 5 & 6. Cumulative N_2O emissions during the 2013 and 2014 growing seasons in the different N rate treatments.

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