Reducing Nitrous Oxide Emissions with Sub-surface drip Irrigation and Split Fertilizer Applications

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Abstract. *Of the three biogenic greenhouse gases, (i.e., carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O), N_2O is considered to be most potent. The overall goal of this study was to determine detailed time series of soil N_2O fluxes at crucial management events for tomatoes subjected to deficit subsurface drip irrigation (SDI) regime and multiple fertilizer application rates. Flux chamber measurements were conducted using an EPA approved methodology to collect air samples that were ultimately analyzed using a Gas Chromatograph. 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 N2O-N emitted and the fertilizer applied (r= 0.64) and with the volume of water applied (r= 0.74). More importantly, these emission rates were relatively constant in both years at 0.002 kg N2O-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 N2O emissions in tomato cropping systems.*

Keywords: Sub-surface drip irrigation; nitrous oxide; greenhouse gases; deficit irrigation.

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 measurements 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 (CDFA, 2012).

With the rapid improvement of irrigation technologies and as vegetable cropping systems continue to transition from furrow to sub- surface drip irrigation (SDI), there is a need to evaluate the impact of SDI on N_2O emissions. Furthermore, it is also essential to investigate the combined effect of SDI and other agronomic and cultural management practices. For example, Kallenbach et al. (2010) compared effects of SDI versus flood irrigation and winter cover crop system versus no cover crop system in tomato on N_2O emissions using a flux chamber method, and concluded that SDI showed promise in reducing overall N_2O emissions in crop rotations with legume cover crops. Similar evaluations are needed for management systems that implement SDI with fertilizer management strategies, such as split application of Nitrogen (N) fertilizers throughout the growing season.

Objective

The overall goal of on-going research is to determine detailed time series of N_2O fluxes and underlying factors at crucial management events (irrigation, fertilization, etc.) in representative vegetable cropping systems in the San Joaquin Valley (SJV) of California. The objective of the current study was to determine the N_2O fluxes from a tomato crop subjected to three SDI 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).

Materials and Methods

The tomato study was conducted on Center for Irrigation Technology (CIT) research plots at California State University, Fresno (Fresno State) located at GPS co-ordinates latitude 36° 81' 51.63" N, longitude -119° 73'21.38" W. Two tomato trials were conducted in 2012 and 2013 with a fresh market cultivar, *Quali T-47*, that is well adapted to the hot summer conditions in the SJV. Soils at the experimental site were characterized as Hanford Fine sandy loam soil.

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 on beds that were 5 feet wide and 75 feet long. 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 also 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. Typical nitrogen application rate in California used by growers is 125-250 lbs/acre.

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}C) in 12 ml Labco glass vials until analyzed with a Gas Chromatograph (GC). Chamber and air temperatures were measured during each gas sampling time, and the ppm data derived from the GC was adjusted for the chamber temperature variation and converted to flux data by following the protocol recommended by the California Air Resources Board (CARB).

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.

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). 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 were 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).

Results

Tomato Yield: 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 1). 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 2). 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 3).

Table 1: Level of Significance from ANOVA for tomato yields obtained in 2012.

Treatment	Total Weight	Non-marketable Weight	Marketable 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 2: 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.*

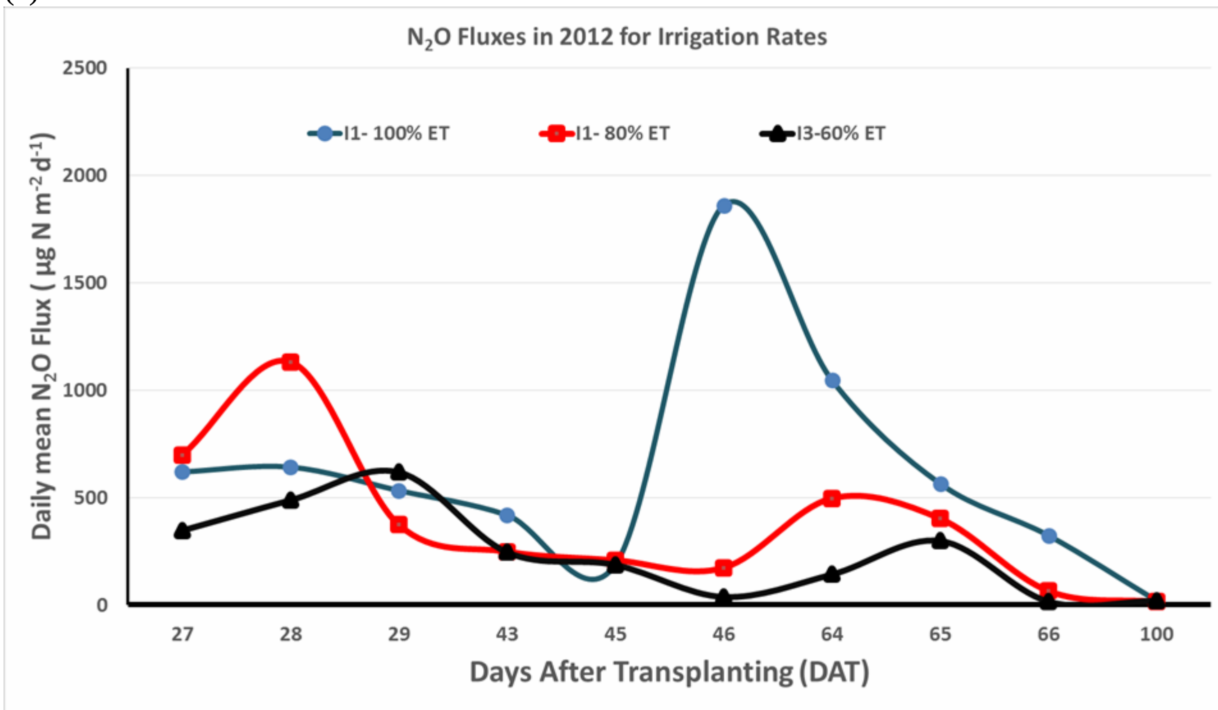
ET Rate (%)	Total Wt.	Non-marketable Weight	Marketable Weight	Green Weight	Breaker Weight	Red Weight	Brix
100	21.93 a	1.74 a	20.183 a	14.86 a	2.5 a	2.82 a	3.68 b
80	14.67 b	1.75 a	12.92 b	9.98 b	1.43 b	1.5 a	3.95 b
60	11.9 b	0.98 a	10.92 b	7.47 c	1.07 b	2.37 a	4.56 a

Table 3: 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

N_2O Emissions from Tomato Crops in 2012 & 2013: 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 1 and 2 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 (a) irrigation (I) and (b) fertilizer (F) rates throughout the 2012 and 2013 as a function of fertilizer and irrigation rates is provided in Table 4. A sampling protocol that included continuous monitoring, or at least more frequent sampling events, would have provided a better depiction of seasonal N_2O fluxes.

(a)



(b)

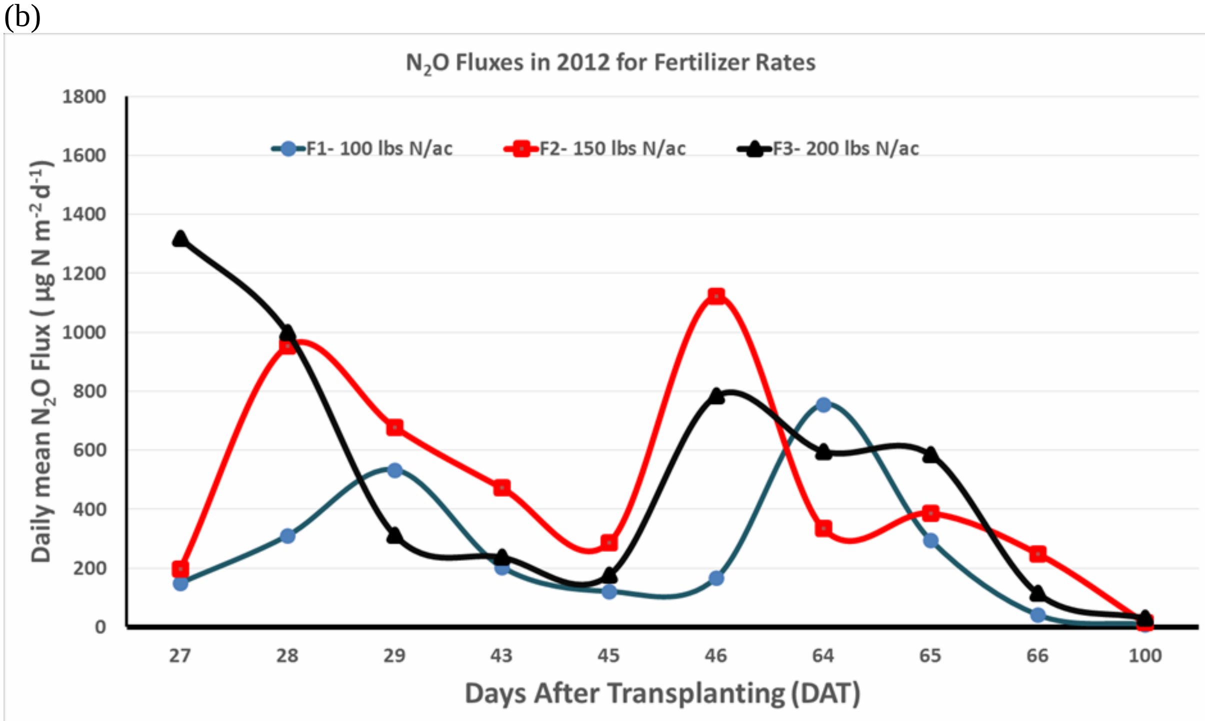
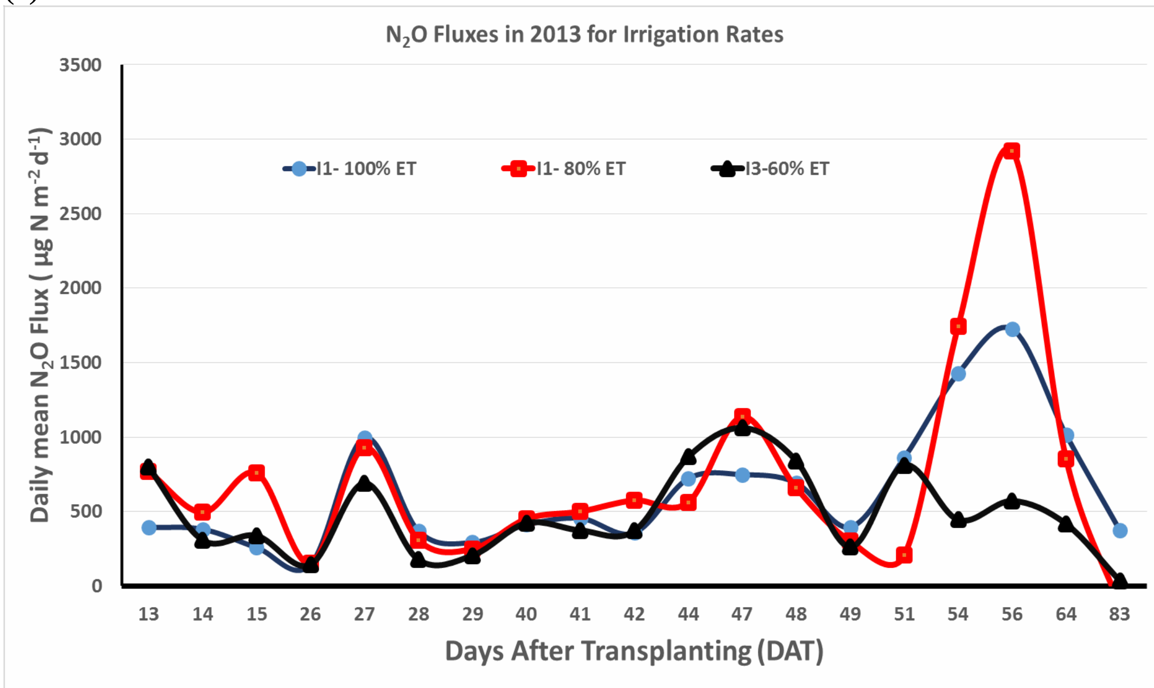


Figure 1. Nitrous oxide emissions as a function of (a) irrigation (I) and (b) fertilizer (F) rates throughout the 2012 tomato season.

(a)



(b)

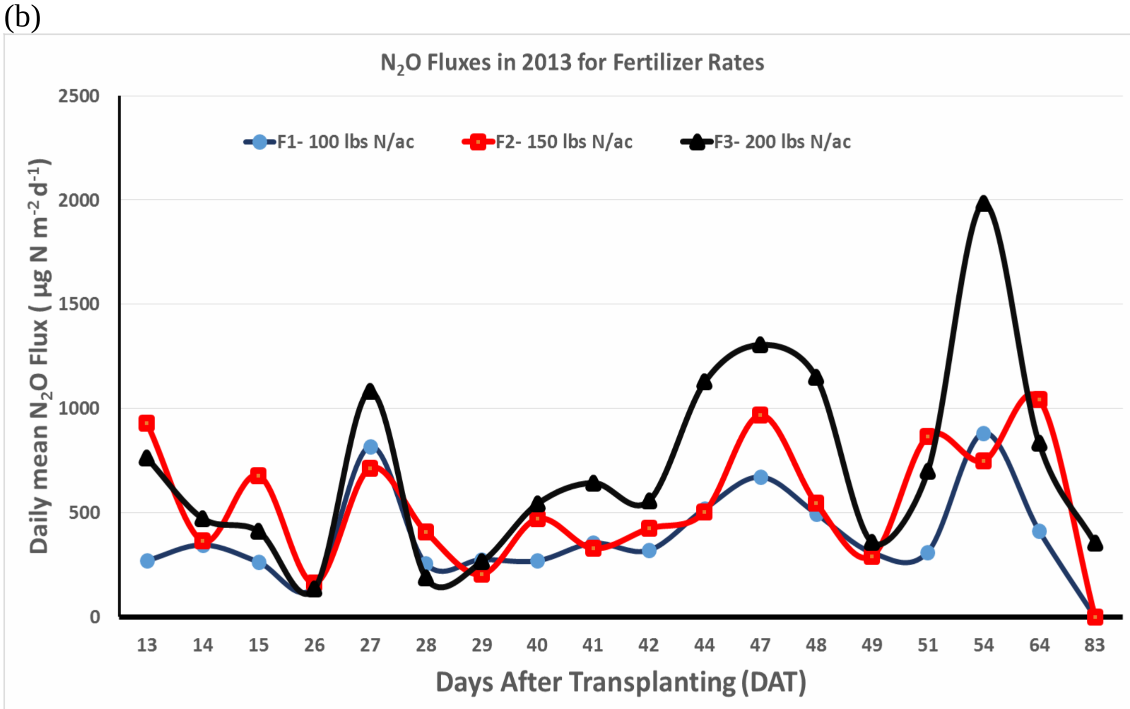


Figure 2. Nitrous oxide emissions as a function of (a) irrigation (I) and (b) fertilizer (F) rates throughout the 2013 tomato season.

Table 4: 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)	16167.6	29134.14	22333.74		20306	35489.1	44350.
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	0.0016	0.0019	0.0011		0.002	0.002	0.002
N2O-N emitted in lbs N/ac/lb	0.0014	0.0017	0.0010		0.001	0.0021	0.0020
Relative Change in emissions	NA	0.06%	-0.15%		NA	0.06%	-0.03%
Irrigation	**I1-**	**I2-**	**I2-**		**I1-**	**I2-**	**I2-**
TOTAL N2O emitted (ug/m2)	42753.1	14731.38	10150.93		45751	47634.7	26616.
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	0.0010	0.0004	0.0004		0.001	0.0013	0.0010
N2O-N emitted in lbs N/ac/ mm	0.0009	0.0004	0.0003		0.000	0.0012	0.0009
Relative Change in emissions	NA	0.06%	0.003%		NA	-0.03%	0.03%

For example, the graphs generated for the 2013 season (Figure 2) which comprised of 22 sampling evens versus that generated for the 2012 season (Figure 1) 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 4, 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 ($r = 0.82$).

Concluding Remarks

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

- 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);
- 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); and,
- The relatively constant emission rates of 0.002 kg N_2O-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.

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