FINAL REPORT

Nitrous oxide emissions in subsurface drip and flood irrigated dairy forage production systems

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Project summary:

Nitrous oxide (N_2O) is an important greenhouse gas that is associated with the application of fertilizers on irrigated farm land. Manure and irrigation management influence crop performance and can significantly affect N_2O emissions. The goal of this project was to evaluate the feasibility of using manure as a nutrient source with subsurface drip irrigation (SDI) in a dairy forage production system and to compare N_2O emissions in a SDI with those in a flood irrigation (FI) system. The N_2O emissions were measured during one year in two adjacent fields during silage wheat and corn forage production on a dairy farm in the California Central Valley. We kept track of nitrogen (N) and water inputs, yields, crop N removal, and power consumption in the two systems. Subsurface drip irrigation and fertigation with liquid manure/freshwater mixtures was largely successful. The SDI system had lower N_2O emissions (2.2 kg N_2O-N year^{-1}) than the FI system (11.2 kg N_2O-N year^{-1}), as well as a lower carbon foot print even though power consumption was higher due to the energy required to operate the SDI system. The yields were lower by 12% during corn production with SDI than with FI, which may have been due to lower water and N availability to corn plants in SDI than FI. More N was unaccounted for in the FI system, which received excessive manure N inputs during the winter season. Supplying water and nutrients via SDI is a promising strategy to lower the carbon foot print and better control N applications in dairy forage production systems.

Introduction

Nitrous oxide (N_2O) is an important greenhouse gas produced by agricultural activities, in particular nitrogen (N) fertilization. There is little doubt that the increase in the greenhouse gas nitrous oxide (N_2O) in the atmosphere is mainly due to the use of fertilizer and manure (Davidson, 2009).

Nitrous oxide is mainly produced by soil microorganisms during nitrification and denitrification and through chemo-denitrification (Firestone and Davidson, 1989; VanCleemput and Samater, 1996; Wrage *et al.*, 2001). In agricultural soil, the rates of N_2O production depend on the quantity and forms of nitrogen applied, but also on biophysical factors, such as soil moisture, temperature, carbon, and oxygen levels, microbial activity, and plant development (Tiedje, 1988; Venterea *et al.*, 2012)

According to the Intergovernmental Panel on Climate Change (IPCC) (2007), the main driver for increasing N_2O emissions in North America is management of manure and manure application to soils. California's dairy herds annually produce roughly 30 million metric tons of manure. Manure management in these dairies involves flushing of feed lanes and free stalls. The manure slurry is mechanically screened to separate larger particles from the liquid fraction. The particles (separator manure) consists mainly of coarse fibrous material, spent bedding, and spilt forage and feed, and is stockpiled with or without a composting process. The resulting liquid manure fraction, consisting mainly of NH_4-N^+, dissolved and some suspended solid organic N, is stored in anaerobic basins or lagoons (Pettygrove et al., 2009a). Liquid manure with high concentrations of NH_4^+ is diluted with irrigation water and applied to crop land surrounding dairies. These irrigation mixtures have traditionally been applied by flood irrigation.

Corn in summer and wheat during the winter rainy season are grown as forage crops for silage. Previous research in flood-irrigated wheat and corn forage production systems has reported annual N_2O emissions ranging from 6.1 -16.2 kg N_2O-N ha^{-1}, with generally higher emissions occurring in corn during the summer irrigation season than during the mostly rainfed wheat forage production in winter (Lazcano *et al.*, 2016). Subsurface drip irrigation has been rapidly adopted in high value vegetable production systems, such as tomato. Annual N_2O emissions in subsurface drip-irrigated tomato have been shown to be less than 1 kg N_2O-N ha^{-1} (Kennedy *et al.*, 2013). Lower N_2O emissions in tomato with subsurface drip than furrow irrigation were also reported by Kallenbach et al. (2010). We hypothesized that N_2O emissions in forage production systems could be considerably reduced if subsurface drip irrigation could be employed and liquid dairy manure could be delivered as fertigation.

The objectives of this project were to compare yields, applied water, crop N use, and N_2O emissions in flood irrigation and SDI systems, and to estimate energy use in the two irrigation systems, during one year encompassing a wheat and a corn forage production cycle. The goal was to use dairy manure as fertility source and as little synthetic fertilizer as possible. Furthermore, a N inventory comprising N inputs and outputs, as well as soil inorganic N content to a depth of 1.5 m, was calculated to assess potential N losses in both irrigation management practices.

Methods

Field site and management

The experiment was set up in a 32 ha dairy forage production field near Chowchilla, CA (37º7'51"N, 120º23'38"W). The predominant soil type in the part of field where the experiment was conducted was Pachappa fine sandy loam, a coarse-loamy, mixed, active, thermic Mollic Haploxeralfs. The soil texture was 63.4% sand and 9% clay. Soil total carbon (C) was 12.5 g C kg^{-1} and total nitrogen (N) 1.27 g N kg^{-1}. The soil pH ranged from 6.4 - 8.3 with a mean of 7.6.

The north-half of the field was managed as traditional flood irrigated (FI) system. In the preceding year, this section of the field was subsurface drip irrigated and fertilized with synthetic N applied through the drip irrigation system. The southern half of the field was under SDI with drip lines at 30 cm depth, spaced 152 cm apart. In the preceding year, this section of the field was irrigated/fertigated via surface drip irrigation and both liquid manure and synthetic fertilizer had been applied through this drip system. In both sections of the field silage wheat and corn had been grown for several years in a row.

In the fall 2015, manure, i.e. mechanical screen solids ('separator manure'), was applied at a rate of 24.7 Mg ha^{-1} in both fields. Both fields were managed as minimum tillage systems. A vertical tillage implement was used to mix the separator manure with the surface layer of the soil before sowing wheat. In the flood irrigated field, before sowing corn in spring 2016, another 24.7 Mg separator manure ha^{-1} was applied and the vertical tillage implement was used. In the SDI field, a strip tillage implement that loosens soil approx. 7.5 cm wide to a depth of about 12 cm was employed before planting corn. Corn was planted in evenly spaced (76 cm) rows at a planting density of 99,000 plants ha^{-1}. Planting and harvest dates are shown in Table 1.

In the SDI system, liquid manure was applied 11 times, approx. weekly, with the irrigation water. In the flood irrigated field, liquid manure was applied with irrigation four times, i.e. with every other water application (total of 8 irrigations).

Irrigation mesurements

Water inflow in the flood system were measured in a 36 m-wide sector ('check') by an area-velocity sensor connected to a datalogger/autosampler (ISCO, Model 6712, Teledyne Technologies Inc, Lincoln, NE). The area-velocity sensors were installed in a PVC pipe connected to the inflow valve, and, at the bottom of the field, in a PVC pipe through which the runoff water was channelled. Water samples were collected by the autosamplers every half hour for inflow and every hour during the time runoff was occurring. In the SDI field, water inflow was monitored with flow meters.

Soil moisture tension was measured by electrical resistance sensors (Watermark, Irrometer Co. Inc., Riverside CA) located at 20, 40, and 60 cm depths near the drip lines, in the middle between two drip lines or, in the flood-irrigated field, near the plant line and in the middle between two plant rows at one location per field (approximately in the center of the fields). The moisture sensors were connected to a data logger in the SDI field. Moisture values were recorded with a hand-held instrument during gas sampling events in the flood irrigated field.

Analytical chemistry procedures and soil sampling

The inflow and runoff samples were filtered through 0.3 μm glass fiber filters (Advantec MFS, Dublin, CA) to separate the solid (TSS, total suspended solids) from the liquid fraction, and ammonium and nitrate concentration, and either total Kjledahl N or dissolved organic N were determined. The solid fraction was dried and analyzed for total N (TSS-N) by dry combustion. The liquid fraction was analyzed colorimetrically for NH_4^+ and NO_3^- (Doane and Horwath, 2003). Total dissolved N was determined by alkaline persulfate oxidation (Cabrera and Beare, 1993). The total N in runoff that was subtracted from the N inputs was calculated from the total volume of runoff and the average N concentration of the collected samples.

Soil inorganic N in the 0-15 cm layer was measured by taking three cores with a soil probe near each gas flux chamber location. The soil was extracted with 1 M potassium chloride and NH_4^+ and NO_3^- concentration was determined as in the irrigation water above. Before wheat and corn sowing and after corn harvest, 7 soil cores to 1.5 m depth in 30 cm increments were collected at three locations per field and the samples were composited for each 30 cm-layer and analyzed for NO_3^-–N by a commercial lab. The soil N content was calculated using bulk density values determined in oven dried soil cores of known volume and the soil concentrations of inorganic N (NH_4^+ and NO_3^-).

Nitrogen inputs vs. outputs

Yields were determined by the number of truck loads harvested and average weights among trucks selected for weighing, and tissue N and crop dry weight was determined by a commercial lab. In addition to total N inputs of manure and synthetic fertilizer N applications, the plant available N (PAN) was estimated based on UC Cooperative Extension guidelines (Pettygrove *et al.*, 2009; Lazcano *et al.*, 2016), i.e. 15% of mechanical screen solids and 45% of organic N in dairy lagoon water was assumed to be mineralized within a year of application and 40% of this amount would be mineralized within 4-8 weeks in winter and 70% in summer. Based on these guidelines, crop N uptake efficiency was calculated by dividing crop N content at harvest by either total N inputs or plant available N. Furthermore, we calculated the systems' N balance, or unaccounted for N, after each harvest by subtracting crop N content at harvest and final soil NO_3^- content to 1.5 m depth from total N inputs plus soil NO_3^- content to 1.5 m depth at planting.

Gas flux and ancillary measurements

Soil-to-atmosphere nitrous oxide (N_2O) gas fluxes were measured from November 2, 2015 (prior to wheat sowing) to September 9, 2016 (corn harvest). The gas fluxes were measured 81 times. In general, gas samples were collected before and immediately following rainfall, irrigation, and fertilization events until the fluxes receded to baseline levels (Zhu Barker *et al.*, 2015; Burger *et al.*, 2016; Lazcano *et al.*, 2016).

Nitrous oxide fluxes were measured using a static chamber technique (Hutchinson and Livingston, 1993), i.e. an area of soil was covered with a chamber and four air samples were removed from the chambers at regular intervals during a period of one hour. During the wheat growing season, four round PVC chamber bases, 25 cm dia., were initially installed at regular intervals in a transect from the head towards the foot in the SDI field. From end of January until April 22, an additional chamber base was installed at each locationIn the SDI field one of the chambers was set above the location of the drip line and the other in the middle between the locations of two drip lines. In the FI field, four pairs of chamber bases (14 x 15 cm) that extended 7 cm into the soil and had a 2 cm-wide horizontal flange at the top that was flush with the soil surface were installed. During the corn growing season also four pairs of chamber bases were installed in each field. The bases during the corn growing season were rectangular stainless chamber bases 50 x 30 cm and 8 cm deep with a 2 cm-wide horizontal flange at the top end that was inserted into the soil, so that the flange rested on the soil surface. Insulated, vented chamber tops (25 cm dia. x 10 cm height in the SDI field and 14 x 15 x 10 cm height in the FI field during the wheat, and 50 x 30 x 10 cm during the corn growing seasons) were placed onto the bases and secured with metal clamps during gas measurements.

The gas samples removed from the chambers at regular intervals were transferred to 13-mL glass vials with grey butyl rubber septa (Exetainer, Labco Ltd., Buckinghamshire, UK). The air temperature inside the chambers was measured with a thermocouple thermometer at each sampling interval. Additionally, at each gas sampling event, soil temperature was measured with a thermocouple thermometer at 5 cm depth, and soil moisture was measured at 7 cm depth with soil moisture probes (5-TE, Decagon Devices

Inc., Pullman WA). During the corn growing season, additional soil moisture sensors were installed at 20 cm depth above the drip line and in the middle between two drip lines. The water-filled pore space was calculated based on the soil moisture measurements and bulk density values at these depths.

Gas chromatography

The gas samples were analyzed by a gas chromatograph (Model GC-2014, Shimadzu Co., Japan) with a ^{63}Ni electron capture detector (ECD) linked to an auto sampler (Model AOC-5000, Shimadzu Co., Japan). The system was calibrated daily using analytical grade N_2O standards (Airgas Inc., Sacramento CA). Quality assurance of the N_2O values generated by the GC and its software was obtained by processing N_2O standards injected into exetainers at the same time and in the same manner as the gas samples collected in the field.

Calculation of N_2O emissions

Nitrous oxide fluxes were calculated from the rate of change in chamber concentration, chamber volume, and soil surface area (Hutchinson and Mosier, 1981; Wagner *et al.*, 1997; Parkin and Venterea, 2010). Volumetric gas concentrations were converted to mass-based values using the ideal gas law and the measured chamber temperature. Seasonal and annual emissions were calculated by trapezoidal integration under the assumption that the measured fluxes represented mean daily fluxes, and that mean daily fluxes changed linearly between measurements (Venterea *et al.*, 2005).

Total greenhouse gas calculations

The seasonal N_2O emissions were converted to carbon dioxide equivalents (CO2eq.) by multiplying the mass of N_2O by 298, using a 100-year timeframe and climate-carbon feedback (IPCC, 2013). Power consumption by the pumps used for irrigation was based on the rating of the pumps, using a conversion factor of 0.746 kW Hp^{-1}, pump rates, and hours of operation. The kWh were converted to CO_2eq. using 0.1937 kg CO_2eq. kWh^{-1} determined by the Pacific Gas & Electric utility Co. (PG&E, 2013) or 0.703 kg CO_2eq. kWh^{-1} recommended by the Environmental Protection Agency (EPA, 2014). To convert diesel fuel usage to CO_2eq., a conversion factor of 10.24 kg CO_2eq. $gallon^{-1}$ proposed by the EPA (EPA, 2014b) for mobile combustion emissions was used.

Results and Discussion

Environmental conditions

During the wheat growing season, a total of 19 cm rainfall was recorded, and this amount was supplemented with two irrigations with a manure water/freshwater mixture (50:50) of 14 cm each in the flood irrigated and several irrigations with the drip system with a total of 13 cm applied mixture of manure water/freshwater.

The water filled pore space has been widely used as an indicator of soil aerobic status with values above 60% indicating the beginning of anaerobic conditions, which promote nitrous oxide formation (Linn and Doran, 1984). Except for some brief periods in January, the water filled pore space in the 0-15 cm remained below 50% (Figure 1).

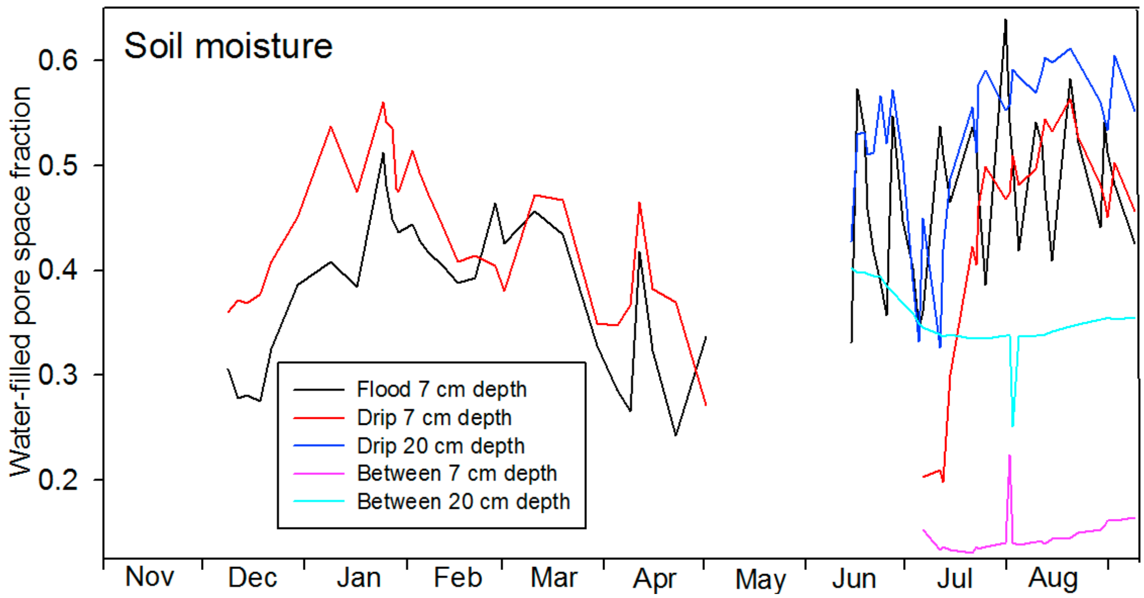

Figure 1. Soil water filled pore space in the flood- and subsurface drip –irrigated fields at various depths and locations. Between = located in the middle between two drip lines, which were located at 30 cm depth.

During the corn growing season, the water filled pore space fluctuated mostly between 40 and 60% in both systems. The exception was the soil farthest away from the drip line (middle between two drip lines), with the surface layer being drier than at 20 cm depth. Interestingly, the soil moisture at 7 cm depth in the SDI system was relatively dry in the early part of the corn growing season only. It appears that percolation in these soils occurs rapidly since even in the FI system, water filled pore space quickly declined to 40-50% after peaking, in general, below 60%.

Soil temperature, in part, regulates the magnitude of N_2O emissions, with higher emissions occurring at higher temperatures. Temperatures were clearly more conducive to N_2O production during the summer growing season with temperatures ranging from 20 – 35 ºC than in winter when soil temperatures at 5 cm depth ranged from about 8 – 15 ºC (Figure 2).

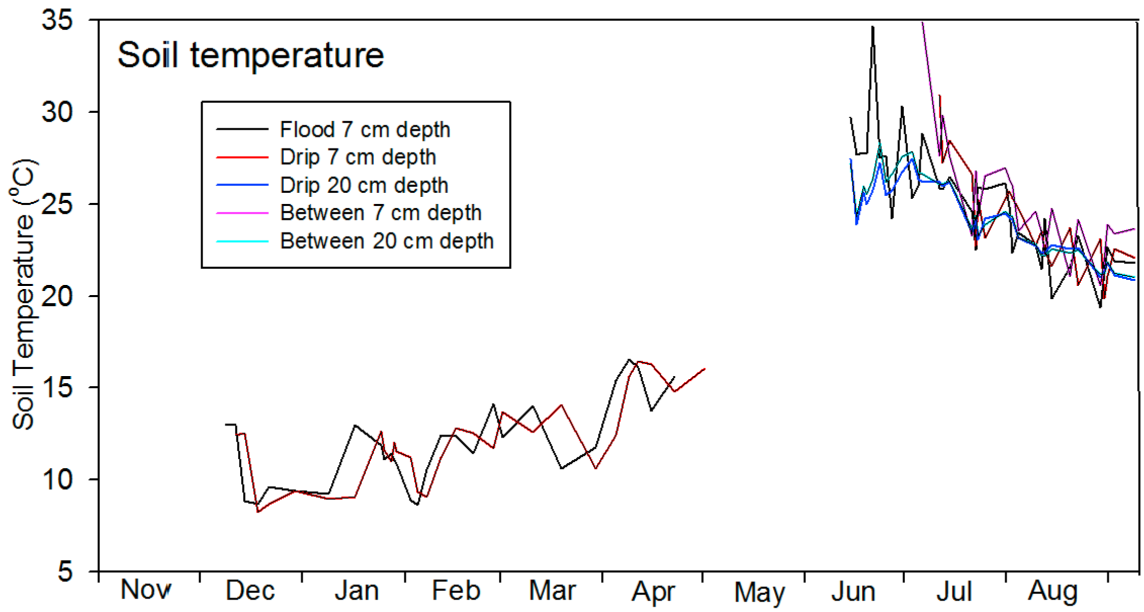

Figure 2. Soil temperature. Between = located in the middle between two drip line locations.

Nitrous oxide emissions

The daily N_2O fluxes are shown in Figure 3. During the wheat growing season, the N_2O emissions in both systems spiked at the beginning of season with the first rainfall and again following rain events in January. However, the irrigations with manure water in the flood irrigated system in late January and February, when each time 350 kg manure NH_4^+-N was applied, as evidenced by high NH_4^+ concentrations in the surface layer of the soil, set off elevated N_2O emissions that lasted approximately 6 weeks. Thus, the emissions in the flood irrigated wheat system were by far the highest with a total of 7.5 kg N_2O-N emitted during that season. The N_2O emissions during the corn season in the SDI system were very low, except for the N_2O fluxes occurring immediately after the initial sprinkler irrigation. The total seasonal emissions in the SDI system amounted to less than 0.4 kg N_2O-N for the whole season, providing additional evidence that SDI significantly reduces N_2O emissions compared to other irrigation systems. In the FI corn system, the N_2O fluxes spiked with every irrigation, even those, in which only fresh water was applied. However, the N_2O emissions in the summer were all short-lived, lasting only one to two days.

The data support the assertion that manure and irrigation management have a strong impact on N_2O emissions. Large manure N applications were responsible for the extended N_2O emissions during winter. It is likely that nitrification was the main pathway of N_2O production during those emission events as the majority of the available N in manure is in NH_4^+ form. The short, but high N_2O emissions following the flood irrigations in summer may have been due to nitrification, but denitrification may have played a role too since every other irrigation was with fresh water. However, our data clearly show that in these soils, water filled pore space cannot be used as predictor of denitrification conditions. Previous research has shown that manure applications stimulate N_2O emissions from other N sources, probably because manures also contain

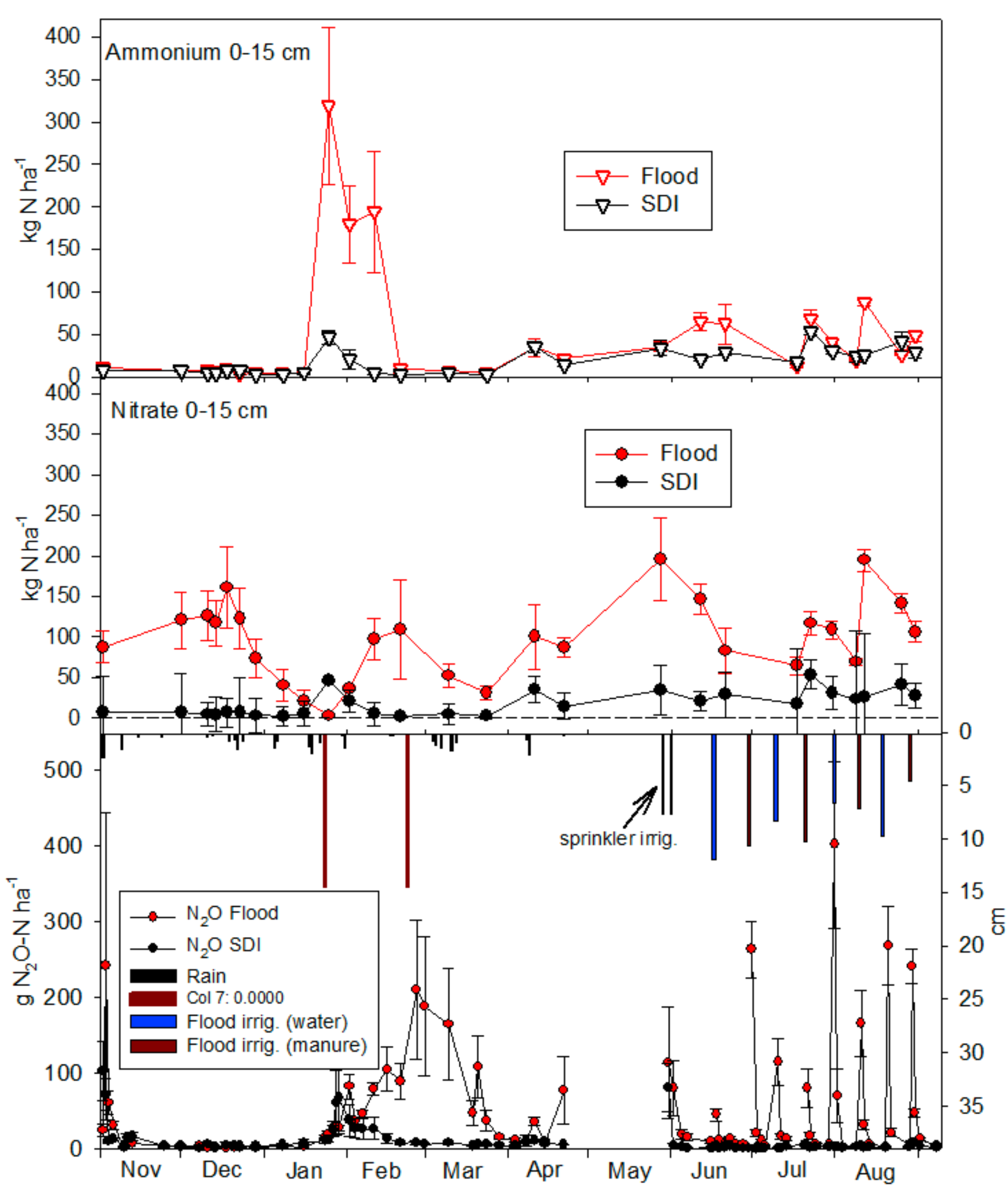

Figure 3. Ammonium and nitrate content, daily N_2O emissions, and water inputs during the rainfed wheat growing season and in the flood- and subsurface drip-irrigated (SDI) corn growing season in 2015/16. Water inputs *via* SDI not shown.

labile carbon sources that lead to increased microbial activity, which may temporarily deplete soil oxygen, a condition that promotes N_2O production by nitrification and denitrification pathways (Heinrich and Pettygrove, 2012; Zhu *et al.*, 2013; Lazcano *et al.*, 2016).

The incremental additions of manure N, the generally lower peak soil moisture levels in the surface soil (Figure 1), the reduced wetted soil volume, as well as the deeper placement of N and water delivery in the SDI system are all factors that probably contributed to the large reduction in N_2O emissions in the SDI system compared to those in the FI field. The seasonal emissions from the gas flux chambers placed above the drip lines were 558 (±166) g N_2O-N ha^{-1} *vs.* 212 (±57) g N_2O-N ha^{-1} from the chambers located in between two drip lines, which suggests that the lower moisture in between the drip lines and/or the location where manure N was applied affected the intensity of N_2O emissions. A recent study also showed evidence for substantial N_2O consumption in the soil (Wolff *et al.*, 2016), a process that may have occurred in the SDI field. The opportunity for N_2O consumption, i.e. conversion to N_2, is larger with SDI than flood irrigation.

Yields and soil moisture distribution

The corn silage yields were lower with SDI than FI by about 12% (Table 1). The wheat yields were about 9% higher in the SDI than in the FI field even though more N was surely available to the crop in the FI treatment, and water inputs were also higher in the FI system. The grower observed more lodging of wheat plants in the FI treatment, most likely because of the greater water inputs and resulting softer ground in this field at certain times.

Table 1. Management dates, water inputs, yields, and yields per unit water applied.

	Dates		Water input (cm)				
	Planting	Harvest	Irrigation	Rainfall	Total	Yield (Mg)	Mg cm^{-1}
SDI							
Wheat 2015-16	Nov 17	May 5	13	19	32	57	1.78
Corn 2016	May 27	Sep 9	68	0	68	71	1.04
Flood							
Wheat 2015-16	Nov 17	May 2	29	19	48	52	1.08
Corn 2016	May 27	Sep 12	83	0	83	81	0.98

Possible reasons for the lower yields are lower N availability to the corn crop in this than in the FI treatment. Based on N inputs and initial soil NO_3^- concentrations there was sufficient N, but corn roots may have not been able to access all this inorganic N because some of the N may have been in relatively dry soil with possibly fewer roots. Soil moisture tension >100 centibar causes water stress to plants (Hanson *et al.*, 2004; Hanson and May, 2006).

In the SDI treatment, the moisture sensors indicated adequate soil moisture tensions (<100 centibar) throughout the growing season only at 90 cm depth and >100 centibar at all other locations at least during part of the season (Figure 4), while in the FI treatment soil moisture tension was <100 centibar all the time. The applied water was lower with SDI than FI (Table 1), but due to the lower yield in SDI, the amount of silage produced relative to the applied water was only 6% lower in the FI treatment. It is possible that some of the water percolated below the root zone in the SDI field. There is some indication that this may have occurred because the N budget discussed below did show some loss of N even in the SDI treatment.

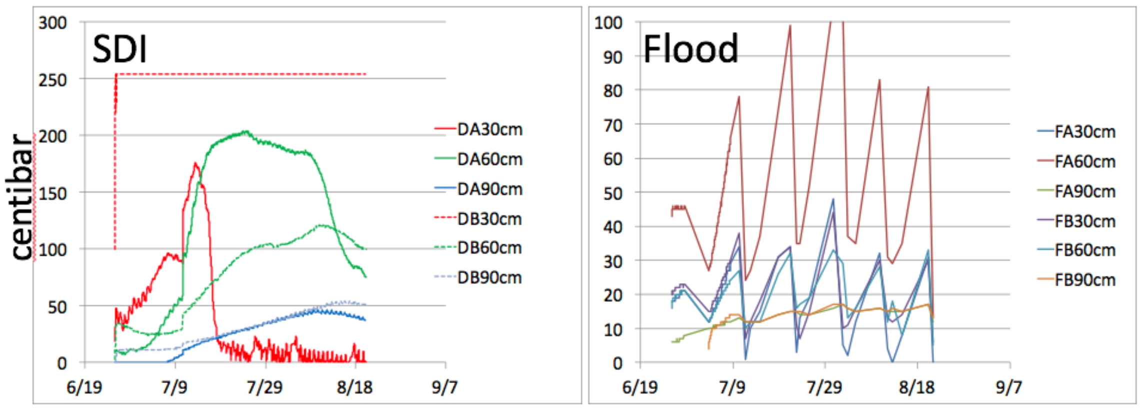

Figure 4. Soil moisture tension (centibar) at 30, 60, and 90 cm depth in the subsurface drip- (SDI) and flood-irrigated (FI) corn systems. DA, location above drip line; DB, in between drip lines; FA, near plant line; FB, in between plant lines.

Nitrogen balance

For each season and system, the unaccounted for N is shown in the column 'system loss' of Table 2. According to these calculations, i.e. system loss = initial soil NO_3^- + N inputs – crop N removal – final soil NO_3^-, N losses during the wheat season were unlikely, as the negative balance shows. However, during the summer irrigation season, both systems had unaccounted for N. The amount of accounted for N was much larger in the FI than in the SDI system. The N inputs were considerably greater in the FI than in the SDI field with the main difference being the two large manure water/freshwater applications during winter. The grower carried out these manure applications because lowering the level of the manure storage pond was mandated in anticipation of a large rainstorm that could have brought the lagoon to overflowing. During the irrigation season, manure N inputs were also lower in the SDI field, in part because frequent flushing of filters prevented N applications. In the FI field, some additional organic N from the large manure applications in winter was likely mineralized during summer. An estimate of this N mineralization is reflected in Table 2. The apparent N uptake efficiency both based on total N and plant available N was lower in the FI system due to the higher N inputs in this system since crop N uptake was similar in the two systems (wheat) or lower in the SDI system (corn) (Table 2).

Table 2. Nitrogen inputs, plant available N inputs, yield, crop N uptake, and apparent N uptake efficiency.

	Total N (kg ha^{-1})	PAN[1] (kg ha^{-1})	% PAN/ total N	Crop yield (Mg ha^{-1})	Crop N (kg ha^{-1})	NUE [2] (%)	NUE_{PAN} (%)	[4]Initial soil NO_3^- kg N ha^{-1}	[4]Final soil NO_3^- kg N ha^{-1}	[5]System loss kg N ha^{-1}
SDI wheat										
Solid manure N	15.9	9.3								
Manure NH_4^+-N	12.0	12.0								
Total	166.9	21.3	13	57	338	203	2130	467	316	-20
SDI corn										
Synth. fertilizer	43.2	43.2								
NO_3^- -N irrig.	35.9	35.9								
Solid manure N		13.9								
Manure NH_4^+-N	76.8	76.8								
Liquid organic N	41.3	13.0								
Total	197.2	182.9	93	71	206	104	113	316	107	200
Flood wheat										
Solid manure N	154.9	9.3								
Manure NH_4^+-N	708.3	708.3								
Liquid organic N	885.4	159.4								
Total	1748.7	877.0	50	52	359	20.5	41	107	1749	-252
Flood corn										
Synth. fertilizer	43.2	43.2								
Solid manure N	154.9	23.2								
Manure NH_4^+-N	230.2	230.3								
Liquid organic N	126.3	278.9								
Total	554.7	575.5	104	81	306	55.2	67	1749	387	1610

[1]PAN= Plant-Available N input; [2]NUE= Nitrogen Uptake efficiency (Crop N/Total N); [3]NUE_{PAN} = Nitrogen Uptake Efficiency of PAN (Crop N/PAN); [4]Soil NO_3^- -N content to 1.5 m depth; [5]System N loss (initial soil NO_3^-+total N inputs – crop N – final soil NO_3^-).

Total greenhouse gas balance

To assess the differences in carbon foot print between the two systems, we converted the N_2O emissions and the consumed power of the two management practices into CO2eq. since these would be main factors affecting the overall greenhouse gas balance. The analysis of the power consumption revealed that the energy used to lift water and manure water and pressurize SDI was about three times larger than the power consumed to apply irrigation water and manure in the FI system (Table 3). The values shown are based on PG&E's carbon emission factor for electricity generation. Had an emission factor based on average U.S. data recommended by the Environmental Protection Agency been used, the overall greenhouse gas emissions would have been higher in SDI corn (2451 kg CO2eq. ha^{-1}) than FI corn (2158 kg CO2eq. ha^{-1}), and SDI wheat would have had the lowest carbon foot print with 1379 kg CO2eq. ha^{-1}, while FI wheat would have had the highest overall emissions (4074 kg CO2eq. ha^{-1}).

The N_2O emissions had a greater impact on the carbon foot print than the power consumption in all but the SDI corn system. In fact, this research showed that managing to reduce N_2O emissions is the most effective strategy to reduce total greenhouse gas emissions in dairy forage production systems. Subsurface drip irrigation greatly reduced N_2O emissions. Greater controls on manure N could lower N_2O emissions, and therefore, total greenhouse gas emissions in the other irrigation management system and during the rainy season.

Table 3. Greenhouse gas emissions and power consumption in carbon dioxide equivalents (CO2eq.).

	Soil emissions		Irrigation				Total
	N_2O (kg ha^{-1})	CO_2eq.[1] (kg ha^{-1})	Electricity kWh ha^{-1}	CO2eq.[2] (kg ha^{-1})	Diesel (gal ha^{-1})	CO2eq.[3] (kg ha^{-1})	CO_2eq. (kg ha^{-1})
SDI wheat	1.81 (0.56)	846.7	492.3	95.4	18.2	186.3	1128.4
SDI corn	0.39 (0.10)	180.3	2965.3	574.8	18.2	186.3	941.5
Flood wheat	7.53 (3.25)	3527.6	512.1	99.3	18.2	186.3	3813.2
Flood corn	3.63 (0.60)	1699.5	387.5	75.1	18.2	186.3	1960.9

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