Carbon Sequestration Opportunities and Greenhouse Gas Production in Almond Orchards

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Interpretive Summary:

Global climate change is associated with atmospheric increases in greenhouse gases (GHG's) such as carbon dioxide (CO_2), nitrous oxide (N_2O) and methane (CH_4). Increased global temperatures as a consequence have been projected to seriously impact upon the natural resources, environment and the agricultural economy of the state of California (Hayhoe *et al.,* 2004). California is the 12th major source of GHG's worldwide, emitting approximately 500 million metric tons of carbon equivalents per annum. Of the total GHG emissions released from the United States, approximately 84% of emissions are from CO_2, 7% and 6 % from N_2O and CH_4 respectively, where approximately 8% of the total emissions are derived from agricultural activities.

CO_2 production by agriculture is largely generated from the oxidation of organic substances, which includes biological respiration; whereas, it is derived mainly via fossil fuel combustion and biomass burning from the energy sector (IPCC, 2007). N_2O and CH_4 are the other two major GHG's emitted by agricultural activities. N_2O is produced from industrial fossil fuel combustions and consumption by the transportation sector and is also produced from production and deposition of nitric acid. Net increases in N_2O concentration in the atmosphere are primarily due to agricultural practices which results in the microbial transformations of nitrogen by nitrification and denitrification processes

following nitrogen fertilizer applications followed by release of such N_2O to the atmosphere. The largest biogenic sources of CH_4 are from enteric fermentation by animals, rice production, organic fertilizer storage, biomass burning and via the anaerobic production of CH_4 in aquatic systems and soils from the microbial process termed methanogenesis.

Continued release of these gases to the atmosphere is predicted to further increase their atmospheric concentration and thus drive changes in regional temperature and seasonal precipitation, which in turn are expected to adversely affect and influence production of California's specialty crops. Recent predition call for diminished yields, diminished quality, and also shifts in suitable growing regions. Due to the mounting concern regarding increases in GHG's and their adverse effects on the economy and environment of the State, the California Global Warming Solutions Act of 2006 (AB 32), has been passed to start to impose GHG emissions caps on certain industries.

In light of this piece of legislation and the potential for a carbon tax credit system, our research has started to account for any possible GHG emissions both produced and consumed (e.g. carbon sequestration) within an almond orchard to enable the preparation of an annual GHG budget under "normal" management practices. This budget may be utilized to investigate the ways in which almond orchards are already contributing GHG mitigation by reducing atmospheric CO_2 emissions through soil carbon sequestration. Here we present our current findings from some recent experiments investigating the effect nitrogen fertilizer and water inputs have upon emissions of N_2O and CO_2.

Objectives:

This project addresses the issue of seasonal uncertainty in the emissions of GHGs from almond orchards, as well as characterizing spatial and temporal variation of CO_2, N_2O and CH_4 fluxes within the soil zone where nitrogen fertilizers and water are applied. The further objective of assessing belowground net primary productivity will enable a more successful assessment of the ability of almond to store carbon. In as much as N_2O and CH_4 have, respectively, 298 and 21 times the global warming potential as does CO_2, the production of N_2O alone based on emissions factors developed by the International Panel on Climate Change (IPCC, 2006) negates any carbon sequestration potential of almond, not including CO_2 production by cultural practices. This observation alone constitutes sufficient merit to investigate management strategies to enhance carbon sequestration and reduce GHG emissions.

1) Assembling a greenhouse gas inventory by quantifying the extent of annual CO_2, N_2O and CH_4 fluxes from almond orchards in comparison to background fluxes from natural "native" grasslands (a requirement by the International Panel on Climate Change, IPCC, in undertaking C sequestration assessments). To assist in understanding and further constrain N_2O emissions from orchard soils we are assessing soil nitrification and denitrification potentials as a function of the soil physical properties known to influence the processes.

2) To determine the effects irrigation systems of surface drip and micro-sprinkler jets have upon GHG emissions (particularly N_2O) and to investigate the effects different forms of nitrogen fertilizer usage have upon GHG emissions and for use in determining future mitigation strategies. A further treatment consisting of a subterranean drip system is being used to determine the effect of deep irrigation on N_2O production.

3) To identify the underlying mechanisms which control the quantity of carbon in almond orchards in order to assess the potential of almond orchards under “normal” management regimes to sequester carbon in contrast to the background carbon storage of unmanaged “native” grassland. A new major thrust in assembling this data will be an effort to establish belowground net primary productivity and also identify any spatial or temporal trends in carbon amount within an orchard itself.

Material and Methods:

GHG Annual Monitoring and Intensive Diurnal Measurements

In order to account for the seasonal and temporal variations in GHG emission, soil GHG efflux of CO_2 and N_2O have been measured on a bi-weekly basis (since October 2007 until present), at the 20 hectare mixed variety almond orchard at the Nickels Soil Laboratory, Arbuckle, Colusa County. Samples are taken from 18 locations throughout the orchard and covers areas serviced by both surface drip and micro-sprinkler jet irrigation systems. As well as locations situated in the “drip zone”, samples are also taken within the tractor rows in order to account for spatial variation within the orchard. Soil gas efflux samples for N_2O and CH_4 were measured using a closed chamber technique (Mosier, 1998), where chambers are sealed for 2 to 3 hours over which time four gas samples are taken using 20 cc evacuated gas vials, samples are obtained between 11am and 3 pm to capture peak mid-day fluxes. The concentrations of N_2O in the samples are determined in the laboratory with a gas chromatographic (GC) system equipped with an electron capture detector (ECD). All efflux measurements are corrected for vapor pressure, soil temperature, and chamber temperature.

Effect of Water Management Practice upon GHG Emissions

In order to establish the seasonal and temporal variation in GHG emission and also to the extent of N_2O and CO_2 emissions following “fertigation” (application of nitrogen fertilizers and irrigation water) events, we conducted several intense diurnal and week-long studies.

The first diurnal experiment occurred in November 2007 to establish a winter baseline for the GHG’s, when no management practices (e.g. irrigation) were occurring. This experiment occurred over 36 hours, where N_2O and $CO_{2,}$ along with soil moisture and temperature were measured every 2 and 3 hours (using the above methods) respectively throughout the whole orchard, which includes two types of irrigation systems, surface drip and micro-sprinkler jets.

In an experiment in March 2008, to investigate the effects the type of nitrogen fertilizer applied has upon the release of N_2O via the microbial denitrification process. We carried out an intensive diurnal study on the micro-sprinkler irrigation system only, where approximately 50 lbs/acre nitrogen was added in the form of nitrate (NO_3^-). Measurements of N_2O and CO_2 occurred every 2 hours for the first 24 hours and then midday measurements were obtained for the next 7 days, with repeated measurements taken at midday on days 10, 21 and 24 after fertigation. Inorganic nitrogen (nitrate, nitrite and ammonium), total soil carbon to nitrogen ratios, soil moisture, temperature were also obtained throughout the experiment.

A final experiment in April 2008 was conducted to ascertain the extent of GHG emission from a “normal” management fertilization practice, where approximately 60 lbs/acre of nitrogen in the form of urea nitrate (UN32), a commonly used fertilizer within the almond industry, was applied to the whole orchard. Within this experiment both the micro-sprinkler and surface drip irrigation systems and their subsequent effects on N_2O and CO_2 emissions were investigated. Measurements of the gases along with ancillary data were obtained from midday measurements for 5 days following the fertigation event.

Carbon Sequestration

Composite soil samples were taken at a depth of 15 cm from within the vicinity of the gas collars placed around the orchard before during and after irrigation in March and April 2008. Samples were dried and ground and have been sent off for total carbon and nitrogen analysis, as well as particle size analysis, results are pending.

Results and Discussion:

Diurnal Studies – Effect of Water Management Practice upon GHG Emissions

Water regimes, irrigation and fertilizer applications are the key factors affecting N_2O emissions from soils. To gain insights into how the irrigation and nitrogen fertilization practices usually utilized within the almond industry affect GHG emissions, we conducted several experiments to investigate the extent of such GHG emissions occurring under “normal” management practices at the Nickels Soil Laboratory, experimental orchard.

In an experiment in November 2007, measurements of CO_2 and N_2O were taken over a 36 hour period to investigate the diurnal effects on trace gas emissions, as well as to look at the differences between two irrigation treatments (surface drip and micro-sprinkler) during a time when there were no management practices (e.g. irrigation or fertilization) occurring. Table 1 shows the averages of soil temperature, soil moisture and the average flux rates for both CO_2 and N_2O, for each of the two irrigation treatments over the whole experiment. Soil moisture was observed to be the same in both treatments, where soil temperature was marginally higher within the surface drip treatment compared to the microsprinkler treatment. Assuming microbial processes that generate N_2O operate with a Q_{10} of roughly 2 then this could have a significant influence on gas production rates from the drip system versus that of microjet.

Table 1: Average soil parameters and gas fluxes over 36 hours for two irrigation treatments.

Irrigation Treatment	Average Soil Temperature (^{o}C)	Average Soil Moisture (%)	Average CO_2 (µmoles CO_2 m^{-2} s^{-1})	Average N_2O (µmoles N_2O m^{-2} s^{-1})
Surface Drip	15.43	11	1.72	0.19
Micro sprinkler	14.63	11	2.08	0.26

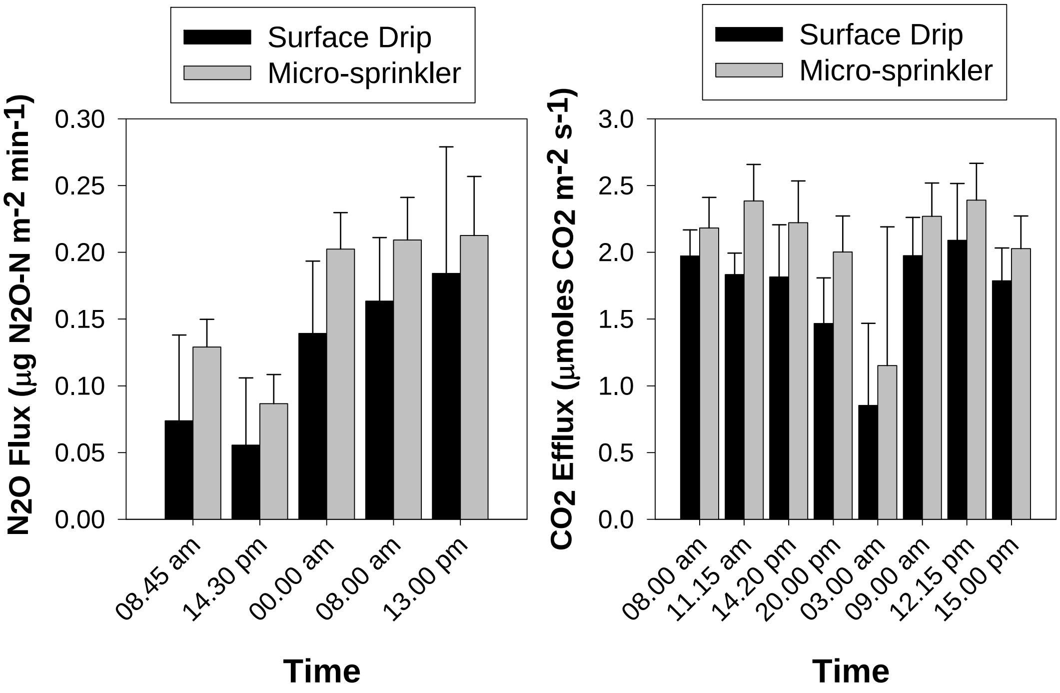

Figure 1: Diurnal soil N_2O emissions (a) and CO2 efflux (b) over a 36 hour period in November 2007, within the surface drip (black bars) and micro-sprinkler (grey bars) irrigation treatments at the Nickels orchard. Error bars indicate standard error of the mean (n = 6).

Figure 1 shows the that the micro-sprinkler irrigation treatment emitted the highest soil emissions of N_2O on average and throughout the whole 36 hour experiment, compared to the surface drip treatment (Table 1). Like most biological processes this difference is most likely due to differences in soil properties (e.g. soil temperature) at each sampling site as well as the differences between the two irrigation systems. Further analysis of this data and future experiments to test for the spatial variability within the orchard are needed.

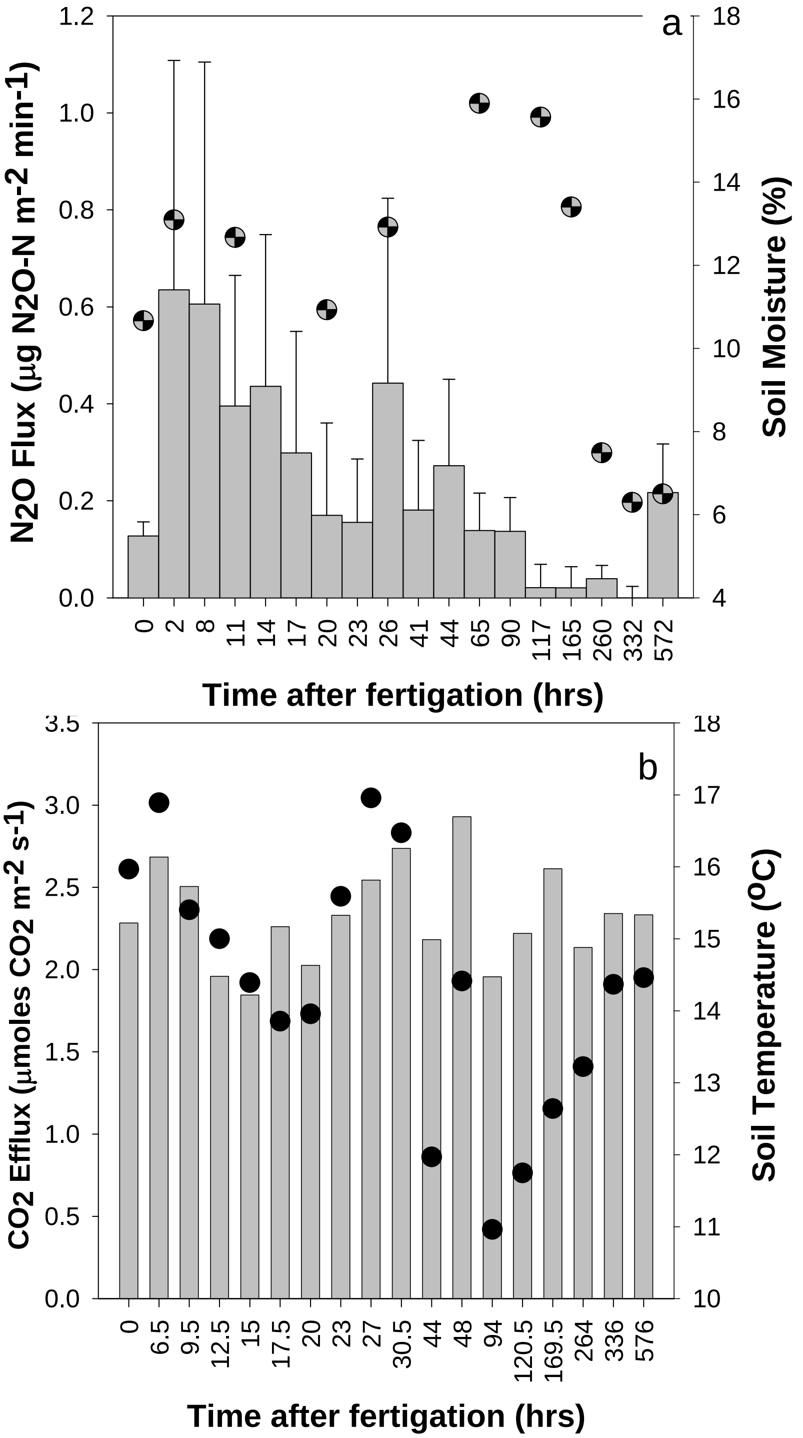

Figure 2: Soil N_2O emissions (grey bars) and soil moisture (black and white circles) (a) and CO2 efflux (grey bars) and soil temperature (black circles) (b) from the micro-sprinkler irrigation treatment, at the Nickels orchard over a 24 day period after the application of 50 lbs/acre "Chilean Nitrate". Error bars indicate standard error of the mean (n = 3).

Figure 2a shows the flux of N_2O and soil moisture before and after the application of 50 lbs/acre "Chilean Nitrate" fertilizer to the micro-sprinkler systems within the orchard. This fertilizer was used in order to ascertain the extent of N_2O emissions arising from the microbial process of denitrification as well as to start looking at the differences in emissions from the utilization of various forms of nitrogen fertilizers. Fluxes of N_2O are higher after the first two hours of fertigation and this corresponds also with the high soil moisture content after irrigation. After the first 24 hours, fluxes remain high and then start to return to background levels after the first week. In figure 2b, soil CO_2 efflux stays relatively stable throughout the course of the experiment and seems to not be affected by the application of the nitrogen fertilizer. A small diurnal influence can be seen where soil CO_2 efflux decreases when soil temperatures are lower at night and early morning.

Soil CO_2 efflux was not influenced by the application of nitrogen, however CO_2 efflux observed within the drip zone areas was observed to be almost double the CO_2 efflux observed within the tractor rows. This may be due to differences in soil moisture content, soil temperature and spatial variability around the orchard itself, as the tractor rows receive little or no water from irrigation. For both sets of data, the differences between the irrigation treatments are not statistically significant.

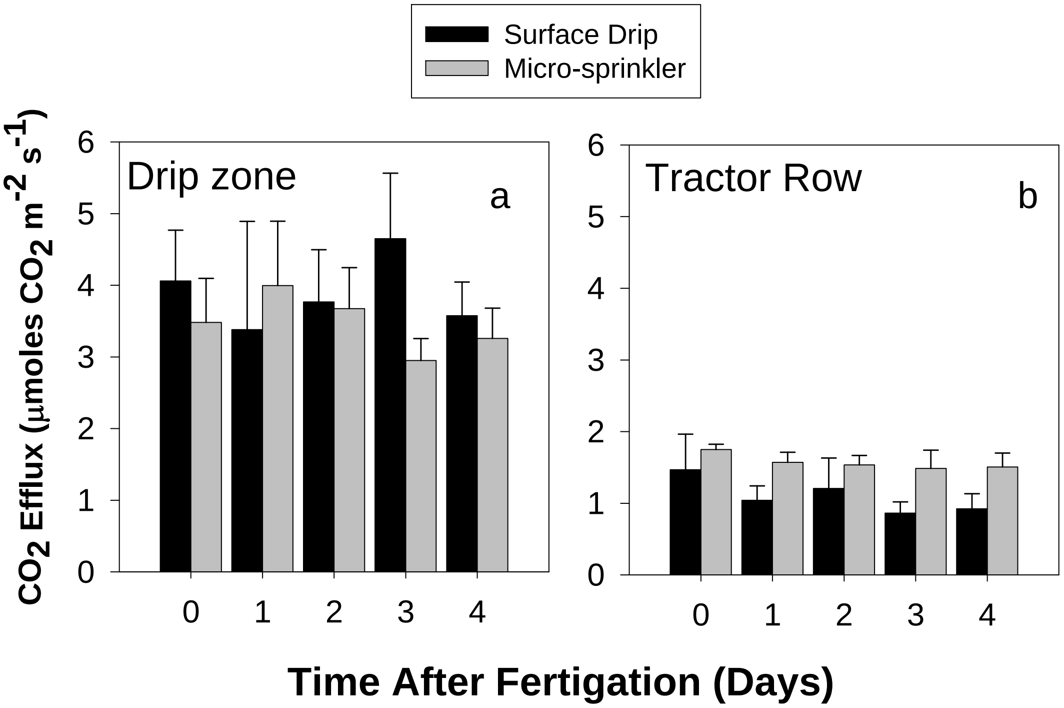

Figure 3: Soil CO_2 efflux from surface drip (black columns) and micro-sprinkler (grey columns) irrigation systems in a four day experiment before, during and after the application of 60 lbs/acre urea nitrate. Samples were obtained from around the Nickels orchard within the drip zone (a) and within the tractor row (b). Error bars indicate standard error of the mean (n = 4).

Figure 4 shows the soil N_2O emissions from surface drip (black columns) and micro-sprinkler (grey columns) irrigation systems after the application of 60 lbs/acre urea nitrate (UN32). Emissions from the surface drip irrigation observed within the drip zone are nearly one order of magnitude higher compared to the relatively low emissions exhibited by the micro-sprinkler irrigation system. This may be due to an over saturation of the micro-sprinkler system due to the high moisture content compared to the moisture content of the surface drip system (Table 2). Within the tractor row, are extremely low and are near ambient concentrations, the micro-sprinkler irrigation system samples are higher than the surface drip; again this could be due to a higher moisture content as the micro-sprinkler systems provide water further into the tractor row than the surface drip.

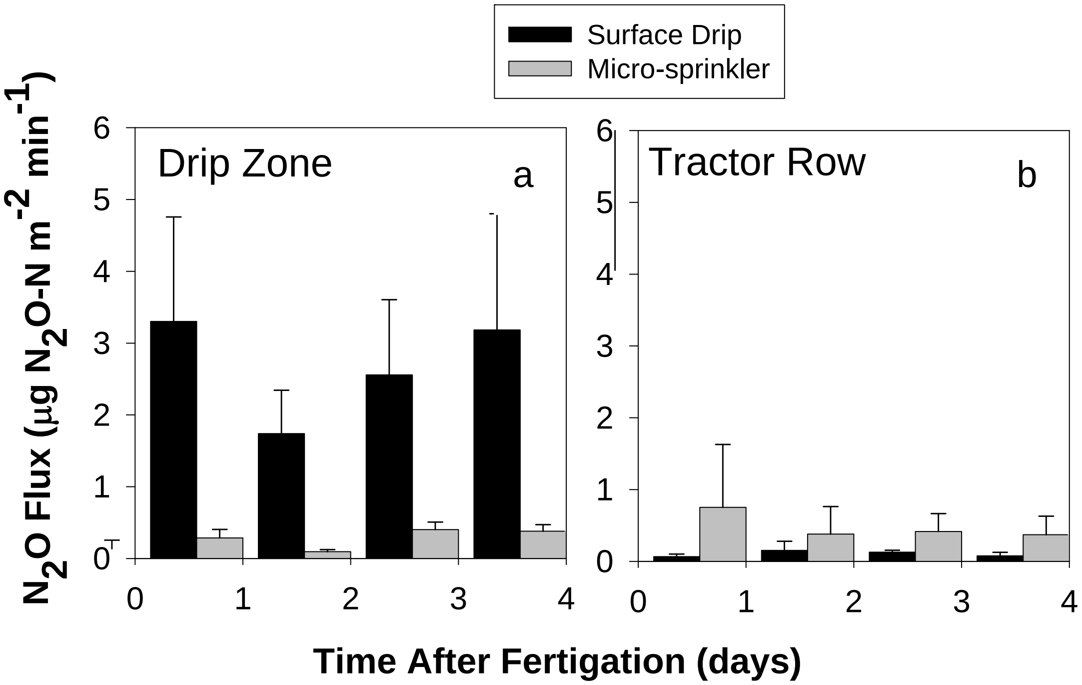

Figure 4: Soil N_2O emissions from surface drip (black columns) and micro-sprinkler (grey columns) irrigation systems in a four day experiment before, during and after the application of 60 lbs/acre urea nitrate. Samples were obtained from around the Nickels orchard within the drip zone (a) and within the tractor row (b). Error bars indicate standard error of the mean (n = 3).

In all cases fluxes were higher in the zone of irrigation/fertigation than it was in the interspaces where cultural operations involving tractors and other machinery occur (see Figures 3 and 4). This is an extremely important finding in as much as it better characterizes emissions from almond orchards on a spatial scale. In other words, it confirms the hypothesis that the majority of N_2O emissions are occurring from within the irrigation and fertilization area, and that those fluxes were much higher than those observed outside these areas.

Table 2: Average soil moisture and soil gas fluxes for both CO_2 (µmoles CO_2 m^{-2} s^{-1}) and N_2O (µmoles N_2O-N m^{-2} s^{-1}) from three experiments investigating the effects of irrigation and nitrogen fertilization upon gas emissions at the Nickels orchard. Data is taken from drip zone region only for the two irrigation treatments.
ND = not determined

Treatment	**Micro-Sprinkler**			**Surface Drip**		
	CO_2	**N_2O**	**% Moisture**	**CO_2**	**N_2O**	**% Moisture**
No management (Winter baseline, Nov 07)	2.08	0.26	11	1.72	0.19	11
Application of 50lbs Chilean Nitrate (March 08)	2.36	0.32	13	ND	ND	ND
Application of 60 lb/acre Urea Nitrate (UN 32) (April 08)	3.47	0.26	15	3.89	2.37	7

Conclusions:

There was tremendous variability within measurement episodes and between both the irrigation systems. Temporal variation (Figure 1) was somewhat easier to constrain than microscale variation. Microscale variation may be a consequence of many different factors such as inherent soil properties such as texture, local areas of compaction or microsites that are richer in available carbon or nitrogen. On a larger scale we were successful in constraining within field emissions rates between areas where water and nitrogen is applied and those where it is not applied (Figures 3 and 4). These results suggest that modifications to the IPCC emissions factors are needed and might take the form of commodity specific or cultural practice specific emissions factors. To try and constrain the variation further analysis is needed concerning targeting fertigation events and to understanding the underlying processes within the orchard system relative to GHG emissions and carbon sequestration processes and the assemblage of an annual GHG budget. With this variation characterized, we will be better equipped to undertake an annual budgeting exercise that can be used for modification of the IPCC emissions factors.

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