Carbon Sequestration Opportunities and Greenhouse Gas Production in Almond Orchards

Project No.:	**08-AIR2-Smart** **(Continuation of Project 07-ENVIR5-Smart)**

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Interpretive Summary:

Global climate change is associated with increases in atmospheric concentrations of greenhouse gases GHG's such as carbon dioxide (CO_2), nitrous oxide (N_2O) and methane (CH_4). Increases in temperature caused by GHGs have been projected to seriously impact upon the natural resources, environment, and agricultural economy of the state of California (Hayhoe *et al.,* 2004). California is the 12^{th} major global emitter of GHG's, emitting approximately 500 million metric tons of carbon equivalents per annum. Of the total GHG emissions released from the United States, approximately 84% of these 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 is largely generated from the oxidation of organic substances, which includes biological respiration, and from the energy sector via fossil fuel combustion and biomass burning (IPCC, 2007). In addition to CO_2, the other two major GHG's emitted as a direct consequence of agricultural practices are N_2O and CH_4 (De Vries *et al.,* 2005). N_2O is also produced by fossil fuel combustion in the industrial and transportation sectors, in addition to nitric acid production and deposition (Kebreab *et al.,* 2006). However, net increases in N_2O released to the atmosphere are primarily due to agricultural practices. The primary practice implicated in N_2O production concerns nitrogen fertilizer loads, the application of which results in acceleration of microbial transformations of nitrogen by nitrification and denitrification that directly and indirectly produce N_2O. 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.

Of concern to the California perennial crops industry is that predicted increases of these GHG's in the atmosphere, and resultant changes in regional temperature and seasonal precipitation are expected to adversely affect production of California's specialty crops through diminished yields, diminished quality and also shifts in suitable growing regions (Gentile et al. 2006). Second, 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), was adopted in June of 2006. This initiative enables the State to begin imposing 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 carbon stocks and GHG emissions both produced and consumed (e.g. carbon sequestration) within an almond orchard. This has enabled us to prepare state of knowledge annual GHG budgets under "normal" management practices and to identify the major knowledge gaps for such an assessment. This budget may be utilized to investigate the ways in which almond orchards are already contributing to GHG mitigation (net emissions reductions through soil and aboveground 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:

The three GHG's discussed above remain the largest and most important drivers of climate change and this project addresses and concentrates on the issue of seasonal uncertainty in the emissions of these 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 and 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 making C sequestration assessments). Also, to further constrain N_2O emissions from orchard soils we will calculate nitrification and denitrification potentials.
2) To determine the effects irrigation systems (surface drip and micro-sprinkle jets) have upon GHG emissions and to investigate the effects different forms of nitrogen fertilizer usage have upon GHG emissions and for use in determining future mitigation strategies.
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.

Materials and Methods:

GHG Annual Monitoring 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 were 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 were sealed for 2 to 3 hours over which time four gas samples are taken using 20 cc evacuated gas vials. Samples were obtained between 11 a.m. and 3 p.m. to capture peak mid-day fluxes. The concentrations of N_2O in the samples were determined in the laboratory with a gas chromatographic (GC) system equipped with an electron capture detector (ECD). All efflux measurements were corrected for vapor pressure, soil temperature, and chamber temperature.

Diurnal Studies – Effect of Management Practices upon GHG Emissions

One of the primary issues in assessing carbon footprints of agricultural systems concerns the erratic spatial and temporal nature of soil N_2O emissions. In order to establish the seasonal and temporal variation in GHG emissions and also constrain of N_2O and CO_2 emissions events following application of nitrogen fertilizers and irrigation water, 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 emissions, 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. The intent of this approach is to allow us to apply 2-dimensional models to the fluxes in order to have more robust estimates for the whole orchard (both from areas where N is applied and alleys where N is not applied).

In an experiment in March 2008, we investigated the effects of the type of nitrogen fertilizer applied 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 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.

Soil Carbon Sequestration

Composite soil samples were taken to 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 Management Practices upon GHG Emissions

Precipitation 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 GHG emissions occurring under "normal" water and nitrogen 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, soils moisture and the averages 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 micro-sprinkler treatment.

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

Irrigation Treatment	Average Soil T (°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
Microspray	14.63	11	2.08	0.26

Figure 1 shows that the micro-sprinkler irrigation treatment emitted the highest soil quantities of N_2O on average, and throughout the entire 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 texture, carbon content etc.) at each sampling site as well as the differences between the two irrigation systems in terms of spatial uniformity of water application. Further analysis of this data and future experiments to test for the spatial variability within the orchard are needed.

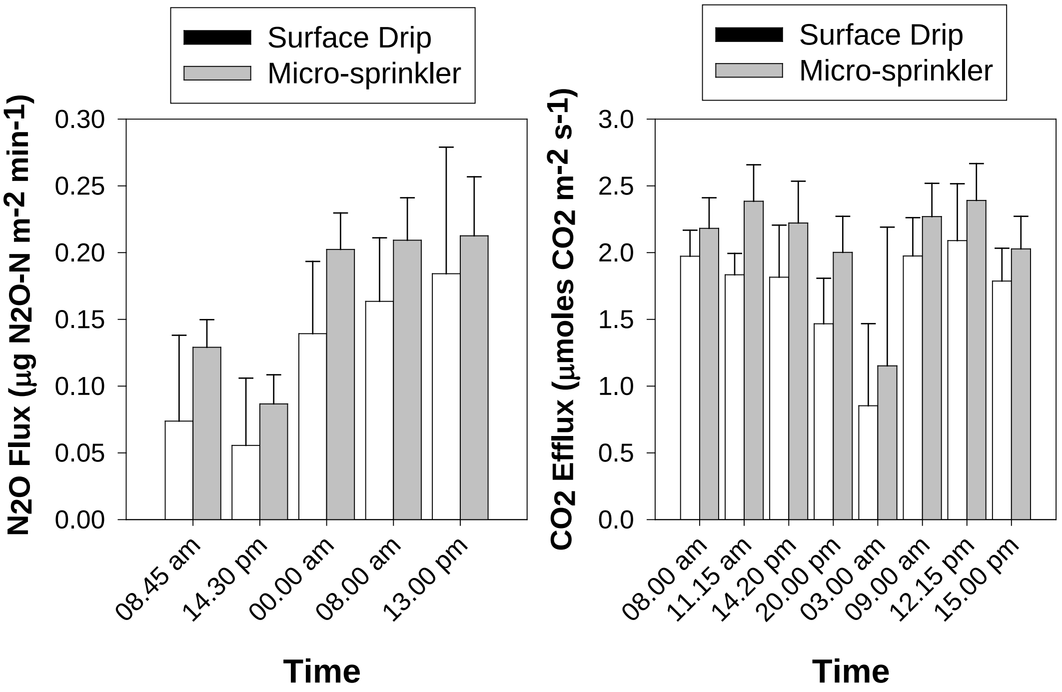

Figure 1. Diurnal soil N_2O emissions (a) and CO_2 efflux (b) over a 36-hour period in November 2007, within the surface drip (black bars) and micro-sprinkler (grey bars) irrigation treatments at the Nickels orchard. Error bars indicate standard error of the mean (n = 6).

Figure 2a shows the flux of N_2O and soil moisture before and after the application of 50 lbs/acre 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.

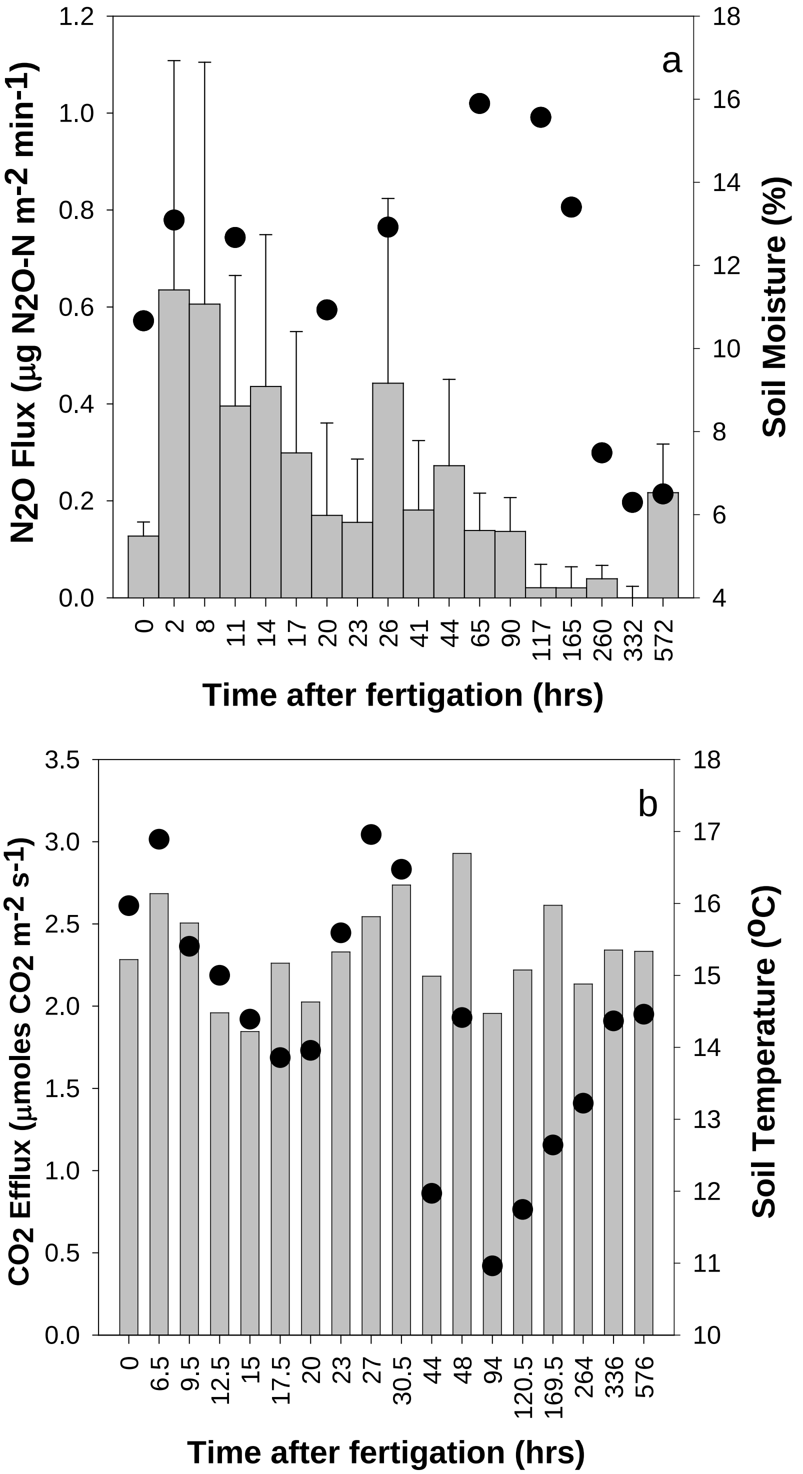

Figure 2. Soil N_2O emissions (grey bars) and soil moisture (black and white circles) (a) and CO_2 efflux (grey bars) and soil temperature (black circles) (b) from the micro-sprinkler irrigation treatment, at the Nickels orchard over a 24 day period after the application of 50 lbs/acre nitrate". Error bars indicate standard error of the mean (n = 3).

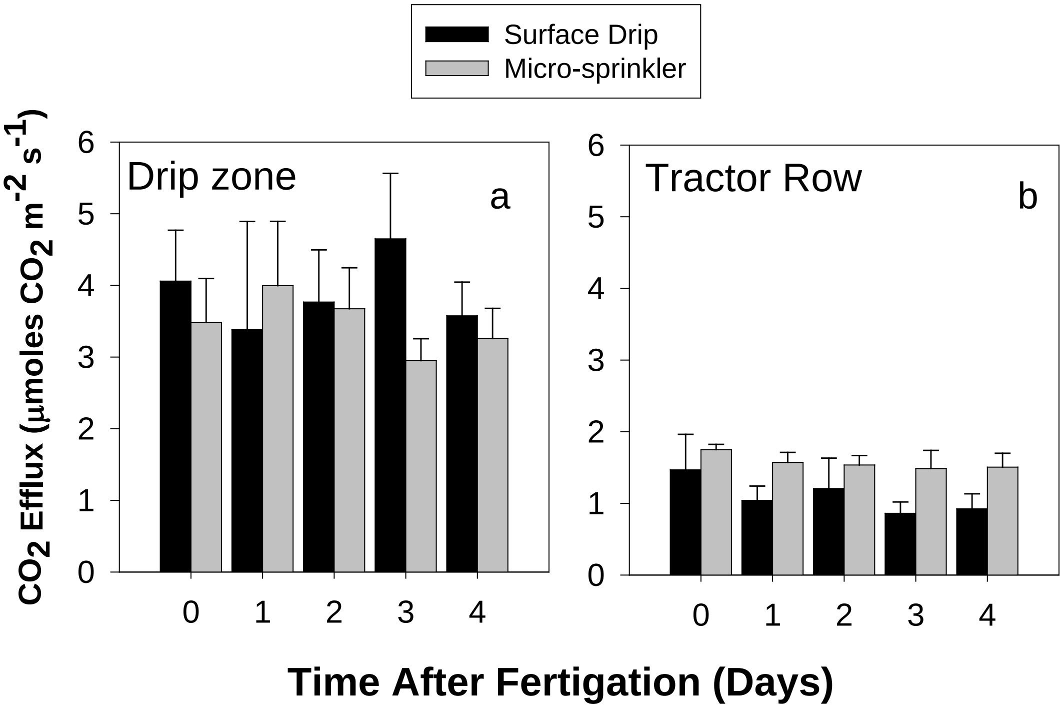

Figure 3. Soil CO_2 efflux from surface drip (black columns) and micro-sprinkler (grey columns) irrigation systems in a four day experiment before, during and after the application of 60 lbs/acre urea nitrate. Samples were obtained from around the Nickels orchard within the drip zone (a) and within the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

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 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, N_2O emissions are extremely low and are near ambient concentrations, while the micro-sprinkler irrigation system tractor row samples are higher than the surface drip. Again this could be due to a higher moisture content as the micro-sprinkler systems apply water to a greater surface area than the surface drip.

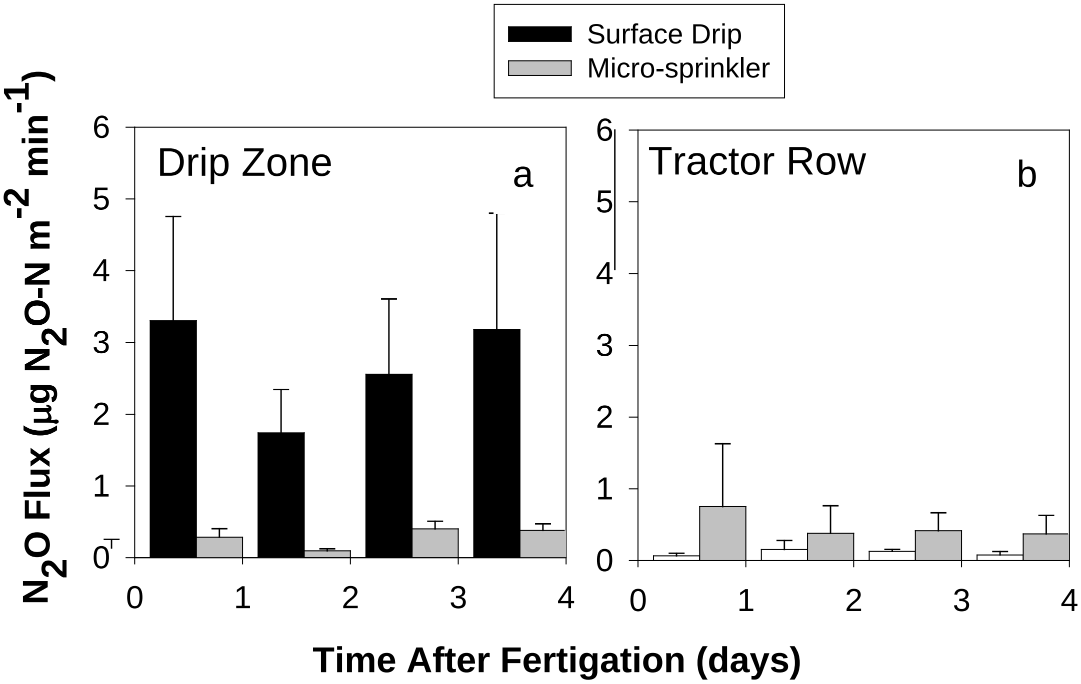

Figure 4. Soil N_2O emissions from surface drip (black columns) and micro-sprinkler (grey columns) irrigation systems in a four day experiment before, during and after the application of 60 lbs/acre urea nitrate. Samples were obtained from around the Nickels orchard within the drip zone (a) and within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

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 **(µmoles m^{-2} s^{-1})**	**N_2O** **(µmoles N m^{-2} s^{-1})**	**θ_v%**	**CO_2** **(µmoles m^{-2} s^{-1})**	**N_2O** **(µmoles N m^{-2} s^{-1})**	**θ_v%**
Winter Baseline	2.08	0.26	11	1.72	0.19	11
50lbs N as NO_3^-	2.36	0.32	13	nd	nd	nd
60 lbs N UN32	3.47	0.26	15	3.89	2.37	7

Conclusions:

There is great variability in N2O emissions between the two irrigation systems, which may be due to factors such as soil properties, seasonal effects, as well as with the different management practices. To try and constrain the variation further, analysis is needed targeting fertigation events to understand the underlying processes within the orchard system relative to GHG emissions and carbon sequestration processes and the assemble an annual GHG budget.

References:

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