Influence of Whole Orchard Recycling on GHG Emissions and Soil Health in a Newly Established Almond Orchard

Project No.: AIR10.Culumber

Project Leader: Catherine Mae Culumber, Ph.D., Nut Crop Advisor, UCCE-Fresno County
550 E Shaw Ave. Suite 210-B, Fresno, CA 93710
559-241-7526 (phone); 559-241-7539 (fax); cmculumber@ucanr.edu

Suduan Gao, Ph.D., Research Soil Scientist USDA-ARS
San Joaquin Valley Agricultural Sciences Center, 9611 S. Riverbend Ave. Parlier, CA 93648
559-596-2870 (phone); 559-596-2851 (fax); Suduan.Gao@ars.usda.gov

Project Cooperators and Personnel:
Brent Holtz, Ph.D., County Director and Farm Advisor, UCCE-San Joaquin County, 2101 E. Earhart Avenue, Suite 200, Stockton, CA 95206, baholtz@ucdavis.edu

Amisha Poret-Peterson, Ph.D., Research Microbiologist, USDA-ARS, Crops Pathology and Genetics Research Unit, UC Davis Department of Plant Pathology, One Shields Ave, Davis, CA 95616, aporetpeterson@ucdavis.edu

Greg Browne, Ph.D., Research Plant Pathologist, USDA-ARS Department of Plant Pathology, 348 Hutchinson Hall, UC-Davis, CA 95616, gtbrowne@ucdavis.edu

A. Summary Whole orchard recycling (WOR) incorporates orchard waste on-site, without burning or moving the debris to another location, preventing the release of air pollutants into the atmosphere. When mulched into the soil, high carbon (C) containing amendments like woodchips increase soil organic matter (SOM). Agricultural research has found both decreases and increases in carbon dioxide (CO_2) and nitrous oxide (N_2O) greenhouse gas (GHG) emissions in response to amendment applications of varying quality and quantity, fertilization rates and types, and soil biological and chemical characteristics. A study was initiated after a 13-year old plum orchard was recycled in late 2017, then replanted to almond in early 2018 in a commercial orchard in Parlier, CA. The objective was to characterize the impact of incorporating a high rate of recycled woodchips (approximately 40 t/ac or 99 t/ha) on N_2O and CO_2 emissions, soil factors, and tree establishment after planting. Woodchip treatments had higher N_2O and CO_2 emissions than controls during the first year after orchard recycling. Compared to the control, higher N_2O fluxes in the woodchip treatment were observed during the first four days after fertigation; other times they were consistently similar. Total seasonal N_2O emission factor (EF) was 0.6% in control plots and 1.0% in wood chip treatments the first year after recycling. The EFs in the second and third year, declined to 0.4% then 0.1% in the control, and 0.6% and 0.2% in the recycled plots in 2019 and 2020. These findings highlight the importance of identifying the optimal rate and application timing of N to limit N losses via N_2O during the first two seasons of establishment in orchards planted after recycling. An estimated 9 tons/ha (3.6 tons/ac) or 17.9% of the C in the initial applied biomass was lost in the first season of 2018. The annual rate of C loss declined to 6.4% by year 3. Soil organic matter (SOM) and total nitrogen (N) levels declined in the first year after replanting, but the wood chip treatments returned to baseline SOM levels (~2.4%) by year 3 with significantly higher levels ($P < 0.0459$) than

the control (1.6%). Orchard N fertility applications were 2.4 times larger than the standard recommendation for newly planted orchards in the 1st year, half guideline rates in the 2nd year, and were consistent with best management recommendations (97 lbs/ac) by the 3rd year. Tree nutrition and growth was not different between conventionally managed and woodchipped trees by the end of 2019. Whole orchard recycled treatment Nonpareil and Monterey yields were not different from the control treatment in 2020. These findings suggest managers may need additional fertilization at planting, but standard fertilization practices can resume in the 2nd year. Further research is needed to pinpoint the optimal timing and necessary season-long fertility rates in the first growing season after recycling.

B. Objectives *(300 words max.)*

1. Goal 1: Monitor field level nitrous oxide (N_2O) and carbon dioxide (CO_2) emissions, after a one-time WOR application in a newly established commercial almond orchard (Gao, Culumber).
2. Goal 2: Describe the effect of WOR on soil carbon and nitrogen cycling and identify the chemical and biological mechanisms (*Culumber, Poret-Peterson, Gao, Holtz)*.
3. Goal 3: Evaluate establishment growth and nutrition in trees following orchard recycling compared to controls in a commercial orchard (*Culumber, Poret-Peterson, Gao, Holtz*).

   Annual Outputs: 3 years of GHG data contributing to understanding of C and N losses in replanted orchards following wood chip incorporation compared to controls has been collected. Additional chemical, physical and biological soil data including microbiological community and functional gene analysis analysis is ongoing. Tree nutrition, growth, and yield information suggests trees established after wood chip incorporation can attain the same productive potential as conventionally managed trees by the second year. Several outreach activites are described below.

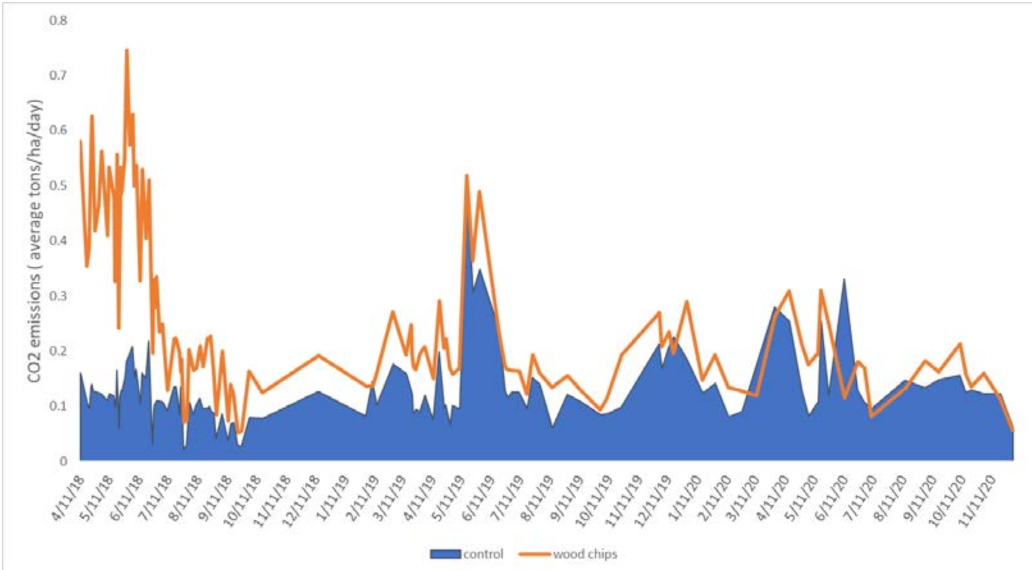
C. Annual Results and Discussion

Goal 1: Monitor field level nitrous oxide (N_2O) and carbon dioxide (CO_2) emissions, after a one-time WOR application in a newly established commercial almond orchard (Gao, Culumber).

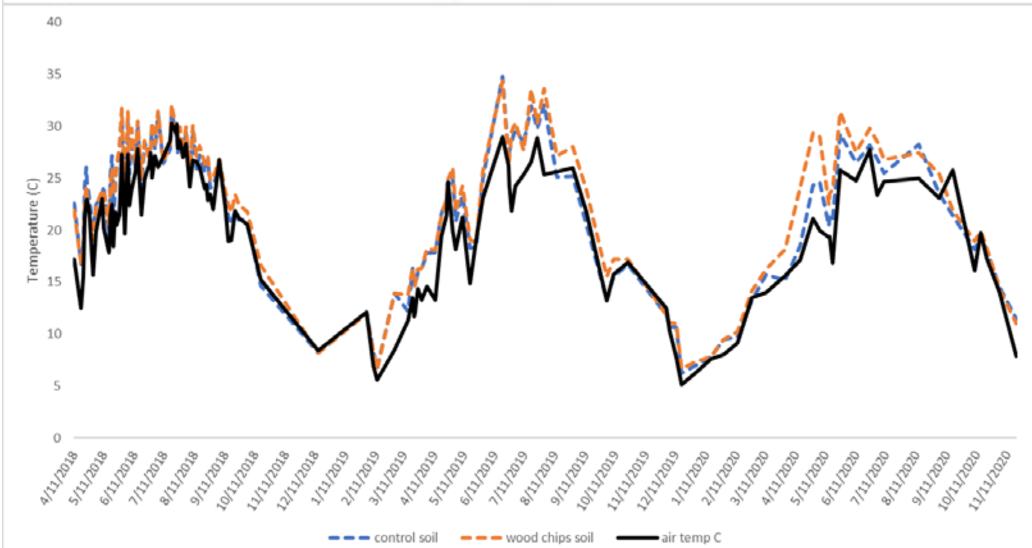
Orchard trees have the potential to store C in woody biomass over decadal or longer time horizons. However, burning the orchard at the end of productive life releases much of this temporary storage into the atmosphere. Keeping tree biomass on-site and incorporating it into the soil conserves C, but losses in the form of GHG following this practice have not been previously studied. Identifying improved methods for determining the initial biomass application and corresponding C addition to the soil will help to better inform models for predicting C sequestration. Pre-plant sampling and sieving and separation of wood chips to determine the WOR biomass application rate was estimated to be 40 dry weight tons/ac (99 tons/ha). Analysis of wood chip biomass found a 50% C content, indicating the initial application contributed 49.4 tons C/ha. This value was needed to make an estimate of the % C loss based on cumulative emissions for each season. Measured CO_2 and N_2O fluxes are summarized by cumulative seasonal loss (Figure 1a and 2). The greatest difference between wood chip and background (assumed equal to the control) CO_2 emissions occurred at the beginning of the trial between March to July 2018. During this time, whole orchard recycling estimated contribution of surface emissions from the berm was 0.15 ±0.01 tons CO_2/ha/day and the alleyway 0.19 ± 0.008 tons CO_2/ha/day, compared to the control berm (0.042 ± 0.002 tons CO_2 /ha/day) and alley (0.072 ± 0.002 tons CO_2 /ha/day). Wood chip and control emissions were more consistently matched from spring 2019 to summer 2020 (Figure 1). An estimated 8.9 tons/ha (3.6 tons/ac) or 17.9% of the C in the initial applied biomass was lost in the first season of 2018 from March to December. The estimated annual rate of C loss declined to 6.4% by year 3. Similar to CO2 emissions, the greatest N_2O losses were observed in the wood chip plots in summer (Jun-Sept) 2018 (Figure 2), when the orchard was newly planted and fertigation frequency was the highest of the trial duration (Table 1). The highest N_2O fluxes in the woodchip treatment were observed during the first four days after fertigation; other times they were consistently similar. The mean N_2O flux from June-Sep 2018 was 0.97 ± 0.41 kg/ha/day in woodchip plots compared to 0.35 ± 0.15 kg/ha/day in the control. The total seasonal N_2O-N emission factor (EF) was 0.6% in control plots and 1.0% in wood chip treatments the first year after recycling. In the second and third year, the EF declined to 0.4% then 0.1% in the control, and 0.6% and 0.2% in the recycled plots in 2019 and 2020 (Figure 3). These findings highlight the importance of identifying the optimal rate and application timing of N to limit losses via N_2O during the first two seasons of establishment in orchards planted after recycling.

Table 1. Monthly lbs of N and ounces N per tree applied from fertilizer and irrigation water for each season. Irrigation water N content is estimated based on an NO3-N content of 6.9 ppm. The estimated ounces per tree assumes 100% uptake efficiency.

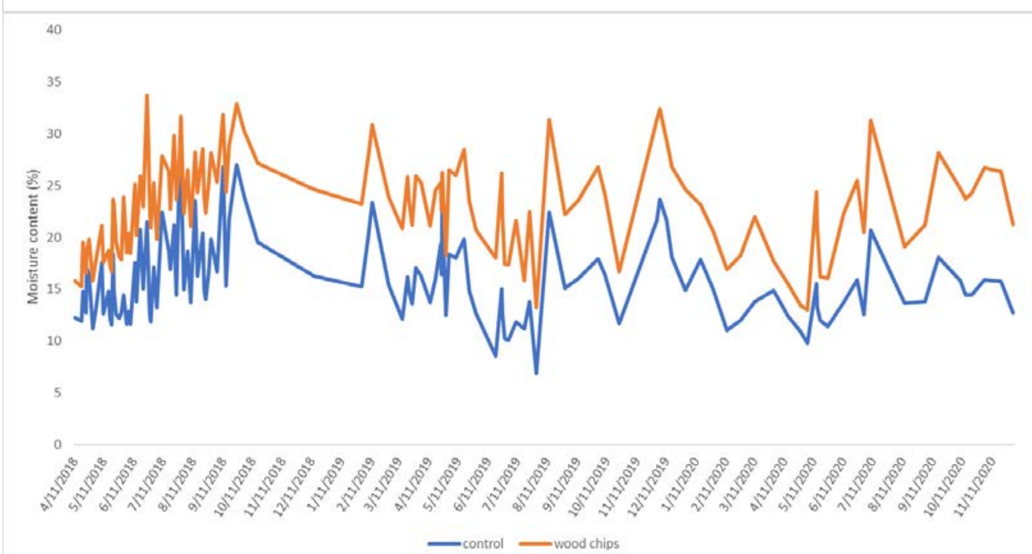
	fertigation lbs N / acre			**Irrigation cumulative lbs N / acre**			**Fertigation + irrigation oz N / tree[a]**		
	2018	**2019**	**2020**	**2018**	**2019**	**2020**	**2018**	**2019**	**2020**
Mar	0	9.65	21.2	1.1	0.5	1.2	0.1	1.4	1.3
Apr	12.5	9.65	0	1.0	2.1	1.0	1.9	1.6	0.1
May	5.8	0	42.0	2.0	1.7	3.8	1.0	0.2	6.4
Jun	25	9.65	0	3.2	3.6	6.1	4.0	1.8	0.8
Jul	12.5	0	0	4.7	7.2	5.8	2.4	1.0	0.8
Aug	12.5	0	0	3.0	5.2	4.8	2.1	0.7	0.7
Sep-Nov	0	0	33.3	5.6	11.2	8.0	0.8	1.6	5.7
Total	68.3	29.0	96.5	20.6	31.4	30.7	12.3	8.4	17.6


CO2 emissions (average tons/ha/day)
control
wood chips

a)


Temperature (C)
control soil
wood chips soil
air temp C

b)


Moisture content (%)
control
wood chips

c)

Figure 1. Average wood chip and control treatment a) CO2 emissions tons/ha/day b) soil temperature Cº plotted with ambient air c) soil moisture content %.

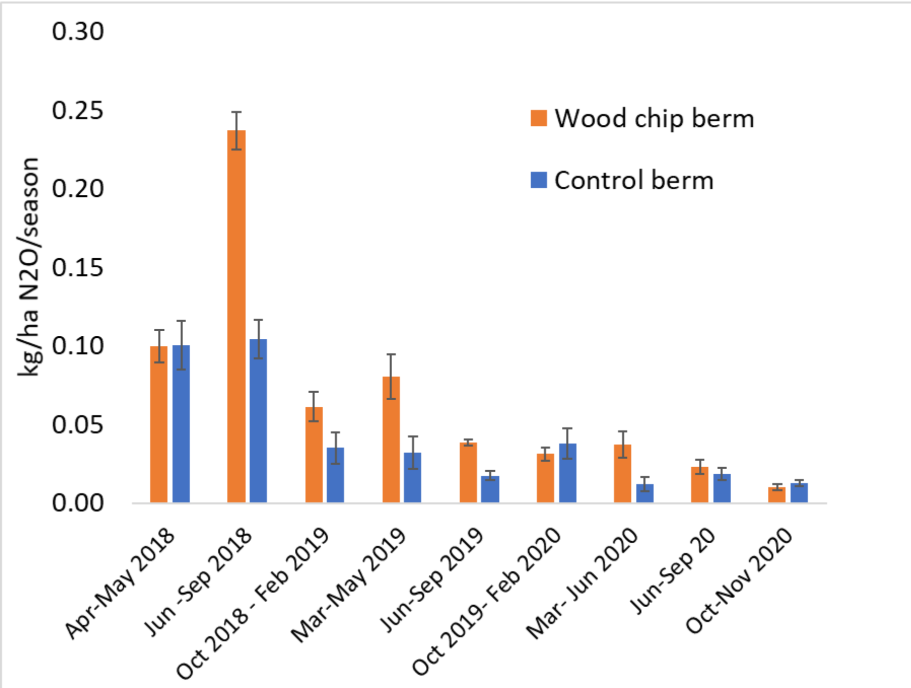


Figure 1 . Wood chip and control treatment N_2O emissions (kg/ha/season) from spring (April) 2018 through summer (October) 2020.

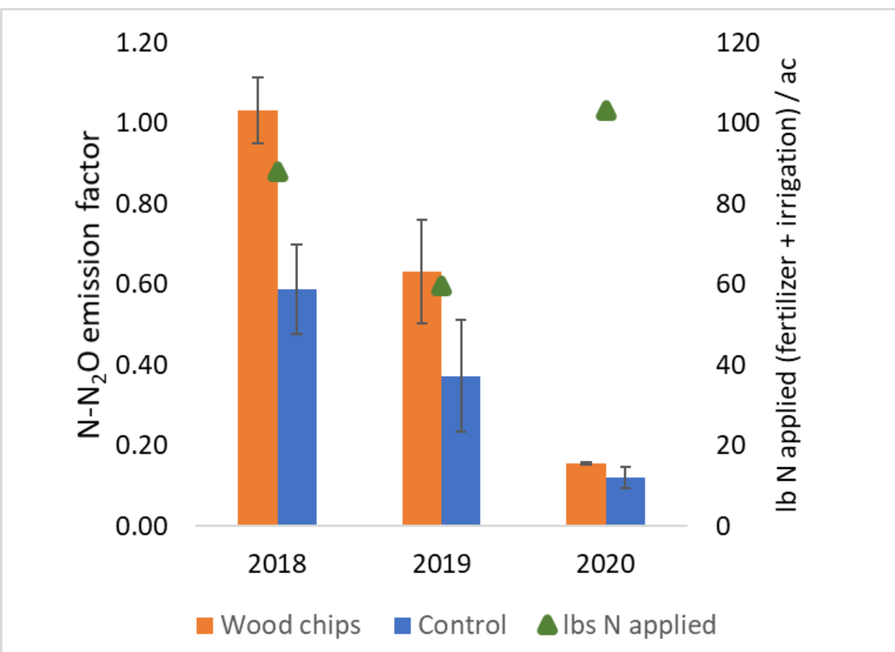


Figure 3. Calculated emission factor for wood chip and control berms from 2018 to 2020. The N_2O emission factor (EF) was calculated annually by dividing the cumulative N-N_2O emitted on the berm by the amount of N applied (fertilizer plus N in applied irrigation water) to determine how much N was lost as N-N_2O.

Goal 2: Describe the effect of WOR on soil carbon and nitrogen cycling (Culumber, Poret-Peterson, Gao, Holtz).

Response of soil attributes to WOR was exclusive to the top 15 cm of the soil profile in the first three years after recycling, with few observed changes in the 50 cm and 80 cm depth composite samples. Soil organic matter, organic C and total N in the 0-15cm, < 2 mm sieved soil fraction, decreased significantly from the time of trial initiation in both treatments from March 2018, to March 2019 (Table 3). By 2020, SOM (2.47 ± 0.15) and OC levels (1.44 ± 0.05) were significantly higher ($P < 0.0459$, and $P < 0.0125$) in wood chips than the control plots with SOM (1.6 ± 0.05) and organic C (0.82 ± 0.04). The orchard is in the historical alluvial plain of the Kings River and the baseline soil had elevated levels SOC (1.2%) higher than average for the Fresno county (0.6%) and much of the arable land throughout the Central Valley. An increase 0.2% SOC in the wood chips plots in less than 3 years is a remarkable increase, suggesting much of the rapidly decomposing wood biomass is stabilizing as organic C. Soil samples collected from 50 cm and 80 cm did not differ by depth or between the two treatments during the first three years after trial initiation (0.63% ±0.15% SOM). Soil pH varied significantly by treatment ($P < 0.0474$) and by year ($P <0.001$). There were no differences between treatments within year and the overall soil pH decreased from 7.7 ± 0.01 at the baseline to 6.7 ± 0.02 by March 2020. Soil EC levels only varied by year ($P < 0.0175$), a likely response to fluctuating levels of winter-time precipitation prior to sample collection in spring of each year. Soil P and soluble K levels were no different between the WOR and control treatment, although P concentrations declined overall from 2018 baseline 95.55 ± 2.86 ppm PO_4-P to 28.63 ± 1.23 ppm PO_4-P in 2020. Potassium (239.43 ± 17.49 ppm K) was consistent across all three-years. Monthly inorganic N levels did not differ between wood chip and control treatments although differences between years and months within years for both nitrate (NO_3^--N) and ammonium (NH_4+-N) reflect the impact of fertilization management on soil N levels (Table 1). Soil NO_3^--N and NH_4^+-N levels were significantly higher ($P < 0.0292$ and $P < 0.0001$) in 2018 than 2019 in response to higher N applications. The highest level of NO_3^--N was observed in September of both years.

September 2018 had the highest concentration (107.7 ± 11.2 ug/g soil) of all observations, nearly two months after the most recent fertilization event, suggesting an over application of nutrients and poor N use efficiency in both treatments for the first growing season. Conversely post-fertigation NH_4^+-N highest levels (35.8 ± 0.6 ug/g soil) occurred in April of 2018, where cold temperatures likely slower nitrification of UAN fertilizer. Inorganic N was extracted from monthly samples in 2020, but problems with analyzer equipment did not allow for 2020 data to be included in time for this report. The 60 cm buried nitrate selective resin capture devices resulted in a collective 74.73 ± 52.83 NO_3^--N (kg/ha) in the control compared to 93.57 ± 48.68 NO_3^--N (kg/ha) in the wood chip treatments. The observed N concentrations in both treatments were well within reach of tree roots at the 60 cm depth and therefore not considered leached. This high level of N carryover from 2018 to 2019 reinforces conclusions from the 15 cm depth, that there was low nitrogen use efficiency of the high N applications (88 lb N/ac or 98.6 kg/ha) in 2018. Laboratory incubation net N mineralization, net N nitrification rates, microbial biomass C and N appeared to be higher but not significant (data not shown) in woodchip treatments compared to the control, suggesting the soil microbial

community may have greater resource availability and efficiency in transforming organic forms of nitrogen. A higher nitrification potential in WOR indicates this process may be play a substantial role in N_2O fluxes after fertigation. The relative importance of different microbial groups in soil N transformations and specifically N_2O emissions is under investigation.
Bulk density was measured once during the project trial in 2019, and no differences were found between treatments in either the berm or the alleyway (1.63 ± 0.007 g/cm^3). Soil moisture and temperature patterns for the top 15 cm were plotted with daily CO_2 fluxes, shown in Figure 1a-c. Temperature patterns were consistent between treatments (Figure 1b) and an overall 30% increase in soil moisture was observed in wood chip plots compared to the control (Figure 1c). The abundances of genes for nitrification (amoA) and denitrification (nirK and nirS) have been enumerated via quantitative PCR for all 2018 samples. The nirK and nirS genes encode two types of nitrite reductases that convert nitrite to nitric oxide.The abundances of nirK and nirS were positively correlated with soil moisture, NO_3^--N and NH_4^+-N, whereas amoA abundances exhibited a positive relationship with soil NO_3^--N only. DNA has been extracted from soil samples collected in 2019 and quantitative PCR analysis is underway. Both 2018 and 2019 samples are being prepared for microbiome sequencing.

Goal 3: Evaluate establishment growth and nutrition in trees following orchard recycling compared to controls in a commercial orchard (Culumber, Poret-Peterson, Gao, Holtz)
Mid-summer leaf tissue nutrition was adequate and consistent for all measured nutrients between the two treatments across all three years. Visual observations and tree leaf tissue analysis in May 2018 indicated the trees planted into recycled wood chips had slower growth and lower nutrition (2.4% N) than the controls (4.1% N) (data not shown). However, by mid-summer the trees appeared to have recovered reaching satisfactory N content (3.1%). Tree N tissue levels were lower in 2019 but considered adequate for non-bearing trees. There was no difference in tree size or yield between conventional and wood chip treatment trees in either variety in 2020. An average 1401.2 ± 33.3 kernel lbs/ac for Nonpareil and 1256.1 ±19.4 kernel lbs/ac. Yield data were obtained by hand harvest which poses challenges with separating leaves and other debris from the estimated field weight. The estimates are several hundred lbs greater than grower reported yields, however the data still provides a relative comparison between the treatments and indicates whole orchard recycling did not have a detrimental impact on yield in the first harvest season.

Outreach Activities

Findings have been presented at 2020 Plant and Soil Conference, Fresno CA. (300 attendees), “Organic almond production in the Northern San Joaquin Valley of California,” Northern San Joaquin Valley Almond Day, Modesto Centre Plaza, 1150 9th Street, January 31, 2020 (400 attendees). San Joaquin County Agricultural Advisory Board Meeting, March 2, 2020 (25 attendees). San Joaquin Farm Bureau Board of Directors Meeting, Stockton, March 11, 2020 (50 attendees). The Atlantic Team and the Almond Board of California, virtual presentation/interview, May 13, 2020 (10 attendees). Establishing Nut Crop Orchards, Summer 2020 Webinar Series, UC ANR Program Support Unit, https://ucanr.edu/sites/PSU/files/329744.pdf, August 12, 2020 (45 attendees). American Society for Horticultural Science Virtual Conference “Influence of Whole Orchard Recycling on GHG Emissions and Soil Health in a New Almond Orchard”. (42 attendees). “Early nitrogen fertilization is important on first-year second generation almond trees following whole orchard recycling," Almond Board of California video filming with Fowler Brothers Orchard Removal, Escalon, October 21, 2020 (8 attendees), "Whole orchard recycling," 2020 Virtual Tree and Vine Expo, Malcolm Media Ag Exp, agespo.biz/2020-tree-vine-expo-schedule/, November 10, 2020 (1,100 Attendees), "Nitrogen considerations in replanted orchards following whole orchard recycling," San Joaquin Valley Almond Day, a virtual event by zoom, January 14, 2021 (200 attendees), http://ucanr.edu/2021sjvalmondday

Materials and Methods

An 13-year old plum orchard located in Parlier, CA was pushed over and chipped in late 2017. Four half-acre (60 m x 33.5 m) plots were established at random to serve as control plots. Wood chip mulch treatment plots of the same size were established adjacent to the controls. Planting berms were fumigated and double line drip irrigation system was installed. A 50-50 mix of Nonpareil and Monterey almond varieties on Viking rootstock were planted in a 5.2 x 6.7 m square pattern, oriented in a north to south direction.

Chamber and gas flux sampling: A static chamber with an automatic sampler was used for N_2O emission measurement, constructed following the USDA Greenhouse Gas Reduction through Agricultural Carbon Enhancement Network (GRACENet) protocols. Carbon dioxide emissions were measured using a LI-8100A automated CO_2 flux System (LI-COR® Biosciences). Gas flux sampling was conducted weekly, and more frequently during fertigation and irrigation management events. Measurements were collected near the drip tape where fertilizer is applied and in the alleyway. The berm locations were assumed to contribute 30%, and the alleyway 70% of the surface area emissions. The N_2O emission factor (EF) was calculated annually by dividing the cumulative N-N_2O emitted on the berm by the amount of N applied (fertilizer plus N in applied irrigation water) to determine how much N was lost as N-N_2O.

Soil attributes related to soil health: Composite samples were collected from 6 locations within each block at 0-15, 15-50, and 50-80 cm annually since March 2018 to monitor net changes in soil organic matter loss on ignition (%), pH, electrical conductivity, bulk density, total carbon and nitrogen, soil inorganic N pools, available phosphorus (ppm) (Olsen P method), and soluble and exchangeable cations. Soil inorganic N pools, labile dissolved organic C and N pools from 0-15 cm were measured monthly, one to two days post fertigation coinciding with GHG measurements. Potential net mineralization and nitrification, and microbial biomass C and N was measured in July 2018 and 2019 for samples collected 0-15cm depth. To detect differences in N movement deeper in the soil profile, four nitrate selective resin PWA5 (Dow) capture devices were buried at a 60 cm depth in each treatment plot treerow berm in March 2018, then extracted before fertilization commenced in 2019. Three EM50 sensors (Meter Group, Pullman, WA) collected continuous soil moisture and temperature data at 15, 50, and 80 cm depth in both treatments in the dripline and the alleyway within a half meter of the chamber.

Nutrition, Growth, Yield, C & N Partitioning: Trunk circumference was measured annually to monitor tree grwoth. Tree leaves were sampled mid-season each year and analyzed for nutrition. Yield data were collected from five consecutive trees for each variety in each plot in 2020. After shaking, nuts were swept, sieved with mesh shovels to remove as much debris as possible, then weighed in the field. A representative 3.63 kg sub-sample was collected from each treatment plot for dry weight, nut count, kernel weight, and shelling percentage determination.

D. Publications that emerged from this work

Holtz, B., Culumber, M., Zuber, C., Browne G., Yaghmour M., Gao, S., Poret-Peterson, A. Gordon, P. 2020. Whole Orchard Recycling in Almond: Early Nitrogen Fertilization is Important in First-Year, Second Generation Trees. West Coast Nut November p. 20-26

Abstracts

Culumber, C.M., S. Gao, A. Poret-Peterson, B. Holtz, G. Browne, A. Gaudin, E. Jahanzad, and E. Marvinney. 2020. "Influence of Whole Orchard Recycling on GHG Emissions and Soil Health in a New Almond Orchard". American Society for Horticultural Science Virtual Conference, August 10-13, online. 2020 ASHS Annual Conference (confex.com)

Camarena, D., Perez J., Shenk R., Hendratna, A, Culumber M., Poret-Peterson A., Holtz B., and S. Gao 2020. "Carbon dioxide and nitrous oxide emissions following whole orchard recycling" American Society of Agronomy California Chapter Plant and Soil Conference. February 5, 2020. Fresno, CA.

Perez J., Camarena, D., Shenk R., Hendratna, A. Pflaum T., Culumber M., Poret-Peterson A., Holtz B., and S. Gao. 2019 "Greenhouse Gas (N2O and CO2) Emissions from High Rate of Woodchip Recycling in an Almond Orchard" American Society of Agronomy California Chapter Plant and Soil Conference. February 1, 2019. Fresno, CA.