Whole almond orchard recycling and the effect on second generation tree growth, yield, light interception, and soil fertility

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Abstract

The grinding and incorporating into soil of whole almond trees, during orchard removal, could provide a sustainable practice that enhances both air and soil quality. We hypothesize that wood debris incorporated into soils could increase organic matter, enhance carbon sequestration, and improve soil quality and tree yield. The objective of this project was to compare on-site grinding up and soil incorporation of whole trees with on-site burning and ash incorporation as a means of orchard removal. In 2008, each treatment was applied to seven replicate plots of an old stone fruit orchard in a randomized block design. An "Iron Wolf," a 45,454 kg rock-crusher, was used to grind up and incorporate the standing tree rows of the old orchard to a soil depth of up to 30 cm. The grinding incorporated an estimated 67,000 kg of woody biomass ha^{-1}. For the burn treatment, trees were pushed into a pile, burned, and the ash was spread evenly throughout the plot. All replicate plots were re-planted with "bare-root" almond trees in 2009. Significantly greater increase in tree circumference was observed in the grind treatment from 2014-2016 when compared to the burn. Also, in 2016, significantly greater photosynthetically active light interception was observed in the grind treatment. Yields were determined from 2011-2017 and the grind treatment cumulative yield was greater by 1,778.49 kg ha^{-1} in the 'Butte' cultivar. Yields were also determined in 'Nonpareil' in 2014, 2016, and 2017 and the grind treatment cumulative yield was 1,120 kg ha^{-1} greater than the burn yield. Significantly more soil nutrients (calcium, manganese, iron, magnesium, boron, nitrate, potassium, copper), higher electrical conductivity, organic matter, total and organic carbon were measured in the grind treatment soils when compared to the burn treatment. Soil pH was significantly lower in the grind treatment plots. Leaf petiole analysis also revealed higher nutrients (nitrogen, potassium, phosphorus, manganese, and iron) and less sodium and magnesium levels in trees growing in the grind treatment. Bud failure severity was lower on the 'Carmel' trees in the grind treatment when compared to the burn treatment. This project demonstrated whole orchard recycling as an alternative to burning in the field or in a co-generation facility. We estimate that over 8,000 ha in California have been ground and incorporated in the last three years.

Keywords: carbon sequestration, carbon recycling, plant nutrition

INTRODUCTION

Before air quality standards were implemented in the San Joaquin Valley (SJV) of California, old orchards being removed were pushed out and burned. But when restrictions on burning (Clean Air Act of 2002) were implemented to improve air quality, orchards were

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ground up with a grinder and the woody debris was hauled out of the orchard and burned for energy in a co-generation plant. The stored carbon in the orchard's biomass was lost from the orchard site. Since 2015, half of California's heavily subsidized biomass co-generation plants have closed. This is partly because utility companies are looking for cleaner sources of energy (sun and wind) and not renewing contracts. The plants still open have limited the amount of wood biomass from agriculture (more forest biomass) and reduced the amount they will pay for wood debris. Tree fruit growers wishing to remove old trees and orchards need to find an alternative method of orchard removal other than burning. The Almond Board of California (ABC) estimates that nearly 30-40 thousand acres of old almond orchards will be removed annually over the next decade.

Whole orchard recycling (WOR), or the grinding and soil incorporation on site of whole trees during orchard removal, like the shredding of annual prunings (Holtz et al., 2004), could provide a sustainable method of tree removal that could enhance both air and soil quality. If whole orchard recycling is adapted as an alternative to biomass co-generation or field burning, we hypothesize that amended soil would sequester carbon from almond orchard biomass, resulting in higher levels of soil organic matter and aggregate stability, increased soil fertility, soil water holding capacity, water infiltration, and resistance to erosion. A high carbon containing amendment, like wood chips, should facilitate nitrogen immobilization and deplete nitrate (NO_3^-) availability, slowing losses to nitrous oxide (N_2O) emissions.

However, almond growers fear that wood grindings will take valuable nutrients away from their second generation trees because of the high carbon to nitrogen ratio that could result if the previous orchard's debris is incorporated into soils before replanting. Another concern is that the woody debris may be so large that it would interfere with normal soil preparation and orchard floor management practices. The orchard floor needs to be free of woody debris by the third year and first almond harvest. The effect of woody soil amendments on replant disease and pathogens has yet to be determined, but there are several reports in the literature where increased soil organic matter has increased microbial diversity and reduced soilborne diseases. If wood grindings can be shown to not take valuable nutrients from trees, and not worsen replant disease or interfere with harvest, then growers would be more likely to adopt grinding and incorporating as an alternative to burning or removing debris from their orchards, especially if advantages to soil health and nutrition can be demonstrated.

Since the Kyoto Protocol, participating countries have begun to examine the possibility of compensating growers that return high carbon amendments to soils as a means of off-setting industrial carbon emissions into the atmosphere (Kimble et al., 2004). The objective of this project is to compare the grinding up of whole trees with burning as a means of orchard removal. We are examining second-generation orchard growth and replant disease between treatments. We will examine the effect of whole tree grinding on the nitrogen to carbon soil ratio, soil organic matter, soil-plant nutrition, soil water holding potential, disease, tree growth and yield. Analysis will also include the characterization of soil chemical and physical properties; extraction, quantification, and characterization of plant parasitic and non-parasitic nematodes; and the isolation and identification of plant disease causing bacteria and fungi.

MATERIALS AND METHODS

Twenty-one rows of an experimental stone fruit orchard on 'Nemaguard' rootstock at the UC Kearney Agricultural Center, Parlier, CA were used in a randomized blocked experiment with two main treatments: whole tree grinding and incorporation into the soil with "The Iron Wolf" (www.ironwolf.com), a 45,000 kg rock crusher, versus tree pushing and burning (completed March/April 2008). There are 7 replications of each treatment and in each plot there were 18 first generation orchard trees. Second generation almond trees ('Nonpareil', 'Carmel', and 'Butte') were planted in January/February 2009, six trees of each cultivar. Tree growth was measured annually by trunk circumference. Soil sampling of each replicated treatment was made for a total of 14 samples at a depth of 10-15 cm. Samples of bulk soil (500 g) from treatment plots were lab oven dried (40°C) and ground to pass through a 2-mm sieve before physical and chemical analysis in the analytical laboratory at the University of California, Davis. Methods are described for each analysis at http://anlab.ucdavis.edu/. Samples were characterized for essential nutrients, texture, pH, electrical conductivity, cation exchange capacity, and organic carbon.

Leaf petiole samples were taken, washed, and dried (at 40°C) and ground for physical and chemical analyses in the analytical laboratory at UC Davis. Methods are described for each analysis at http://anlab.ucdavis.edu/. Trunk circumference measurements were taken annually when trees were dormant. Trees were given the same amount of nitrogen and irrigation water and plots were harvested in September by mechanically shaking the fruit to the ground, drying for 7-10 days, and then collecting and weighing the fruit from each tree by hand. Leaf stem water potentials were taken with a pressure chamber periodically throughout the 2017 season.

RESULTS AND DISCUSSION

Tree growth and yield

Analysis of tree circumferences data from second generation replanted trees, for all three cultivars, showed no significant effect on tree growth between 2009-2011. However, by the fourth season (2012-2016) trees growing where the previous orchard was ground up and incorporated began to show significantly greater tree circumference ('Butte', Table 1) when compared to the burn treatment. By 2016 the trees in the grid plot averaged more than 2.57 cm more in circumference than the trees growing in the burn plots.

Table 1. Influence of orchard grinding and burning of first generation trees on the tree circumference of second generation trees.

Year	Tree circumference 'Butte' (cm)		P value
	Grind	Burn	
2009	4.87	4.96	P=0.19
2010	14.56	15.22	P=0.07
2011	22.39	22.72	P=0.38
2012	30.53	30.23	P=0.18
2013	38.52	37.73	P=0.09
2014	46.50 a	45.24 b	P=0.01
2015	55.71 a	53.79 b	P=0.01
2016	63.15 a	60.58 b	P=0.007

Paired columns with different letters were statistically different when compared in a Student's T-test (P<0.05).

Yields were determined on the 'Butte' almond cultivar from 2011-2017 corresponding to the third through seventh season after planting. No significant difference in yield was observed in the first two seasons but by the third harvest the trees growing in the grind treatment had significantly greater yield (P=0.05) than trees growing in the burn plots (Table 2). No significant differences in yields were observed in the next four seasons (2014-2017), however the trees growing in the grind treatment plots consistently had higher yields than the trees growing in the burn treatment plots. In 2017 the P value was very close to being significant (P=0.07). After seven harvest seasons the 'Butte' almond in the grind treatment trees produced over 1,778.49 kg ha^{-1} more kernel nuts than the burn treatment trees. Yields were also determined on the 'Nonpareil' almond for the 2014, 2016, and 2017 seasons. In all three seasons the 'Nonpareil' trees, growing in the grind treatment plots, significantly out produced the trees growing in the burn plots, producing more than 1,120.47 kg ha^{-1} kernels (Table 3).

Table 2. Influence of orchard grinding and burning of first generation trees on the yield of second generation trees of 'Butte'.

Year	'Butte', kernel kilograms per hectare (kg ha^{-1})		
	Grind	Burn	Difference
2011	770.47	770.43	0.04 (P=0.49)
2012	1,650.26	1,546.05	104.21 (P=0.19)
2013	2,140.32	1,869.39	270.93 (P=0.05)
2014	2,546.58	1,980.73	565.84 (P=0.12)
2015	1,202.51	983.55	218.96 (P=0.11)
2016	1,504.07	1,352.76	151.31 (P=0.14)
2017	2,192.29	1,725.10	467.18 (P=0.07)
Total	12,006.49	10,227.99	1,778.49

Paired columns with different letters were statistically different when compared in a Student's T-test (P<0.05). The P value was significant (P=0.05) in 2013 and 2017, while yields were always higher in the grind treatment plots.

Table 3. Influence of orchard grinding and burning of first generation trees on the yield of second generation trees of 'Nonpareil'.

Year	'Nonpareil', kernel kilograms per hectare (kg ha^{-1})		
	Grind	Burn	Difference
2014	2,406.48	2,194.57	211.89 (P=0.02)
2016	3,162.86	2,674.35	488.50 (P=0.03)
2017	2,518.15	2,098.06	420.08 (P=0.01)
Total	8,087.49	6,966.98	1,120.47

Paired columns with different letters were statistically different when compared in a Student's T-test (P<0.05). Yields were significantly greater in all three years 'Nonpareil' yield was determined.

Soil and plant nutrient analysis

In 2010, more carbon, organic matter, and a greater cation exchange capacity were observed in the burned plots (Holtz et al., 2014), but, starting in 2012, the grind plots have significantly higher organic carbon content along with more calcium, manganese, iron, magnesium, boron, nitrate, copper and electrical conductivity (Holtz et al., 2016) (Table 4). In addition, sodium, ammonia, potassium, were significantly greater in the grind treatment plots when compared to the burn plots from. Boron was significantly less in the grind treatment plots when compared to the burn plots from 2013-2016. Through the first six years of this study the soil pH was significantly lower in the grind treatment plots (Table 4). The percent organic carbon and soil organic matter increased significantly and gradually throughout the study from 2010-2017 (Figure 1). Leaf stem water potentials consistently showed better tree water status in the grind treatment plots when compared to the burn treatment plots (Figure 2).

Throughout eight seasons (2010-2017) leaf petiole analysis showed significantly greater levels of nitrogen, potassium, and manganese from trees growing in the grind treatment when compared to trees growing in the burn treatment. Magnesium and sodium levels were significantly less in trees growing in the grind treatment. In 2010, 2013, and 2014 leaf petiole analysis showed significantly greater levels of phosphorus from trees growing in the grind treatment.

Table 4. Influence of orchard grinding versus burning on soil chemicals.

	2013		2014		2015	
	Grind	Burn	Grind	Burn	Grind	Burn
Ca (meq L^{-1})	3.78 a	3.25 b	7.55 a	5.45 b	4.02 a	1.36 b
Na (mg kg^{-1})	2.74 a	1.90 b	3.41 a	2.34 b	2.32 a	1.21 b
Mn (mg kg^{-1})	26.35 a	5.71 b	14.46 a	10.65 b	7.31 a	4.67 b
Fe (mg kg^{-1})	32.56 a	20.38 b	38.58 a	29.30 b	24.29 a	17.21 b
Mg (mg kg^{-1})	2.15 a	1.20 b	3.61 a	2.57 b	2.01 a	0.68 b
B (mg L^{-1})	0.06 a	0.07 a	0.07 a	0.10 a	0.05 a	0.07 b
NO_3-N (mg kg^{-1})	20.11 a	12.27 b	26.53 a	18.89 b	20.64 a	5.23 b
NH_4-N (mg kg^{-1})	0.37 a	0.33 a	1.59 a	1.36 b	0.89 a	0.65 b
K (mg L^{-1})	94.50	84.88	28.50 a	13.60 b	19.76 a	16.96 b
pH	7.39 a	7.53 b	6.95 a	7.06 a	7.27 a	7.60 b
EC (dS m^{-1})	0.91 a	0.68 b	1.54 a	1.08 b	0.90 a	0.38 b
CEC (meq 100 g^{-1})	9.54	10.16	7.78 a	8.30 a	5.16 a	5.14 a
OM %	1.55 a	1.06 b	1.21 a	0.93 b	1.37 a	1.08 b
C (total) %	0.87 a	0.51 b	0.71 a	0.54 b	0.66 a	0.50 b
C-Org %	0.87 a	0.61 b	0.70 a	0.54 b	0.79 a	0.62 b
Cu (mg kg^{-1})	8.26 a	7.11 a	8.03 a	7.73 a	7.51 a	7.03 b

Paired columns with different letters were statistically different when compared in a Student's T-test ($P<0.05$).

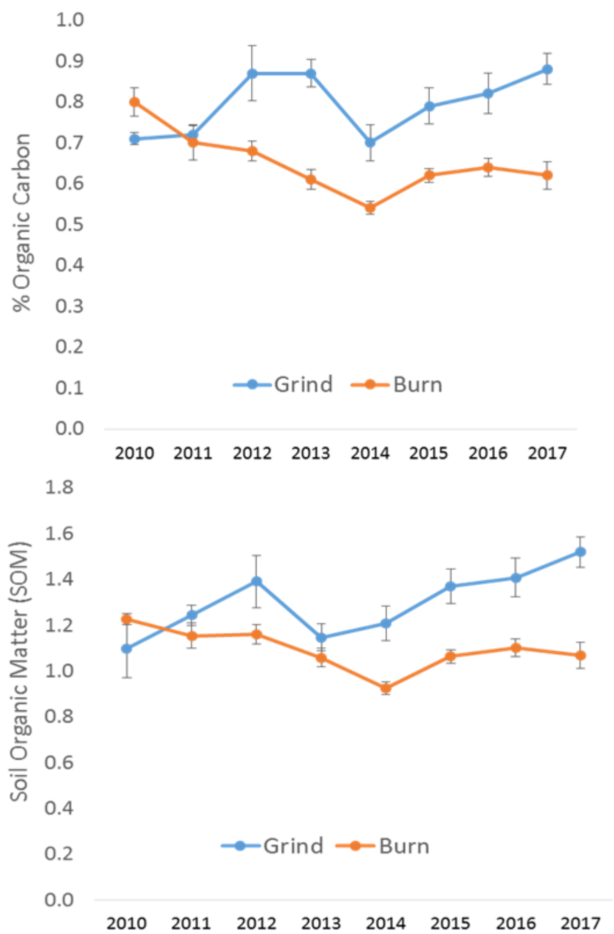

Figure 1. The percent organic carbon and soil organic matter increased significantly and gradually throughout the study from 2010-2017.

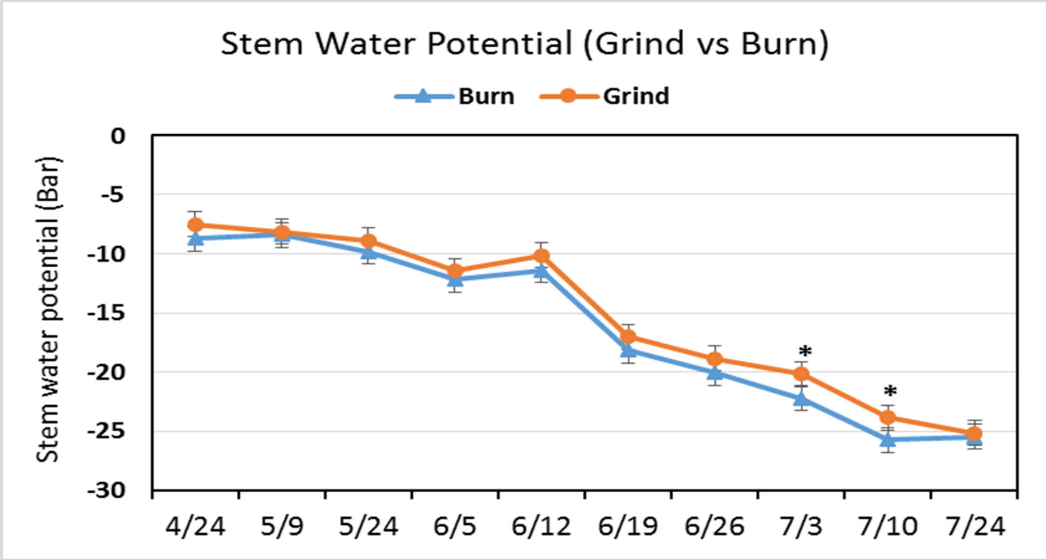

Figure 2. Leaf stem water potentials showed consistently less stress from trees growing in the grind treatment plots when compared to trees growing in the burn treatment plots during the 2017 season. Deficit irrigation treatments were implemented in July and the trees in the grind treatment plots still showed less stress.

CONCLUSIONS

The whole tree grinding and incorporation, estimated at 67,000 kg ha^{-1}, did not stunt replanted tree growth after the first eight growing seasons. Replanted trees were given average nitrogen levels through the micro-irrigation system, never exceeding 30 g of actual nitrogen $tree^{-1}$ $irrigation^{-1}$. In our first soil analysis, one year after grinding and burning (2010), the burn treatment plots had significantly more organic matter, carbon, electrical conductivity, calcium, sodium, and cation exchange capacity in the top 10-15 cm than the grind treatment plots. The carbon and nutrients found in the ash from the burn treatment were quickly and more readily available than organic nutrients still captured in the large chunks of woody debris from the grind treatment that were not yet decomposed. However, two years later (2012) decomposition and mineralization of the added organic matter significantly increased soil calcium, manganese, iron, magnesium, boron, nitrate, copper, electrical conductivity, organic matter, total carbon, and organic carbon contents. We expect to see the grind and incorporated wood chip treatment to ultimately sequester more carbon than the burn treatment. Nutrients released by the organic matter decomposition appear to be accessible to the almond trees growing in the grind treatment plots as detectable differences in leaf petiole analysis were observed. By 2013 leaf petiole analysis showed significantly greater levels of nitrogen, potassium, phosphorus, manganese, and iron from trees growing in the grind treatment, while magnesium and sodium levels were again significantly less. By the fourth growing season (2012) trees growing in the grind treatment plots began to show significantly greater tree circumference and greater yields starting in 2013 when compared to trees growing in the burn treatment plots. Soil pH was significantly lower in the grind treatment plots while leaf stem water potentials indicated that trees in the grind plots were less stressed. Bud failure severity was lower on 'Carmel' trees in the grind treatment when compared to the burn treatment, indicating less water stress. Increasing soil organic C has been shown in many agricultural studies to have a positive impact on soil nutrient reservoirs and water holding capacity over time. In California, over 8,000 ha of old orchards have been ground up and incorporated in the last three years as growers seek an alternative to biomass burning.

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Literature cited

Holtz, B.A., McKenry, M.V., and Caesar-TonThat, T.C. (2004). Wood chipping almond brush and its effect on the almond rhizosphere, soil aggregation, & soil nutrients. Acta Hortic. *638*, 127–137 https://doi.org/10.17660/ActaHortic.2004.638.15.

Holtz, B.A., Doll, D., and Browne, G. (2014). Orchard carbon and nutrient recycling. Acta Hortic. *1028*, 347–350 https://doi.org/10.17660/ActaHortic.2014.1028.56.

Holtz, B.A., Doll, D.A., and Browne, G. (2016). Whole almond orchard recycling and the effect on second generation tree growth, soil carbon, and fertility. Acta Hortic. *1112*, 315–320 https://doi.org/10.17660/ActaHortic.2016.1112.42.

Kimble, J.M., Lal, R., and Follett, R.F., eds. (2004). Agricultural Practices and Policies for Carbon Sequestration in Soil (Boca Raton, FL: CRC Press).