Whole almond orchard recycling and the effect on second generation tree growth, soil carbon, and fertility

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Abstract

The grinding and incorporating into soil of whole almond trees, during orchard removal, may provide a sustainable practice that could enhance air and soil quality. Removed orchards are typically either pushed out and burned or ground up and removed. Stored carbon is lost from the orchard site. Woody 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 the grinding up of whole trees with burning as a means of orchard removal. Twenty-two rows of an experimental orchard were used in a randomized blocked experiment with two main treatments, whole tree grinding and incorporation into the soil versus tree pushing and burning. The whole tree grinding did not stunt replanted tree growth. Sampling from plots showed elevated levels of fungal and bacterial feeding nematodes (*Tylenchidae*) along with associated woody soil aggregates in the grind treatment. Fungal mycelium was readily observed colonizing woody aggregates and significantly more basidiomycetes (mushrooms) were observed in the grind plots. No difference in yield was observed in 2011, however, in 2012 and 2013 (P=0.08) greater yields were observed in the grind treatment when compared to the burn. In 2010, more carbon, organic matter, and a greater cation exchange capacity were initially observed in the burned plots, but by 2012 and 2013 the grind plots had significantly more calcium, manganese, iron, magnesium, boron, nitrate, copper, as well as higher electrical conductivity, organic matter, total carbon, and organic carbon. Soil pH was significantly lower in the grind treatment plots. Leaf petiole analysis in 2013 showed significantly greater levels of nitrogen, potassium, phosphorus, manganese, and iron from trees growing in the grind treatment, while magnesium and sodium levels were significantly less.

Keywords: carbon sequestration, carbon recycling, plant nutrition

INTRODUCTION

The San Joaquin Valley Unified Air Pollution Control District restricts the burning of agricultural wastes. The adoption of wood chipping or shredding of annual prunings, instead of burning, has provided a sustainable alternative farming practice that improves air quality while adding valuable organic matter to soils (Holtz, 2003; Holtz et al., 2004, 2006). Nearly all of California's half million hectares of almond shred their annual prunings. In previous studies soil nutrient levels were elevated by wood chipping while organic matter also increased (Holtz et al., 2004). Free living nematode populations were found to increase with the addition of wood chips as well as basidiomycete (mushrooms) populations, (Holtz et al., 2004, 2006, 2014). Our previous work demonstrated the long life of woody lignic materials on the soil surface of an orchard (Holtz et al., 2009, 2013).

The grinding of whole trees during orchard removal, like the shredding of annual prunings, could also provide an alternative to burning that could add valuable organic

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matter to San Joaquin Valley soils typically low in organic matter. Growers, however, fear that whole tree grinding and incorporating will take nutrients away from their next generation trees because of the high carbon to nitrogen ratio believed to result. 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 (Holtz et al., 2009). We hypothesize that soils amended with woody debris will sequester carbon at a higher rate, and have higher levels of soil organic matter, increased soil fertility, and increased water retention. 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 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 rototiller, 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', '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.

Sampling for plant pathogenic and bacterial and fungal feeding nematodes occurred in both the grind and burn plots in the root zone of replanted trees. Approximately 500 cm^3 of soil was sampled at a depth of 10-15 cm. In the laboratory, soil was passed through a coarse sieve to remove roots and rocks and nematodes were extracted from 200 cm^3 by a modified sieving – Baermann funnel technique (Baermann, 1917). The total number of nematodes in each sample was counted (the first 100 encountered on a slide) and a random subsample identified. 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/. Trees 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.

RESULTS AND DISCUSSION

Tree growth and yield

Analysis of tree circumferences data from second generation replanted trees, for all three cultivars, showed no effect in tree growth between trees growing in plots where whole tree grinding had been performed when compared to trees in plots where the previous orchard had been burned. Yields were determined on the 'Butte' almond cultivar in 2011, 2012, and 2013 (3rd through 5th leaf). No significant differences in yields were observed in the first three harvests, however, the grind treatment trees consistently had higher yields than the burn treatment trees (Table 1). In 2013 the P value was very close to being significant (P=0.08).

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

	Yield kg^{-1}		
	Green weight 6 tree $plots^{-1}$ (kg)		
	Grind	Burn	P value
2011	75.7 a	69.5 a	(P=0.26)
2012	121.6 a	115.1 a	(P=0.20)
2013	157.8 a	139.2 a	(P=0.08)[1]

Paired columns with different letters were statistically different when compared in a Student's T-test (P<0.05).
[1]In 2013 the P value was very close to being significant (P=0.08).

Fungal and bacterial feeding nematodes and soil and plant nutrients

Soil sampling from plots showed significantly more free-living (fungal and bacterial feeding) nematodes, in the family *Tylenchidae*, associated with woody soil aggregates in the grind treatment (Figure 1). There were more pin nematodes (*Paratylenchus* spp.) in the grind treatment plots, but differences were not significant (Figure 1). Fungal mycelium was readily observed colonizing woody aggregates, and more basidiomycetes (mushrooms) were observed in the grind plots (data not shown). In 2010, more carbon, organic matter, and a greater cation exchange capacity were observed in the burned plots, but by 2012 the grind plots had significantly more calcium, manganese, iron, magnesium, boron, nitrate, copper, electrical conductivity, total carbon, and organic carbon content in the soil (Table 2). The soil pH was significantly lower in the grind treatment plots. In 2011 and 2012 leaf petiole analysis showed significantly greater levels of potassium from trees growing in the grind treatment, while magnesium and sodium levels were significantly less (Table 3). In 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 (Table 3).

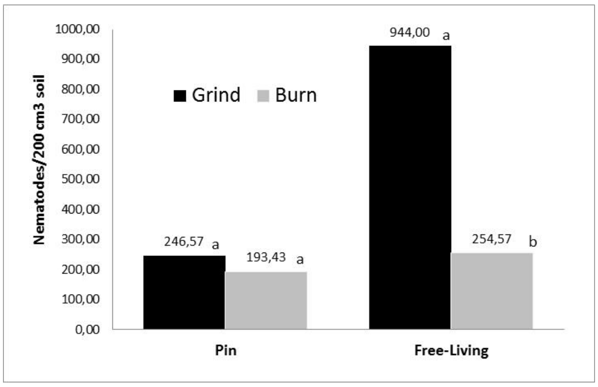

Figure 1. Influence of orchard grinding versus burning on populations of free living and Pin nematodes. Pin nematodes (*Paratylenchus* spp.) are the smallest plant parasitic nematodes, and are usually not associated with reduced tree vigor. Free-living nematodes include both fungal and bacterial feeding species in the family *Tylenchidae*, which are generally considered beneficial or none yield reducing. Paired columns with different letters were statistically different when compared in a Student's T-test (P<0.05).

Table 2. Influence of orchard grinding versus burning on soil chemical and physical properties.

	2010		2011		2012	
	Grind	Burn	Grind	Burn	Grind	Burn
Ca (meq L^{-1})	4.06 a	4.40 b	2.93 a	3.82 b	4.27 a	3.17 b
Na (mg kg^{-1})	19.43 a	28.14 b	13.00 a	11.33 b	11.67 a	12.67 a
Mn (mg kg^{-1})	11.83 a	8.86 b	12.78 a	9.19 b	29.82 a	15.82 b
Fe (mg kg^{-1})	32.47 a	26.59 b	27.78 a	22.82 b	62.48 a	36.17 b
Mg (mg kg^{-1})	0.76 a	1.52 b	1.34 a	1.66 a	2.05 a	1.46 b
B (mg L^{-1})	0.08 a	0.07 a	0.08 a	0.08 a	0.08 a	0.05 b
NO_3-N (mg kg^{-1})	3.90 a	14.34 b	8.99 a	11.60 a	19.97 a	10.80 b
NH_4-N (mg kg^{-1})	1.03 a	1.06 a	2.68 a	2.28 a	1.09 a	1.06 a
pH	7.41 a	7.36 a	6.96 a	7.15 b	6.78 a	7.12 b
EC (dS m^{-1})	0.33 a	0.64 b	0.53 a	0.64 a	0.82 a	0.59 b
CEC(meq 100 g^{-1})	7.40 a	8.47 b	8.04 a	7.88 a	5.34 a	5.32 a
OM %	1.22 a	1.38 b	1.24 a	1.20 a	1.50 a	1.18 b
C (total) %	0.73 a	0.81 a	0.79 a	0.73 a	0.81 a	0.63 b
C-Org %	0.71 a	0.80 b	0.72 a	0.70 a	0.87 a	0.68 b
Cu (mg kg^{-1})	6.94 a	6.99 a	7.94 a	7.54 a	8.87 a	7.92 b

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

Table 3. Influence of orchard grinding and burning of first generation trees on the leaf petiole analysis of second generation almond trees.

	Nitrogen (%)		Phosphorus (%)		Potassium (%)		Magnesium (%)	
	Grind	Burn	Grind	Burn	Grind	Burn	Grind	Burn
2011	2.58 a	2.58 a	0.14 a	0.14 a	1.92 a	1.67 b	0.66 a	0.71 b
2012	2.46 a	2.44 a	0.13 a	0.13 a	1.14 a	1.02 b	0.87 a	0.90 a
2013	2.57 a	2.49 b	0.112 a	0.106 b	0.94 a	0.73 b	1.04 a	1.12 b

	Manganese (mg kg^{-1})		Iron (mg kg^{-1})		Sodium (mg kg^{-1})	
	Grind	Burn	Grind	Burn	Grind	Burn
2011	25.70 a	24.91 a	91.34 a	93.75 a	19.38 a	54.00 b
2012	20.13 a	19.13 a	84.84 a	83.95 a	24.88 a	49.50 b
2013	27.83 a	23.25 b	113.59 a	102.79 b	634.6 a	957.5 b

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

CONCLUSIONS

The whole tree grinding, estimated at 61,000 kg ha^{-1}, did not stunt replanted tree growth after the first three 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. Apparently the carbon and nutrients found in the ash from the burn treatment were more readily detected in the soil analysis when compared to the carbon and nutrients still captured in the large chunks of woody debris from the grind treatment, not yet decomposed. The burn treatment and resulting ash most likely released nutrients more quickly into the soil than the grind treatment. However, two years later (2012) the grind treatment plots had significantly more calcium, manganese, iron, magnesium, boron, nitrate, copper, electrical conductivity, organic matter, total carbon, and organic carbon. Apparently, the nutrients released by the decomposition of the woody debris are beginning to become available in soil analysis. Fungal decomposition of organic matter may be contributing to available nutrient levels which would be gradually released as the woody aggregates are decomposed. We expect to see the grind or incorporated treatment to ultimately sequester more carbon and have higher levels 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 have been observed when compared to trees growing in the burn treatment. 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.

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