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Wood chipping almond brush to reduce air pollution and its effect on soil and petiole nutrients, soil aggregation, water infiltration, and nematode and basidiomycete populations

Brent Allen Holtz[1] and TheCan Caesar-TonThat[2]
[1]University of California, 328 Madera Ave, Madera, CA 93637, USA
[2]USDA-Agricultural Research, 1500 North Central Ave., Sidney, MT 59270, USA

Abstract

The wood chipping of almond prunings in California, instead of burning, can reduce air pollution and sequester carbon while returning organic matter to soils low in soil organic matter. The success of wood chipping depends on whether the chips do not deplete critical nutrients necessary for tree growth and that they do not interfere or become mixed in with almond nuts knocked to the ground to

Correspondence/Reprint request: Dr. Brent Allen Holtz, University of California, 328 Madera Ave, Madera, CA 93637, USA. E-mail: baholtz@ucdavis.edu

dry during harvest. Wood chipped orchard soils were sampled and compared to non-wood chipped orchard soils. Soil was also mixed with or without wood chips and placed in containers, each with an almond tree, in an experiment to investigate the effect of wood chips on leaf-petiole and soil nutrient status, plant parasitic and free-living nematode populations, water infiltration, and basidiomycete populations and their ability to aggregate soil.

Soil analysis after three years showed higher levels of calcium, magnesium, sodium, chloride, boron, zinc, manganese, iron, copper, carbon, phosphorus, potassium, ammonium, and % organic matter in wood chipped soils. There was less manganese, iron, and nitrate in the wood chipped soils after two years but by the third year manganese and iron levels were significantly increased while nitrate levels were higher in wood chipped soils. The soil pH was significantly reduced all three years. Tissue analysis was performed on leaf petioles for four years. After the first year trees growing with wood chips had significantly less nitrogen, zinc, and manganese, while phosphorus was significantly increased. After the second season trees with wood chips no longer had significantly less nitrogen or manganese while phosphorus and potassium levels were significantly increased. Zinc levels were still significantly decreased in trees growing with wood chips after the second season. After the third season trees growing with wood chips had higher nitrogen levels and significantly higher levels of phosphorus, potassium, calcium, zinc, manganese and iron. By the fourth season nitrogen and iron levels were significantly higher in leaf petioles from trees growing with wood chips. After four years potassium and calcium levels were no longer significantly greater in trees growing with wood chips, while phosphorus, zinc, manganese, and boron levels remained significantly higher. After two years, trees growing with wood chips had less shoot growth, but by third and fourth year trees growing with wood chips had significantly more current season shoot growth. The time taken for water infiltration was significantly shorter in wood chipped soils. There were more free-living bacterial (bacterivorous) and fungal feeding (fungivorous) nematodes in the wood chipped soils when compared to non-chipped soils. More basidiomycetes were counted in wood chipped soils and detected at higher levels with ELISA. Larger soil aggregates were found in wood chipped soils. Undisturbed wood chipped soils had more soil aggregates than disturbed soils. The practice of wood chipping almond prunings instead of burning appears to be a promising alternative to agricultural burning, providing nut growers with a sustainable method of brush removal that enhances soil organic matter and soil quality.

Introduction

In the San Joaquin Valley of California almond trees are pruned every year after harvest in the late fall or early winter. Prunings are typically removed from orchards with a “buck-rake” mounted on a tractor. Prunings are usually placed in burn piles and burned green, generating large amounts of smoke. In 2003, the San Joaquin Valley had 214,574 bearing hectares of almonds. Preliminary studies have shown that approximately 2,240 kilograms (kg) per hectare of prunings are removed annually [1]. This would result in the burning of approximately 480 million kg of green almond prunings per year. The San Joaquin Valley Unified Air Pollution Control District restricts the burning of agricultural wastes and further restrictions have recently been approved (Calif. Senate Bill 700) due to worsening air pollution. Since the passing of The Federal Clean Air Act Amendments of 1990 the San Joaquin Valley of California has not met national ambient air quality standards for particulate matter 10 microns (PM-10) or less.

The wood chipping or shredding of almond prunings could provide an alternative to burning that could add valuable organic matter to San Joaquin Valley soils typically low in organic matter. A small percentage of almond growers have been chipping or shredding their prunings, some for over 14 years, because they are farming on the agricultural-urban interface where brush burning is prohibited because of its close proximity to urban housing. Other growers have chipped or shredded their prunings solely to add organic matter to their soils. But many growers fear that wood chips or shreddings will take valuable nutrients away from their trees because of the high carbon to nitrogen ratio. If wood chips can be shown not to interfere with harvest or take valuable nutrients from trees, then growers would be more likely to adopt chipping or shredding as an alternative to burning, especially if advantages to soil health and nutrition could also be demonstrated.

In addition to reducing air pollution there is considerable concern over increasing atmospheric carbon dioxide levels and consequent effects upon climate change and global warming [2]. It is estimated that if the world’s emission of greenhouse gases continues unabated that atmospheric concentrations of carbon dioxide may double by the end of the 21st century [3]. Responding to this concern, world communities signed the Kyoto Protocol in 1997 under the United Nations Framework Convention on Climate Change in order to reduce emissions (not ratified by the U.S. Senate). The Kyoto Protocol also proposes sequestering carbon in terrestrial sinks [3] that include agricultural soils. Using agricultural soils to sequester carbon in order to mitigate greenhouse gases may allow industrialized countries to receive credits for creating terrestrial carbon sinks [3]. Agricultural practices that sequester carbon reduce the loss of soil organic matter while increasing the humification rate and soil organic matter, leading to increased soil fertility, water retention, reduced soil erosion, and a reduction in the leaching of nutrients and pesticides [3]. It is estimated that by using new technologies and sustainable management practices that cropland in the United States could potentially sequester 4,000 – 6,000 million metric tons (MMT) of soil organic carbon and thus help to reduce emissions of greenhouse gases causing global climate change [4]. The addition of wood chips to San Joaquin soils would also enhance carbon sequestration by returning carbon to soils as a carbon sink, instead of releasing the carbon into the atmosphere as a result of agricultural burning.

Typically in San Joaquin Valley, synthetic fertilizers have been used to meet tree crop nutrient demands and very little organic matter is returned to soils. The loss of soil organic matter has been associated with a number of cropping problems while the benefits of organic matter to soils are well documented [5]. Soil organic matter content is frequently identified as a primary component of soil quality and increasing soil organic matter is a goal of improving soil quality [6]. Organic matter has been shown to release a number of nutrients that are readily absorbed by plants, it supports symbiotic and free-living bacteria capable of converting atmospheric nitrogen, not available to plants, into forms of nitrogen such as nitrate [5]. Organic matter supports mycorrhizae, fungi that help in plant nutrient availability, and it supports other fungi and bacteria that bind soil particles into soil aggregates [5]. Soil aggregates improve soil structure by improving water infiltration, increasing air porosity, and improving soil tilth [5].

Organic material has been shown to increase the humic content of soil [7], the nutrient holding capacity of soils [6, 8], and the cation-exchange-capacity [9], which is a measure of the ability of soil to hold nutrients such as ammonium nitrogen, potassium, calcium, and magnesium. Soil organic matter has also been shown to increase the water holding capacity of soil, to improve infiltration rates [6], the pH buffering capacity, the microbial diversity of soils [10], and to even reduce plant parasitic nematode populations [11]. Organic matter has also been shown to improve aggregate stability [7] and saprophytic lignin-decomposing basidiomycetes have been shown to produce large quantities of extracellular materials that bind soil particles into aggregates [12].

Soil organic matter can serve as a reservoir for plant macronutrients, especially nitrogen, and also aid in plant micronutient nutrition. Furthermore, soil organic matter can enhance the infiltration of water and air into soil, it can increase the retention of water in soil, and it is important in maintaining soil tilth [6]. Organic matter in soils exists in the form of recently added materials or material that has decomposed beyond recognition into soil organic matter. The original organic matter usually consists of lignin, carbohydrates, amino acids, and low protein levels that are quickly decomposed. The more resistant lignins and slower decomposing carbohydrates, tannins, waxes, resins, and chitins are combined with uronic acids to form soil organic matter. Humus is a relatively stable portion of soil organic matter and it is combined with the biomass of soil organisms to make up soil organic matter [5]. Young succulent plant materials such as leaves break down more rapidly than stems, roots, or wood chips. Plant sugars, starches, amino acids, and some proteins that are present in large amounts in young tissues and leaves will break down quickly, while hemicelluloses and lignins found in woody materials such as stems and branches and wood chips will decompose much more slowly. Young succulent materials have C:N ratios closer to those of microorganisms (10:1) that allow rapid decomposition while older woody materials that are rich in lignins and polyphenols and lower in nitrogen with C:N ratios of 75:1 –100:1 decompose much more slowly [13].

Native organic matter levels are relatively low in California soils, generally ranging from less than 1 % to a little more than 2 %, and organic matter levels fall when soils are brought under cultivation. Studies have show that it is unreasonable to expect to increase appreciably overall soil organic matter [14], but that small increases in soil organic matter may have dramatic changes on soil quality and productivity [6]. Residues that are slow to decompose are more efficient at producing humus than more readily decomposable materials such as green manure residues [9]. In preliminary studies wood chips have taken as long as 5-7 years to completely decompose [15].

Almond growers have moved from disking or plowing their fields towards a form of conservation tillage that has most likely reduced soil carbon loss and enhanced soil carbon management. Almonds are harvested from trees by first shaking the nuts to the ground, where they then dry for several days before they are swept to the middle of tree rows by mechanical sweepers [16]. After the nuts are swept into rows they are then mechanically picked up and taken out of the orchard. Since drying, sweeping, and harvesting are performed on the soil surface, it is important that the orchard floor be flat and smooth and as free of vegetation as possible before harvest. Almond growers have found that it is more efficient to keep the ground smooth and non-tilled year round and to mow weeds between rows rather than tilling and then having to re-smooth their orchard floors every year before harvest. Though conservation tillage was developed for erosion control in other parts of the US, non-tillage has probably helped to reduce soil carbon loses and improve soil quality and sustain productivity in California's almond orchard soils. We believe that the wood chipping of almond prunings, or prunings from tree fruit, nut, or horticultural trees, will improve soil quality and the sustainability of orchard soils while also reducing air pollution.

The major difference between conservation and conventional tillage is the placement of residues and fertilizer on the soil surface rather than the uniform mixing of these materials into the plow layer. Residues left on the surface decompose at a slower rate than buried residue and release nutrients over a longer period of time [17]. Continuous surface applications of fertilizer in conservation tillage without mixing leads to the stratification of some nutrients, with high concentrations at the surface and rapidly decreasing concentrations with depth [18-20].

Adopting the practice of wood chipping prunings could have dramatic effects on soil nutrients. There is concern that nutrients in a system where prunings are chipped and placed on the soil surface may become less available to trees than under a conventional growing system where the prunings are burned. Remnants of the decomposing wood chips would accumulate on the orchard floor and are relatively slow to decompose because of their high lignin content. If this is the case more fertilizers would be required and farmers would be less willing to adapt wood chipping as an alternative to burning. Therefore, it is important to know how nutrients will cycle in the soil environment of an almond orchard where pruning are being wood chipped.

The effect of wood chips on soil and petiole nutrients, soil aggregation, water infiltration, and nematode and basidiomycete populations was initiated in a replicated experiment where soil was amended with and without wood chips [21]. If results were available to growers that showed enhanced nutrient value due to wood chipping, it would speed adoption of the practice and ultimately help reduce air pollution in the San Joaquin Valley of California. There are over 250,000 hectares of almonds in California, and burning is still the primary method of brush disposal.

Materials and methods

Wood chipping, tree placement, and water infiltration

In 2000 almond prunings were chipped with a brush bandit wood chipper (Bandit Industries, Remus, MI). The wood chips were mixed with Tujunga loamy sand high in ring (*Macroposthonia* spp.) and root lesion (*Paratylenchus* spp.) plant pathogenic nematode populations taken from almond orchard soil (L.D. James Ranch, Modesto, CA). The wood chips were mixed with soil at approximately 1/3 part wood chips to 2/3 parts soil, and placed in 133 liter barrels (Monsanto, St. Louis, MO), with a single 1-year old bare root ‘Nonpareil’ almond tree per barrel. Five trees each were planted in barrels with and without wood chips. The barrels were placed in an almond orchard in a replicated manner, consisting of five single-tree replicates per treatment. The barrels prevented the mixing of roots, wood chips, and microbial communities and allowed placement of a replicated trial in a small area. Trees were not fertilized but were irrigated twice weekly with a drip irrigation system from ground water. The time in seconds for 18.9 liters (5 gallons) of water to infiltrate soil amended with and without wood chips was measured on four occasions.

Leaf, shoot growth, and soil sampling

Fifty - 75 leaves were collected randomly from non-fruiting spurs from each tree in July of 2000, 2001, and 2002. One kg of soil was removed from just under the surface of each barrel in October of 2000, 2001, and 2002. Half of each sample was assayed for nematodes while the other half was analyzed for nutrients. Leaf and soil samples were analyzed for mineral content by the University of California's Division of Agriculture and Natural Resources (DANR) Laboratory (Davis, CA). Current season shoot growth was measured (cm) in May of 2000, 2001, 2002, and 2003. The five longest shoots per tree were selected and measured.

Nematode and basidiomycete sampling

Ring nematodes were assayed with the sugar centrifugation method [22] where 1-2 kg of soil is placed into a pan with water and mixed. Nematodes were suspended in water and decanted. A 1-molar solution of sugar plus separan was added to a cylinder and stirred. After 1 minute the nematode-soil separation was passed through a 400-mesh screen. With a small quantity of water, the nematodes were washed from the screen into a counting dish. Nematodes per 1 kg of soil (250 cc) were reported. Root lesion and free-living nematodes were extracted by a combined sieve-mist extraction method where the final screenings from a 500-mesh sieve containing 20 grams of root plant tissues were placed into a funnel and then into a mist chamber. After 3-5 days the nematodes were removed and counted. Basidiomycetes were counted in plots (mushrooms/barrel) when they appeared, usually after January and February winter rainfall.

Orchard soil sampling and separation of soil aggregates

In January 2001, Tujunga loamy sand soils were sampled from a 30 year-old almond orchard where prunings were chipped and left on the orchard floor annually for 14 years. Soil samples were collected from 2 treatment sites: 1) where the orchard floor soil had been left undisturbed, and 2) where the orchard floor soil was disturbed prior to harvest (August 2000) with a rotary-tiller (Maschio, Padova, Italy) to a depth of 12-15 cm. Soil samples were collected from three areas in each site. At each site three soil cores were taken to a depth of 20 cm using a step-down soil probe and divided into increments of 0-to-5, 5-to-10, and 10-to-15 cm. The three samples at each depth were mixed to form a composite sample. Samples were collected using a stratified sampling scheme so that within-row and between-row areas of the plots comprised the proper proportion of the composite sample [12]. Soils were dried in a forced-air oven at 50^{o}C and then passed through a series of sieves (>2mm, 0.84mm, 0.42mm, and 0.25mm-mesh).

Enzyme Linked Immunosorbent Assay (ELISA)

Presence of soil aggregating basidiomycetes were determined for each soil aggregate size fraction using Enzyme Linked Immunosorbent Assay (ELISA) [23]. Dry soil samples (500 mg/ml) were prepared by homogenization of samples in a mortar and pestle in carbonate buffer (20 mM $NaHCO_3$, 28 mM Na_2CO_3, pH 9.6), and a dilution series (1.17 to 75 mg/ml) was prepared in this buffer. Homogenates were centrifuged for 10 min (14,000 *g*) after which 100 µl of the supernatant was loaded in flat bottom microtiter plate wells (Immulon 4HBX, Dynex Technologies Inc., Chantilly, VA) followed by incubation overnight at 55^{o}C. After three washings with 0.01M phosphate buffer saline-Tween 20, 0.138 M NaCl, 2.7 mM KCl, pH 7.4 (PBST, Sigma, St Louis, MO), 100 µl of a 1/10,000 dilution of the third boost rabbit serum was added to each well. Microtiter plates were incubated for 90 min at 22^{o}C on an orbital shaker, washed 3× with PBST, and incubated for 60 min at 22^{o}C with a 1/13,000 dilution of horseradish peroxidase-conjugated goat anti-rabbit polyspecific immunoglobulins (Sigma, St Louis, MO) added to each well. After three further PBST washings, the substrate, consisting of a solution of 3,3', 5,5' tetramethylbenzidine (0.4 g/l) (Pierce, Rockford, IL) and 0.02% hydrogen peroxide, was added. The reaction was stopped after 30 min with 2.5 M sulfuric acid. Absorbance was read at dual wavelength of 450 nm/655 nm using a BioRad 550 microplate reader, controlled by a computer using the Plate Reader Manage program (BioRad, Hercules, CA). All incubation steps were performed at room temperature. All samples were processed in triplicate.

Results

Leaf petiole analysis

Leaf petiole analysis showed that trees growing in soil amended with wood chips had significantly less nitrogen (N) after the first growing season, reduced levels their second season, and higher levels of nitrogen by the third and fourth seasons (Table 1).

Phosphorus (P) was increased significantly in trees growing in soil amended with wood chips the first three seasons. Potassium (K) was significantly increased in trees grown with wood chips after the second and third season, but by the fourth season differences were no longer significant (Table 1). Calcium (Ca) and boron (B) levels increased significantly in trees grown with wood chips in the third and fourth seasons (Table 1). Zinc (Zn) and manganese (Mn) levels decreased significantly in trees grown in soil amended with wood chips after the first two seasons, but by the third and fourth seasons both levels were significantly greater in trees grown with wood chips (Table 1). Sodium (Na) and magnesium (Mg) levels were unaffected by the addition of wood chips.

Table 1. Leaf petioles were sampled in July 2000-2003 from trees growing in soil amended with and without wood chips (no-chips) and analyzed for nutrient content.

	2000		2001		2002		2003	
	Wood chips	No-chips	Wood chips	No-chips	Wood chips	No-chips	Wood chips	No-chips
% N	1.55 a	2.21 b	1.38	1.58	1.92	1.6	1.84 a	1.62 b
% P	0.33 a	0.18 b	0.96 a	0.31 b	0.66 a	0.43 b	0.36 a	0.28 a
% K	2.69	2.67	2.47 a	2.01 b	1.92 a	1.62 b	1.74 a	1.66 a
% Na	0.02	0.02	0.02	0.01	0.02	0.02	0.024 a	0.020 a
% CA	1.63	1.62	2.69	2.48	3.04 a	2.76 b	4.08 a	3.86 a
% Mg	0.5	0.39	0.78	0.86	0.7	0.74	0.74 a	0.74 a
Zn ppm	41.0 a	88.0 b	53.0 a	63.23 b	10.0 a	6.5 b	12.8 a	8.0 b
Mn ppm	163:0 a	245.66 b	93.75	90.75	18.4 a	48.4 b	12.8 a	41.6 b
B ppm	51.0	50.66	47.5	43.5	45.6 a	37.0 b	44.0 a	36.0 b
Fe ppm	196.0	183.0	323.5	292.5	54.0	57.4	51.2 a	46.8 b
Cu ppm	11.66	9.33	16.75	17.0	4.4	4.0	4.0 a	4.0 a

*Paired columns within the same year with different letters were statistically different when compared in a Student's T-test (P # 0.05).

Shoot growth

Trees growing in soil amended with wood chips had significantly less current season shoot growth in their first and second seasons when compared to trees growing in soil without wood chips, but by their third and fourth seasons the trees growing in soil amended with wood chips had significantly more shoot growth (Figure 1).

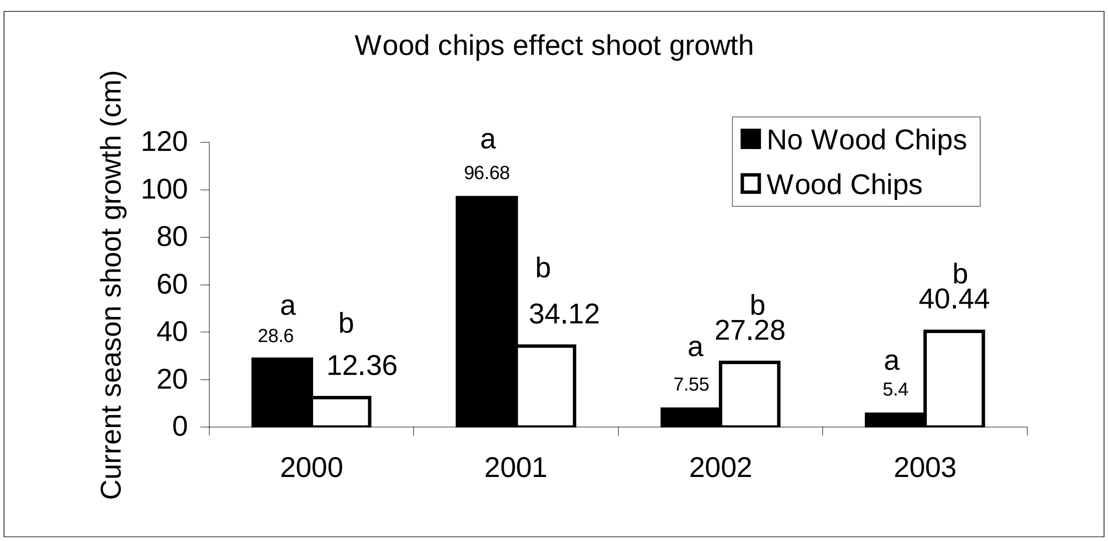

Figure 1. Ten trees were planted in soil amended with wood chips and another ten trees in soil without wood chips. The five longest shoots per tree were selected and measured. Paired columns within the same year with different letters were statistically different when compared in a Student's T-test (P # 0.05).

Soil analysis

Soil analysis showed that the addition of wood chips to soil significantly increased soil electrical conductivity (EC), calcium (Ca), magnesium (Mg), sodium (Na), chloride (Cl), zinc (Zn), copper (Cu), phosphorus (P), potassium (K), ammonia (NH_4-N), percent carbon (C-Tot %), and percent organic matter (OM %) (Table 2). Boron (B) levels were significantly higher in soil amended with wood chips by the second season (2001). The cation-exchange-capacity (CEC) was higher in wood chip amended soil in the first (2000) and third seasons (2002). The addition of wood chips significantly lowered soil pH all three seasons (Table 2). Nitrate levels (NO_3-N) were significantly lowered by the addition of wood chips in 2000 and 2001, but by 2002 nitrate levels in wood chipped soils were actually higher than in non-wood chip amended soils. Manganese (Mn) and iron (Fe) levels were initially lowered by the addition of wood chips in 2001, but by 2002 their levels with were significantly increased (Table 2).

Table 2. Soil samples were taken in October 2000, 2001, and 2002 from trees growing in soil with and without (no-chips) wood chips and analyzed for nutrient content*

	2000		2001		2002	
	Wood chips	No-chips	Wood chips	No-chips	Wood chips	No-chips
pH	6.5 a*	7.2 b	6.7 a	7.5 b	6.88 a	7.38 b
EC	0.5 a	0.3 b	0.5 a	0.3 b	0.48 a	0.29 b
Ca	2.8 a	1.2 b	2.8 a	1.4 b	3.20 a	1.47 b
Mg	1.6 a	0.8 b	1.6 a	1.0 b	1.97 a	0.98 b
Na	0.90 a	1.00 a	1.5 a	1.1 b	0.93 a	0.62 b
Cl	0.50 a	0.50 a	0.60 a	0.60 a	1.15 a	0.48 b
B ppm	0.50 a	0.60 a	0.8 a	0.5 b	***	***
Zn ppm	12.2 a	4.7 b	5.7 a	3.2 b	6.80 a	3.58 b
Mn ppm	34.30 a	34.70 a	8.7 a	25.4 b	7.98 a	3.37 b
Fe ppm	176.40 a	122.00 a	18.6 a	67.5 b	16.88 a	10.17 b
Cu ppm	8.4 a	3.8 b	4.1 a	2.4 b	4.98 a	2.73 b
C-Tot %	6.6 a	0.4 b	1.0 a	0.4 b	1.09 a	0.40 b
NH_4-Nppm	10.7 a	3.1 b	6.8 a	2.7 b	8.78 a	2.75 b
NO_3-N ppm	0.7 a	2.2 b	0.1 a	0.6 b	0.65 a	0.32 a
Bray P ppm	56.9 a	46.3 b	46.9 a	24.2 b	39.62 a	17.55 b
X-K ppm	114.4 a	49 b	94.2 a	55.8 b	54.17 a	36.50 b
CEC meq/100g	9.0 a	5.9 b	3.90 a	3.40 a	6.83 a	4.52 b
OM %	6.4 a	0.5 b	1.2 a	0.4 b	1.36 a	0.50 b

*Paired columns within the same year with different letters were statistically different compared in a Student's T-test (P # 0.05)

***---- data was unavailable

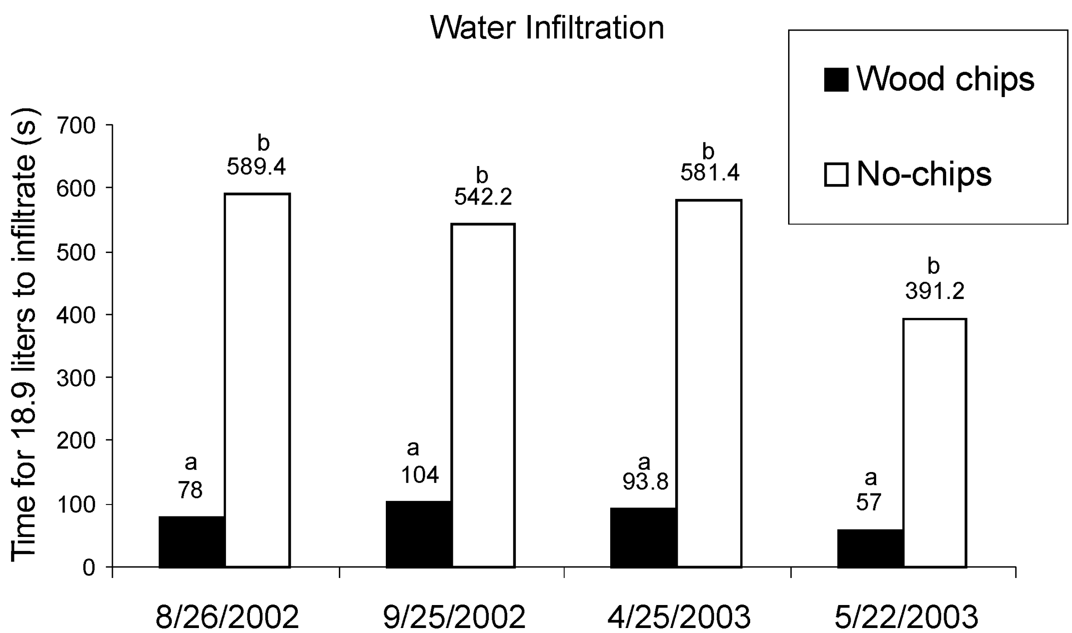

Figure 2. The time in seconds (s) for 18.9 liters (5 gallons) of water to infiltrate soil amended with and without wood chips was measured on four occasions. Paired columns on the same day with different letters were statistically different when compared in a Student's T-test ($P \leq 0.05$).

Water infiltration rate and mid day leaf stem water potential

The rate at which water infiltrated soil amended with and without wood chips was measured on four occasions. In soils amended with wood chips we observed significantly faster water infiltration times when compared to soils not amended with wood chips (Figure 2).

Nematode and basidiomycete sampling

The effect of wood chips in soil on plant parasitic and free-living nematode populations were examined. In 2000, *Macroposthonia* (ring) populations were significantly reduced while *Bunonema* and *Dorylaimida* and free-living nematode populations were significantly increased in wood chip amended soils (Table 3).

In 2001 and 2002 *Macroposthonia* (ring) populations were lower while *Paratylenchus* (root lesion) species were significantly reduced in wood chip amended soils. Free-living bacterial and fungal feeding nematodes were significantly increased in wood chip amended soils (Table 3). In 2001 and 2002 *Bunonema, Trichodorus, Dorylaimida*, and *Monochida* species appeared unaffected by the addition of wood chips to soil. The effect of wood chips in soil on basidiomycete populations was also examined. Basidiomycetes were

Table 3. One kg soil samples were taken in 2000, 2001, and 2002 from soil amended with and without wood chips and assayed for the following nematodes

	2000		2001		2002	
	Wood chips	No chips	Wood chips	No chips	Wood chips	No chips
Macroposthonia spp.	15.4 a*	53.0 b	298.0 a	392.0 a	545.0 a	399.6 a
Bunonema spp.	40.8 a	0.0 b	0.0 a	0.0 a	0.0 a	0.0 a
Trichodorus spp.	0.0 a	6.6 a	0.0 a	0.0 a	0.0 a	0.0 a
Dorylaimida spp.	159.4 a	19.6 b	2.2 a	36.2 a	47.4 a	38.6 a
Monochida spp.	0.0 a	0.4 a	0.0 a	0.0 a	55.0 a	59.4 a
Paratylenchus spp.	0.0 a	1.8 a	0.0 a	138.8 b	24.4 a	255 b
Free-living spp.	1307.2 a	690.4 b	1703.4 a	246.0 b	1006.4 a	437.4 b
Bacterial feeding spp.	987.2 a	612.0 b	1371.3 a	223.3 b	872.128 a	394.1 b
Fungal feeding spp.	320 a	78.4 b	332.1 a	22.7 b	134.272 a	43.4 b

*Paired columns within the same year with different letters were statistically different when compared in a Student's T-test (P # 0.05)

only found in plots where soil was amended with wood chips, averaging 5.8 mushrooms per barrel. Basidiomycetes were never found in plots without wood chips.

Soil aggregation

There were significantly more soil aggregates >2 mm in all the layers (0-3 cm, 3-8 cm, 8-13 cm, and 13-18 cm) of undisturbed soils amended with wood

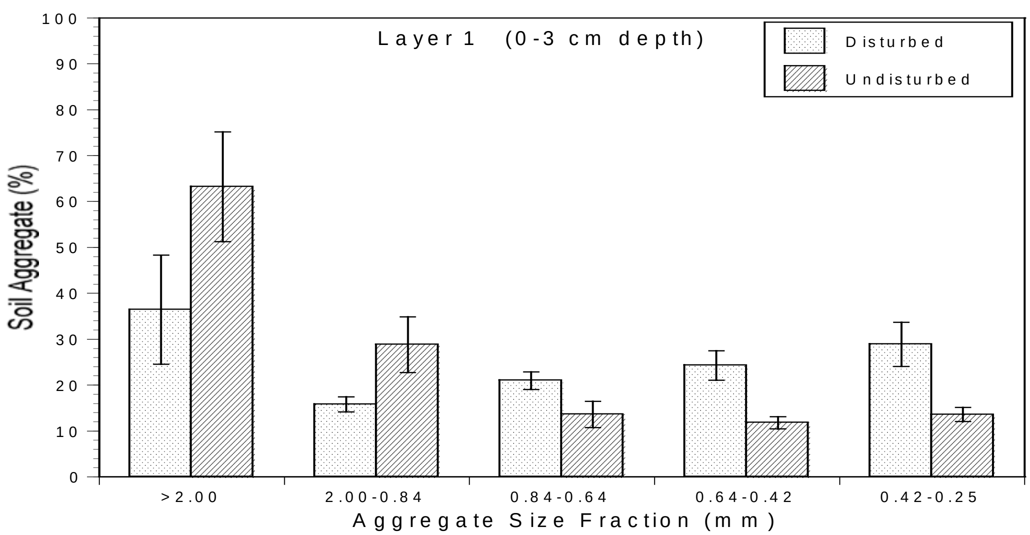

Figure 3. Soils were sampled from disturbed (with a rotary-tiller) and undisturbed plots from and almond orchard where wood chipped prunings were added seasonally for 14 years. Soils were obtained from four debts with layer 1 (0-3 cm) shown here. Soils were dried in a forced-air oven at 50°C and then passed through a series of sieves (>2mm, 0.84mm, 0.42mm, and 0.25mm-mesh) in order to collect soil aggregates.

chips than in disturbed soils also amended with wood chips. In layer 1 (0-5 cm) (shown in Figure 3), 63.2 % of >2 mm soil aggregates were in undisturbed soils compared to 36.43 % in disturbed soils.

In layer 2 (5-10 cm), 69.10 % compared to 16.80 %, and in layer 3 (10-15 cm), 80.87 % compared to 30.10 %. In layer 1, the size fractions smaller than 2 mm aggregates were higher in soils from the disturbed compared to the undisturbed site, except for the 0.8-2 mm size-fraction, which is significantly higher in the undisturbed soils. In all soil layers, undisturbed soils amended with wood chips contained significantly greater amounts of >2 mm aggregates when compared to the other size fractions. In contrast there were no significant differences among the aggregate size fractions in disturbed soils amended with wood chips.

Enzyme Linked Immunosorbent Assay (ELISA)

The same size fractionated soil samples from undisturbed and disturbed sites amended with wood chips were analyzed using ELISA to detect and quantify populations of specific soil aggregating basidiomycete fungi (Figure 4).

Results showed a greater response to antibodies in soils from undisturbed sites when compared to disturbed sites in the four soil layers. In the surface soil layer, the amount of soil-aggregating fungi was significantly greater in the undisturbed soils when compared to disturbed soils, and a greater response to

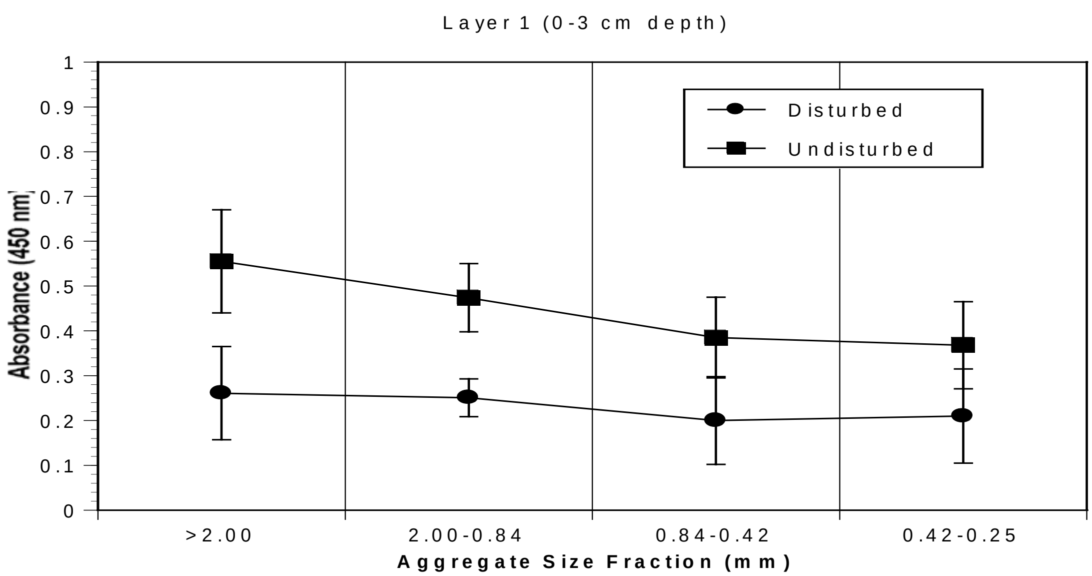

Figure 4. Presence of soil aggregating basidiomycetes was determined for each soil aggregate size fraction using ELISA by quantifying the response to antibodies in soil. The same size fractionated soil samples from undisturbed and disturbed sites amended with wood chips were analyzed using ELISA to detect and quantify populations of specific soil aggregating basidiomycete fungi. Absorbance was read at dual wavelength of 450 nm.

the antibodies was observed in the >2 mm and 2-0.84 mm aggregate size fractions. In the other deeper layers, no differences in populations of these fungi were detected.

Discussion

Soil organic matter and carbon

Three years after returning almond prunings to soil, soil organic matter was significantly increased from 0.5 % in non-wood chipped plots to 1.4 % in wood chipped plots. During the same time, percent carbon increased from 0.4 % in non-wood chipped plots to 1.1 % in wood chipped plots. We believe that due to the high lignin and low carbon to nitrogen ratio of wood chipped prunings, they will decompose more slowly and accumulate higher levels of soil organic mater and carbon than what other researches have observed when conventionally tilled soils were compared to conservation tillage. Studies have shown that conservation tillage systems can accumulate large amounts of crop residue on the soil surface, and that soil carbon concentrations have increased accordingly [17, 24, 25]. The length of time a tillage regime is practiced will also affect the distribution of carbon substrates. After implementing conservation tillage, levels of organic matter increased rapidly within the first five year period [17, 26, 27]. After five years of conservation tillage however, increases in soil organic matter of untilled soils occurred at a slower rate and was similar to that of tilled systems [28]. When comparing conservation tillage systems with conventional tillage, the same amount of organic material is left in the field, either on the soil surface as with conservation tillage or plowed under and mixed with the soil in conventional tillage. But when comparing wood chipped orchards with non-wood chipped orchards, large amounts of lignin-based carbon is only accumulated in soils where wood chips are added and not accumulated in the orchard soils where the prunings are burned. Since wood chipping would continually add more organic matter and carbon than burning, we believe that soil organic matter would substantially increase in wood chipped orchards when compared to orchards where prunings are burned. We believe that the amount of soil organic matter present would ultimately level off as a soil organic matter equilibrium is reached, but that this soil organic matter equilibrium will be significantly higher in orchards where almond prunings are wood chipped and left on the soil surface instead of burned.

Nutrient availability

Soil organic matter provides a valuable balanced source of many major and minor elements for crop plants [6]. Organic matter decomposition in soil can provide needed nitrogen, phosphorus, and sulfur needed for crop nutrition. Phosphorus from organic amendments reacts quickly and is bound to soil minerals and moves very little from where it is placed [29]. Potassium, calcium, and magnesium are relatively soluble from plant residues obtained from soil organic matter fractions. Organic matter can also provide a valuable balanced source of many minor elements needed for plant growth [6]. Increased levels of nutrient availability have been observed when conservation tillage systems have been implemented, resulting from an accumulation of organic matter and nutrients on the soil surface. Higher concentrations of roots and greater soil water content in the surface horizon have also been observed and may account for greater nutrient use and crop productivity [17, 30].

Initially, the organic matter fraction, on the soil surface of conservation tillage systems, has been shown to bind nutrients and only gradually release them over time. But the slow release of nutrients from an increasing organic matter fraction from residue based conservation tillage will eventually come to equal the rapid release of the gradually decreasing pool of organic matter that occurs in plow or conventional tillage [31]. We believe this will also occur in almond orchard soils where wood chipped prunings are annually shredded and added to the soil surface.

Nitrogen

The addition of wood chipped prunings to soil planted with almond trees initially reduced leaf petiole and soil nitrate levels when compared to petioles and soil from trees not grown in wood chip amended soils. By the second year leaf petiole levels were less, but no longer significantly less, from trees planted in soils with wood chips. But by the third year both leaf petiole nitrate levels were higher in leaves and soils from trees grown in wood chip amended soils. Four years after adding wood chipped prunings, significantly higher leaf petiole nitrogen was observed in the leaves from trees in soil amended with wood chips. This data was supported by greater current season shoot growth from trees grown in wood chip amended soils in the third and fourth seasons, providing evidence that even though wood chips initially tied up nitrogen, as they decomposed they returned more nutrients to soils than otherwise would have been present.

Soil microbial populations compete with the growing crop for mineralized nitrogen and will also limit crop responses to rates and timing of applied amendments [10, 14]. In soils there is strong competition for nitrogen between plants and microbes, with microbes generally prevailing [17]. Plants depend on microbes to transform the nitrogen that is trapped in organic residues into a usable form. Whether nitrogen is immobilized by microbes or becomes available to plants depends on the same environmental factors that influence organic matter breakdown. Climate, season, and crop residue type, quality, and management practices influence the activities of microbes, which in turn affects the mineralization or immobilization properties of the soil. Usually a relatively small portion of the nitrogen from organic amendments is readily available in mineral forms, but if organic matter levels are high, enough mineralized nitrogen may be available for plants in a typical row crop environment such that fertilization may not be necessary [17].

Changes in tillage that affect microbial activity and nitrogen and carbon cycling are due to the greater amount of organic matter at the soil surface in conservation tillage systems and the lack of mechanical soil mixing. These differences in the soil environment will have a profound impact on the fate and availability of soil and fertilizer nitrogen. Tillage practices influence not only crop residue decomposition but also nitrogen cycling pathways and use efficiency. Just as with organic residue decomposition, nitrogen is cycled more slowly under conservation tillage than when soils are plowed [17]. Plowing creates favorable conditions for organic matter decomposition through a number of mechanisms [18]. Plowing or tilling disrupts soil aggregates, increasing microbial access to carbon sources be exposing organic compounds that were previously protected by physical entrapment. Tillage also creates better soil aeration and physical conditions that are more favorable to microbial (bacterial) activity and decomposition. Organic residues are broken apart, increasing the surface area of residue available for microbial attack. Incorporation of residues into the soil places them in a constantly moist environment, whereas residues on the surface can become desiccated. All of these factors seem to favor more rapid decomposition of organic residues and release of nutrients under plowed or conventional systems [17].

Most almond growers that are wood chipping their almond brush are placing the wood chips on the soil surface creating conditions similar to conservation tillage. In conservation tillage systems the organic material that is concentrated at the surface of untilled soils generally has a high carbon to nitrogen ratio, which will favor the immobilization of nitrogen [32]. We expect that this would also be the case in wood chipped almond orchards where the high lignin based organic matter has a high carbon to nitrogen ratio. In conservation tillage systems nitrogen added at low levels to the soil surface may become immobilized by accumulated organic matter with a high carbon to nitrogen ratio [33]. Crop residue management will have a major influence on the amount of nitrogen that is mineralized and the amount of nitrogen that is retained in soil organic matter in a potentially mineralized state.

If high rates of nitrogen fertilization occur there may be adequate nitrogen for both crop plants and microbes decomposing the organic matter. Most almond growers will add in the excess of two hundred pounds of mineral nitrogen per acre per year to mature almond orchard soils. In our study, no nitrogen or any other nutrient was added to our almond trees in order to study the nutrient availability from decomposing wood chips. In almond orchards that are annually wood chipped and fertilized, we have not noticed a depletion in available nitrogen or any other nutrient. In fact, we speculate that the organic matter from the decomposing wood chips may help bind excess nitrogen that would have leached through the root profile and become unavailable for tree use and become a possible source of ground water contamination. We speculate that this bound nitrogen would then speed the decomposition of the wood chips and then gradually become mineralized and available to the almond trees at a more natural rate then large applications of synthetic fertilizer.

Many studies have found higher nitrate pools in plowed soils while more nitrogen is retained in the organic phase in soils under conservation tillage [25, 34, 35]. This suggests better nutrient storage capacity under conservation tillage and is apparently related to the higher microbial biomass and carbon substrate and the slower rate of mineralization when no tillage occurs. Twice as much nitrogen was immobilized in a conservation tilled soil when compared to a tilled soil in as little as seven days after ^{15}N application [36]. Most of the immobilized nitrogen in no tillage was recovered in nonmicrobial biomass organic nitrogen, suggesting a more stable source of nitrogen [37]. Some of the possible reasons for this outcome are ideal environmental conditions for mineralization, higher nutrient retention and cycling capacity, and the accumulation of recoverable organic matter at the surface of conservation tilled soils. This seems to make sense as higher amounts of slower decomposing organic matter in the no till treatment was better able to supply a continuous source of mineralizable nitrogen throughout the season [17]. Under conservation tillage, a new steady state is eventually approached with regard to organic carbon and nitrogen, in which, mineralization continues to occur at a faster rate in tilled soils but is compensated for by a growing pool of total carbon and nitrogen in conservation tilled soils [35]. In the long run, however, amounts of nitrogen that have been incorporated into relatively stable organic matter pools will provide a higher level of nitrogen fertility and cycling efficiency [35]. Smith and Blevins [35] found that during the first 5 years of no tillage, plowed systems had more available nitrogen, but after 5 and 10 years net mineralization became similar among tillage regimes. Our data shows that after four years of adding wood chips to almond orchard soils there was increased levels of mineralized nitrogen available. We believe that wood chipped orchard soils will ultimately have higher levels of mineralized nitrogen when compared to non wood chipped soils, and that this difference will be greater than the differences observed between conventional and conservation tillage. Because when conventional and conservation tillage practices are compared, the same amount of organic matter is either left on the soil surface or incorporated. But when wood chipped orchards are compared to non wood chipped orchards, only the wood chipping practice incorporates over a ton of organic matter per acre per year while the non wood chipping or burning does not accumulate any organic matter in the orchard.

The observation that more nitrogen was accumulated in growing crops when organic residues are tilled under when compared to surface residues seems to be easily explained by greater decomposition and faster mineralization under plowed soils [38, 39]. Other studies that found greater nitrogen uptake under conservation tilled soils when compared to conventionally tilled assumed that it was because of a higher water content in non tilled soils [40].

Initially nitrogen appears to be cycled more slowly under no tillage cropping practices and is used less efficiently when compared to conventional tillage [39]. Every reaction that can cause lower nitrogen availability is favored by no tillage, however, there is a reorganization of nitrogen storage and movement in conservation tillage, as more nitrogen is conserved and a higher nitrogen retention and recycling capacity is maintained. Conversely, continuous plowing eventually depletes organic matter and acts as a stress rather than an energy subsidy. In conservation tillage ecosystems and when almond brush is wood chipped and left on the soil surface, crop and weed residue are decomposed exclusively through the activity of soil microbes, and this critical role between soil biota and organic matter appears to maintain efficient nutrient cycling and retention [38, 39, 41].

Soil pH

The addition of wood chipped almond prunings to soil significantly decreased soil pH when compared to soils not amended with wood chips. A significant decrease in pH was observed every year of our study [41]. Numerous studies report a decrease in soil pH after adoption of conservation tillage [42]. When crop residues are left on the soil surface and no mixing of the soil takes place, any acid producing fertilizer that is added will be concentrated in the uppermost portion of the soil profile. Each ammonium ion is oxidized to nitrite producing two hydrogen ions that increase acidity. And to a lesser extent, the higher soil moisture in conservation tillage systems will also contribute to a decrease in pH by allowing more leaching of base cations. Increased water movement through the soil profile together with an increase in continuous pore space in conservation tillage can lead to increased acidity because hydrogen ions replace leached base cations on the exchange complex [17]. The soil surface pH of wood chipped almond orchards will most likely decrease based on these findings and our study. The acidification of the soil surface in conservation tillage can lead to reduced availability of phosphorus, increased loss of calcium, as well as increased levels of aluminum. Fortunately, the addition of appropriate levels of lime to the surface of reduced tillage systems appears to adequately overcome these problems [17]. Many almond orchards are planted on alkaline soils that would benefit from a reduction in soil pH. This statement applies to California, which produces 99% of US almonds (about 75% of the world's production), and to Spain, the next largest producer.

Soil phosphorus

The addition of wood chipped prunings to soil planted with almond trees significantly increased leaf petiole and soil phosphorous levels when compared to petioles and soil from trees not grown in wood chip amended soils [21, 41]. A significant increase in phosphorous was observed throughout the study. The accumulation of organic matter at the soil surface has been shown to effect phosphorus levels. Organic matter increases phosphorus availability by decreasing the effectiveness of phosphorus fixation sites [17]. This occurs with organic matter shielding Fe and Al particles and by organic anions replacing phosphorus on Fe and Al complexes, both of which help to maintain the solubility of phosphate in solution [19, 20]. Several studies have found a high positive correlation between levels of crop residue and available soil phosphorus concentrations [24, 43]. Increases in organic phosphorus are likely in the higher residue environment of non tillage [44] and wood chipped orchards, providing a sustainable long-term source of phosphorus. The availability of phosphorus tends to be affected by changes in tillage. Conservation of soil moisture in reduced tillage systems can also allow for increased diffusion of phosphorus to plant roots [17]. Another factor to influence phosphorus availability is soil pH. Since pH has been shown to decrease at the surface of unlimed no-tilled soils, additional adsorption of phosphorus by Fe and Al oxides would be expected, due to the increased solubility of Fe and Al at a lower pH [17].

Soil calcium

The addition of wood chipped prunings to soil planted with almond trees significantly increased leaf petiole and soil calcium levels when compared to petioles and soil from trees not grown in wood chip amended soils. This significant increase in calcium was observed immediately when soil calcium levels were compared, but when leaf petiole levels were compared, significant differences did not occur until the third and fourth year of the experiment [41]. Calcium availability has also increased under conservation tillage. As soil moisture increases under conservation tillage, more water and moisture results in a greater flow of calcium to plants and potentially higher uptake of calcium [17]. In dry climates higher concentrations of calcium were found in the surface of no tilled soils when compared to plowed fields, suggesting that calcium moved upward in the soil profile by evaporative water during dry periods [45]. Also, a decreasing pH, usually resulting from the application of nitrogen fertilizers to the soil surface, causes the replacement of calcium ions by hydrogen ions on the soil exchange site. As a result, calcium is susceptible to leaching. The more acidic a soil surface becomes the more exchangeable calcium is released [25, 46, 47].

Soil potassium

The addition of wood chipped prunings to soil planted with almond trees significantly increased soil potassium levels in our study. Leaf petioles from trees grown in soil amended with wood chips did not show an increase in potassium until the second and third year of our study, and by the fourth year this difference was no longer significant. Several studies have shown higher concentrations of exchangeable potassium in the surface layers of conservation tillage systems when compared to plowed tillage systems [25, 46, 48]. However, other studies have found similar levels of potassium in conservation tilled and conventional tilled soils [40, 49]. Soil potassium does not appear to be significantly affected by conservation tillage [31, 50]. Because potassium is a monovalent cation, it is held relatively tightly and therefore would not be leached in significant amounts except in soils that have a low cation exchange capacity [17]. Below the surface layer soil potassium decreases sharply with depth in conservation tillage [17]. Perhaps higher soil potassium levels are observed in wood chipped orchard soils because they are receiving an organic amendment that non-wood chipped orchard soils are not.

Soil magnesium

The addition of wood chipped prunings to soil planted with almond trees significantly increased soil magnesium levels in our study. However, leaf petioles from trees grown in soil amended with wood chips did not show an increase in magnesium in any year of our study. Perhaps because most soils, with the exception of real sandy soils, tend to have a continuous source of magnesium from the gradual weathering of clay minerals [31]. Differences between conventional and conservation tillage with respect to magnesium levels are rarely observed due to the slowly available source of mineral magnesium in most soils [17]. When soil pH is high there was no difference in magnesium concentrations between conservational and conventional tillage systems [51]. When lime was added to conservation tilled soils, magnesium levels tended to be higher on the surface when compared to conventionally tilled soils [46, 52]. Like calcium, exchangeable magnesium losses are intensified with increasing levels of nitrogen fertilizer. The excess of hydrogen ions tends to replace magnesium ions on the exchange sites as the soil environment becomes acidified due to the nitrification of ammonium based fertilizers. Soil magnesium concentrations under conservation tillage were lower than under conventional tillage [46]. Other cations present in soils, such as potassium, can affect exchangeable magnesium levels. Increased levels of potassium at the surface of conservation tilled soils reduced the amount of exchangeable magnesium [30].

Soil cation exchange capacity (CEC)

The addition of wood chipped prunings to soil planted with almond trees significantly increased the cation exchange capacity (CEC) in our study in the first and third year. In the second year however there were no significant differences in the cation exchange capacity. Conversion from conventional tillage to conservation tillage has been found to increase both the cation exchange capacity and base saturation of soils [45, 49, 51, 53]. In conventional tillage systems, increases in the cation exchange capacity have occurred exclusively in the upper four to eight inches (10-20 cm) of the soil profile and have been attributed to increases in organic matter on the soil surface.

Microbial activity

Wood rotting basidiomycetes (mushrooms) were only found growing in soil that was amended with wood chips and were never found in plots without wood chips. Obviously, wood chips are the primary food source for wood rotting fungi, and as a consequence we would expect to find more basidiomycetes in orchards where prunings are wood chipped and left on the soil surface and less basidiomycetes in orchards where prunings are not chipped. Caesar-TonThat et al. [12, 23] found higher populations of soil aggregating basidiomycetes in undisturbed or non-tilled soils when compared to tilled or conventional tillage. We found higher populations of soil aggregating basidiomycetes in undisturbed wood chipped almond orchard soils we compared to tilled or disturbed wood chipped almond orchard soils [41]. We also found higher levels of soil aggregating basidiomycetes in almond soils that had been amended with wood chips when compared to almond orchard soils that had not received wood chips.

Numerous studies have shown that soils treated with long-term organic amendments tend to have higher microbial populations and activities than those receiving inorganic amendments [28, 54]. Soil microbial levels have been closely associated with organic carbon and can also be affected by soil temperature and water content [18, 55, 56]. A primary prerequisite for heterotrophic microbial growth is the presence of carbon substrates, and since tillage systems are inherently different in how organic residues are distributed they will also differ in how microbial populations are dispersed throughout the soil.

Microbes under conservation tillage systems would be expected to concentrate at the soil surface, accompanying the distribution of organic carbon. Many studies have shown higher counts of microbes in the surface of conservation tilled soils as compared with conventionally tilled soils [18, 57].

The surface residues of conservation tillage promote higher proportions of fungi whereas tilled systems foster more bacteria [58, 59]. This may be because fungi have greater tolerance of drier, more acidic and lower nutrient environments. With their lengthening hyphal networks, fungi are able to better utilize soil N reserves and surface residue carbon. A greater ratio of fungi present in conservation tilled soils appears to enhance long-term substrate use efficiency. Factors that can potentially limit microbial growth include tillage, soil moisture, temperature, aeration, and pH. Placement of residues, on the surface or incorporated, and the type or quality of the residue can also effect the microbial population of soils. Tillage has been shown to speed decomposition and enhance bacterial populations while leaving organic matter on the soil surface appears to enhance fungal populations. Soil arthropods are more abundant in conservation tillage soils due to favorable moisture and temperature conditions that occur under surface applied residues [60]. In tilled soils, arthropods mobility is reduced due to the destruction of large channels that accompanies plowing.

Nematodes

The addition of wood chipped prunings to soil planted with almond trees significantly decreased root lesion and reduced ring plant parasitic nematodes while free-living bacterial (bacterivorous) and fungal feeding (fungivorous) nematode populations were significantly increased [61]. We presume that the increased number of fungal and bacterial feeding nematodes observed is partially due to an increase in the populations of wood decomposing microbes on which free-living nematodes feed, and we speculate that the increased numbers of free-living nematodes are competing in some manner with the plant parasitic nematodes present. The number of bacterivorous nematodes were greater in organic plots when compared to conventional plots in a sustainable agriculture tomato farming system [62]. Population densities of nematode-trapping fungi were ten times greater in a wheat field with high organic matter content than in a barley field with low organic matter content [63]. In another study more nematode trapping fungi were found in organic plots when compared to conventional plots [64]. A future area of interest would be to investigate the presence of nematode trapping fungi in wood chipped orchards.

Soil moisture

We found that the addition of wood chips appears to enhance the water holding capacity of soils when mid day leaf stem pressure bomb data was obtained from trees growing with and without wood chips (*Holtz-unpublished data*). Soils under conservation tillage generally have higher moisture contents than tilled soils and rain water can move deeper into the soil profile than under conventional tillage [65]. Conservation tilled soils also tend to have more continuous pores, large cracks, and earthworm and root channels throughout the soil profile because they are not destroyed during tillage but rather are left to develop year after year [57].

Water infiltration

The addition of wood chips to almond orchard soils also enhanced water infiltration rate. Water also serves as a medium for microbial activity as well as acting to solubilize organic substrates. A water filled pore space of 60 % is regarded as maximum for aerobic microbial activity [66]. The water filled pore space of no-till conservation tillage treatments was found at or near 60% while most of the plowed or conventionally tilled soil treatments were well below this level [60]. On well drained soils this would be another advantage of conservation tillage, but on poorly drained soils, this effect would tend to promote anaerobic conditions following rain events or over irrigation, creating the potential for denitrification [60]. Most soils in the San Joaquin Valley of California, where almond and other fruit trees are grown, are well drained and anaerobic conditions are only observed if the orchards are over irrigated or receive heavy winter rains.

Conclusions

Most nutrients were significantly higher in soil amended with wood chips and from leaf petioles from trees grown in wood chip amended soils. The addition of wood chips significantly lowered soil pH while soil carbon and soil organic matter were increased. Water infiltrated wood chip amended soil much more quickly when compared to soils without wood chips. Wood chips also appear to be reducing ring and root lesion plant pathogenic nematodes while increasing free-living bacterial and fungal feeding non-pathogenic nematodes. More wood rotting basidiomycete fungi were counted in soils amended with wood chips, and more soil-aggregating basiciomycetes were detected at higher levels with ELISA. The practice of wood chipping almond prunings instead of burning appears to be a promising alternative to agricultural burning that could reduce air pollution and provide almond growers with a more sustainable method of brush removal that would enhance soil quality while also reducing air pollution.

The practice of regularly chipping prunings and even whole trees during orchard removal could provide a sustainable method of brush and tree removal for any tree fruit or nut crop that is regularly pruned or ultimately removed. Since the Kyoto Protocol to improve world carbon emissions participating countries have begun to examine the possibility of compensating growers to return high carbon amendments into their soils as a means of off setting industrial carbon emissions into the atmosphere [3]. Wood chipped prunings from any tree crop amended to agricultural soils would not only improve soil quality and reduce air pollution but enhance carbon sequestration and help to reduce the global emission of greenhouse gases. Perhaps someday the United States will join the other countries of the world that have signed the Kyoto Protocol and ultimately pay tree fruit and nut growers to wood chip their prunings to return carbon to their soils.

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References

1. California, A.B.o., *Years of discovery*; *a compendium of research reports 1972-1998*. 1998. pp 223.
2. Johnson, D.W., *Role of carbon in the cycling of other nutrients in forested ecosystems*, in *Carbon Forms and Functions in Forest Soils*, W.W. McFee and J.M. Kelly, Editors. 1995, Soil Science Society of America, Inc., Madison, WI.
3. Kimble, J.M., Lal, R., and Follett, R.F., *Agricultural practices and policies for carbon sequestration in soi*. 2004: CRC Press, Boca Raton, FL.
4. Lal, R., Kimble, L.M., Follett, R.F., and Cole, C.V., *The Potential of U.S. Cropland to Sequester carbon and Mitigate the Greenhouse Effect*. 1998: Ann Arbor Press, Chelsea, MI.
5. Wolf, B. and Snyder, G.H., *Sustainable soils the place of organic matter in sustaining soils and their productivity*. 2003: Food Products Press, An Imprint of The Haworth Press, Inc.
6. Gaskell, M., Fouche, B., Koike, S., Lanini, T., Mitchell, J., and Smith, R., 2000. *HortTechnology*. **10**:699-713.
7. Sikora, L.J. and Stott, D.E., *Soil organic carbon and nitrogen, in Methods for assessing soil quality*, J.W. Doran and A.J. Jones, Editors. 1996, Soil Science Society of America Special Publication 49. pp 157-167.
8. Hartz, T.K., Mitchell, J.P., and Giannini, C., 2000. *HortScience*. **35**:209-212.
9. Fox, R.H., Myers, R.J.K., and Vallis, I., 1990. *Plant and Soil*. **129**:251-259.
10. Scow, K.M., Sinasco, O., Gunapala, N., Lau, S., Venette, R., Herris, H., Miller, R., and Shennan, C., 1994. *California Agriculture*. **48**:20-26.
11. Leary, J. and DeFrank, J., 2000. *HortTechnology*. **10**:692-698.
12. Caesar-TonThat, T. and Cochran, V.L., 2000. *Biology and Fertility of Soils*. **32**:374-380.

13. Handayanto, E., Cadish, G., and Giller, K.E., *Regulating N mineralization from plant residues by manipulation of quality, in Driven by Nature; Plant Litter Decomposition*, G. Kadish and K.E. Giller, Editors. 1997, CAB International, Wallingford, UK.
14. Scow, K.M., *Soil microbial communities and carbon flow in agroecosystems, in Ecology of agriculture*, L.E. Jackson, Editor. 1997, Academic Press, New York. pp 367-412.
15. Holtz, B.A. and McKenry, M.V. Wood chipping almond brush and its effect on the almond rhizosphere and soil nutrient status. in *26th International Horticulture Congress Procedings*. 2002.
16. Connell, J.H., Asai, W.K., and Meith, H.C., *Orchard floor management, in Almond production manual*., W.C. Micke, Editor. 1996, Univ. Calif. Div. Agr. Natural Resources Publ 3364. pp 196-201.
17. Johnson, A.M. and Hoyt, G.D., 1999. *HortTechnology*. **9**:380-393.
18. Blevins, R.L., Smith, M.S., and Thomas, G.W., *Changes in soil properties under no tillage, in No-tillage agriculture: Principals and practices*., S.H. Phillips and R.E. Phillips, Editors. 1984, Van Norstrand and Reinhold, New York. pp 190-230.
19. Logan, T.J., Lal, R., and Dick, W.A., 1991. Soil and Tillage Research. **20**:241-270.
20. Schomberg, H.H., Ford, P.B., and Hargrove, W.L., *Influence of crop residues on nutrient cycling and soil chemical properties*, in *Managing agricultural residues*, P.W. Unger, Editor. 1994, Lewis Publishers, Boca Raton, FL. pp 99-121.
21. Holtz, B.A. and McKenry, M.V. Wood chipping to reduce air pollution and build soil organic matter. in *29th Annual almond board of California proceedings*. 2001.
22. McKenry, M.V. and Roberts, P.A., *Phytonematology study guide*. 1985: University of California Publication # 4045.
23. Caesar-TonThat, T., Shelver, W.L., Thorn, R.G., and Cochran, V.L., 2001. *Applied Soil Ecology*. **18**:99-116.
24. Black, A.L., 1973. *Soil Science Society of America Journal*. **37**:943-946.
25. Blevins, R.L., Thomas, G.W., Smith, M.S., Frye, W.W., and Cornelius, P.L., 1983a. *Soil and Tillage Research*. **3**:135-146.
26. Dick, W.A., 1983. *Soil Science Society of America Journal*. **47**:102-107.
27. Dick, W.A., 1984. *Soil Science Society of America Journal*. **48**:569-574.
28. Dick, W.A., Rasmussen, P.E., and Kerle, E.A., 1988. *Biology and Fertility of Soils.* **6**:159-164.
29. Parnes, R., Fertile Soil: *A grower's guide to organic and inorganic fertilizers*. 1990: Fertile Ground Books, Davis, CA.
30. Estes, G.O., 1972. *Agronomy Journal*. **64**:733-735.
31. Thomas, G.W., *Mineral nutrition and fertilizer placement, in No-tillage and surface tillage agriculture*, M.A. Sprague and G.B. Triplett, Editors. 1986, Wiley, New York. pp 93-116.
32. Fox, R.H. and Bandel, V.A., *Nitrogen utilization with no-tillage, in No tillage and surface tillage agriculture*, M.A. Sprague and G.B. Triplett, Editors. 1986, Wiley, New York. pp 117-148.
33. Kitur, B.K., Smith, M.S., Blevins, R.L., and Frye, W.W., 1984. *Agronomy Journal*. **76**:240-242.
34. Doran, J.W., 1980. *Soil Science Society of America Journal*. **44**:765-771.

35. Smith, M.S. and Blevins, R.L., *Effect of conservation tillage on biological and chemical soil conditions: Regional and temporal variability, in Effect of conservation tillage on groundwater quality*: Nitrates and pesticides, T. J. Logan, J.M. Davidson, J.L. Baker, and M.R. Overcash, Editors. 1987, Lewis Publishers, Chelsea, MI. pp 149-166.
36. Rice, C.W. and Smith, M.S., 1983. *Soil Science Society of America Journal*. **48**:295-297.
37. Carter, M.R. and Rennie, D.A., 1987. *Soil and Tillage Research*. **9**:33-43.
38. House, G.J., Stinner, B.R., Crossley, D.A., and Odum, E.P., 1984a. *Journal of Applied Ecology*. **21**:991-1012.
39. House, G.J., Stinner, B.R., Crossley, J., D. A. , Odum, E.P., and Langdale, G.W., 1984b. *Journal of Soil and Water Conservation*. **39**:194-200.
40. Ekeberg, E. and Riley, H.C.F., 1996. *Soil and Tillage Research.* **39**:131-142.
41. Holtz, B.A., McKenry, M.V., and Caesar-TonThat, T., 2003a. *Acta Horticulturae*:(in press).
42. Dick, W.A., McCoy, E.L., Edwards, W.M., and Lal, R., 1991. *Agronomy Journal.* **83**:65-73.
43. Larson, W.E., Clapp, C.E., Pierre, W.H., and Marachan, Y.B., 1972. *Agronomy Journal*. **64**:204-208.
44. Stewart, J.W.B. and Sharpley, A.N., *Controls on dynamics of soil and fertilizer phosphorus and sulfur, in Fertility and organic matter as critical components of production systems*, A.-S.S.P. 19., Editor. 1987, ASA-SSSA. pp 101-121.
45. Lal, R., 1976. *Soil Science Society of America Journal.* **40**:762-768.
46. Blevins, R.L., Smith, M.S., Thomas, G.W., and Frye, W.W., 1983b. *Journal of Soil and Water Conservation*. **38**:301-305.
47. Ismail, I., Blevins, R.L., and Frye, W.W., 1994. *Soil Science Society of America Journal*. **58**:193-198.
48. Hargrove, W.L., 1985. *Agronomy Journal*. **77**:763-768.
49. Moschler, W.W., Martens, D.C., and Shear, G.M., 1975. *Agronomy Journal*. **67**:45-48.
50. Thomas, G.W. and Frye, W.W., *Fertilization and liming*, in *No-tillage agriculture: Principles and practices*, R.E. Phillips and S.H. Philips, Editors. 1984, Van Nostrand Reinhold, New York. pp 87-126.
51. Lal, R., Logan, T.J., and Fausey, N.R., 1990. *Soil and Tillage Research*. **15**:371-382.
52. Blevins, R.L., Murdock, L.W., and Thomas, G.W., 1978. *Agronomy Journal.* **70**:322-326.
53. Gallaher, R.N. and Ferrer, M.B., 1987. *Communications in Soil Science and Plant Analysis*. **18**:1061-1076.
54. Fraser, D.G., Doran, J.W., Sahs, W.W., and Lesoning, G.W., 1988. *Journal of Environmental Quality*. **17**:585-590.
55. Doran, J.W., 1987. *Biology and Fertility of Soils*. **5**:68-75.
56. Hendrix, P.F., Han, C.R., and Groffman, P.M., 1988. *Soil and Tillage Research.* **12**:135-148.
57. Douglas, J.T., Goss, M.J., and Hill, D., 1980. *Soil and Tillage Research.* **1**:11-18.
58. Hendrix, P.F., Parmalee, R.W., Crossby, J., D. A., Coleman, D.C., Odom, E.P., and Groffman, P.M., 1986. *BioScience.* **36**:374-380.

59. Holland, E.A. and Coleman, D.C., 1987. *Ecology*. **68**:425-433.
60. Smith, M.S. and Rice, C.W., *Soil biology and biochemical nitrogen transformations in no-tilled soils, in Environmentally sound agriculture: Selected papers from the 4th international conference of the International Federation of Organic Agriculture Movements*, W. Lockeretz, Editor. 1983, Praeger Scientific, Cambridege, MA. pp 215-227.
61. Holtz, B.A., McKenry, M.V., and Caesar-TonThat, T. Wood chipping almond brush and its effect on nematodes, basidiomycetes, soil aggregation, soil nutrients, and almond tree growth. in *8th International Congress of Plant Pathology*. 2003b. Christchurch, New Zealand.
62. Ferris, H., Venette, R.C., and Lau, S.S., 1996. *Applied Soil Ecology*. **3**:161-175.
63. Van den Boogert, P.H.J.F., Velvis, H., Ettema, C.H., and Bouwman, L.A., 1994. *Nematologica*. **40**:249-257.
64. Jaffee, B.A., Ferris, H., and Scow, K.M., 1998. *Phytopathology*. **88**:344-350.
65. Phillips, R.E., *Soil moisture*, in *No-tillage agriculture: Principles and practices*, R.E. Phillips and S.H. Phillips, Editors. 1984, Van Norstand and Reinhold, New York. pp 66-86.
66. Linn, D.M. and Doran, J.W., 1984. *Soil Science Society of America Journal*. **48**:1267-1272.