Potential of Whole Orchard Recycling to Build Sustainability and Resilience of Almond Production

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Mohammad Yaghmour, Farm Advisor, Kern County, UC-ANR Cooperative Extension
Almond Board of California
The challenge

- Large amount of orchards are being turned over and replanted with almond
  - Drought
  - High commodity prices
- What to do with the retired trees?
  - Burning restrictions
  - Biomass power plant closure
- We need new outlets for tree residues
- Opportunity to use residue mulching to recycle nutrients (Carbon, Nitrogen)
- Multiple potential co-benefits to soil health
- Improve the sustainability and drought resilience of the Almond industry?
Whole orchard recycling
Incorporating biomass back to soil before replanting

Wood chipper and spreader

Land clearing equipment

New generation plantings
(Manteca site)
Knowledge gaps our work addresses

Webinar Outline

• Can WOR help improve soil health and in particular soil physical properties? (E. Jahanzad)
• How does that influence water retention/conservation and response to deficit irrigation? (E. Jahanzad)
• What are the short and longer term benefits for almond growth and nutrition, and how can N best be managed after WOR? (B. Holtz)
• Are there implications of WOR for almond disease management? (G. Browne)
• What are the added costs to implement WOR? (B. Holtz)
• What is the overall GHG footprint of this technology? (E. Marvinney)
Research Sites

Short term effects (2+ years):

- **Tallerico Farms (Manteca)**
- **Wonderful Orchards (Bakersfield)**

Whole tree chipping with a horizontal grinder or tub grinder (4-6”) and spreading vs removal

Long-term effects: (10 years)

- **Kearney Agricultural Research and Extension Center (Parlier)**

Whole tree grinding and incorporation (4 to 18”) with “Iron Wolf” rock crusher vs tree burning and ashes reapplied
Soil health and resiliency of recycled orchards to water shortage

Emad Jahanzad
Post-Doctoral Scholar, Plant Sciences, UC Davis
ejahanzad@ucdavis.edu
Soil health, also referred to as soil quality, is defined as the continued capacity of soil to function as a vital living ecosystem that sustains plants, animals, and humans (USDA).

Through provision of multiple ecosystem services, healthy soils can help build sustainability and resilience of almond production systems.
Aggregation, compaction, and infiltration

WOR Improved wet aggregate stability (+19%)

WOR reduced bulk density (-4%) and soil compaction (-14%) compared to the Burn treatment
Carbon storage, and soil chemical properties

Positive changes:

- Higher total carbon content in the Grind soil compared to Burn (35% vs 28%)
- Higher total nitrogen content in the Grind soil compared to Burn (51% vs 36%)

No significant changes:

- Soil pH
- Electrical conductivity
- Cation Exchange Capacity
- Ca, Mg, K, B, Fe, Cu, Zn

WOR led to + 8 tons more C stored per hectare
Soil biology (Microbial biomass and enzyme activity)

Soil microbial Biomass C (MBC) and N (MBN)

WOR Increased:
- Soil microbial biomass Carbon (+47%)
- Soil microbial biomass Nitrogen (+13%)

Enzyme activity

WOR Increased:
- Activity of enzymes involved in cycling of Carbon (+38%, CB and BG) and Nitrogen (+46%, NAG).
Soil Hydraulic properties

- WOR increased water retention in the Grind soil compared to Burn
- 30% higher volumetric water content at the field capacity

Soil moisture retention curves (Hyprop)

- The smallest % water content was observed in the deficit Burn plots (Top soil and at depth)
Tree response to water shortage:
Regular irrigation (100%ET) vs. deficit (80%ET)

Stem water potential (Avg. of treatments)
Grind trees maintained less negative SWP indicating less stress level

Weekly measurement of SWP
Grind trees were less water stressed on the most stressed day of deficit irrigation experiment
Grind treatment assisted trees in their post stress recovery

Stomatal conductivity measurement
Tree leaves showed less stomata closure in the Grind treatment under both irrigation scenarios
Higher stomatal conductance and photosynthesis rate in the Grind trees
Yield benefits of the Grind treatment under both regular (up to 20% increase) and deficit irrigation treatments.

• 20% improvement in irrigation water use efficiency of the Grind treatment
The effect of WOR on second generation almond tree growth, yield, and fertility

Brent Holtz
UC Cooperative Extension, San Joaquin County

## WOR effects on almond yield over time

**Butte Variety, Kernel pounds/acre**

<table>
<thead>
<tr>
<th>Year</th>
<th>Grind</th>
<th>Burn</th>
<th>Difference</th>
</tr>
</thead>
<tbody>
<tr>
<td>2011</td>
<td>687.40 lbs/ac</td>
<td>687.37 lbs/ac</td>
<td>0.03 lbs/ac (P= 0.49)</td>
</tr>
<tr>
<td>2012</td>
<td>1,472.40 lbs/ac</td>
<td>1,379.42 lbs/ac</td>
<td>92.98 lbs/ac (P=0.19)</td>
</tr>
<tr>
<td>2013</td>
<td>1,909.64 lbs/ac</td>
<td>1,667.91 lbs/ac</td>
<td>241.73 lbs/ac (P=0.05)</td>
</tr>
<tr>
<td>2014</td>
<td>2,272.11 lbs/ac</td>
<td>1,767.25 lbs/ac</td>
<td>504.86 lbs/ac (P=0.12)</td>
</tr>
<tr>
<td>2015</td>
<td>1,072.90 lbs/ac</td>
<td>877.54 lbs/ac</td>
<td>195.36 lbs/ac (P=0.11)</td>
</tr>
<tr>
<td>2016</td>
<td>1,341.97 lbs/ac</td>
<td>1,206.96 lbs/ac</td>
<td>135.01 lbs/ac (P=0.14)</td>
</tr>
<tr>
<td>2017</td>
<td>1,956.01 lbs/ac</td>
<td>1,539.17 lbs/ac</td>
<td>416.84 lbs/ac (P=0.07)</td>
</tr>
<tr>
<td>Total</td>
<td>10,712.43 lbs/ac</td>
<td>9,125.62 lbs/ac</td>
<td>1,586.81 lbs/ac</td>
</tr>
</tbody>
</table>
## Trunk Diameter in Replanted Orchard After Grinding Vs Burning

### Butte Variety (cm)

<table>
<thead>
<tr>
<th>Year</th>
<th>Grind</th>
<th>Burn</th>
<th>P value</th>
</tr>
</thead>
<tbody>
<tr>
<td>2009</td>
<td>4.87</td>
<td>4.96</td>
<td>P= 0.19</td>
</tr>
<tr>
<td>2010</td>
<td>14.56</td>
<td>15.22</td>
<td>P=0.07</td>
</tr>
<tr>
<td>2011</td>
<td>22.39</td>
<td>22.72</td>
<td>P=0.38</td>
</tr>
<tr>
<td>2012</td>
<td>30.53</td>
<td>30.23</td>
<td>P=0.18</td>
</tr>
<tr>
<td>2013</td>
<td>38.52</td>
<td>37.73</td>
<td>P=0.09</td>
</tr>
<tr>
<td>2014</td>
<td>46.50 a</td>
<td>45.24 b</td>
<td>P=0.01</td>
</tr>
<tr>
<td>2015</td>
<td>55.71 a</td>
<td>53.79 b</td>
<td>P=0.01</td>
</tr>
<tr>
<td>2016</td>
<td>63.15 a</td>
<td>60.58 b</td>
<td>P=0.007</td>
</tr>
</tbody>
</table>
# Soil Analysis in Replanted Orchard after Grinding Vs Burning

<table>
<thead>
<tr>
<th></th>
<th>2010</th>
<th>2011</th>
<th>2012</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Grind</td>
<td>Burn</td>
<td>Grind</td>
</tr>
<tr>
<td>Ca (meq/L)</td>
<td>4.06 a</td>
<td>4.40 b</td>
<td>2.93 a</td>
</tr>
<tr>
<td>Na (ppm)</td>
<td>19.43 a</td>
<td>28.14 b</td>
<td>13.00 a</td>
</tr>
<tr>
<td>Mn (ppm)</td>
<td>11.83 a</td>
<td>8.86 b</td>
<td>12.78 a</td>
</tr>
<tr>
<td>Fe (ppm)</td>
<td>32.47 a</td>
<td>26.59 b</td>
<td>27.78 a</td>
</tr>
<tr>
<td>Mg (ppm)</td>
<td>0.76 a</td>
<td>1.52 b</td>
<td>1.34 a</td>
</tr>
<tr>
<td>B (mg/L)</td>
<td>0.08 a</td>
<td>0.07 a</td>
<td>0.08 a</td>
</tr>
<tr>
<td>NO₃-N (ppm)</td>
<td>3.90 a</td>
<td>14.34 b</td>
<td>8.99 a</td>
</tr>
<tr>
<td>NH₄-N (ppm)</td>
<td>1.03 a</td>
<td>1.06 a</td>
<td>2.68 a</td>
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<tr>
<td>pH</td>
<td>7.41</td>
<td>7.36</td>
<td>6.96 a</td>
</tr>
<tr>
<td>EC (dS/m)</td>
<td>0.33 a</td>
<td>0.64 b</td>
<td>0.53</td>
</tr>
<tr>
<td>CEC (meq/100g)</td>
<td>7.40 a</td>
<td>8.47 b</td>
<td>8.04</td>
</tr>
<tr>
<td>OM %</td>
<td>1.22 a</td>
<td>1.38 b</td>
<td>1.24</td>
</tr>
<tr>
<td>C (total) %</td>
<td>0.73 a</td>
<td>0.81 a</td>
<td>0.79 a</td>
</tr>
<tr>
<td>C-Org-LOI</td>
<td>0.71 a</td>
<td>0.80 b</td>
<td>0.72</td>
</tr>
<tr>
<td>Cu (ppm)</td>
<td>6.94 a</td>
<td>6.99 a</td>
<td>7.94 a</td>
</tr>
</tbody>
</table>

**Blue Pair = grinding significantly less than burning**

**Yellow pair = grinding significantly greater than burning**
# Leaf Analysis After Grinding vs Burning

<table>
<thead>
<tr>
<th>Year</th>
<th>Nitrogen %</th>
<th>Phosphorus %</th>
<th>Potassium %</th>
<th>Magnesium %</th>
<th>Manganese ppm</th>
<th>Iron ppm</th>
<th>Sodium ppm</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Grind</td>
<td>Burn</td>
<td>Grind</td>
<td>Burn</td>
<td>Grind</td>
<td>Burn</td>
<td>Grind</td>
</tr>
<tr>
<td>2010</td>
<td>2.40 a</td>
<td>2.33 b</td>
<td>0.11 a</td>
<td>0.10 b</td>
<td>1.76 a</td>
<td>1.44 b</td>
<td>0.98 a</td>
</tr>
<tr>
<td>2011</td>
<td>2.58</td>
<td>2.58</td>
<td>0.14</td>
<td>0.14</td>
<td>1.92 a</td>
<td>1.67 b</td>
<td>0.66 a</td>
</tr>
<tr>
<td>2012</td>
<td>2.46</td>
<td>2.44</td>
<td>0.13</td>
<td>0.13</td>
<td>1.14 a</td>
<td>1.02 b</td>
<td>0.87</td>
</tr>
<tr>
<td>2013</td>
<td>2.57 a</td>
<td>2.49 b</td>
<td>0.112 a</td>
<td>0.106 b</td>
<td>0.94 a</td>
<td>0.73 b</td>
<td>1.04 a</td>
</tr>
<tr>
<td>2014</td>
<td>2.40 a</td>
<td>2.33 b</td>
<td>0.11 a</td>
<td>0.10 b</td>
<td>1.76 a</td>
<td>1.44 b</td>
<td>0.98 a</td>
</tr>
<tr>
<td>2015</td>
<td>2.42</td>
<td>2.39</td>
<td>0.12</td>
<td>0.11</td>
<td>1.66 a</td>
<td>1.43 b</td>
<td>0.97</td>
</tr>
<tr>
<td>2016</td>
<td>2.77</td>
<td>2.75</td>
<td>0.14</td>
<td>0.14</td>
<td>1.35 a</td>
<td>1.16 b</td>
<td>0.93</td>
</tr>
<tr>
<td>2017</td>
<td>2.57 a</td>
<td>2.50 b</td>
<td>0.12</td>
<td>0.12</td>
<td>1.28</td>
<td>1.20</td>
<td>1.09</td>
</tr>
</tbody>
</table>

**Blue Pair = grinding significantly less than burning**

**Yellow pair = grinding significantly greater than burning**
Nitrogen rates after Whole Orchard Recycling

Control

0.8 oz of N applied in March
Nitrogen recommendations in the first leaf

- **Trunk diameter (mm):** 2.7, 2.9, 3.1, 3.3, 3.5, 3.7, 3.9, 4.1
- **Average % Nitrogen:**
  - May: 3.9, June: 3.7, July: 3.6, August: 3.5, September: 3.4
- **Nitrogen recommendations in the first leaf:**
  - Control: 68.2 lbs N
  - 0.4 oz 15-15-15: 82.7 lbs N
  - 0.6 oz 15-15-15: 89.9 lbs N
  - 0.8 oz 15-15-15: 97.2 lbs N
  - 1.0 oz 15-15-15: 104.4 lbs N
Assessing potential impacts of WOR on almond diseases

Gregory Browne  
USDA-ARS, Dept. of Plant Pathology, UC Davis  
&  
Andreas Westphal  
UC Riverside, Dept. Nematology, KARE
“Replant problems”

- Phytopathogenic nematodes
- Prunus replant disease (PRD)

Additional soilborne diseases

- Phytophthora crown and root rots
- Butt rot / trunk decay
- Armillaria root rot (oak root fungus)
- Botryosphaeria canker
- Crown gall

Photos: B. Johnson

Healthy tree  PRD-affected tree  Phytophthora crown rot  Armillaria root rot
Soil microbes perform functions essential to soil and orchard health.

But, the communities can mediate negative effects in *Prunus* replanted after *Prunus*

*Prunus* replant disease (PRD), induced by a crop-specific soilborne complex, suppresses early growth and yields.

Preplant soil fumigation can prevent PRD.

Key questions about WOR:

- Impacts on PRD?
- Does WOR help or hinder management of PRD, with or without preplant soil fumigation?
Examining impacts of WOR and preplant fumigation, orchard replant trials

Data collected:
- Increase in trunk cross sectional area (TCSA) after planting
- Soil and root microbial community composition
- Soil physiochemical properties
- Tree nutrition

Preplant treatments table:

<table>
<thead>
<tr>
<th>Treatment</th>
<th>WOR</th>
<th>Fumigation</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>no</td>
<td>no</td>
</tr>
<tr>
<td>2</td>
<td>yes</td>
<td>no</td>
</tr>
<tr>
<td>3</td>
<td>no</td>
<td>yes</td>
</tr>
<tr>
<td>4</td>
<td>yes</td>
<td>yes</td>
</tr>
</tbody>
</table>
Impacts of WOR and fumigation on replanted tree growth

In years 1 & 2 after replanting:

- WOR suppressed growth, with or without soil fumigation
- Preplant fumigation increased growth, with or without WOR
- No sig. interaction of WOR x fumigation; therefore no impact of WOR on PRD
- New trials show extra N fertilizer can mitigate WOR suppression
Impacts of WOR and fumigation on soil microbial communities

**Bacteria**

- **Significant:** Fum interaction w/ Month ($P=0.04$)
- **Non-significant:** WOR & interactions ($P=0.12-0.77$)

**Fungi**

- **Significant:** Month ($P=0.007$), WOR ($P=0.002$), Fum ($P=0.002$)
- **Non-significant:** all interactions ($P=0.15-0.67$)
Summary, impacts on soilborne diseases in WOR trials

Facts:

• Potential for WOR to temporarily suppress replanted orchard growth; can manage with N fertilizer
• No sig. interactions of WOR w/ Fum or PRD detected
• Only one WOR trial >3 years old; not possible to reliably assess WOR impacts on other diseases

Considerations:

• WOR unlikely to aggravate Phytophthora diseases (improved water drainage and cellulose degradation in soil; mulching experience with other tree crops)
• Not advisable to recycle orchards with Armillaria (survival and spread in wood chips)
• May be risky to conduct WOR where there are severe problems with Butt rot or Crown gall disease
• Chip wood to ≤2” across, let dry before incorporation to reduce survival of wood rot fungi (B. Johnson, work with Ganoderma)
• Consult with UC Farm Advisors for cases with severe soilborne disease problems before WOR
Effects of orchard recycling on nematode population densities
Andreas Westphal, UC Riverside, Dept. Nematology, KARE

At five of the seven sites, population density of free-living nematodes (bacterial and fungal feeders) tended to be elevated after chip amendment compared to the non-amended treatment.

At the seven sites, population density of root lesion nematodes were similar between chip-amended and non-amended treatments.
Costs for Implementing WOR

Brent Holtz
UC Cooperative Extension, San Joaquin County
Orchard removal typically involves five machines and costs between $600-700/acre. Horizontal grinders can chip up 15-20 acres per day. Two inch screen sizes are recommended rather than four inch screens to reduce chip size.
Costs to Implement Whole Orchard Recycling

Kuhn & Knight manure spreaders were modified to spread wood chips.

Keeping the chips and having them spread back onto your orchard floor will cost an additional $300-400 per acre.

Wood chips are spread uniformly over entire field surface.
When 64 tons of wood chips are returned to the soil per acre:

N = 0.31 %, 396 lbs/ac
K = 0.20 %, 256 lbs/ac
Ca = 0.60 %, 768 lbs/ac
C = 50 %, 64,000 lbs/ac

The nutrients will be released gradually and naturally.
Incentives for growers to implement WOR

The San Joaquin Valley Air Pollution Control District (SJVAD) has recently approved a program that will reward growers with funding from $300-600 per acre up to $60,000 per year to implement whole orchard recycling.

For more information on these incentive programs, contact Jacob Whitson with SJVAD at 559-230-5800 or at Jacob.Whitson@ValleyAir.org.
Assessing the greenhouse gas footprint of WOR

Elias Marvinney
Post-doctoral Scholar
Dept. of Civil and Environmental Engineering, UC Davis
Agricultural Life Cycle Assessment (LCA)

Most retail-level food products result from complex production and supply chains with highly variable **environmental** and **resource** impacts.

Perennial cropping systems such as the orchards of California’s Central Valley may also result in environmental and resource use **benefits**, due to long **lifespans** and high **biomass productivity**.

Life cycle assessment (LCA) is the **preferred method** for understanding the environmental impacts and benefits of food products across their complete supply chain and life cycle.
Explanation of Biomass Co-product Disposal Scenarios

Regional Variation and Business-as-Usual (BaU) LCA scenario

- Each growing region has a distinct mix of end-of-life (EoL) practices and impacts for a BaU or “typical” acre
- Open Burn: cheap, easy, but restricted for air quality
- Bioenergy: less available now due to plant closure, clearing cost offset by payments from facilities, still some air quality issues
- Surface Mulch: Increased carbon storage, but may cause problems with harvest
- WOR: Best carbon storage option, possible benefits to soil health, but high on-site diesel consumption

Sacramento Valley (SV)
BaU: 37% bioenergy, 32% burn, 30% mulch, 1% WOR

San Joaquin Valley (SJV)
BaU: 70% bioenergy, 15% burn, 14% mulch, 1% WOR

Tulare Lake (TL)
BaU: 22% bioenergy, 39% burn, 37% mulch, 2% WOR

Almond 2014
Almond 2017
Trade-offs between Orchard Biomass Disposal Practices

- Effect of EoL practice on system impacts as compared to a BaU scenario:

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Whole Orchard Recycling</th>
<th>Surface Mulch</th>
<th>Bioenergy Production</th>
<th>Open Burn</th>
</tr>
</thead>
<tbody>
<tr>
<td>Carbon Storage</td>
<td>High</td>
<td>Moderate</td>
<td>None</td>
<td>None</td>
</tr>
<tr>
<td>Diesel Combustion</td>
<td>High</td>
<td>Moderate</td>
<td>Moderate</td>
<td>Low</td>
</tr>
<tr>
<td>Fossil Energy Displaced</td>
<td>None</td>
<td>None</td>
<td>High</td>
<td>None</td>
</tr>
<tr>
<td>Transportation</td>
<td>None</td>
<td>None</td>
<td>High</td>
<td>None</td>
</tr>
<tr>
<td>Air Pollution</td>
<td>Low</td>
<td>Low</td>
<td>Moderate</td>
<td>High</td>
</tr>
<tr>
<td>Cost</td>
<td>High</td>
<td>Low</td>
<td>Low</td>
<td>Moderate</td>
</tr>
</tbody>
</table>
Carbon Storage in the Orchard System

**Standing Biomass**
- C Residence time: 15 - 50 years

**Atmosphere**
- C Residence time: long-term

**Wood Chips**
- C Residence time: 5 - 10 years

**Soil Carbon**
- C Residence time: ?

**Soil**
- C Residence time: long-term

**Groundwater**
- C Residence time: long-term

**CARBON FLOW**
- Short-Term Carbon Storage
- Long-Term Carbon Storage

**PHOTOSYNTHESIS**

**RESPIRATION**

**MINERALIZATION**

**LEACHING**
Orchard LCA Model Results

- Biomass disposal scenarios by growing region
- Scenarios follow a Business-as-Usual orchard life cycle

Cumulative TAWP

Sacramento Valley | San Joaquin Valley | Tulare Lake

Orchard Year

Cumulative TAWP_{100} (tonnes CO_2 eq ac^{-1})
Benefits of whole orchard recycling:

- Improvement in **soil physical properties**
- **Higher yields** in mature trees
- No documented increase in **disease pressure**, if starting with a healthy orchard
- Decrease in **greenhouse gas footprint** compared to other orchard disposal options
- **No interference with later orchard operations** if grinding chips to small size and incorporating deeply

Ongoing research:

- Nitrogen nutrition and cycling under WOR
- Long-term cost/benefit analysis
For more information:

https://orchardrecycling.ucdavis.edu

For questions about the research, contact Amélie Gaudin, agaudin@ucdavis.edu or Brent Holtz, baholtz@ucanr.edu
For questions about the website, contact Sonja Brodt, sbbrodt@ucdavis.edu

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