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

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Almond Board of California

CALIFORNIA DEPARTMENT OF FOOD & AGRICULTURE

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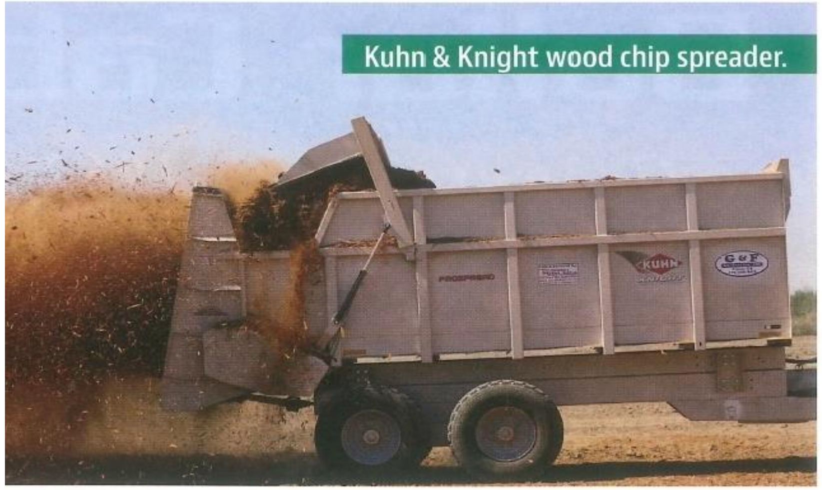
The challenge

- 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

Photo Credit: Brent Holtz



Land clearing equipment

New generation plantings
(Manteca site)

Knowledge gaps our work addresses
Webinar Outline

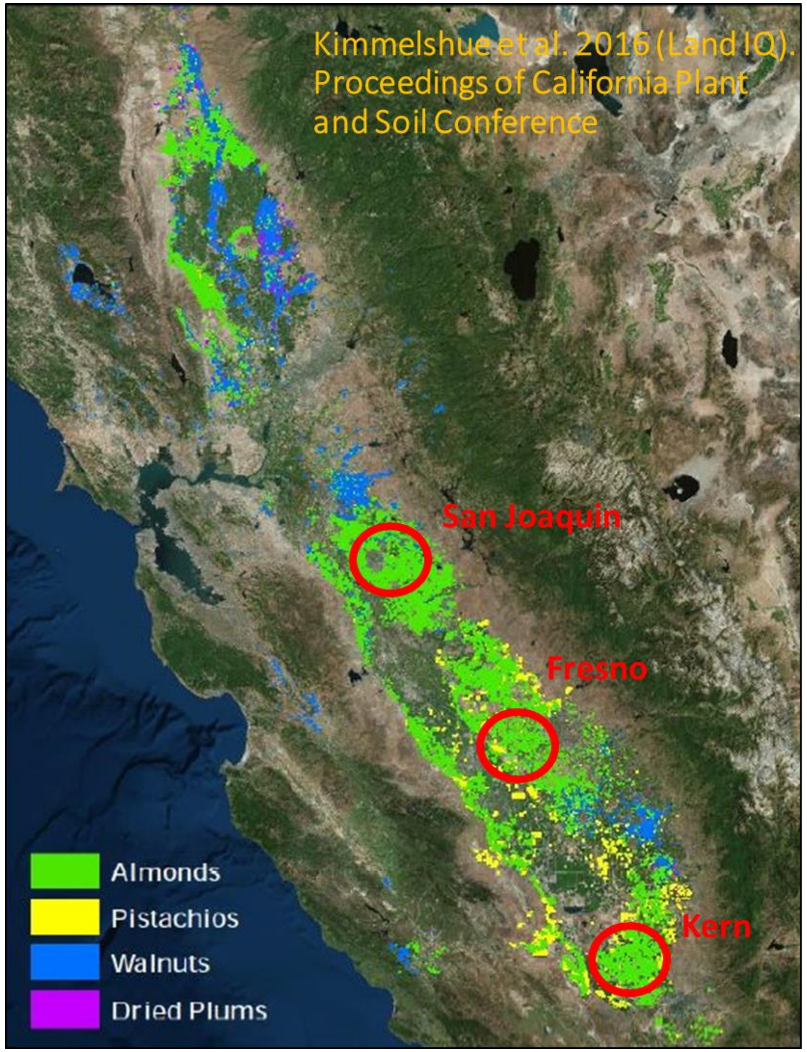
- **Can WOR help improve soil health and in particular soil physical properties? (E. Jahanzad)**
- **How does that influence water retention/conservation and response to deficit irrigation? (E.Jahanzad)**
- **What are the short and longer term benefits for almond growth and nutrition, and how can N best 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

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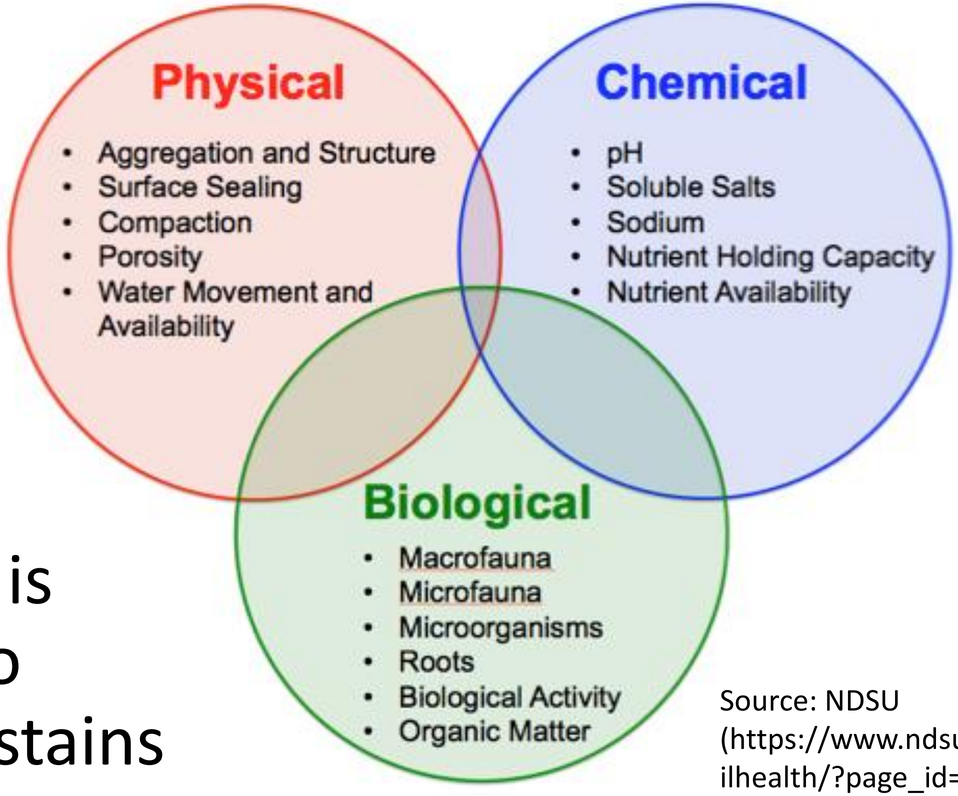
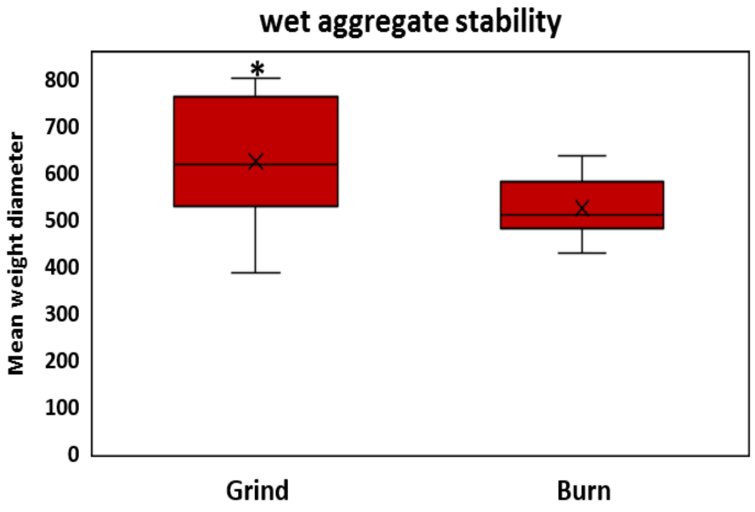


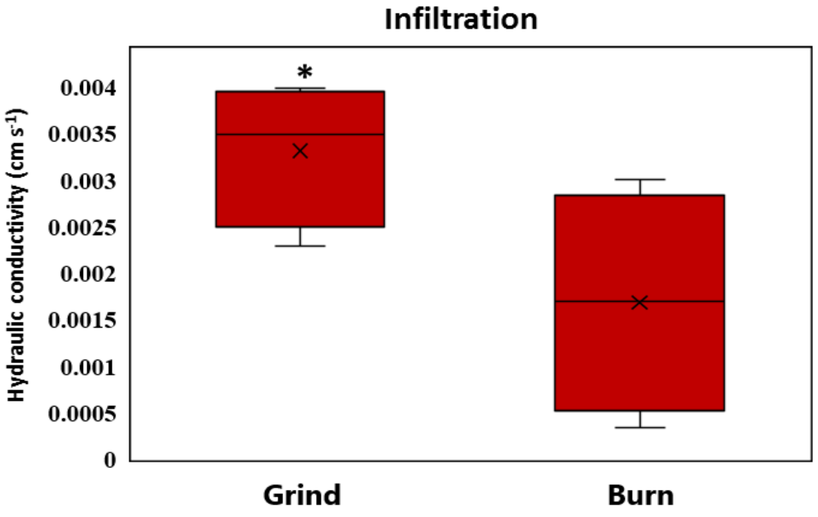
Source: NDSU (https://www.ndsu.edu/soilhealth/?page_id=37)

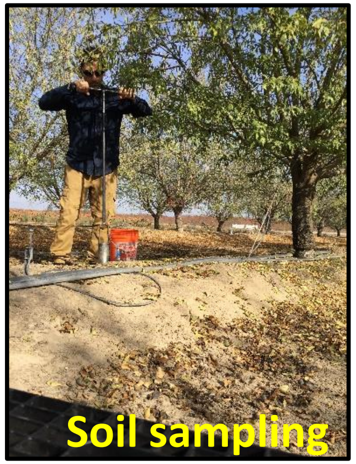
Soil health, also referred to as soil quality, is defined as the continued capacity of soil to function as a vital living ecosystem that sustains plants, animals, and humans (USDA)

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

Aggregation, compaction, and infiltration

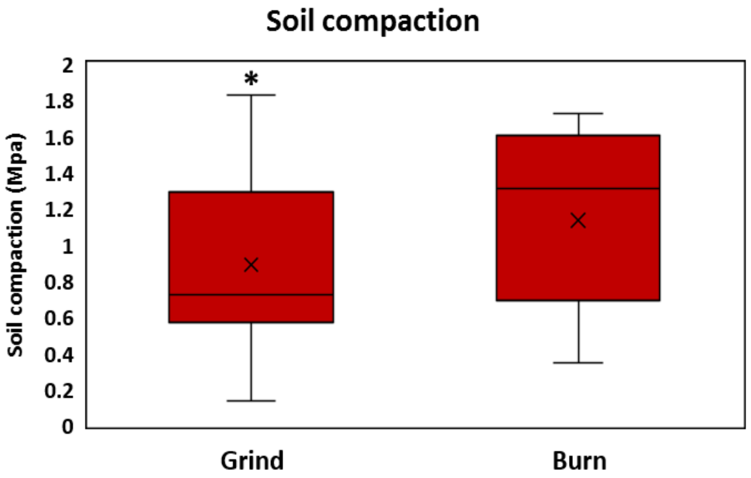


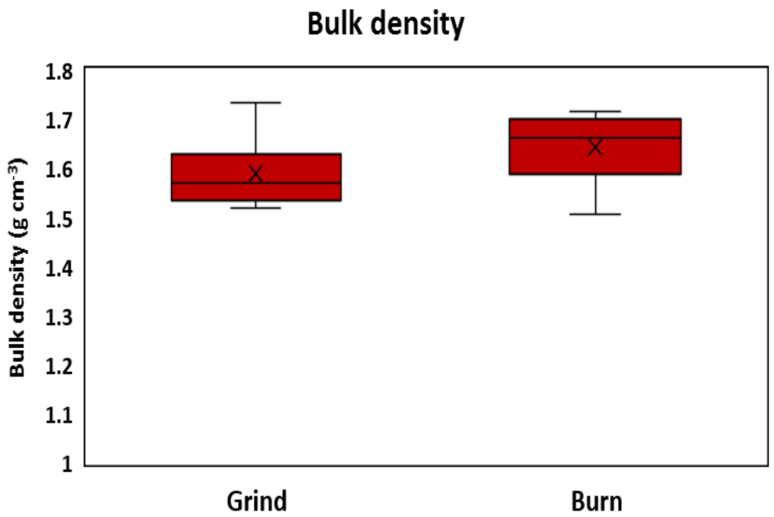




WOR Improved wet aggregate stability (+19%)

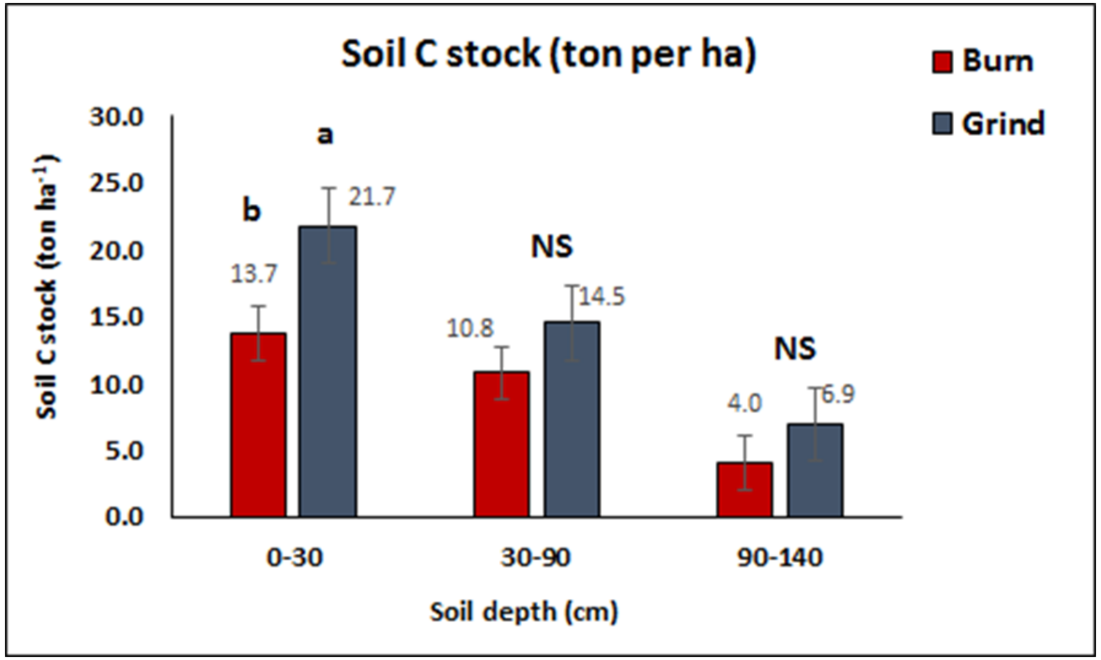
WOR improved infiltration rate (+200%)





WOR reduced bulk density (-4%) and soil compaction (-14%) compared to the Burn treatment

Carbon storage, and soil chemical properties



WOR led to + 8 tons more C stored per hectare

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%)

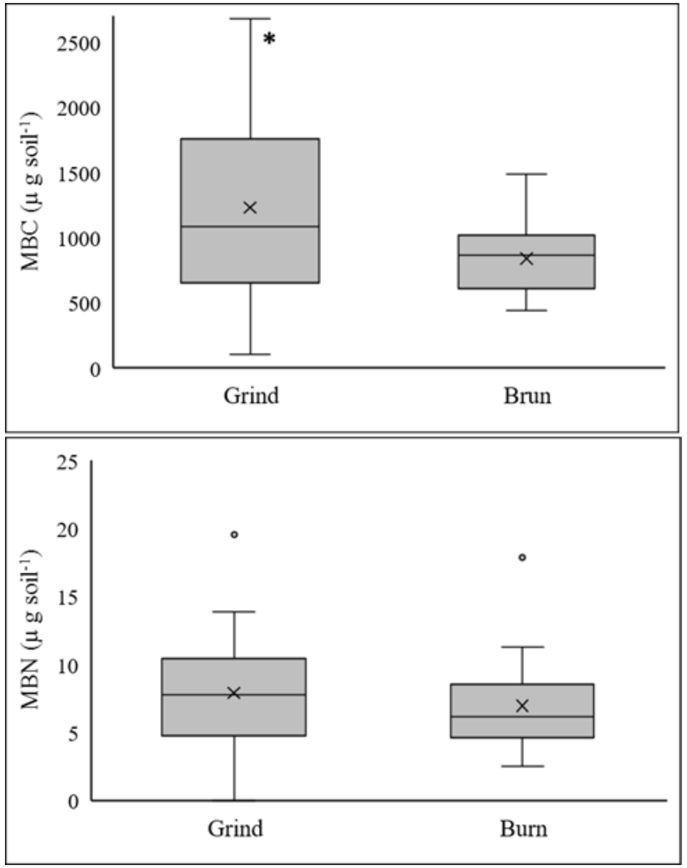
No significant changes:

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

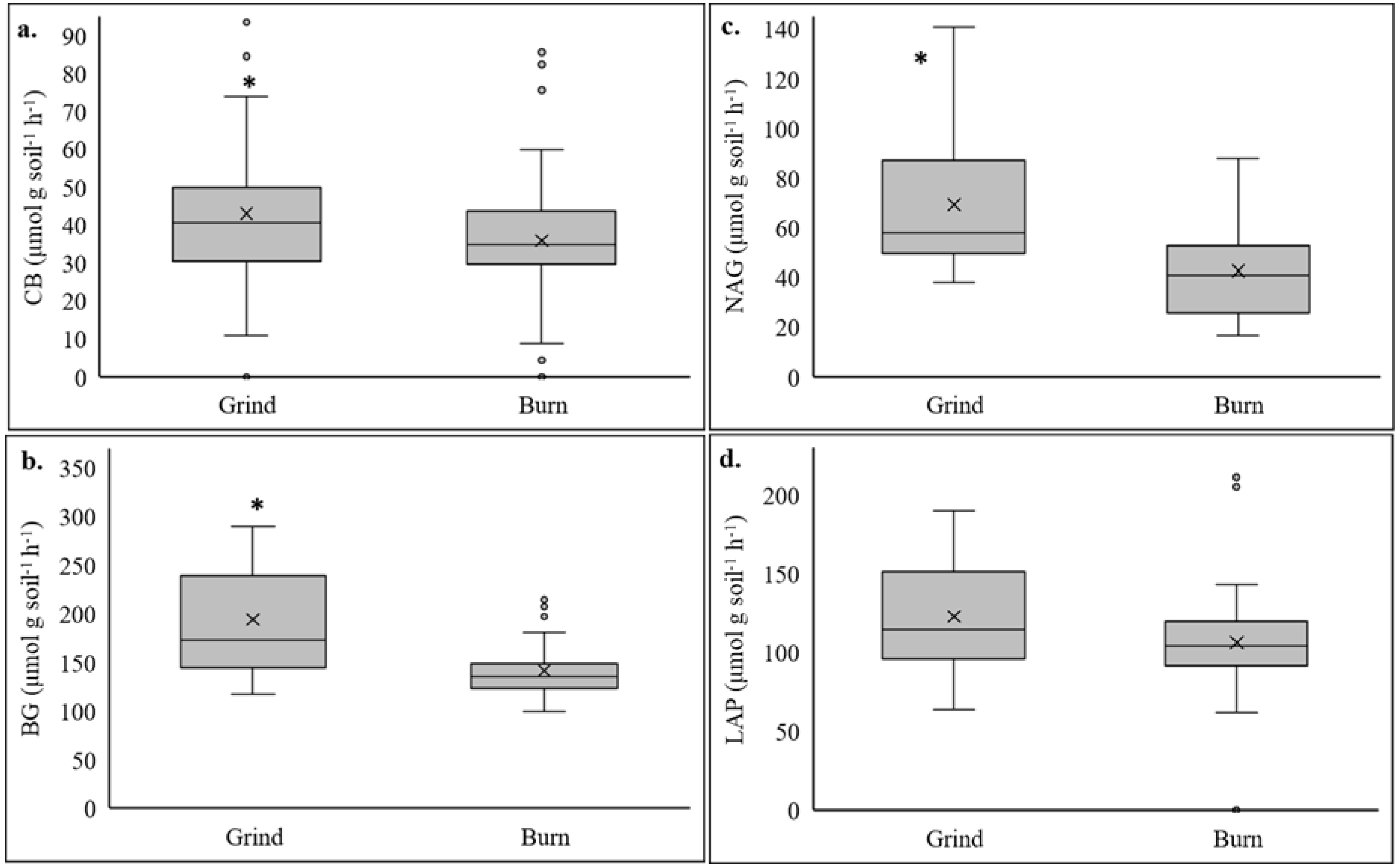
Deep soil cores (Geoprobe)

Soil biology (Microbial biomass and enzyme activity)

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



Enzyme activity



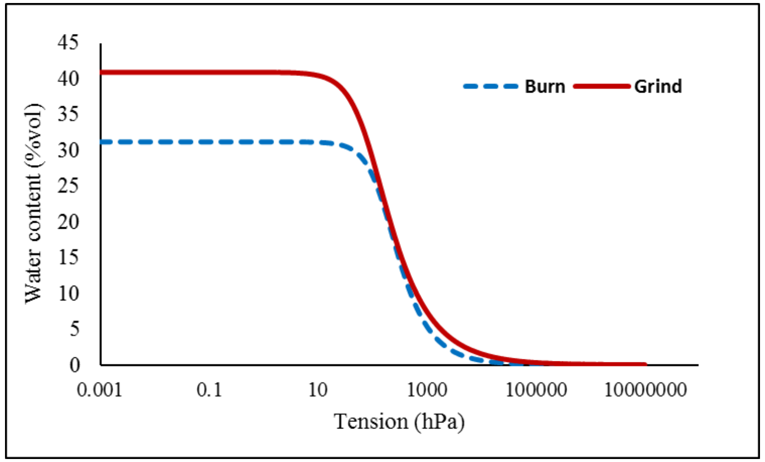
WOR Increased:

Soil microbial biomass Carbon (+47%)
Soil microbial biomass Nitrogen (+13%)

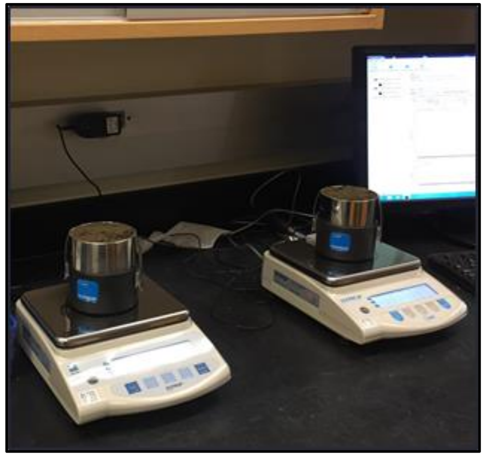
WOR Increased:

Activity of enzymes involved in cycling of Carbon (+38%, CB and BG) and Nitrogen (+46%, NAG).

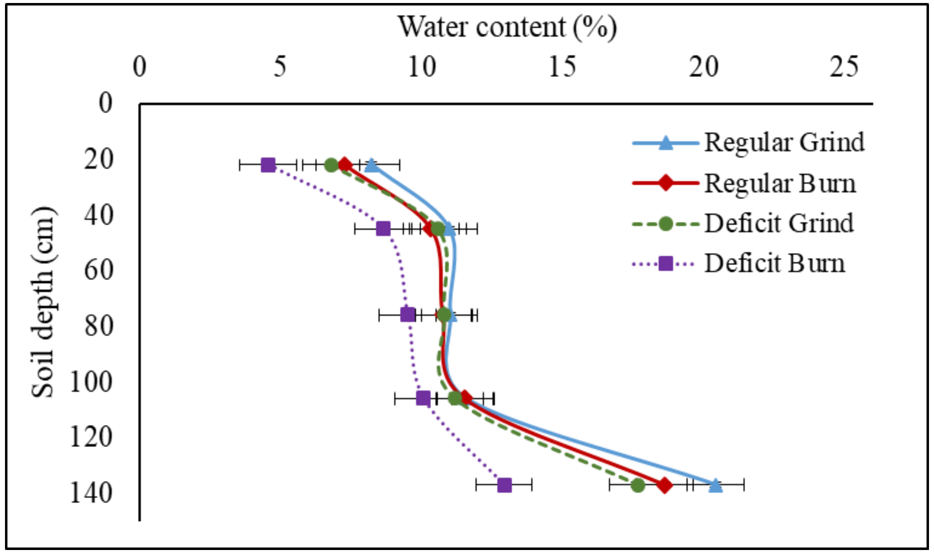
Soil Hydraulic properties



- **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)

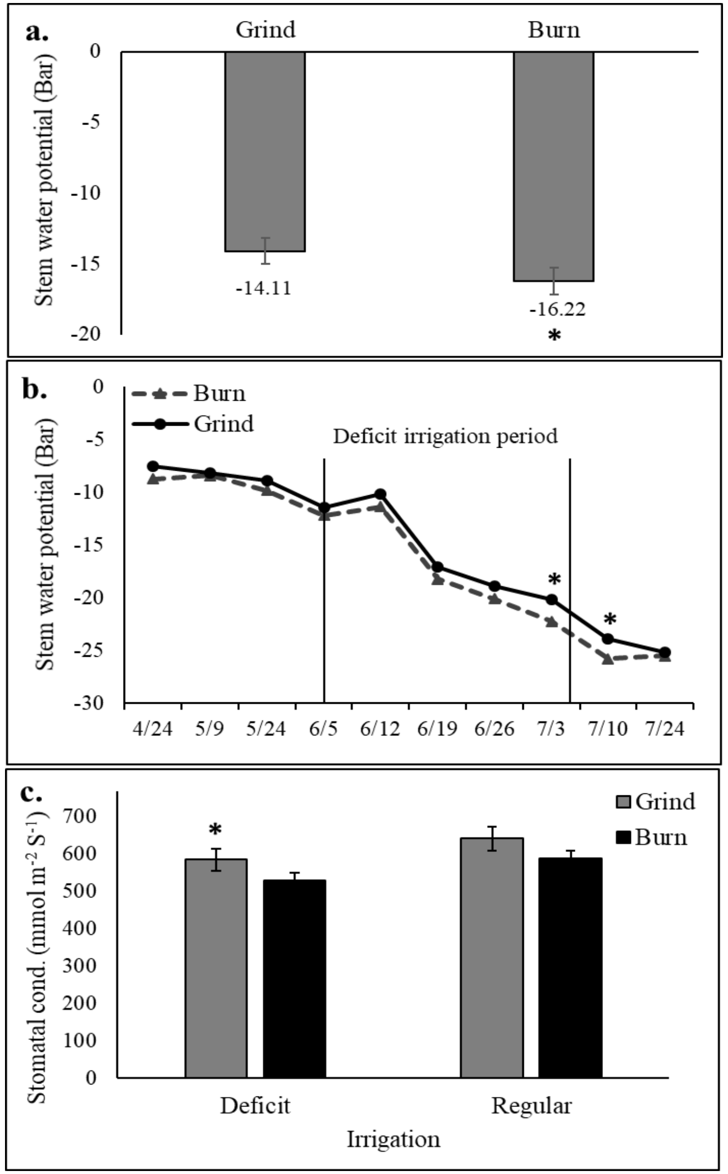


- **The smallest % water content was observed in the deficit Burn plots (Top soil and at depth)**

Soil moisture measurement at different soil depths (CPN-Neutron probe)

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

Stem water potential (pressure bomb)

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

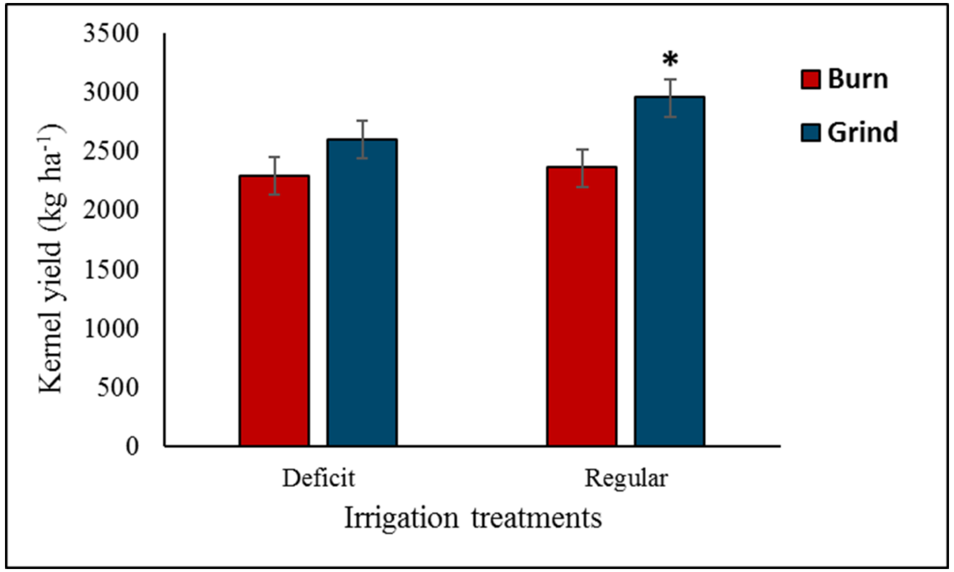
Tree leaves showed less stomata closure in the Grind treatment under both irrigation scenarios

Higher stomatal conductance and photosynthesis rate in the Grind trees

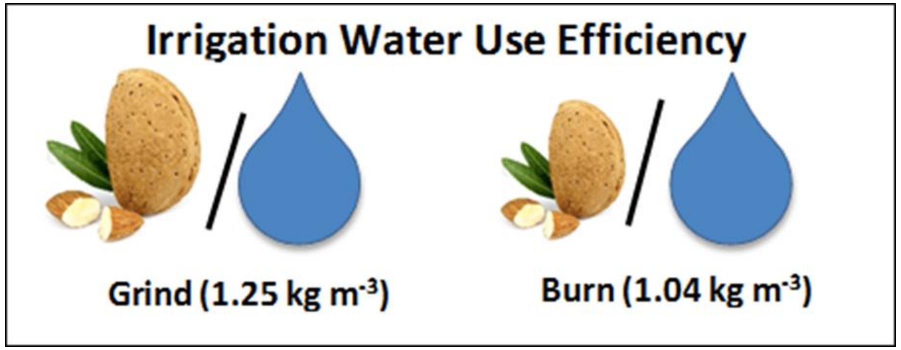
Stomatal conductance (Porometer)

Yield and irrigation water use efficiency

Kernel yield

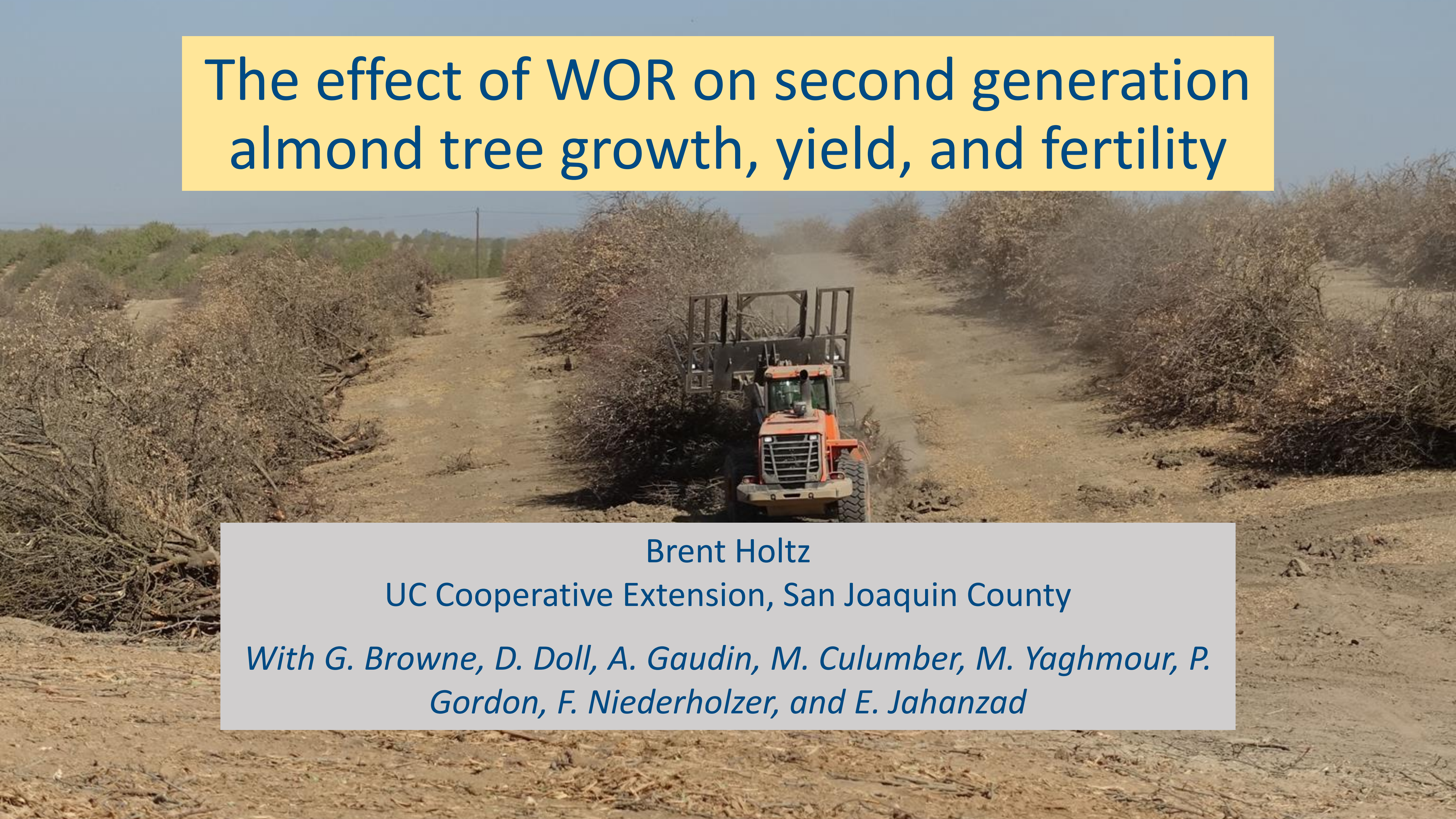


Irrigation water use efficiency



- 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

With G. Browne, D. Doll, A. Gaudin, M. Culumber, M. Yaghmour, P. Gordon, F. Niederholzer, and E. Jahanzad

WOR effects on almond yield over time

Butte Variety, Kernel pounds/acre

Year	Grind	Burn	Difference
2011	687.40 lbs/ac	687.37 lbs/ac	0.03 lbs/ac (P= 0.49)
2012	1,472.40 lbs/ac	1,379.42 lbs/ac	92.98 lbs/ac (P=0.19)
2013	1909.64 lbs/ac	1667.91 lbs/ac	241.73 lbs/ac (P=0.05)
2014	2272.11 lbs/ac	1767.25 lbs/ac	504.86 lbs/ac (P=0.12)
2015	1,072.90 lbs/ac	877.54 lbs/ac	195.36 lbs/ac (P=0.11)
2016	1,341.97 lbs/ac	1,206.96 lbs/ac	135.01 lbs/ac (P=0.14)
2017	1956.01 lbs/ac	1539.17 lbs/ac	416.84 lbs/ac (P=0.07)
Total	**10,712.43 lbs/ac**	**9,125.62 lbs/ac**	**1,586.81 lbs/ac**

Trunk Diameter in Replanted Orchard After Grinding Vs Burning

Butte Variety (cm)

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

Soil Analysis in Replanted Orchard after Grinding Vs Burning

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

Blue Pair = grinding significantly less than burning

Yellow pair = grinding significantly greater than burning

Leaf Analysis After Grinding vs Burning

	Nitrogen %		Phosphorus %		Potassium %		Magnesium %		Manganese ppm		Iron ppm		Sodium ppm	
	Grind	Burn	Grind	Burn	Grind	Burn	Grind	Burn	Grind	Burn	Grind	Burn	Grind	Burn
2010	2.40 a	2.33 b	0.11 a	0.10 b	1.76 a	1.44 b	0.98 a	1.03 b	23.63 a	17.44 b	102.5	104.3	340.5 a	455.5 b
2011	2.58	2.58	0.14	0.14	1.92 a	1.67 b	0.66 a	0.71 b	25.70	24.91	91.34	93.75	19.38 a	54.00 b
2012	2.46	2.44	0.13	0.13	1.14 a	1.02 b	0.87	0.90	20.13	19.13	84.84	83.95	24.88 a	49.50 b
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	27.83 a	23.25 b	113.59 a	102.79 b	634.6 a	957.5 b
2014	2.40 a	2.33 b	0.11 a	0.10 b	1.76 a	1.44 b	0.98 a	1.03 b	23.63 a	17.44 b	102.5	104.0	340.5 a	455.5 b
2015	2.42	2.39	0.12	0.11	1.66 a	1.43 b	0.97	1.01	23.96 a	17.88 b	142.5	148.22	243.8 a	358.22 b
2016	2.77	2.75	0.14	0.14	1.35 a	1.16b	0.93	0.97	24.46 a	21.58 b	97.09 a	88.20 b	207.1 a	335.38 b
2017	2.57 a	2.50 b	0.12	0.12	1.28	1.20	1.09	1.09	29.23 a	27.11 b	199.50 a	225.63 b	353.50	392.88

Blue Pair = grinding significantly less than burning

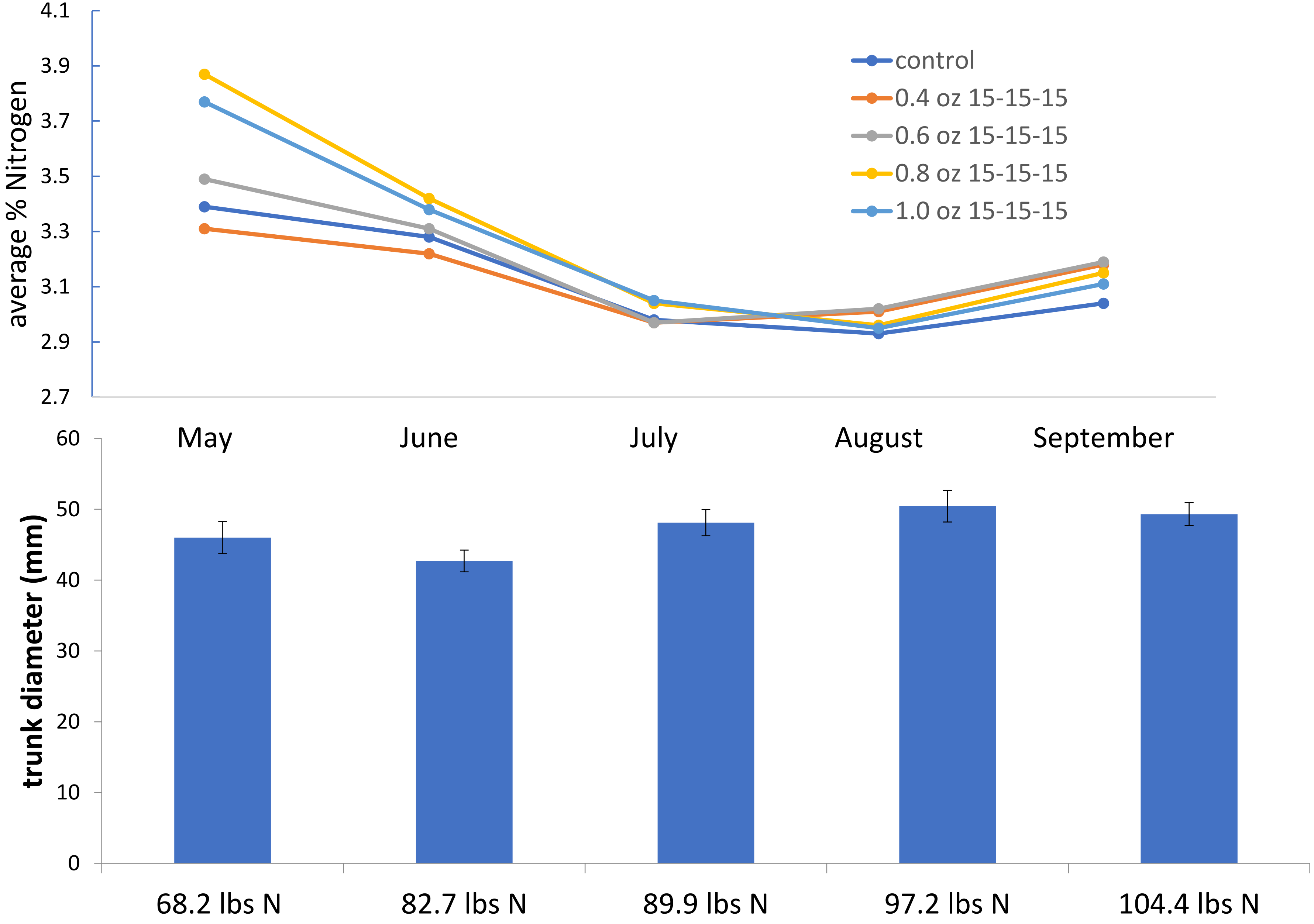
Yellow pair = grinding significantly greater than burning

Nitrogen rates after Whole Orchard Recycling

Control

0.8 oz of N applied in March

Nitrogen recommendations in the first leaf



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)**

Healthy tree

PRD-affected tree

Additional soilborne diseases

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

Phytophthora crown rot

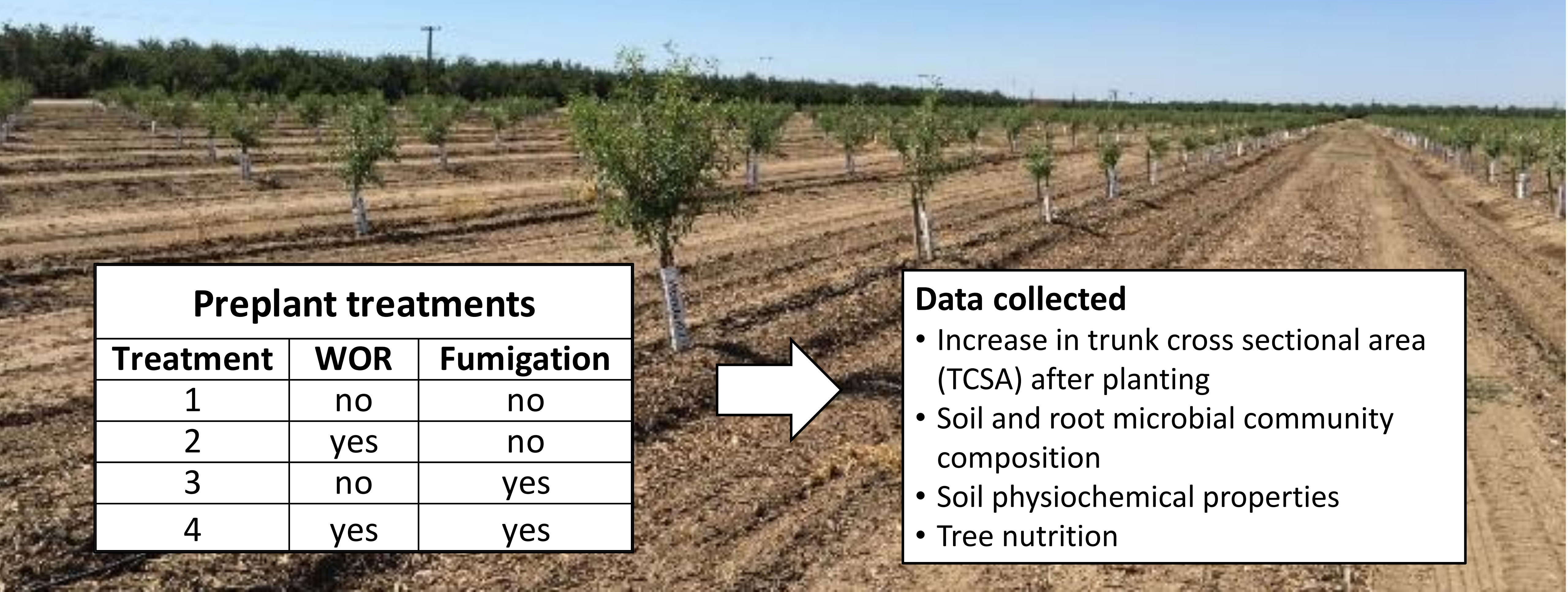
Butt rot / trunk decay

Armillaria root rot

Replant problems: *Soil microbial communities, PRD, and WOR*

- 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



Preplant treatments

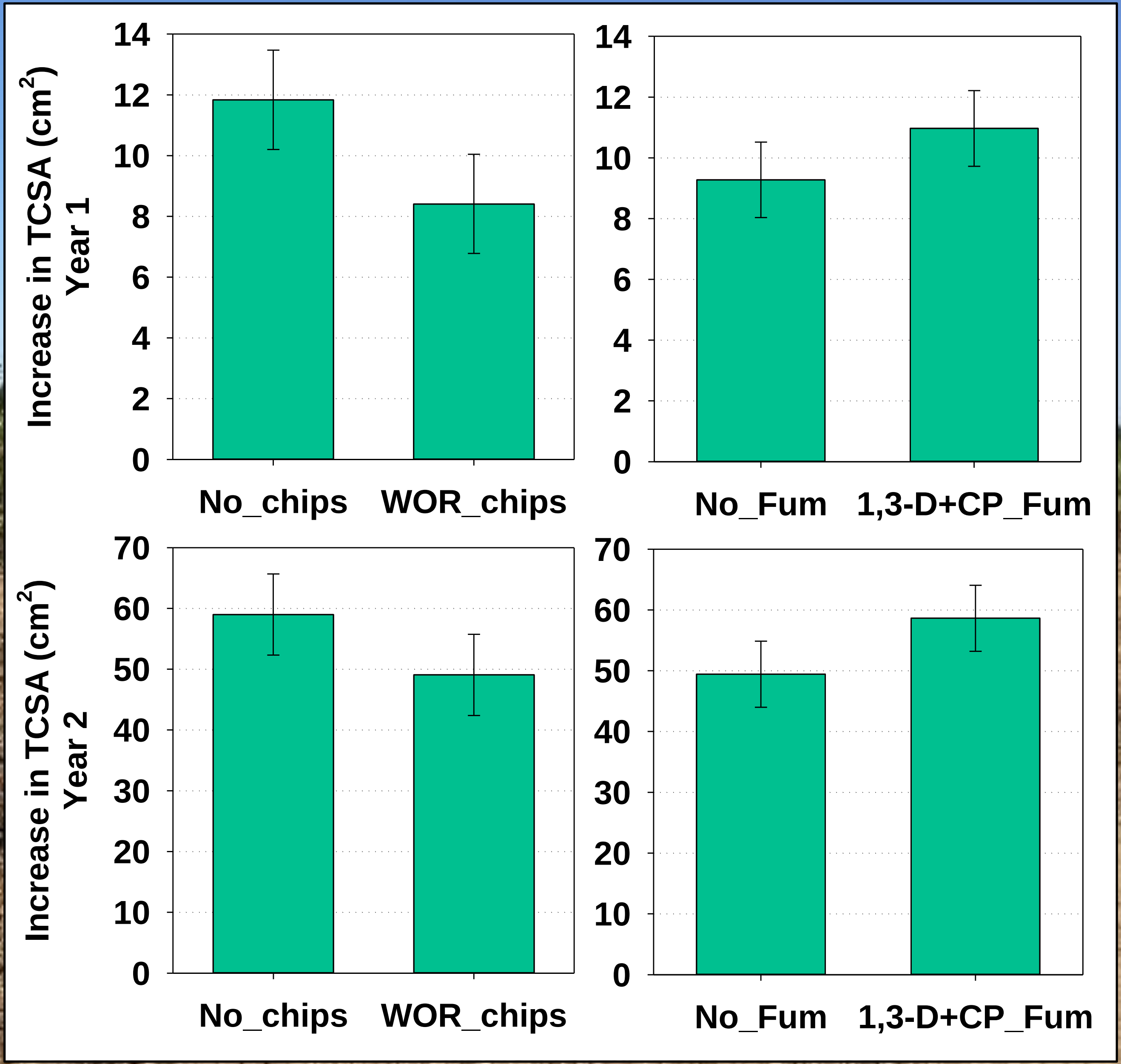
Treatment	WOR	Fumigation
1	no	no
2	yes	no
3	no	yes
4	yes	yes

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

Impacts of WOR and fumigation on replanted tree growth

In years 1 & 2 after replanting:

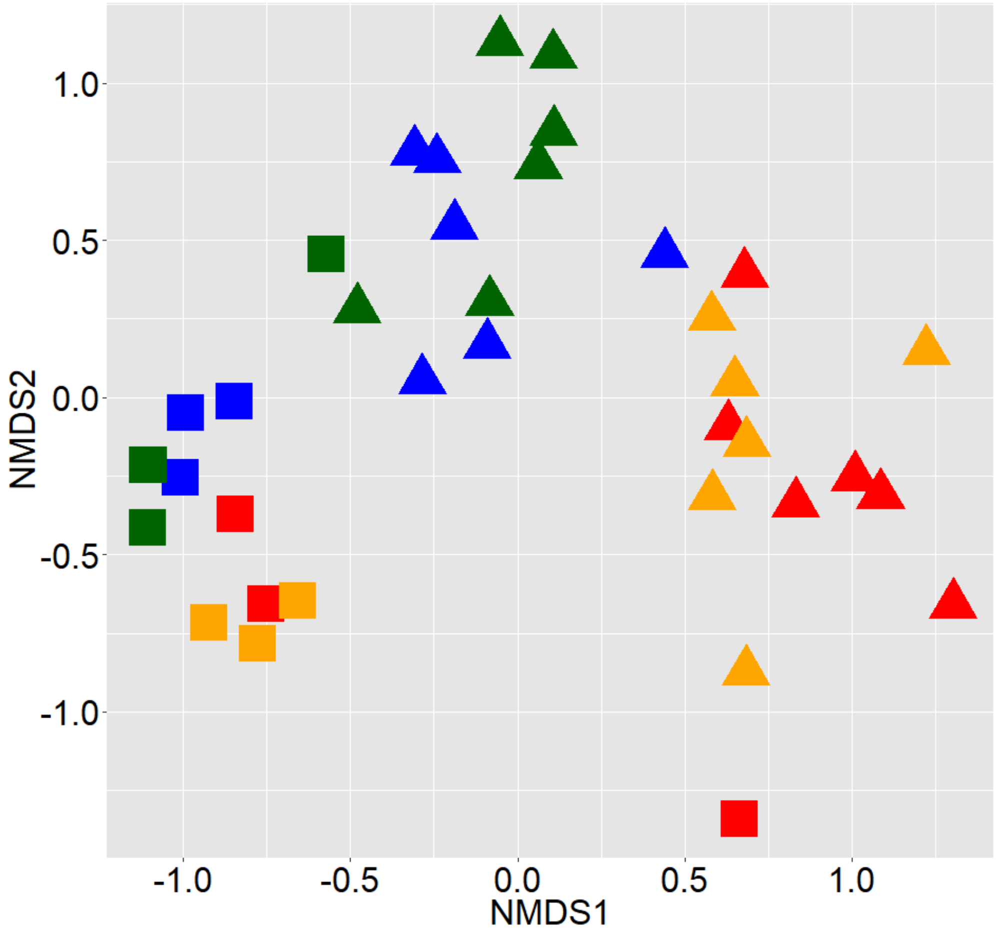
- WOR suppressed growth, with or without soil fumigation
- Preplant fumigation increased growth, with or without WOR
- No sig. interaction of WOR x fumigation; therefore no impact of WOR on PRD
- New trials show extra N fertilizer can mitigate WOR suppression

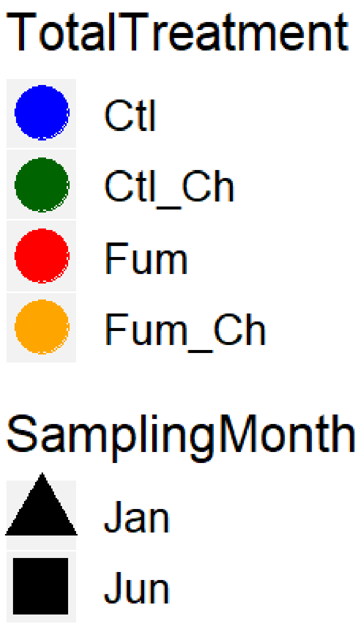


Impacts of WOR and fumigation on soil microbial communities

Bacteria

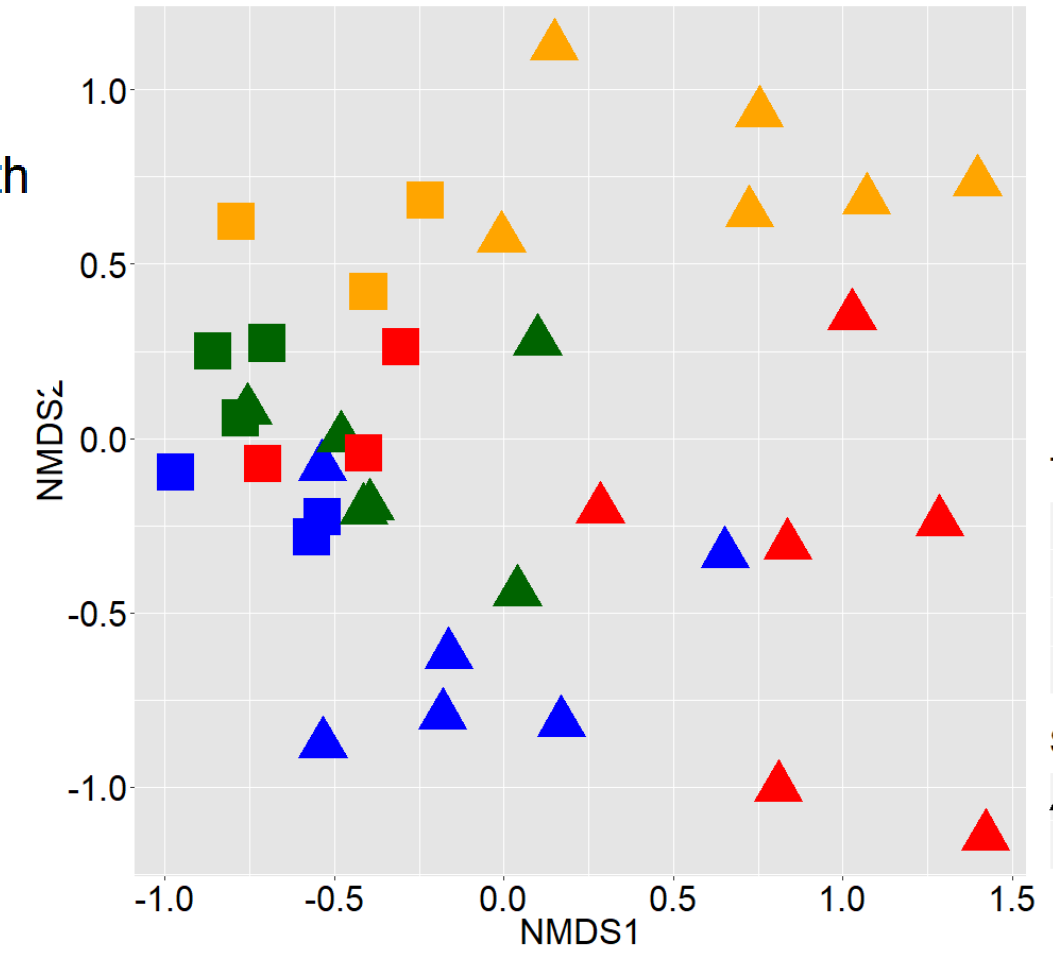
Significant: Fum interaction w/ Month (*P*=0.04)
Non-significant: WOR & interactions (*P*=0.12-0.77)





Fungi

Significant: Month (*P*=0.007),
WOR (*P*=0.002), Fum (*P*=0.002)
Non-sigificant: all interactions (*P*=0.15-0.67)



Summary, impacts on soilborne diseases in WOR trials

Facts:

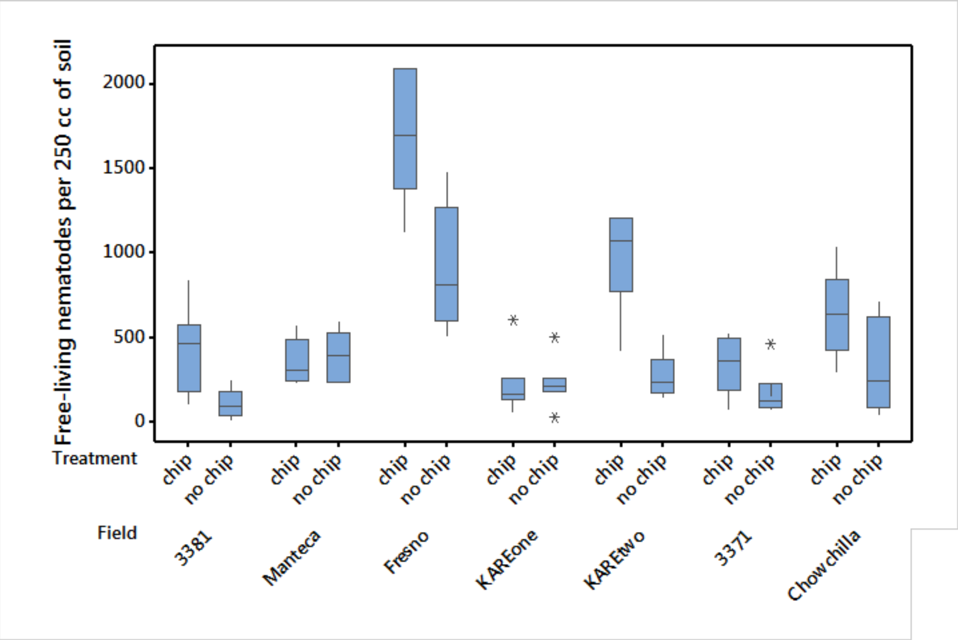
- Potential for WOR to temporarily suppress replanted orchard growth; can manage with N fertilizer
- No sig. interactions of WOR w/ Fum or PRD detected
- Only one WOR trial >3 years old; not possible to reliably assess WOR impacts on other diseases

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

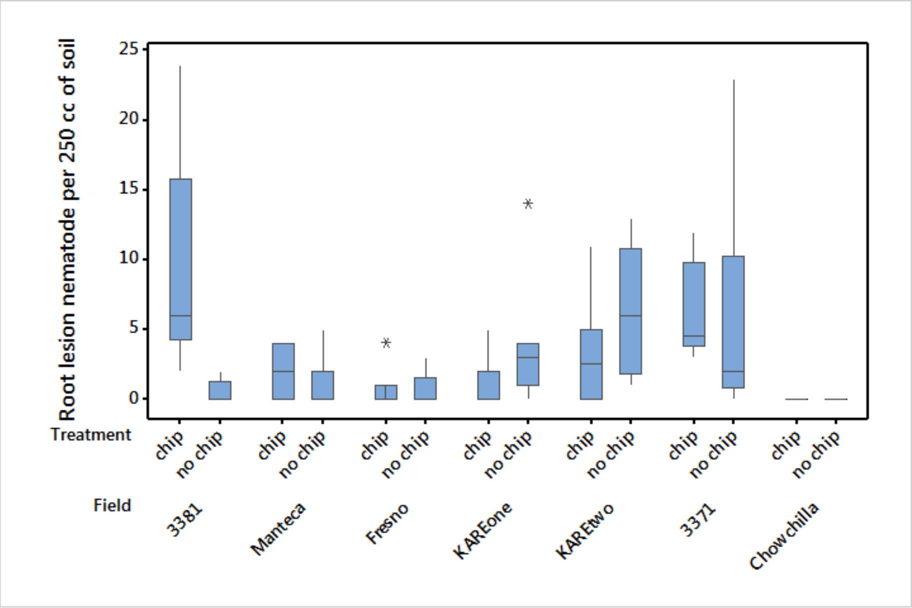
Effects of orchard recycling on nematode population densities

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

Costs to Implement Whole Orchard Recycling

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 and additional $300-400 acre.

Wood chips are spread uniformly over entire field surface

Potential for nutrient additions over time

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

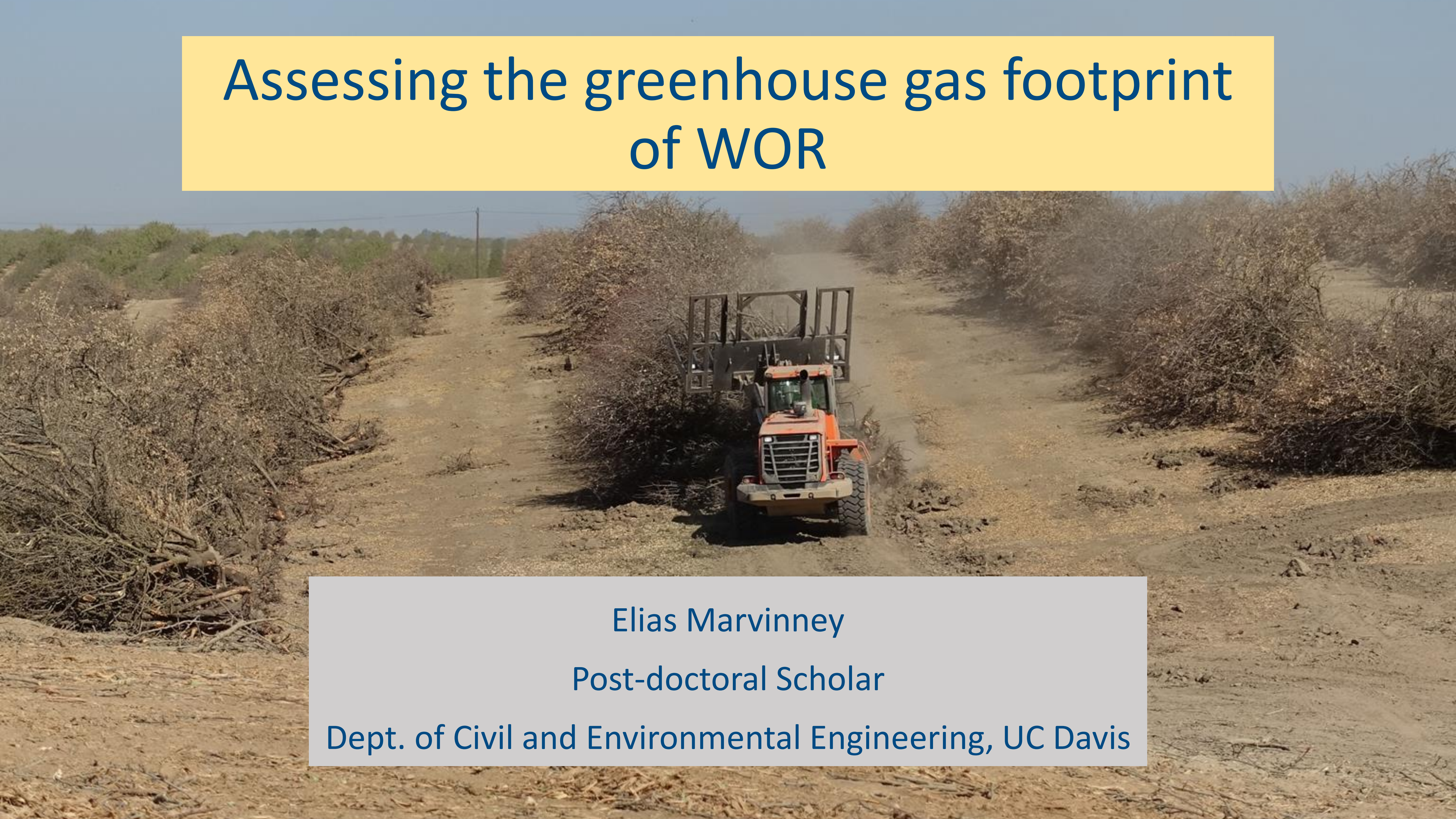
Incentives for growers to implement WOR

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.

San Joaquin Valley
Air Pollution
Control District

Assessing the greenhouse gas footprint of WOR



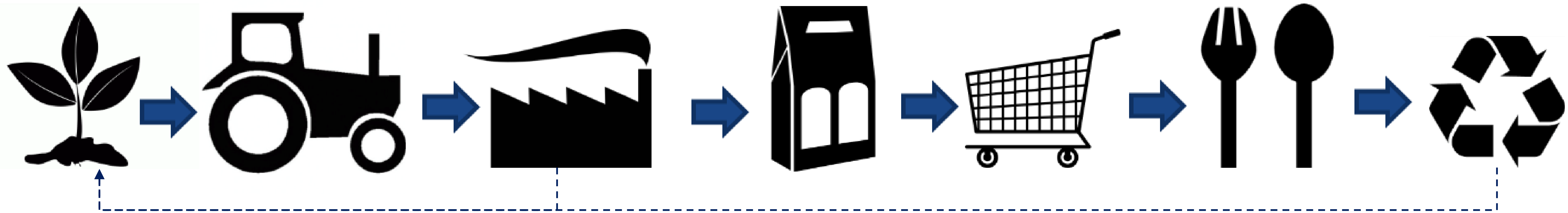
Elias Marvinney

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.



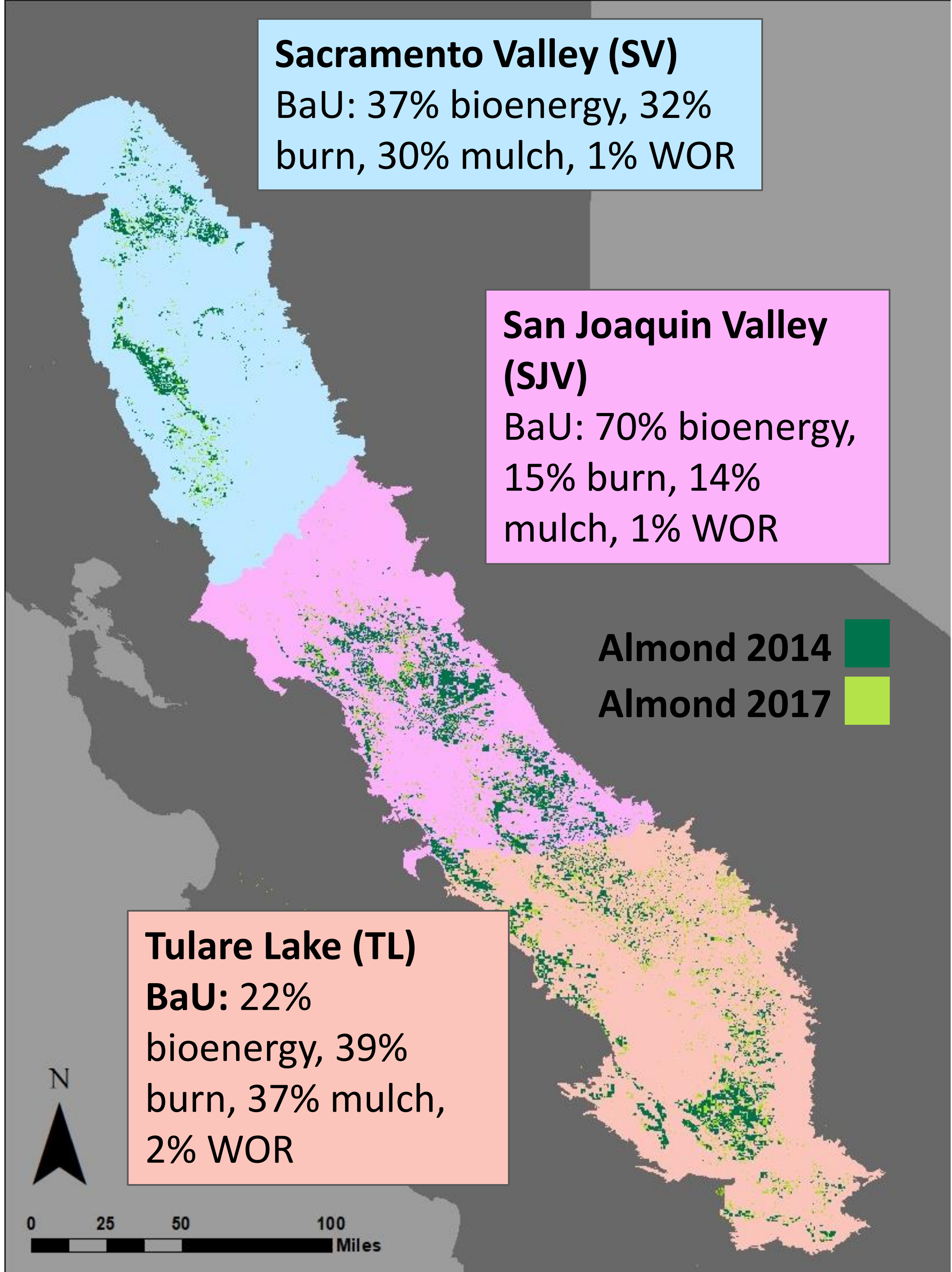
Perennial cropping systems such as the orchards of California's Central Valley may also result in environmental and resource use **benefits**, due to long **lifespans** and high **biomass productivity**.

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



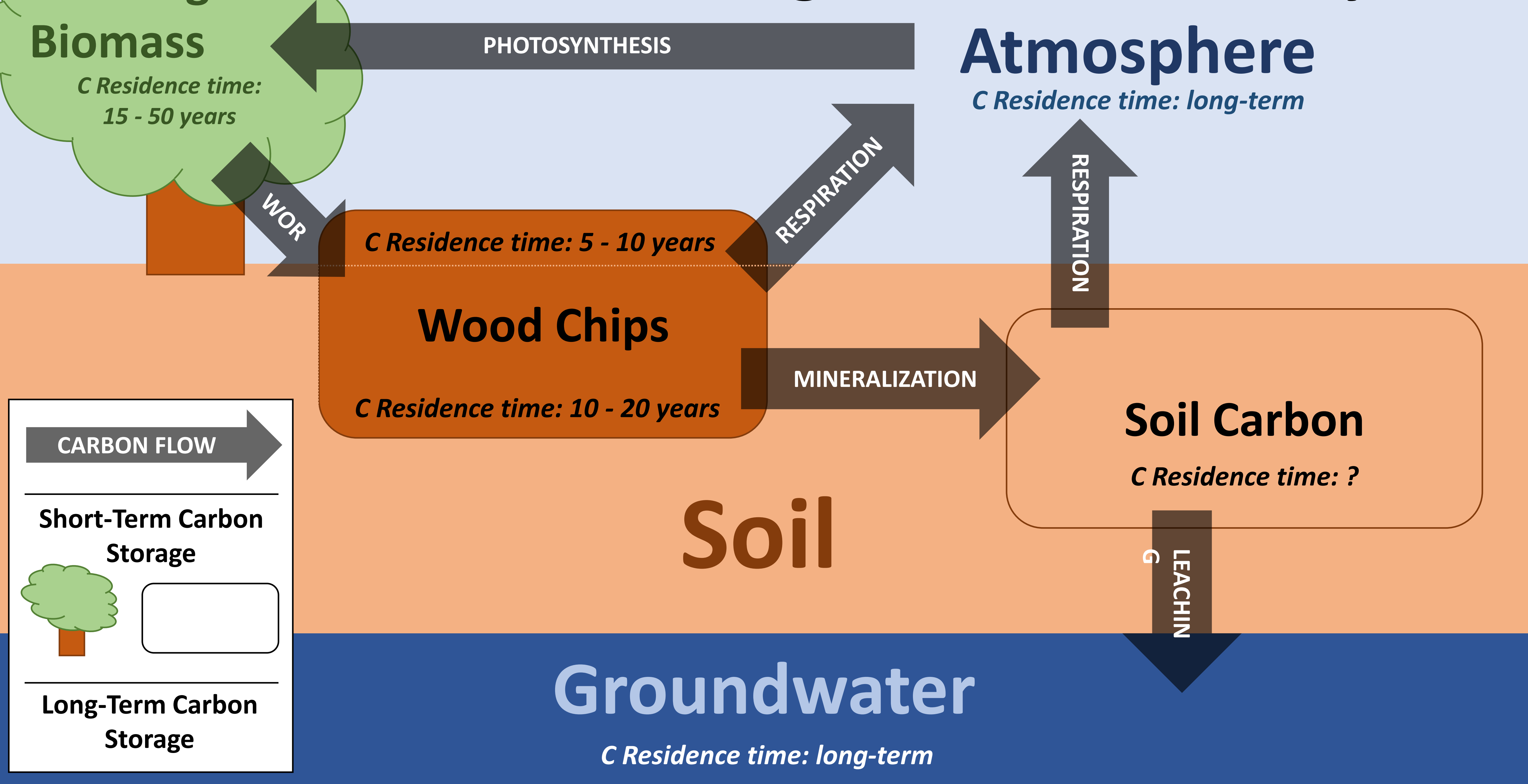
Trade-offs between Orchard Biomass Disposal Practices

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

Beneficial — Parameter Magnitude — Detrimental

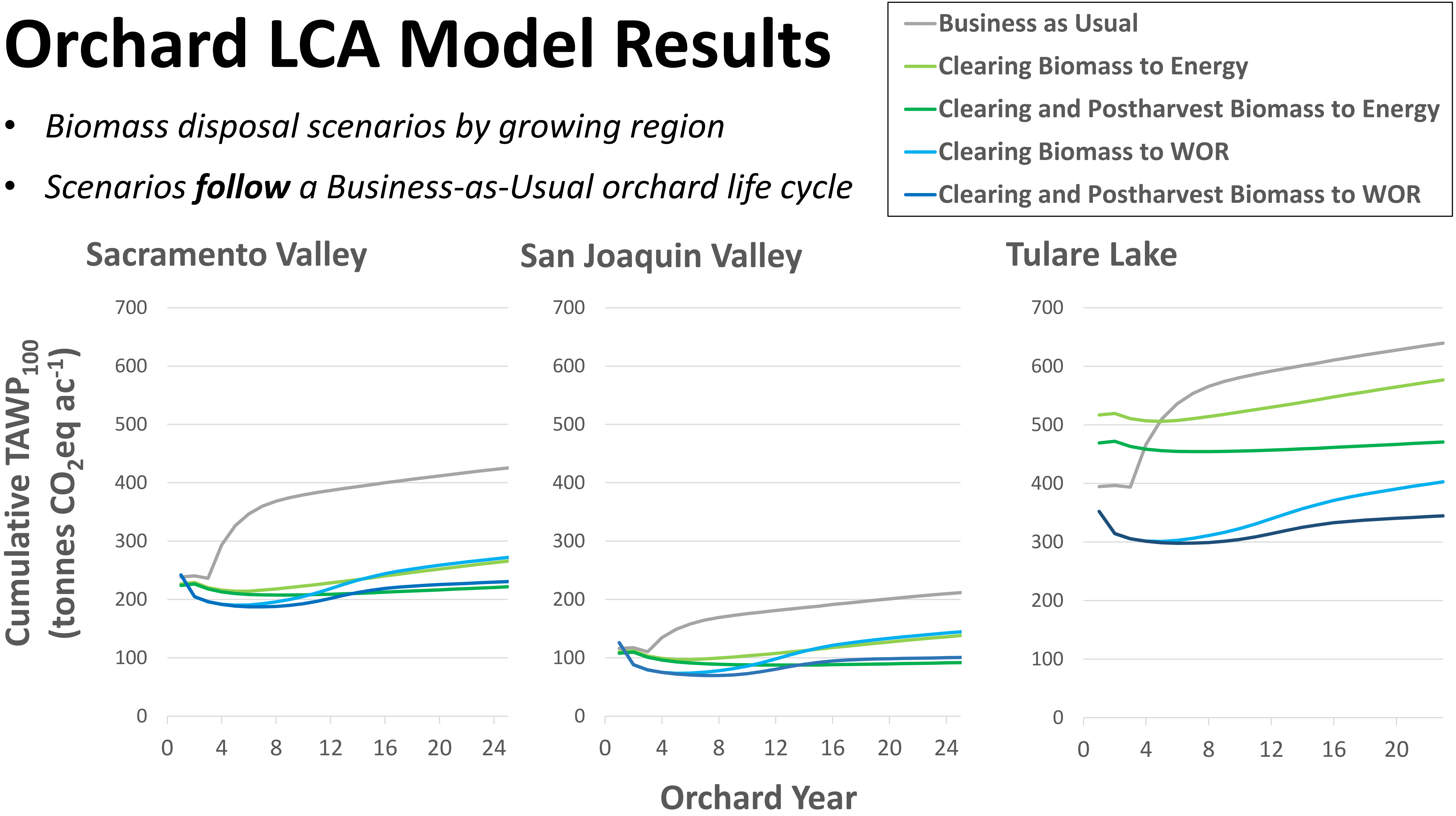
Parameter \ Practice	Whole Orchard Recycling	Surface Mulch	Bioenergy Production	Open Burn
Carbon Storage	High	Moderate	None	None
Diesel Combustion	High	Moderate	Moderate	Low
Fossil Energy Displaced	None	None	High	None
Transportation	None	None	High	None
Air Pollution	Low	Low	Moderate	High
Cost	High	Low	Low	Moderate

Carbon Storage in the Orchard System



Orchard LCA Model Results

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



In summary……

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

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