Greenhouse gas emissions of long-lived perennial cropping systems: Almond and pistachio production in California.

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Motivation

Orchard crop production is of great commercial and ecological importance in California, with production systems spanning 500 miles of the Central Valley and including many high value crops comprising a significant share of US agricultural exports and domestic consumption. Of these, almond and pistachio production are among the most important, with California production accounting for approximately 80% of the worlds almond exports and 50% of pistachio exports[1]. Worldwide, GHG and energy use impacts of these systems represent a significant proportion of global agricultural impacts.

Research Goals

- Develop a consistent and accurate framework for process-based life cycle GHG measurement of orchard production systems;
- Develop a model to account for management practices, environmental conditions, tree growth, and chemical/ fuel inputs to calculate the total greenhouse gas (GHG) emission, energy use, and environmental footprint of almond and pistachio production systems in California.
- Determine hotspots for best practice, environmental performance improvement
- Improve available data for industry reporting and transparency

Methods

System Definition and Boundary

- Spatial: 1 hectare of orchard in California
- Temporal: 60 years
  - Land preparation/ nursery production
  - Orchard establishment
  - Maturity to yield decline
  - Orchard clearing

Functional Units

- Orchard area (hectare)
- Mass orchard product (kg kernel)
- Nutritional calorie (kcal)

Data Sources

- UC Davis ARE cost and return studies[2,3,4,5]
- Survey and interview
- Life cycle inventory (LCI) databases[6,7,8]

Soil and Combustion Emissions

- Regionally specific data for N_2O emissions as per IPCC tier 2 methodology[9]
- Direct and indirect emission factors calculated[10,11,12]
- OFFROAD model[13]

Transportation

- Transportation emissions modeled based on orchard distribution (Fig 1), with emissions factors from US LCI database[8]

Irrigation

- System energy use calculated based on region, irrigation system, and water source (Fig 1)[14,15]
- Mean emissions per hectare calculated using annual water use, irrigation system prevalence, and regional orchard distribution

Co-products

- Major co-products: woody biomass including whole trees, prunings, hulls, and shells
- Co-product fates: standing tree biomass, in-field mulching or burning, roughage replacement in cattle feed, and electricity generation
- Potential GHG reduction credits calculated by displacement of emissions from fossil fuel electricity generation

Impact Assessment

- 100-year IPCC global warming potential to convert GHGs to CO_2eq[16]

*See supplementary material for citations

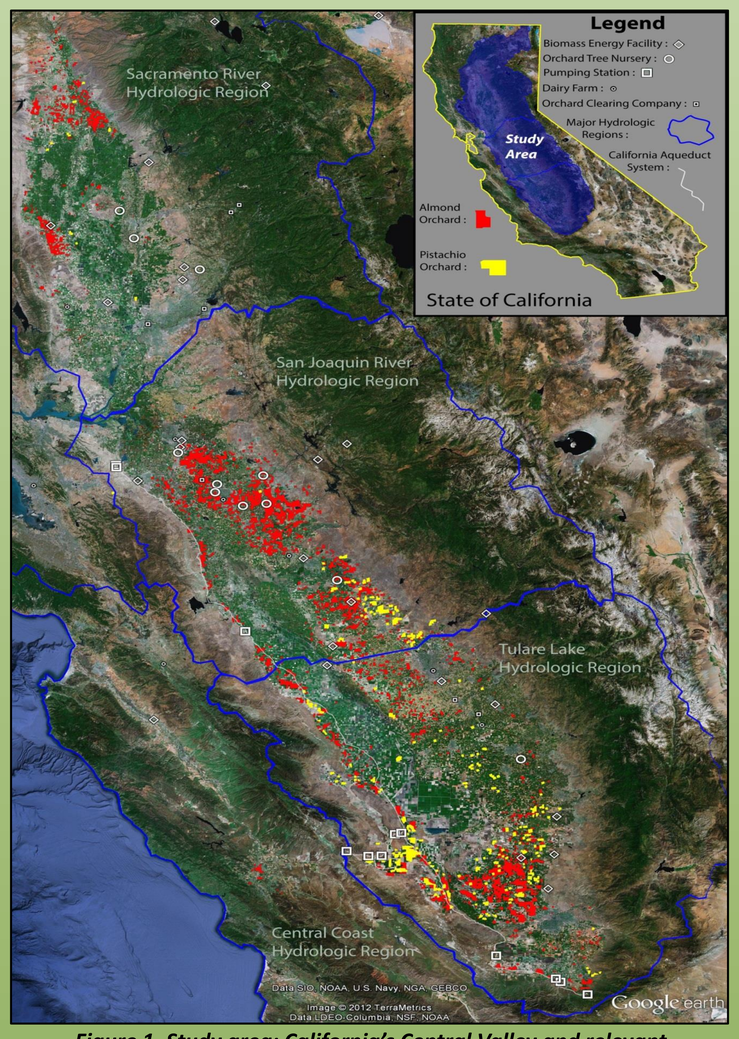

Figure 1. Study area: California's Central Valley and relevant features and hydrologic regions.

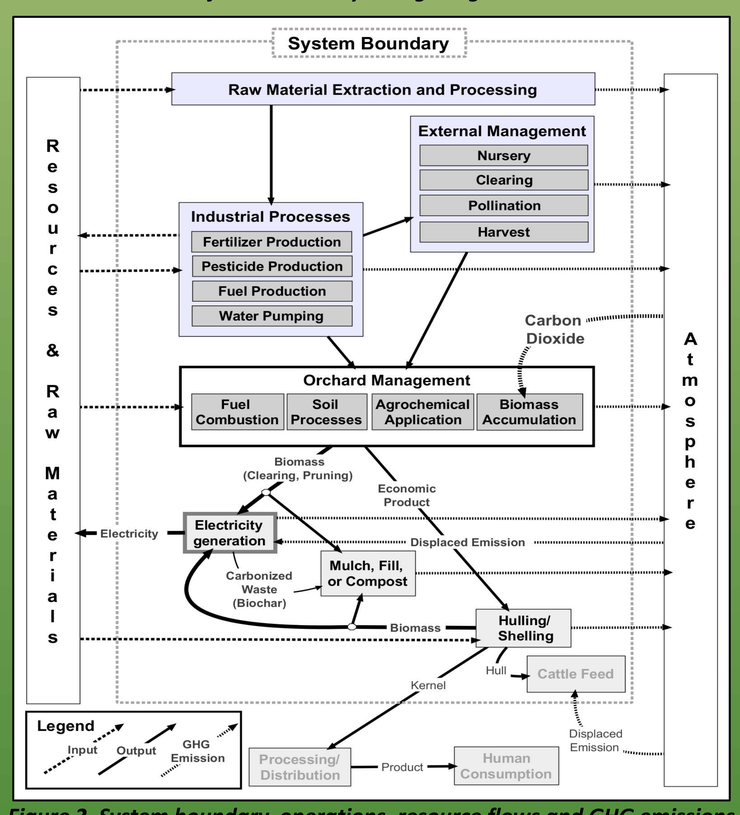

Figure 2. System boundary, operations, resource flows and GHG emissions.

Results

- Almond and pistachio **compare favorably** to other high-protein agricultural products (Fig. 3), **without** considering potential carbon credits.
- GHG emission and energy use footprints in both systems are dominated by **nutrient management** and **irrigation**, respectively. Pest and biomass management are also large contributors to orchard impact (Fig. 4).
- Net emissions under various biomass use scenarios were calculated (Fig. 5). Under typical California management, GHG offset credits for biomass energy production can help orchard production systems **approach net CO_2 neutrality**.

Discussion and Future Work

This study highlights the comparatively **low GHG footprint** of almond and pistachio production when **emission offset credits** are accounted for. The relative lifespan, management, and biomass accumulation of different orchards determine their potential to generate carbon sequestration or emission offset credits. With adoption of more **efficient energy conversion technologies** the full potential of biomass utilization may be approached, resulting in **net carbon negative** orchard production systems. Future iterations of this model will explore the **economic effects** of biomass-based credits, and include **peach, prune, and walnut** production.

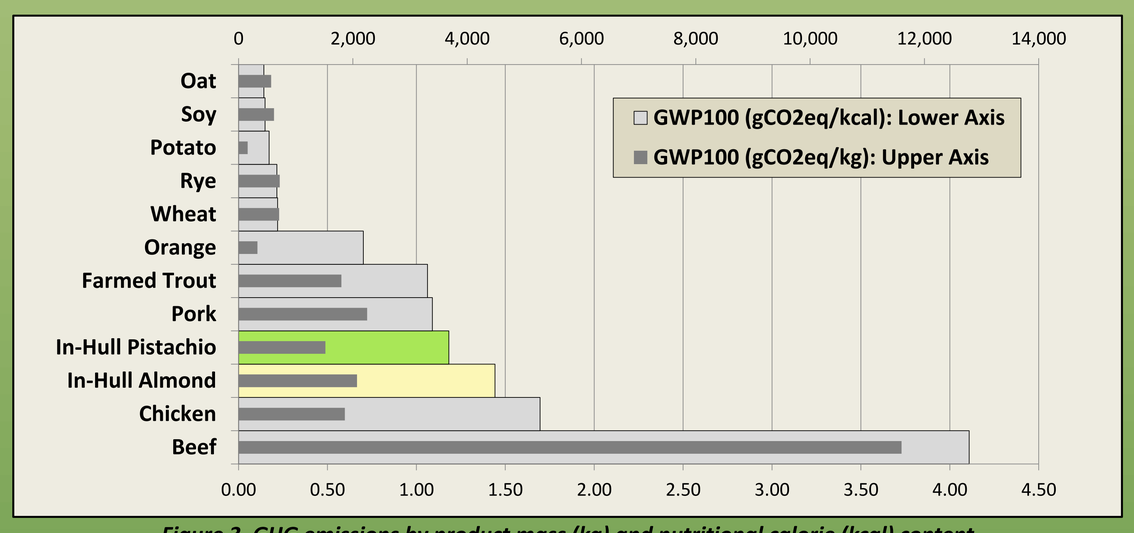

Figure 3. GHG emissions by product mass (kg) and nutritional calorie (kcal) content.

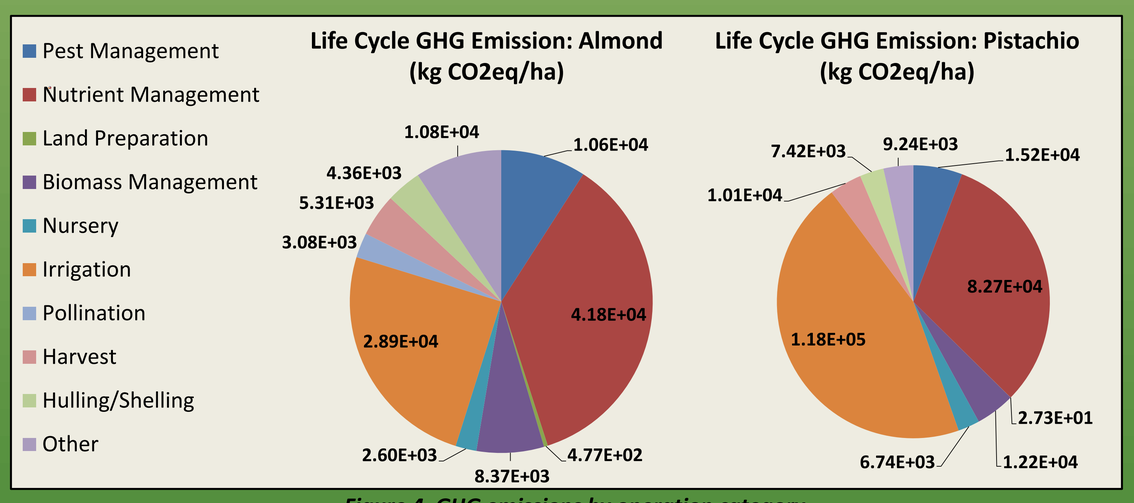

Figure 4. GHG emissions by operation category.

Figure 5. Annual potential offsets from biomass management (A,B), and potential net emissions (C,D) for one hectare of "typical" almond or pistachio orchard over a 60-year time period. The upper bound of the ranges shown represents a worst case scenario for biomass fate, and the lower bound represents a best case scenario. The baseline scenario represents current representative practice.

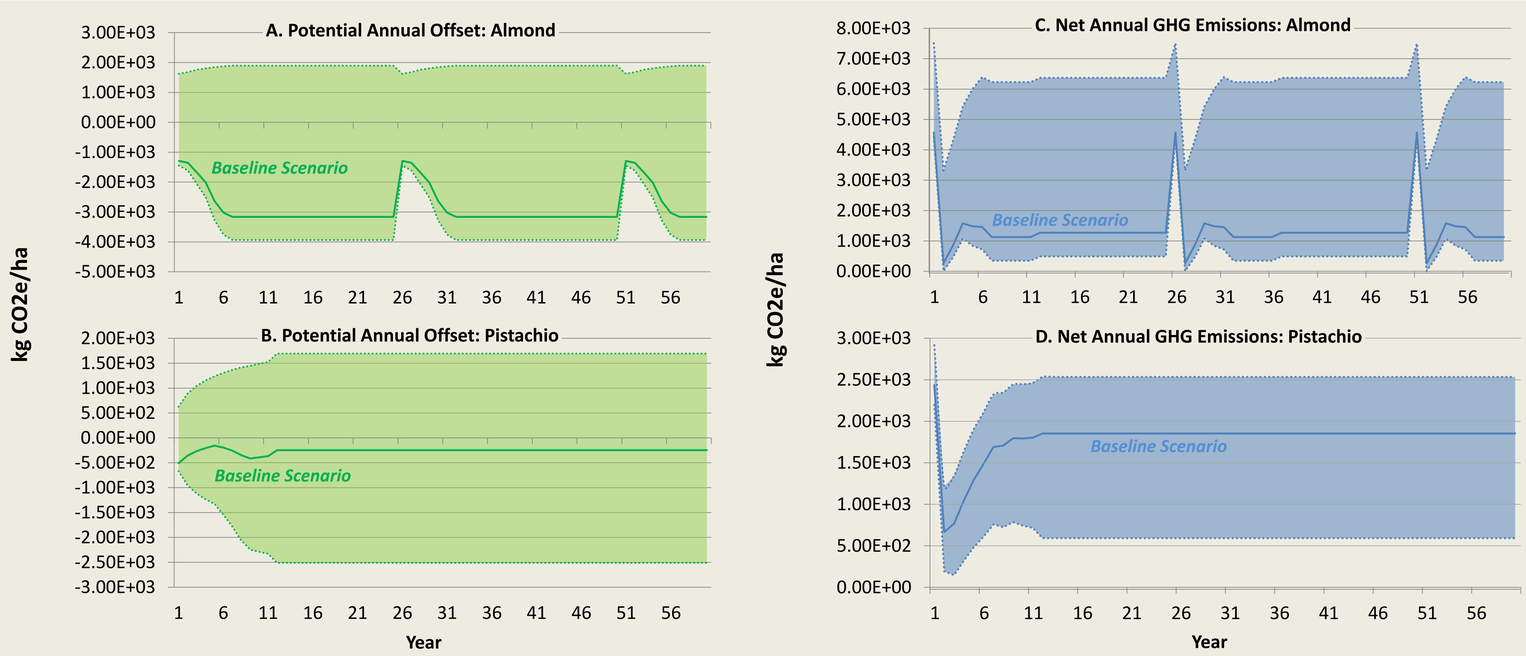

Figure 5. GHG emission and biomass co-product credits over 60 year timeframe for almond and pistachio orchards.

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