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 world’s almonds and 50% of pistachios. Worldwide, GHG and energy use impacts of these systems represent a significant proportion of global agricultural impacts.

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
• Survey and interview
• Life cycle inventory (LCI) databases

Soil and Combustion Emissions
Regionally specific data for N₂O emissions as per IPCC tier 2 methodology
• Direct and indirect emission factors calculated
• OFFROAD model

Transportation
• Transportation emissions modeled based on orchard distribution (Fig 1), with emissions factors from US LCI database

Irrigation
• System energy use calculated based on region, irrigation system, and water source (Fig 1)
• 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, and shells
• Co-products: fate: 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 GWP global warming potential to convert GHG to CO₂eq

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 CO₂ 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.