
Continued assessment of almond orchard performance and soil health following biosolarization using almond residue amendments

Project No.: PATH19

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A. Summary

Soil and tree monitoring were conducted at an orchard that underwent biosolarization in the summer of 2017. The data showed that biosolarized soils had persistent elevation of nitrogen, potassium, carbon, and organic matter. Furthermore, solarized and biosolarized soils showed multi-year control of phytoparasitic nematodes unlike untreated control soils. For the first year of growth, almond trees from Bennett-Hickman, Monterey, and Nonpareil varieties showed slower growth relative to control soils that were not biosolarized. However, in their second year, trees in biosolarized soils began to exhibit increased growth rate with the effect being most pronounced in the Monterey variety. These data suggest that almond trees may require a period of adaptation to biosolarized soils beyond which accelerated tree growth may be observed. Additional monitoring of the field site is required to determine if soil health benefits and accelerated tree growth continue in biosolarized soils and to connect tree growth effects with yield.

B. Objectives

1. Monitor an existing biosolarization field trial site for changes in nematode ecology and re-emergence of phytoparasitic nematodes relative to control soils.
2. Measure trends in soil phytonutrient content between biosolarized and control soils.
3. Measure growth and vigor for trees established in biosolarized and control soils.

C. Results and Discussion

Data from a prior ABC-funded project showed that biosolarization with almond residues led to generation of biopesticidal organic acids in the soil. These may have directly affected soil pests like phytoparasitic nematodes but may also signal soil fermentation and soil oxygen depletion that may also be antagonistic to certain soil pests. Indeed, biosolarization led to more rapid inactivation kinetics for both root lesion and ring nematodes at the field site. Subsequent field operations at the site, such as deep tillage, suppressed remaining phytoparasitic nematodes across all test plots. Periodic monitoring was conducted to determine if reinfestation occurred and, if so, whether reinfestation occurred selectively in certain soil treatments. To date, the data show that root lesion nematode levels have rebounded in the untreated control soils. However, these pests remain suppressed in the biosolarized and solarized soils roughly 30 months after treatment (Figure 1). This long-term control is a significant finding and indicates efficacy on par with conventional soil fumigation.

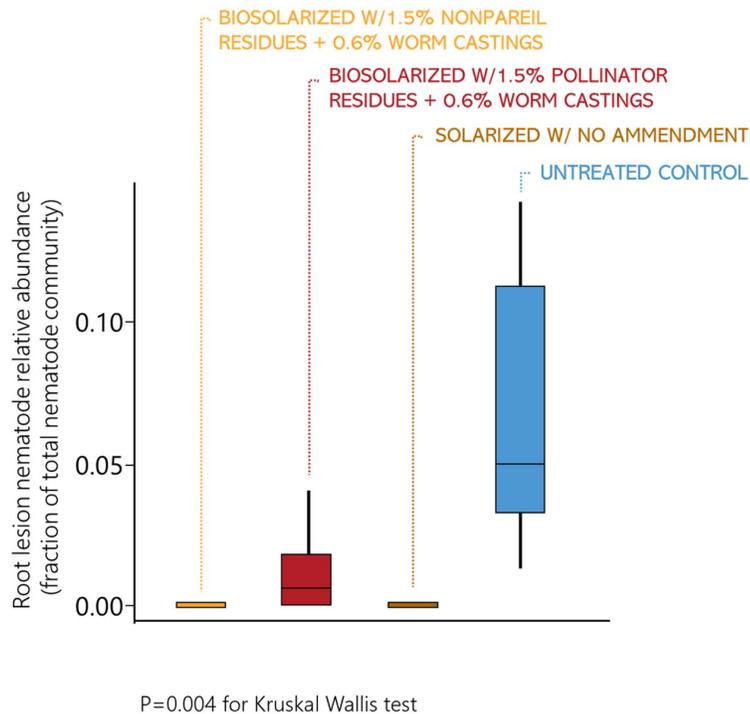


Figure 1. Root lesion nematode (*Pratylenchus penetrans*) levels in treated and untreated soils.

Soil phytonutrient data showed a significant and sustained elevation in soil nitrogen and potassium for the biosolarized plots relative to the control plots ($p < 0.001$ for both as of January 2020) (Figure 2). There were no significant differences in soil phosphorus levels between the treatments (data not shown). Soil carbon measurements also showed significant increases in biosolarized soils compared to controls ($p < 0.001$ for August 2019 timepoint, which represents the most recent measurement) (Figure 2). In agreement with the carbon measurements, soil organic

matter remained significantly elevated in the biosolarized soils compared to the non-amended soils ($p=0.01$). These results indicate that biosolarization with almond residues can deliver long term benefits to soil health as an complementary benefit to pest control. Furthermore, biosolarization with these amendments also led to sequestration of carbon in the soil over the observation period. This may deliver environmental benefits spanning carbon removal from the atmosphere to enhanced water holding capacity of the soil.

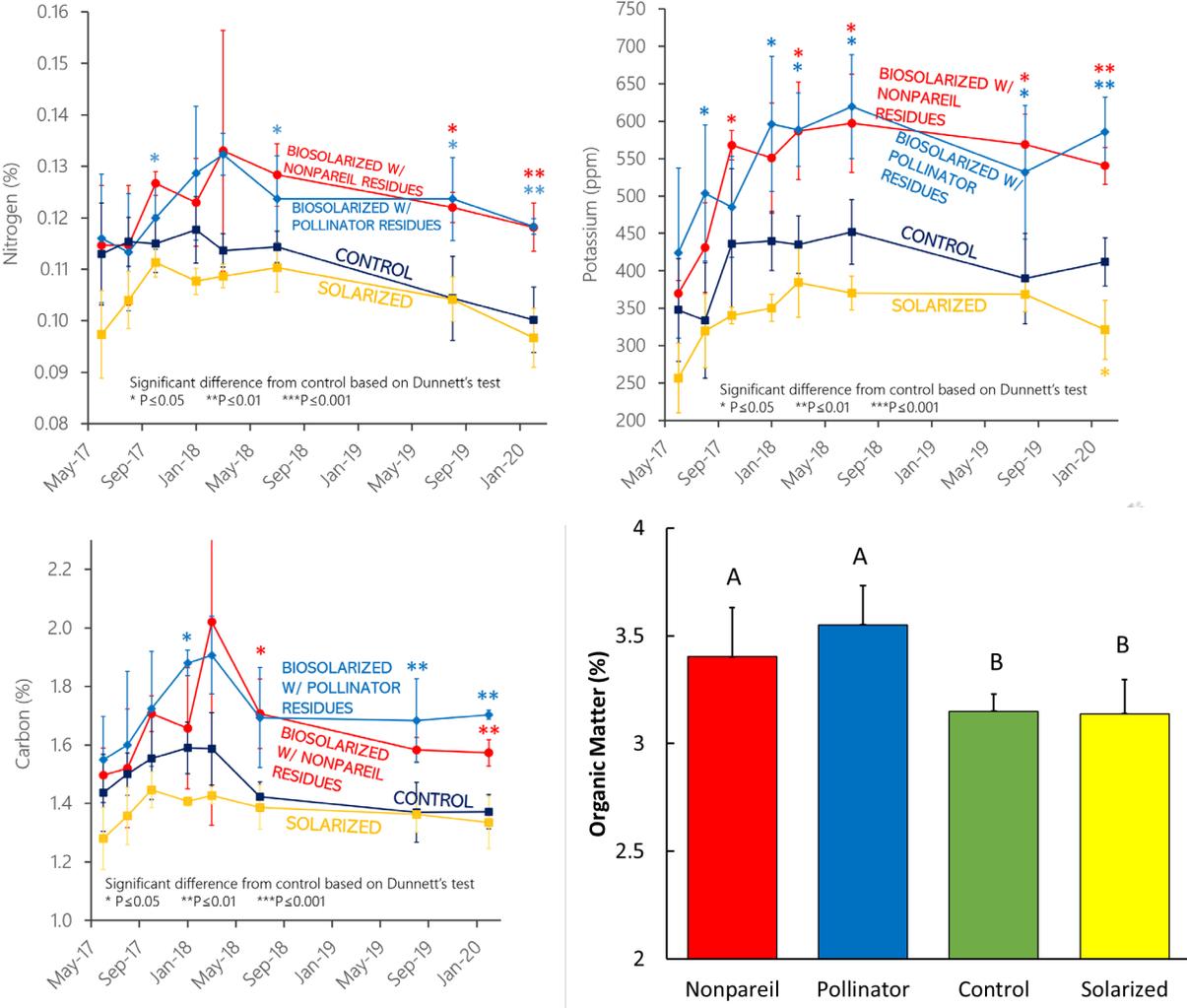


Figure 2. Nitrogen, potassium, carbon, and organic matter content in biosolarized and control soils. Within graphs, labels indicated the biosolarization treatments and their amendments or the control treatments (solarization and completely untreated). In the organic matter figure, data correspond to August of 2019 and columns not connected by the same letter are significantly different ($p<0.05$).

Measurement of trunk diameter initially showed decreased growth rate for all varieties grown in biosolarized soils relative to control soils. However, at the most recent time points roughly 20-24 months after planting, trees in biosolarized soils exhibited accelerated growth. Within that period, each variety had at least one time point where

trees in biosolarized soils showed statistically significant elevations in growth rate compared to trees in untreated control plots (Figure 3). These data indicate that trees require a period of adaptation following biosolarization before increased growth rates are observed. Additional monitoring of the trees is needed to determine if these elevated growth rates are sustained.

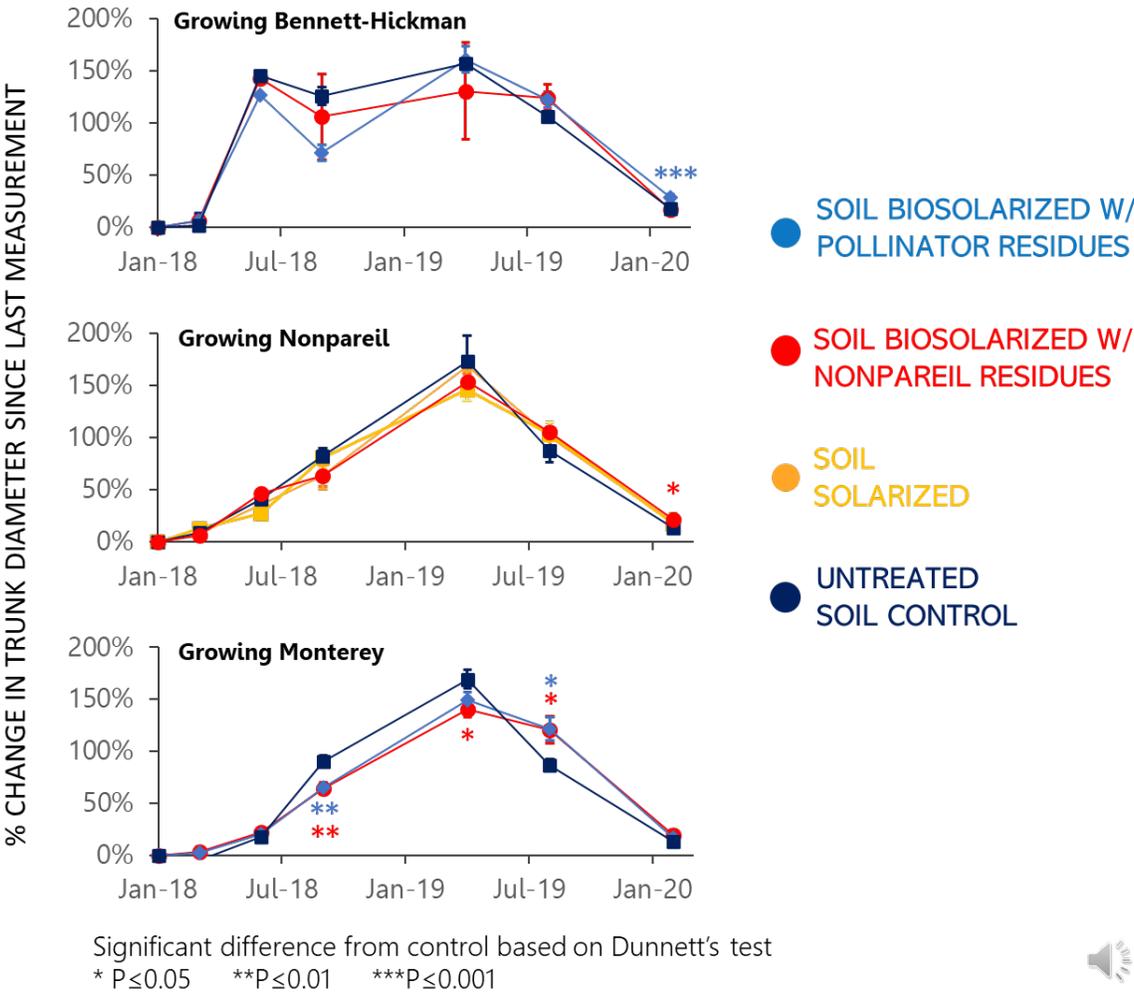


Figure 3. Change in trunk diameter relative to previous timepoint for Bennett-Hickman, Nonpareil, and Monterey varieties grown in biosolarized and control soils.

Multispectral imaging of trees in field plots was used to complement measurements of trunk diameter. Imaging data were used to compute normalized difference vegetation index (NDVI) values for trees grown in each soil treatment. NDVI values provide a measurement of cumulative stress and plant growth over time. The data showed no significant difference in NDVI values across trees grown in the different soil treatments (Figure 4), suggesting similar vigor among the trees. However, NDVI values showed and significant positive correlation (Figure 5), which suggests that observed differences in trunk growth rate may eventually manifest in NDVI value differences.

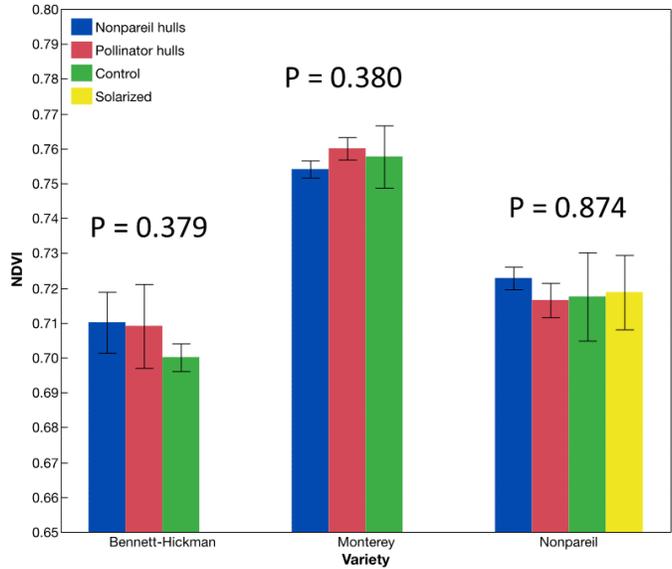


Figure 4. NDVI values for each tree variety grown in each soil treatment. Data represent measurements made in October 2019.

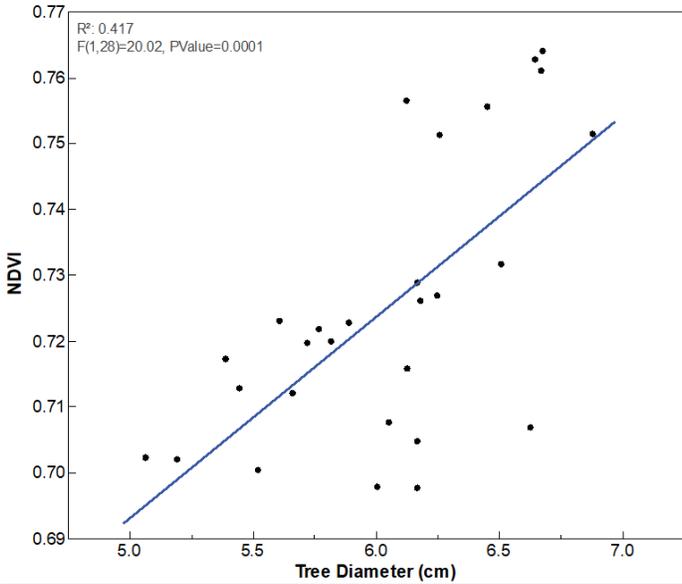


Figure 5. Linear regression of NDVI values against trunk diameter values.

Together, the nematode, soil health, and tree growth data indicate significant benefits associated with biosolarization that may become more pronounced over time. The tree growth data in particular show that trees in biosolarized soils only recently adapted to the amended soils to enter a period of accelerated growth. There is a need for additional monitoring of the field site to determine whether improved growth in biosolarized soils continues. Additionally, observed elevation of nitrogen and carbon in biosolarized soils motivates additional monitoring to define changes in nitrogen transformation and tree uptake along with the longer term carbon sequestration benefits.

D. Outreach Activities

1. Presented current findings of study to stakeholder audience via oral and poster presentations at the 2019 Almond Conference (Dec 11, 2019; Sacramento, CA; Alternatives for Managing Replant Pests and Problematic Weeds; approximately 300 growers, researchers, vendors, and reporters in attendance).
2. Presented current findings of study to stakeholder audience via poster presentation at 2019 Methyl Bromide Alternatives Outreach (MBAO) Conference (Nov 12, 2019; San Diego, CA; Preplant Orchard Biosolarization with Almond Residue Amendments Decreases Lesion and Ring Nematodes in Soil; approximately 120 researchers and growers).
3. Presented current findings of the study to researcher audience via an invited presentation at the 2020 virtual meeting and expo of the American Chemical Society (Aug 20, 2020; Utilization of almond processing residual biomass for soil biosolarization).
4. Interviewed for article “Almond Hulls, Shells Help Fuel an Alternative to Fumigation.” How We Grow; Nov/Dec 2020 issue 12. Almond Board of California.

E. Materials and Methods:

The field site, located on a commercial orchard owned by the Nicolaus Nut Company in Chico, was biosolarized in the summer of 2017. Two biosolarization treatments were used, which used either 1.5% (dry weight basis) nonpareil hull/shell mixture or pollinator hull/shell mixture. Both biosolarization treatments used 0.6% worm castings (dry weight basis) in the soil. All amendments were incorporated down to 7 inches depth. Solarized (i.e., solar heated but lacking amendment) and untreated soils were used as controls. All plots were treated for 6 weeks and then allowed to remain fallow until planting in early 2018. Nonpareil, Bennett-Hickman, and Monterey varieties were planted.

The soil responses and trunk diameters were measured periodically while the multispectral imaging was conducted once in the fall of 2019 when there was abundant vegetation. To mirror the sampling approach used in the prior project, three planted rows from each soil treatment were sampled from for each of the tree almond varieties. Several 12-inch soil core samples were obtained across each row and consolidated for analysis. 36 trees were randomly selected for growth measurement from each row.

Total and phytoparasitic nematodes, particularly ring and root lesion nematodes, were measured in soil samples to determine if the historic infestation at the site had been selectively controlled long-term via biosolarization. Nematode metabolic footprints were also calculated, which estimated the contribution of different functional guilds of nematodes to carbon and nutrient cycling based on their size-dependent metabolic activity. The structure metabolic footprint was used to quantify the trophic complexity of the nematode food web and its contribution to pest suppression, while the enrichment footprint measured nematodes involved in nutrient processing.

Measures of soil health, including major plant nutrient content and organic matter content were tracked in soil samples to determine whether soil amendment with almond biomass during biosolarization delivered long term benefits to agriculturally relevant soil properties.

Trunk diameter was measured as a common metric of tree growth. This was complemented by aerial multispectral imaging data from which normalized difference vegetation index (NDVI) values were calculated.

F. Publications that emerged from this work

1. Submitted to Applied Soil Ecology: Shea, Emily; Fernandez-Bayo, Jesus; Hodson, Amanda; Parr, Amy; Lopez, Emily; Achmon, Yigal; Toniato, Juliano; Milkereit, Janina; Crowley, Rory; Stapleton, James; VanderGheynst, Jean; Simmons, Christopher. Preplant Orchard Biosolarization with Almond Residue Amendments Decreases *Pratylenchus vulnus* and *Mesocriconema xenoplax* levels in soil.
2. Published: Shea, Emily and Simmons, Christopher. New Outlooks for Hull and Shell Management Options Using Biosolarization. West Coast Nut. November 2019 Issue < <https://www.wcngg.com/2019/11/04/new-outlooks-for-hull-and-shell-management-options-using-biosolarization/>>