# FINAL REPORT

# Evaluating benefits of secondary crops on Yuma soil health

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## 1. Background and Objectives

In a 2020 survey by the Yuma County Cooperative Extension, soil health conservation was identified as a top research priority preferred by local growers. The USDA defines *soil health* as the continued capacity of soil to function as a vital, living ecosystem that sustains plants, animals, and humans. Conserving and improving soil health in Yuma and other desert croplands will help ensure the long-term sustainability of global food production.

Declining soil health is related to a breakdown of the physical, chemical, and biological structure of soils. The biggest cause of this breakdown is depletion of soil organic matter (SOM). Desert soils start with little SOM and are very slow to accumulate it naturally. Therefore, Yuma soil health will decline over time if SOM decreases. Soils with less SOM tend to have a lower capacity to hold water, resist erosion, supply nutrients, and support diverse microbial communities that can help fend off crop pests and pathogens such as Fusarium wilt of lettuce.

Therefore, Yuma growers urgently need proven methods to improve soil health. Growers also need a framework for evaluating soil health that is tailored for desert agriculture. In a national survey of agricultural research needs, the top-ranked issue was developing soil health best management practices to build SOM.

Secondary cropping is one potential solution for improving multiple components of soil health, including SOM. Secondary and cover crops provide physical soil cover during the "off season" when primary cash crops cannot be grown. After incorporating secondary and cover crops into soils, the residues can provide much needed organic matter that directly improves physical and chemical soil health and indirectly improves biological soil health by feeding beneficial microorganisms.

Although most secondary and cover crop research has been done in wetter regions, benefits to soil health may be greatest in arid regions. It is assumed that secondary cropping benefits soil health in dry climates similar to wet climates. However, there are no data quantifying the net effects of secondary crops on multiple components of desert soil health. For example, cover/secondary crops increase soil microbial abundance, activity, and diversity in wetter climates, but what about in a hyper-arid climate like Yuma?

Therefore, the primary objective of this seed grant project was to advance the development and validation of secondary cropping best management practices (BMPs) to improve desert soil health. My research team quantified effects of multiple Yuma secondary crops on a suite of physical, chemical, and biological soil health metrics to answer the following research questions:

(1) Does secondary cropping improve soil health compared to bare, fallow soil?

(2) If so, which type of currently used secondary crop has the greatest benefits to soil health—wheat or sudangrass?

## 2. Methods

To address the primary research objective, my team compared effects of wheat, sudangrass, and no secondary crop (i.e., bare fallow) on soil organic matter (SOM) and other key physical, chemical, and biological desert soil health metrics at JV Farms in Yuma Valley. All three blocks had the same soil type and winter vegetable crop (iceberg lettuce), but the blocks were treated differently during the spring and summer of 2020. Durum wheat grew in the first block, sorghum-sudangrass grew in the second block, and the third block was left bare fallow without a spring/summer secondary crop. In each of the three blocks, we randomly selected eight locations to collect soil samples (24 total locations). Each location was at least 30 feet apart to capture spatial variation in soil and crop health. To assess soil health after secondary crops were incorporated but before fall vegetables were planted, we sampled soils (0-6 inches deep) on July 13$^{th}$, 2020 after secondary crop residues were disked into soils.

The field-based soil health metrics consisted of bulk density (AMS bulk density sampler) and water infiltration (METER Group mini-disk infiltrometer). The laboratory-based soil health metrics consisted of water-holding capacity, alkalinity, salinity, plant-available phosphorus, total nitrogen, total carbon (primarily SOM), microbial activity/biodegradable SOM, and microbial abundance and diversity. Water-holding capacity was measured to assess soil water storage using the gravimetric method. Alkalinity was measured using a pH meter. Salinity was measured using an electrical conductivity meter. Carbon, nitrogen, and Olsen-extractable phosphorus were measured using an elemental combustion system and microplate spectrophotometer. Biodegradable SOM and microbial activity were measured using a 4-day respiration incubation. Microbial abundances and diversity were measured using phospholipid fatty acid (PLFA) analysis. Because of the cost of PLFA analysis, for this measurement only, we combined soils across all locations and depths within a block to create three analytical replicates per treatment. A one-way analysis of variance (ANOVA) test was used for each soil health metric to identify statistical differences between wheat, sudangrass, and fallow treatments.

## 3. Results

*Physical soil health metrics*

Sudangrass increased soil bulk density relative to bare fallow conditions, but wheat showed no difference with bare fallow. Both sudangrass and wheat increased soil water-holding capacity relative to bare fallow. Neither secondary crop altered water infiltration rate relative to bare fallow.

*Chemical soil health metrics*

There was no effect of either secondary crop on soil pH relative to bare fallow. Wheat had higher soil salinity (564 μS/cm) than sudangrass (219 μS/cm), but neither was statistically different from bare fallow (334 μS/cm). Total soil carbon was greater in both sudangrass (1.97% by soil mass) and wheat (2.00%) than in bare fallow (1.87%). Total soil nitrogen was greatest in bare fallow (0.064% by soil mass), lowest in wheat (0.051%), and intermediate in sudangrass (0.057%). Soil carbon-to-nitrogen ratio was highest in wheat (39.2), which is indicative of nitrogen limitation, but lowest in bare fallow (29.5) and intermediate in sudangrass (34.5). Plant-available soil phosphorus was greatest in wheat (33 ppm), lowest in sudangrass (20 ppm), and intermediate in bare fallow (26 ppm).

*Biological soil health metrics*

Cumulative 4-day $CO_2$ emission from soils was greatest in wheat (127 mg C/g soil) and significantly lower for both sudangrass (69 mg C/g soil) and bare fallow (54 mg C/g soil). Soil microbial community PLFA measurements showed: 1) the most total fungi in sudangrass and the least total fungi in wheat (with bare fallow intermediate); 2) the most arbuscular mycorrhizal fungi in sudangrass relative to bare fallow and wheat; 3) the highest fungi-to-bacteria ratio in sudangrass and the lowest fungi-to-bacteria ratio in wheat (with bare fallow intermediate); 4) the lowest gram positive-to-gram negative bacterial ratio in sudangrass indicative of a more balanced and diverse bacterial community; 5) the highest gram-negative bacterial stress in wheat; and 6) more actinomycetes in bare fallow and wheat relative to sudangrass.

## 4. Conclusions

***Does secondary cropping improve soil health compared to bare, fallow soil?***

For physical indicators of soil health, it depends. For water-holding capacity, secondary crops were beneficial. But for soil bulk density and hydraulic conductivity, secondary crops either had no effect or were harmful.

For chemical indicators of soil health, secondary crops were beneficial for soil carbon. But, otherwise, secondary crops either had no effect compared to bare fallow (i.e., pH, salinity, phosphorus) or were harmful (i.e., greater nitrogen limitation).

For biological indicators of soil health, effects were highly dependent on the type of secondary crop (see more below).

***If so, which type of currently used secondary crop has the greatest benefits to soil health—wheat or sudangrass?***

For physical indicators of soil health, both secondary crops had similar effects.

For chemical indicators of soil health, sudangrass was more beneficial than wheat because sudangrass did not increase soil salinity (compared to bare fallow) and did not cause as much nitrogen limitation.

For biological indicators of soil health, sudangrass was more beneficial than wheat because sudangrass promoted more total and arbuscular mycorrhizal fungi, showed less gram-negative bacterial stress, and showed a more balanced and diverse bacterial community.

Therefore, I recommend planting sudangrass instead of wheat in desert cropping rotations when possible because sudangrass has larger number of benefits for soil health.

## 5. Products

*Manuscript in preparation*

Blankinship JC, Hoglund SR, and SJ Rathke. Effects of secondary crops on soil health in desert agriculture compare to bare fallow conditions. *Plant and Soil.*

*Oral Presentations*

Invited Presentation, "The dry side of soil health: Developing a new framework for measuring and enhancing soil health in arid agroecosystems." USDA NRCS Dynamic Soil Properties for Soil Health (DSP4SH) Annual Meeting, Virtual (2021)

Presentation, "Hung out to dry: How the reliance on metrics developed for soil health assessment in temperate systems may lead to erroneous management advice in arid systems." National Cooperative Soil Survey National Conference, Virtual (2021)

Invited Presentation, "Roles and opportunities of organic matter and microorganisms for arid soil health," Southwest Agricultural Summit, Yuma, AZ (2021)

Invited Presentation, "Soil health research in desert cropping systems." Yuma Center of Excellence for Desert Agriculture Donor/Board of Directors Meeting, Virtual (2021)

Invited Presentation, "Assessing and enhancing soil health to mitigate dust, rehabilitate rangelands, and sustain croplands." Environmental Science Departmental Seminar, University of Arizona, Tucson, AZ (2021)

Invited Presentation "Soil organic matter as a holistic indicator of soil health." Desert Southwest Soil Health Webinar, Virtual. (2020)

Invited Presentation, "Evaluating and nurturing soil health in desert agriculture," Southwest Agricultural Summit, Yuma, AZ (2020)

Invited Presentation, "Assessing and enhancing soil health to mitigate dust, rehabilitate rangelands, and sustain croplands." Forestry Departmental Seminar, Northern Arizona University, Virtual (2020)

## 6. Return on Investment

**A) Funded Federal Grant, Sole PI, 2022-2024, "Improving assessment and management of soil health in xeric croplands." USDA Natural Resources Conservation Service, $204,033.**
The first year of the project is a continued collaboration with JV Farms that focuses on comparing effects of four different cropping rotations, including bare fallow and a novel cover crop (sesbania), on a broader suite of soil health metrics tailored to desert croplands.

**B) Desert Agriculture Soil Health Initiative (DASHI), in collaboration with YCEDA, 2023-2024, $72,500 of industry contributions so far.**

There are three initial phases of DASHI during the 2023-24 academic year that will jump start this initiative for decades to come. The first phase is a workshop in Yuma in November 2023 with crop growers to identify and align on essential components of healthy desert agricultural soils, what growers view as success when managing soil health, common threats and barriers preventing soil health improvement, and high-priority knowledge gaps about desert cropland soil health for researchers to address--including soil health assessment, water and salt management, nutrient management, crop nutrient density, carbon and climate-smart agriculture, food safety, and soil-borne pathogens. The second phase is a Desert Agriculture Research Symposium on Soil Health in Yuma in January 2024 for researchers to communicate cutting-edge science and participate in a workshop to map knowledge gaps, define expert networks, and build teams to target specific funding opportunities. The third phase is to develop and distribute a comprehensive strategic plan in spring 2024 for advancing the science and practicality of desert agricultural soil health, as well as outreach in Washington, D.C. to encourage funding managers and policymakers. Another essential component of the third phase of this initiative is to form industry partnerships with soil health-promoting companies, including manufacturers and retailers of fertilizers, mineral soil amendments, compost, biochar, microbial inoculants, field equipment, and remote sensing technologies.

**C) Pending Federal Grant, Co-PI with PI Debankur Sanyal, 2024-2028, "Evaluating the impacts of novel crop rotations on soil health and sustainability of the desert agroecosystems." USDA AFRI Foundational Program, $749,975.**

The proposed goals and objectives are to 1) evaluate novel crop rotations for water use, soil health improvement, and cash crop (cotton and wheat) production; 2) evaluate the impacts of the novel crop rotations on soil health and crop productivity under current and future climatic conditions at the regional scale; and 3) develop intensive and inclusive education and outreach opportunities to facilitate and promote the adoption of novel approaches for soil health improvements in the desert agroecosystems.