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Investigating Soil Health Changes After Irrigation Sanitizer Application in Desert Southwest Production Systems

Part I: A Guide to Soil Health

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Purpose of This Series

This is the first in a series of articles evaluating soil health in agricultural systems that utilize pre-harvest irrigation water treatments. The purpose of this first installation is to define soil health and how it is measured, prior to the following installations which will describe the soil health status of fields after treatment.

What is Soil Health?

Soil is an integral part of all ecosystems, including agricultural ecosystems. This is due to the fact that soil is the point where the atmosphere (the planet's air), the biosphere (the planet's living things), the hydrosphere (the planet's water), and the lithosphere (the planet's rock) meet. These connections, pictured in Figure 1, work together to make life possible.

Measuring soil health is complex and considers many different but interrelated parameters. These parameters determine the soil's abilities (e.g., filtering water, storing carbon, and helping with plant growth; NRCS, accessed December 10, 2025). These functions often require a diverse and abundant microbiome, which are the collection of bacteria, viruses, and fungi within the soil (Rieke & Cappellazzi, 2021). The microbiota, perform actions like forming plant-available nutrients in exchange for easy-to-digest carbon sources that they use as food (Ahammed et al., 2025).

Assessing Soil Health

Soil health indicators (SHIs) are selected soil properties that can be monitored to assess the overall health of soil. Currently, the US Department of Agriculture (USDA) Natural Resources Conservation Service (NRCS), lists a range of indicators including forms of soil carbon and nitrogen as well as soil physical and chemical properties that are especially useful when assessing the health of soil.

These parameters can be utilized not only to determine the health status of the soil, but also to determine steps that can be taken to improve soil function (e.g., increasing crop yield through supplemental nitrogen additions). Soil sampling throughout the year can be an important tool used to understand the current soil health profile for a field. Utilizing soil monitoring allows the grower to have a more complete picture of the status of the soil and can inform the best treatment for their crop or soil.

Soil Carbon

Soil carbon can be incredibly beneficial to soil health. The soil carbon fractions (the different types of carbon within the soil) listed in Table 1 are used as indicators of soil health, and include organic and inorganic carbon fractions, as well as indicators of carbon cycling. While it

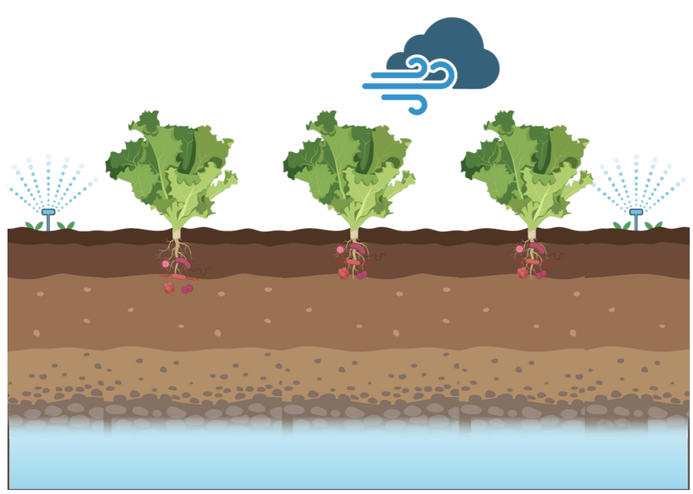

Figure 1. Soil is at the center of every ecosystem, where the atmosphere (the air), biosphere (all life, including plants and microbes), the hydrosphere (all water, including irrigation and groundwater), and the lithosphere (rock, including the mineral soil) meet.

Table 1. Indicators of soil carbon dynamics, including total soil carbon, soil organic carbon, soil inorganic carbon, soil organic matter, soil respiration, permanganate-oxidizable carbon, and ß-glucosidase. These SHIs give insight into the potential and actualized ability of the soil to support microbial and plant life.

Soil Carbon Parameters	Abbreviation	Explanation
Total Soil Carbon	TC	The total amount of carbon in the soil.
Soil Organic Carbon	SOC	The carbon in the soil that is held within soil organic matter.
Soil Inorganic Carbon	SIC	The mineral form of carbon, like calcium carbonate, also known as 'caliche.'
Soil Organic Matter	SOM	The decomposing plant and animal tissues in soil.
Soil Respiration	SR	The carbon dioxide released from the soil as microbes perform their functions; also known as 'carbon mineralization' or 'CO2 burst.'
Permanganate-Oxidizable Carbon	POx-C	A measurement of the preferred food source of microbes in the soils.
Beta (ß) - glucosidase		An enzyme secreted by soil microorganisms, which breaks down complex carbon like cellulose into molecules which microbes can more easily consume.

can be helpful to know the total amount of carbon in the soil, knowing the various forms of carbon can help assess different functions in the soil as well.

Organic carbon fractions in the soil include the carbon derived from once-living things. Those which are considered indicative of soil health are soil organic carbon (SOC; the total amount of organic carbon in the soil), active carbon (measured as permanganate-oxidizable carbon; the ideal food source for microbiota in the soil), soil organic matter (SOM; indicative of how much decomposing plant and microbial tissue is in the soil), and ß-glucosidase (beta-glucosidase; an enzyme that is produced that helps break down hard-to-digest molecules into easy-to-digest molecules for soil microbiota). These carbon indicators all serve functions in the soil, typically to do with providing a food source for microbes, who can in turn provide nutrients for plants. As these carbon fractions tend to be low in Arizona's soils, it is most often beneficial to add organic carbon into your soil. Treatment recommendations include cover cropping various species like grasses, which can add in organic carbon fractions to the soil while acting as an armor against wind and water erosion (Arp et al., 2024; Sanyal & Arp, 2025) and the application of organic amendments like compost or biochar.

Inorganic carbon fractions include soil inorganic carbon (SIC; calcium carbonate) and soil respiration (the amount of carbon dioxide microbes "breathe out" when they perform their activities). Soil respiration will naturally increase with the addition of more organic carbon, which will spike microbial activity. Soils in the US Southwest tend to have a high amount of SIC, leading to a buildup of caliche. Caliche is a cement-like crust or chunks of lime in or on the soil (University of Arizona Cooperative Extension, 2025). This crusting can prevent water infiltration during irrigation events, creating more runoff and evaporation, decreasing irrigation efficiency. Because SIC occurs naturally in the soils in the region, it is important to increase SOC fractions through amendments to adjust the ratio of SOC to SIC, as SIC cannot be removed from the soil. Additionally, for growers looking to manage caliche in their soils, the University of Arizona Cooperative Extension released a quick guide in 2025 with management tips and tricks.

Soil Nitrogen

Even though the planet's atmosphere is almost 80 percent nitrogen, this gaseous nitrogen (the nitrogen in gas form) is not accessible to crops. Therefore, plants team up with soil microbes that can take the nitrogen from the air and turn it into the plant-available mineral form. Soil nitrogen is one of the most important parameters that can limit plant growth in agroecosystems (Zak & Whitford, 1988; Cui et al., 2019). The NRCS-recognized nitrogen parameters are included in Table 2 below. and much like soil carbon, this includes both organic and inorganic forms of nitrogen.

Organic forms of nitrogen include soil proteins (which are proteins from plants and microbes, which serve as nitrogen stores in the soil that are harder to break down) and potentially mineralizable nitrogen (the nitrogen in organic matter that microbes can more easily transform into

Table 2. Soil nitrogen fractions including total soil nitrogen, soil nitrates, potentially mineralizable nitrogen, and soil protein. These SHIs and parameters are indicative of a soil's resilience and ability to resist erosion and degradation, as soil nitrogen fractions are not only important to the soil microbes, but to the plants as well.

Soil Nitrogen Parameters	Abbreviation	Explanation
Total Soil Nitrogen	TN	The total amount of nitrogen in the soil in all forms.
Nitrates	NO_3	The mineral carbon fraction that plants can readily consume. Also called available nitrogen.
Potentially Mineralizable Nitrogen	PMN	Organic nitrogen available for microbial consumption in the soil that can be mineralized, or transformed, into mineral nitrogen fractions that plants can consume.
Soil Protein	ACE Protein	An organic nitrogen fraction that exists within the proteins inside of the soil. These proteins are produced by plants and microbes, and can be broken down to create more available nitrogen that plants can consume.

ammonium and nitrates). Inorganic forms of nitrogen are mainly soil nitrates, which some microbes can create when given organic nitrogen (Grzyb et al., 2021). By increasing organic matter in the soil using the same recommendations to increase soil organic carbon, you can reduce the required amount of nitrogen amendments throughout the growing season. Additionally, cover cropping leguminous plants is especially helpful, as these are species that can host nitrogen fixing bacteria in their root systems that will naturally add more nitrogen into the soil.

Soil Physical & Chemical Properties

Soil physical and chemical properties include soil pH, which is the measurement of how acidic or alkaline the soil is, soil electrical conductivity (EC), which is a measurement of the salts in the soil, as well as aggregate stability (how resistant the soil is to erosion) and nutrient composition (mostly plant macro- and micronutrients like calcium, iron, manganese, among others). A list and summary of these parameters is included in Table 3. Together, these various properties can paint a picture of how much food and water is available to the plants and microbes in the soil. With fewer stable aggregates (a lower wet aggregate stability value), the soil is more susceptible to erosion, which can lead to nutrient loss and pollution of the local ecosystem. With more alkalinity (high pH), plants may not be able to take up as many nutrients. With more salts (higher soil EC), plants may be unable to take up essential nutrients and water. These are all qualities the soils in the Southwest tend to share.

Because these fields in the US Southwest tend to have these qualities, treatment may be required to maximize yield. If a particular field has low aggregate stability, a gradual approach of cover cropping to increase organic carbon fractions in the soil could help. Increasing aggregate stability by improving soil organic matter can have effects like helping salts leach from the soil as well. If the soils have a high measured pH (e.g., the pH exceeds 8), additional sulfur-based amendments such as sulfur burner can also be useful to bring the pH to a more neutral range (Mullen et al., 2016). The addition of gypsum followed by leaching the soil with plenty of water can help mitigate sodium and salt concentrations as well (Bello et al., 2021).

Conclusion

Production systems that use pre-harvest agricultural water treatments apply the water/antimicrobial mixture to the crops and soils. As so much of soil health is dependent on the soil microbiota, measuring soil health in treated operations provides insights into what changes may (or may not) be happening. In such assessments, noting the interplay between the SHIs is of key importance. This type of complex assessment can provide insight into measures that can be taken to improve the ability of the soil to perform ecosystem functions, including increasing crop yield.

Assessing soil health and soil properties can be done through commercial soil health labs. While cost varies between each lab, ranges of costs that can be expected are

Table 3. Additional soil physical and chemical properties, including soil pH, soil electrical conductivity or soluble salts, cation exchange capacity, wet aggregate stability, and exchangeable nutrient composition. These properties can provide insight into a soil's resilience to weather-related stressors, ability to resist degradation, and ability to provide key nutrients to the plants and microbes within.

Soil Physical/Chemical Property	Abbreviation	Summary
Soil pH	pH	A measurement of the acidity or alkalinity of the soil, with a pH of 7 being neutral (like that of water). Neutral pH is often beneficial to crops, as it allows many nutrients to be available within the soil.
Soil soluble salts	EC	A measurement of the amount of salts in the soil. High salt concentrations can create osmotic stress, ensuring that less water is able to penetrate into the plant if there are more salts in the soil.
Cation exchange capacity	CEC	A measurement of the exchangeable ions, or nutrients, within the soil.
Wet aggregate stability	WAS	The resilience of the soil, or its ability to resist erosion or degradation. With more stable aggregates, there is greater potential for water infiltration and soil aeration, allowing plants and microbes more access to air and water.
Exchangeable [cation]	%[Cation] (e.g., %Ca)	Specific concentrations of nutrient ions in the soil.

provided in Table 4. These ranges are compiled from three prominent commercial laboratories, including the Cornell Soil Health Laboratory (Cornell Soil Health Laboratory, accessed December 27, 2025), WARD Laboratories (WARD Laboratories, Inc., accessed December 27, 2025), and Oregon State University's Soil Labs (Oregon State University Crop & Soil Science, 2025) . While each soil test can be relatively inexpensive, performing all tests can be fairly costly. These costs can be mitigated by:

1. Ordering bundles of soil tests.
   - Most or all commercial laboratories will have bundle options available that allow for many soil health tests to be performed for more affordable prices. The cost can vary from $25-$150 per sample depending on how many tests you wish to have done.
2. Reducing how often you test.
   - Not all tests need to be performed frequently. Some tests like cation exchange capacity, wet aggregate stability, and others are unlikely to change significantly throughout the year, and therefore can be performed annually or every two years.
3. Working directly with an agronomist like those at the University of Arizona's Cooperative Extension's Sanyal Soil Health Lab.
   - Agronomists often have preexisting ties to commercial labs, may sometimes be able to perform tests in-house for reduced cost, and can assist with identifying which packages are the most cost-effective and necessary.

Once such assessments are completed, it is possible to make informed decisions about treatments, many of which involve increasing soil cover and biodiversity by the use of cover crops, which can increase some key soil parameters that are important to microbial and plant growth and function. Additionally, the unique characteristics of the US Desert Southwest tend to suggest the soils may benefit from additional sulfur amendments to reduce the pH to a more neutral range. Ultimately, the management of the soil and any additional steps taken depend on the desires of the growers.

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Table 4. Cost estimates for soil property tests gathered from the Cornell Soil Health Laboratory, WARD Laboratories, and Oregon State University Soil Labs. Similar prices are expected at different commercial laboratories, though it may often be cheaper to go through an agronomist like those at the University of Arizona Cooperative Extension's Sanyal Soil Health Lab. A timeline of one year or longer in between sampling and testing events is likely suitable; exceptions are for nutrients like nitrates and phosphorus, which are more likely to limit yield.

Test	How Often Should You Test?	Expected Cost Per Sample
Total Carbon	Annually	$10-$30 (includes Organic Carbon, Total Nitrogen)
Soil Organic Carbon	Annually	$10-$30 (includes Total Carbon, Total Nitrogen)
Soil Inorganic Carbon	Annually	$7
Soil Organic Matter	Annually	$11.50
Soil Respiration	Annually	$18-$30
Active Carbon (POx-C)	Seasonally	$18-$30
ß-Glucosidase Enzyme	Annually	$29
Total Nitrogen	Annually	$10-$30 (includes Total Carbon, Organic Carbon)
Soil Nitrates	Seasonally	$33
Potentially Mineralizable Nitrogen (PMN)	Annually	$19-$21
Soil Protein (Autoclaved Citrate-Extractable Protein)	Annually	$17-$30
Soil pH	Annually	$9
Soil Electrical Conductivity (Soil Soluble Salts)	Annually	$15
Cation Exchange Capacity	Annually	$31
Wet Aggregate Stability	Annually	$30-$38
Available Phosphorus	Seasonally	$18
Other Nutrients	Annually	$26-$53

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