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IMPROVING SOIL QUALITY ON IRRIGATED SOILS IN THE COLUMBIA BASIN

By
David Granatstein, Sustainable Agriculture Specialist, WSU Extension & CSANR, Wenatchee, WA. **Andrew McGuire**, Irrigated Cropping Systems Agronomist, WSU Extension & CSANR, Moses Lake, WA. **Mark Amara**, Moses Lake, WA

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Soil Quality

Soil quality or health can be defined as the capacity of a specific kind of soil to function, within natural or managed ecosystem boundaries, to (1) sustain plant and animal productivity, (2) maintain or enhance water and air quality, and (3) support human health and habitation (Karlen et al. 1997). Soil quality encompasses the interrelated physical, chemical, and biological aspects of soil. For example, soil organisms decompose crop residues to release nutrients and drive the nitrogen cycle (mineralization, immobilization, denitrification). Soil fungi play a large role in formation of soil aggregates and structure, a physical property. Soil biota are in turn affected by soil pH (chemical property) where there is generally lower biological activity in more acidic soils, and waterlogging or compaction of soil (physical properties) often favor anaerobic organisms, some of which cause disease and others that cause nitrogen loss via gaseous forms (Granatstein 2003). Some soil properties, such as soil respiration, change quickly and are highly variable while others, like soil carbon, can take years or decades to change. Soil texture (sand, silt, clay) is generally considered fixed, but organic matter levels can ameliorate some of the negatives. For example, sandy soils have good aeration and drainage but relatively poor water-holding capacity and nutrient retention. Organic matter can increase the latter two. On the other end of the spectrum, clay soils have high water and nutrient retention but poor aeration and physical structure, and organic matter can address these limitations.

The soil properties are influenced by the natural environment (e.g., climate, geology, vegetation) as well as by human activity (e.g., erosion, fertilization, irrigation, plants). However, soil quality itself is not a soil property but rather a human judgment about how well a given soil can perform desired functions (Sojka and Upchurch 1999). Soil quality is important to growers since it plays a large role in crop production as well as on the environmental performance of a farm, affecting soil erosion, air and water quality, and greenhouse gas relations.

One factor in evaluating soil quality is your reference point. Often it has been the native soil in your location. So the prairie or grassland soils are a reasonable reference point for soil quality in a wheat field in Kansas or the Palouse. However, many soils had very different properties in their native ecosystems compared with their status when farmed, as is the case for the irrigated Columbia Basin. What should be the reference point for an irrigated potato field in Washington State that was once shrub-steppe? Perhaps pasture becomes the most universal reference point for most temperate agricultural soils, as it exhibits many favorable soil properties for crop production. Or the direction of change in a soil can be used; with evaluation over years, you can determine whether the soil is being improved or degraded for the particular properties of interest. The reference point then becomes when you started evaluation.

Evaluations of soil quality rely on choosing a set of indicator properties that can be quantitatively measured and related to a baseline or reference point for comparison. Indicators should reflect a problem to be solved or a desired state to be achieved. For example, if poor water infiltration is a problem, then indicators related to this property such as infiltration rate should be used to monitor whether management changes have the desired effect. Various studies have sought to find an ideal suite of soil measurements for evaluating soil quality (Hefner et al. 2009; Moebius-Clune et al. 2016). Of these, one of the better developed and practical is the Cornell Soil Health Assessment which measures 10 properties, normalizes them, rates them according to specific criteria, and then calculates an overall soil health rating. However, this assessment was developed for soils in the northeastern US, which differ greatly from western US soils in organic matter levels (higher) and chemical properties (more highly weathered, in general). Therefore, this test can be useful in comparing different management but may not reflect optimal conditions for western US soils. Often the crop itself can be used as an indicator of soil quality change, as it integrates the effects of the different soil properties. Improved crop performance is an outcome desired by growers and one they can usually measure quantitatively.

Soils and Columbia Basin Agriculture

Irrigated growers in the Columbia Basin of Washington State have expressed increased interest in improving soil quality and in learning about the benefits versus the costs of implementing soil improvement practices. In addition, producers have been under increasing public scrutiny concerning efforts to maintain and improve soil resources, especially for off-farm impacts such as wind erosion and water quality. A 2012 survey of attendees at the WSU Building Soils for Better Crops Workshop in Moses Lake, Washington, showed that 73% had increased their use of soil improvement practices in the last five years, with “improved soil tilth” as the most recognized benefit (Granatstein and McGuire 2012).

The soils in the western US are much different than those in the eastern part of the country, where the concept of soil quality was developed (Doran and Parkin 1994). In the Columbia Basin, the arid climate and sandy textures have produced soils naturally low in organic matter. If these soils were found in the central Corn Belt, their organic matter levels would be considered inadequate for proper function (Loveland and Webb 2003). Yet with irrigation, agricultural inputs, and management, they can be highly productive. Nevertheless, farmers do have challenges with these soils.

Columbia Basin soils are susceptible to wind erosion, especially during the spring and fall when bare soils often coincide with high wind events (Figure 1). Water erosion caused by irrigating soils that have low infiltration rates (the result of intensive tillage and associated loss of soil aggregates) can also be a problem. Related problems of soil crusting, poor drainage, and ponding can cause reductions in crop growth and yield. Soils often have low buffering capacity and can experience an undesirable pH decline due to continued use of acid-forming nitrogen fertilizers (Bouman et al. 1995).

While the low level of organic matter in soils causes some problems, it also allows for improvement. Since the 1950s, when irrigation and higher yielding crops were introduced to the Columbia Basin, organic matter has generally increased over the native levels of less than 1% (Cochran et al. 2006). This is in stark contrast to the Midwest where farmers struggle to maintain high organic matter levels formed under tallgrass prairie.

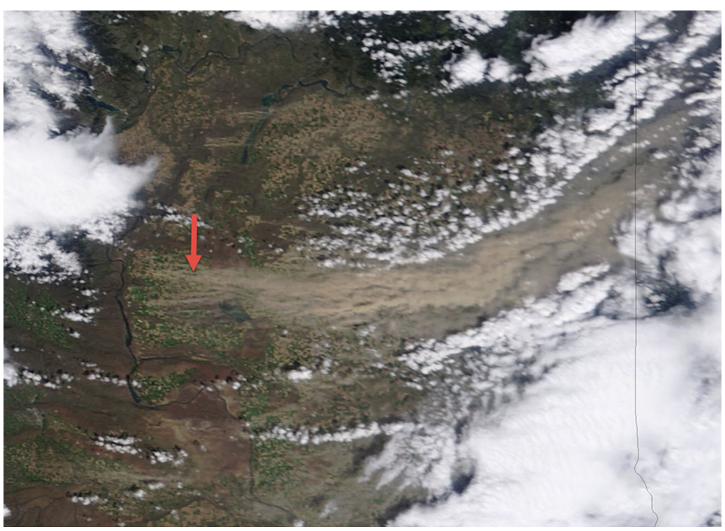

Figure 1. NASA satellite photo of a May 3, 2010, dust storm in the Columbia Basin of Washington. Arrow shows origin of dust plume.

Factors Affecting Soil Management

Soil management is complicated by the diversity of crops grown in the region. Some crops, such as potatoes and onions, require intensive tillage for planting and harvest and, along with other vegetable crops, leave low amounts of crop residue after harvest. Tillage is reduced in perennial forage crops, such as alfalfa and timothy, but crop residue additions to the soil are low as they are nearly all harvested for hay. Their root contributions are important but their root biomass is lower than that of many native perennial grasses (Kramer and Weaver 1936). To maintain soils, low residue crops should be rotated with high residue crops, like wheat and corn, but the latter are often less profitable. Adding perennial crops, which reduce tillage frequency, also helps. Furthermore, much of the land is farmed under short-term leases, which lessens the motivation to pursue the long-term benefits of soil improvement.

Although the region’s farmers are applying soil improvement practices the costs and benefits of these practices have not been evaluated. Potential benefits of improved soils include reduced erosion, improved nutrient cycling and soil tilth, reduced pressure from soilborne diseases, and improved water-holding capacity and infiltration, all of which combine to maintain or even improve crop yields. In order to further justify the investment in soil improvement practices and encourage more farmers to implement them, a 2015 WSU study assessed the impacts of soil improvement practices in the Columbia Basin by conducting a suite of soil quality tests on soils from adjacent fields with and without soil improvement practices. Interviews with growers about the costs of the practices and the benefits they perceive or measure were also conducted (see the companion publication TB41E An Evaluation of Soil Improvement Practices Being Used on Irrigated Soils in the Columbia Basin).

Soil Improvement Practices

Soil improvement in the Columbia Basin can be divided into three broad categories, each of which contains specific practices. These are covered below.

Organic Soil Amendments

Various materials from plants or animals may be used as organic soil amendments (Magdoff and van Es 2010). Generally, wastes from either food processing (cull vegetables or mint slugs), livestock production (manure), or human waste (biosolids) can be applied raw or composted (Figure 2).

Figure 2. Precision application of organic amendments is a commercially available option offered by several companies in the Columbia Basin.

Figure 3. Mustard no-tilled into wheat stubble, an example of a fall green manure crop in the Columbia Basin.

Composts are processed products managed to meet pathogen reduction standards, are more uniform and decomposed, and should contain few to no viable weed seeds. Composts help to improve soil tilth and provide a slow-release source of nutrients. They can originate from any of the above-mentioned organically derived materials. Manures are a mixture of bedding and raw fecal material which contains organic matter and nutrients. They may contain raw and aged materials, foodborne pathogens, and weed seeds, usually have a relatively high nutrient content, and can help improve soil tilth. These materials are imported to fields either from other parts of the farm or from off the farm, and they are applied in higher quantities than fertilizers due to their bulky nature and lower nutrient concentration. Thus, they typically involve high transport and handling costs and are usually more expensive than field-grown plant material (cover crops, crop residues). However, these amendments also import nutrients into the system and may replace other purchased fertilizer, which mustard green manures (non-legume) and high residue farming do not do. Organic amendments should be carefully selected to avoid unwanted contaminants (e.g., herbicide residues, plastics, heavy metals) and weed seeds.

Cover Crops and Green Manures

Cover crops are not normally harvested; they are either killed or allowed to winterkill, remaining on the soil surface for soil protection while their root systems contribute directly to soil improvement. Green manures (Figure 3) are cover crops that are grown specifically to be incorporated into the soil with tillage (Clark 2008).

Both green manure and cover crops can provide multiple benefits including increasing soil organic matter; improving soil structure; providing wind and water erosion control, nitrogen fixation (legumes) and nutrient recycling, weed control, and suppression of soilborne diseases and nematodes; and enhancing soil microbial activity. While growing, both can provide nectar to pollinators and habitat for wildlife.

High residue Farming

High residue farming refers to cropping systems in which the volume of soil that is tilled is reduced in order to maintain residue cover of the soil (McGuire 2014). No-till (direct seeding), strip till, vertical tillage, and zone tillage are all considered variations of high residue farming (Figure 4). Farmers adopting one of these methods benefit through reduced equipment use, operating time, and fuel, increased water conservation, less incidence of wind erosion, and improved soil tilth. For more information on high residue farming under irrigation see the Other Resources section below.

Figure 4. Dry edible beans direct-seeded into an alfalfa stand near George, WA.

Measurements of Soil Quality

The following soil properties can all be measured quantitatively and are directly relevant to the soil quality issues in the Columbia Basin. Most tests are available from a commercial laboratory. Standard chemical soil analyses include key soil quality tests such as pH or salinity that should also be considered.

Soil Organic Matter

Soil organic matter is the driver of soil quality in most soils. This is especially true for the low organic matter soils of the arid West. It is a source of carbon for soil biology, it can hold several times its weight in water, and it adds to the nutrient retention ability of soil by increasing cation and/or anion exchange capacity. Soil organic matter acts like a sponge, holding water and nutrients and making them available to the crops over time. Increases in soil organic matter help reduce plant stress during dry periods. Soil organic matter supplies much of the food for the soil biota, which in turn help create soil aggregates through the “glues” they exude and the action of fungal hyphae. More stable aggregates on the soil surface reduce the risk of wind erosion, which can damage young seedlings and cause off-site problems from blowing dust. Better surface aggregation can help maintain water infiltration and avoid surface sealing, which helps with irrigation efficiency and reducing water runoff. Loss of soil aggregation and structure can lead to poor soil aeration, which favors certain fungal diseases in the soil. Soil organic matter influences all these functions and more. Increased activity by the soil biota also helps cycle nutrients which can provide them to crops as well as prevent their loss. Taking repeated soil organic matter tests over time is a good way to monitor long-term soil improvement, but tests should be done at the same location in a field, at the same time of year, at the same depth of soil, in a similar place in the management cycle (e.g., rotation, manure application), and with the same laboratory method to allow for meaningful comparison over time.

Soil Respiration

Most living organisms in the soil respire (breath), giving off carbon dioxide. So soil respiration is a measure of the level of biological activity in the soil at the time of the test. It can increase with warming temperatures, soil wetting, and the application of organic materials (food for microbes) but also with tillage, which, with an influx of oxygen, stimulates an increased breakdown of existing organic matter. Interpretation of soil respiration, therefore, must take into account recent management. This measurement can be highly variable within a day and during a growing season, making interpretation more difficult. The test does not provide information about what organisms are most abundant or what functions they are providing. It does indicate whether different practices (e.g., one strip with a green manure and another without), all other factors being equal (same soil, same history, same crop, etc.), have a stimulating effect on the soil biota.

Available Water Capacity

Available water capacity reflects a soil’s ability to store water for use by plants. It is considered to be the water held between field capacity (about 30 cbars of tension) and the permanent wilting point (about 150 cbars of tension). It is affected by texture (lower for sands, higher for silty soils) and organic matter, which acts as a sponge in the soil. It is important for irrigated agriculture because, given a certain weather pattern, it dictates the interval between irrigations. Increasing the available water capacity means you can go longer between irrigations, or that your crops may be less stressed during a very hot period. This property can be measured at any time.

Water Infiltration

Water cannot be stored if it runs off before entering a soil. Therefore, a high water infiltration rate is important for efficient irrigation, especially in the outside spans of center pivot sprinkler irrigation systems where applications rates are high. Although freshly tilled soils may have a higher infiltration rate initially, the rate often decreases after the first irrigation. This is caused by a breakdown of aggregates at the soil surface leading to a sealing layer of fine soil particles. When soil organic matter is added through soil improvement practices, the formation of water-stable aggregates can increase, which then helps resist degradation and maintain high infiltration rates. Crop residues on the soil surface also serve to protect the soil from water droplet impact, which can also maintain higher infiltration rates. Water infiltration is generally measured in the field in undisturbed (not recently tilled) locations using various devices, such as the simple single-ring infiltrometer. Multiple measurements should be made in a field since there is large spatial variation for this property.

Bulk Density

Bulk density is a measure of how much of the soil material, the sand, silt, clay and organic matter, is packed into a certain volume. In general, lower bulk density is better, as that means there are more empty spaces for air and water movement. Bulk density can affect water infiltration and also root growth. In untilled soils, bulk density can be misleading as the effects of higher bulk density can be offset by semi-permanent pores from earthworms and old root channels that are not found in tilled soils. Special soil sampling probes are used to collect an undisturbed core of soil of known volume that is then dried and weighed.

Soil Conditioning Index

The USDA Natural Resources Conservation Service (NRCS) developed a tool called the Soil Conditioning Index in the 1960s to assess what we now call soil quality. The Index uses three components: organic matter returned to the soil and removed, effects of tillage and field operations, and predicted soil erosion. It is currently part of the RUSLE2 model that NRCS uses with growers for conservation planning. The model generates three values, one for each component, and sums them for an overall soil condition rating. The components are weighted, with organic matter at 40%, field operations at 40%, and soil erosion at 20%. Scores can be negative (indicating a decline in soil condition), zero (maintaining soil condition), or positive (improving soil condition). By seeing the component scores, you can identify where a major problem may be and focus on management changes that will most readily influence that component. Growers can access this index through their local NRCS office.

Cornell Soil Health Test

Researchers at Cornell University responded to growing interest among growers for a more quantitative approach to monitoring soil quality. They evaluated many different laboratory tests that were generally used in research settings to determine which would produce meaningful values for physical, chemical, and biological properties of soils that are affected by management, and that also could be done in a commercial lab at a cost a grower could afford. This resulted in the current packages of 10–12 different tests they will conduct. As stated earlier, data are normalized and scored based on northeastern US soils, but this can be a useful test for side-by-side comparisons here in Washington. Oregon State University now offers a soil health package based on the Cornell program.

Potential for Improving Soils in the Columbia Basin

Soils in the Columbia Basin are highly productive for agriculture but can have problems related to their physical properties (e.g., poor water infiltration on loamy soils, wind erosion) that can be influenced by different soil improvement practices. The low native levels of soil organic matter can also be increased through management, even in systems that have regular soil tillage. Various tests are available to help growers monitor changes in their soil quality over time. A 2015 study of soils in the Columbia Basin found that several key soil properties were improved with the use of organic amendments, green manures, or high residue farming, and the potential benefits to the grower equaled or exceeded the costs of the soil improvement practices (McGuire et al. 2017).

Other Resources

Economics of Improving Soils

Ransom, M., R. Holcomb, and L. Hedrick. 2014. Why Grow a Crop You Don't Sell? USDA-NRCS Conservation Webinar.

Soil Quality Testing

Cornell Soil Health Assessment.

Oregon State University Soil Health Test.

Soil Conditioning Index.

Organic Soil Amendments

WSU Compost and Nutrient Management website.

WSU Manure as a Resource website.

Sullivan, D., C. Cogger, and A. Bary. 2015. Fertilizing with Biosolids. Pacific Northwest Extension Publication PNW508. Oregon State University.

Green Manures

Mustard Cover Cropping in Potatoes. REACCH Case Studies, Dale Gies System profile.

McGuire, A. 2016. Mustard Green Manures. Washington State University Extension Publication FS219E.

McGuire, A. 2016. Using Green Manures in Potato Cropping Systems. Washington State University Extension Publication FS218E.

High Residue Farming

McGuire, A. 2014. High Residue Farming under Irrigation Series:

EM071E High Residue Farming under Irrigation: What and Why

EM072E High Residue Farming under Irrigation: Crop Rotation

EM073E High Residue Farming under Irrigation: Residue Management through Planting

EM074E High Residue Farming under Irrigation: Pest Management Considerations

EM036E High Residue Farming under Irrigation: Strip-till

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