



Managing Soils for Water: How Five Principles of Soil Health Support Water Infiltration and Storage

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Well aggregated, healthy soil: the result of regular additions of organic matter and diverse rotations. The aggregates consist of sand, silt, and clay particles held together by fungal and bacterial glues. The soil aggregates allow water and air to infiltrate into the soil.

Photos: Rex Dufour, NCAT



In contrast, a soil with little or no aggregation: the fine clay particles were not held in soil aggregates, and with rainfall (or irrigation droplets) the clay particles form a seal on the surface layer, preventing infiltration of both air and water. This farmer keeps his orchard floor clean and does not provide regular additions of organic matter.

Introduction

Worldwide, water is becoming scarcer and more expensive due to the effects of climate change. Significant adaptation will be necessary to ensure adequate supply and efficient use of a diminishing resource. This reduction in the supply of water will affect agriculture and will require a change in focus from increasing productivity of land to increasing productivity per unit of water consumed. The need for increased water-use efficiency will be arising in a changing climate that will create abrupt fluctuations of temperature, precipitation patterns, drought, heat waves, stronger storms, flooding, wild fires, and pest outbreaks. Our soils, and our soil management, are not ready to meet these additional stresses. Too often, the approach to dealing with water deficits has focused on better technology: deeper wells, better drip emitters, more efficient

micro-sprinklers, and variable-speed drives on pumps—all of which are important. However, a different approach to dealing with the oscillation between too little and too much water uses an appropriate technology that focuses on maintaining healthy soils by following five basic principles discussed in detail in the following sections.

Healthy soil, with its thriving biological activity, creates a system of air and water pores that both allow water to infiltrate the soil and hold that water in place. These pores help plant roots grow deep, holding soil in place while allowing water to infiltrate deep into the soil profile. As the amount of organic matter, or carbon, in the soil increases, so does the ability of that soil to hold water, release nutrients to the crop, and prevent erosion (Funderburg, 2001).

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Attaining Healthy Soils

Soil experts across the country, including land grant universities, the USDA Natural Resources Conservation Service (NRCS), soil consultants, and farmer activists, have come to broad agreement about some general principles for restoring and maintaining soil health. These principles, when conscientiously applied to most farming systems, will improve soil health and function and likely reduce inputs. Water infiltration into soils is also improved, as well as the soil's water storage capacity—important qualities when considering increasingly extreme rainfall patterns. Here we present five general principles for soil management that are responsible for increasing soil health and function.

The first principle: ***Protect the soil surface.*** Some people call this “soil armor.” This includes the use of cover crops and mulch, which provide many benefits for the land, including the following:

- Wind and water erosion are brought under control. Cover crops and mulch protect the soil as wind or water move across the soil surface. This holds the soil in place and allows increased water infiltration, not to mention providing organic matter and nutrients to the soil.
- Mulch reduces evaporation from the soil surface, reserving more moisture for plant use.
- Soil temperatures are moderated with cover crops and mulch, which act as a buffer, shielding the soil from extreme temperatures. The

soil food web functions better when not subjected to extreme temperatures and humidity.

- Soil aggregation is preserved when rainfall hits the cover crop or mulch, dissipating the raindrop's energy. When rainfall hits bare soil, soil aggregates are destroyed, erosion by wind and water is increased, and the soil is starved of oxygen and water. Fine clay particles seal the soil surface, dramatically reducing water infiltration and oxygen exchange into the soil.
- Weed growth is suppressed through competition with the cover crop and/or smothered with mulch.
- Habitat is provided by cover crops for beneficial insects and pollinators. Biological mulches/plant residue provides habitat for spiders, an important predator of agricultural pests.

The second soil health principle is to ***minimize soil disturbance of all kinds.*** Both physical (tillage) and chemical (overuse of fertilizers and pesticides) disturbance can disrupt the soil food web. Continuous tillage over time, without regular and significant additions of organic matter to the soil, degrades soil function and reduces soil pore space, which in turn restricts water infiltration and destroys the biological glues that hold soil together. Tillage in combination with overuse of fertilizers is like throwing gas on a fire. The excess nitrogen feeds bacterial populations, which explode when exposed to oxygen through tillage.



At this Georgia cotton farm, the farmer chem-killed a small-grain cover crop and no-tilled cotton into it. The mulch adds organic matter, protects the soil from rains, and reduces water usage.

Photos: Rex Dufour, NCAT



Raised beds with vetch cover crop, which protects the soil and provides N. On this California farm, the farmer protects his soil from heavy winter rains by planting vetch cover crops on raised beds. In the spring, he'll mow the cover crop, lightly incorporate the residue, and transplant processing-tomato seedlings into the beds.

The problem is, these bacteria are feeding on the organic matter, which reduces organic matter levels unless significant crop residues, compost, or cover crops are added to the soil on a regular basis. Repeated tillage and overuse of chemical N, season after season, degrades soil structure and causes the soil aggregates that hold sand, silt, and clay together to fall apart, for lack of biological glues. This makes the soil an easy target for both water and wind erosion. Clay particles, released from soil aggregates by rainfall or irrigation droplets, will form an effective seal on the soil surface, preventing water infiltration to the root zone (or water table), increasing runoff and also creating anaerobic conditions in the root zone.

The third soil health principle is *plant diversity*. Original landscapes in which soils were built over geological time consisted of a varied plant diversity, which was largely replaced by an annual (or perennial) monoculture when Europeans arrived. The soil food web used to receive carbon exudates (food) from the roots of a diverse group of perennial and annual plants. Each species of plant provides a unique set of root exudates, which in turn host a microbial community with some unique members, so a diverse aboveground plant community provides for a very diverse microbial community in the soil. In most cases, soils now receive root exudates from only one species of annual or perennial plant at a time. By using crop rotation, or rotating alley crops in orchards, we can start to better mimic the original plant diversity that benefits the soil food web. This, in turn, improves rainfall and irrigation-water infiltration and nutrient



Soil physical disturbance—tillage—is hard on the soil ecosystem. Farmers who minimize tillage not only save money on labor and equipment wear and tear, but they're also taking a step toward healthier soil. Chemical disturbance can be equally detrimental to soil health. Photo: Rex Dufour, NCAT

cycling, while reducing disease and pests. Diverse rotations in annual crops, which provide plant diversity over time, can keep soil healthy. For perennial crops, it's important to rotate cover crops in alleys, as that will help ensure a healthy soil ecology and help prevent the build-up of soil pathogens. In pasture and rangeland, carefully managed grazing encourages plant diversity.

The fourth soil health principle is the concept of *continual live plants/roots in the soil*. The native vegetation in converted agricultural areas consisted of continuous stands of perennial and annual grasses and broadleaves providing carbon exudates to the soil food web during most of the



Having a diversity of crops on a field or a diverse rotation of different crops from different plant families both support a diverse soil ecology.

Photos: Rex Dufour, NCAT



A diverse cover crop of more than a dozen species of grasses, legumes, and mustards helped the farmer at this Northern California walnut farm reduce his lesion nematode population from a count of more than 5,000 to "undetectable" over five years.



Large expanses of bare soil are an all-too-common scene in much of the United States. Lack of living roots in the soil starves the soil ecology, exposes the soil to both wind and rain erosion, and provides no habitat for beneficial organisms. We must do better to protect this precious resource.



In contrast, the farmer managing this farm has invested in the farm's soil, adding organic matter both from the plant material and from root exudates. Vetch also provides significant amounts of nitrogen for the following crop and helps maintain a highly functioning soil ecology.

Photos: Rex Dufour, NCAT

growing season. Today's croplands typically grow annual crops with an extended crop-free period of bare soil before planting or after harvest. It is extremely rare in nature to see vast expanses of bare soil. Bare soil does not receive any root exudates, and this starves the soil microbial community. Cover crops are able to fill in this crop-free period, providing cover to the soil and root exudates to the soil's food web. Cover crops address a number of resource concerns already listed in Principle 1 and also provide an opportunity for livestock integration into cropping systems. In pasture systems, a diverse mix of warm-season and cool-season forage plants lengthens plant productivity over the course of the year, maximizing root exudation.

The fifth principle of soil health is the concept of ***livestock integration***. Animals, plants, and soil have played a synergistic role together through geological time. Fewer farms are including animals as part of their operations, due to increasing specialization in growing only crops, combined with an increase in the number of confined animal operations. Returning animals to the agricultural landscape can contribute to soil health by adding some biology to the soil, especially if the land hasn't had grazing animals on it. Livestock also convert high-carbon annual crop residue to low-carbon, high-nitrogen organic material, i.e., manure, which is beneficial to the soil. Some cover crops can be grazed without damage. Conversely, livestock



The grower at this operation has sheep grazing in the orchard, which is essentially providing two crops: grass and walnuts. This provides the grower savings on orchard floor management, as well as providing his trees additional nutrients. These sheep will be removed from the orchard four months prior to any harvest.



This grower planted a cover crop of bell beans, Austrian pea, and vetch, which all provide nitrogen to the walnut trees.

Photos: Rex Dufour, NCAT



Sheep have grazed on in-tree-row grasses, as well as the cover crop, except for the bell beans, which they left mostly untouched. Sheep provide a biological boost to the orchard trees, gain significant weight from the cover crop, and provide cover crop management services. Photos: Rex Dufour, NCAT

can be used to manage an overly vigorous cover crop. Thoughtful integration of livestock onto cropping land can reduce weed pressure, herbicide use, and livestock waste associated with confinement, thereby improving water quality and addressing nutrient-management concerns.

Soils, Organic Matter, and Water: Why organic matter stores more water than sand, silt, and clay

Organic matter in the soil is made up of living, dead, and decomposed organisms. The living organisms in the soil, which represent roughly 15% of the total organic matter in the soil, vary from microorganisms like fungi, bacteria, and viruses to insects, plant roots, earthworms, and mammals. The dead organisms are recently deceased microbes, insects, earthworms, animals, and decaying plant material. The living organisms feed on both the living and the dead organisms, releasing proteins, sugars, and amino acids that feed plants and decomposers. The decomposition process and its various by-products also produce substances that hold sand, silt, and clay particles together to form aggregates and give them structure. This structure allows for efficient infiltration

of rain and irrigation water into the root zone and, ultimately, into the water table. The smallest organic matter particles in the soil are called humus. Humus is a relatively stable part of the soil, a complex component that can buffer a plant from exposure to harmful chemicals, reduce the effect of compaction, improve drainage in clay soils, and improve water retention in sandy soils (Magdoff and van Es. 2009). This stable organic matter has surface charges that allow water to adhere to the surface. In addition, organic matter, being generally negatively charged, attracts positively charged ions (cations), many of which are important plant nutrients.

Increasing levels of soil organic matter can increase the cation exchange capacity (CEC) of soils, providing a reservoir of nutrients and micronutrients (calcium, potassium, magnesium, iron, manganese, ammonium, and others) especially needed in sandy soils with very low CEC levels. In fact, organic matter can have four to 50 times higher CEC per given weight than clay (Ketterings et al., 2007).

Earlier research demonstrated that a silt loam soil with 4% organic matter holds more than twice the water of a silt loam with 1% organic matter (Hudson, 1994). Further recent research has shown that there have been overestimations on the relative contribution of soil organic matter to water-holding capacity, and it is influenced greatly by the soil physical properties (particle size, texture, and bulk density) and mineralogy. The increase of water-holding capacity as levels of organic matter are increased was more pronounced for sandy soils than for loam and clay soils (Minasny and McBratney, 2017; Libohova et al., 2018). This more recent research still suggests that for every percent of soil organic matter (SOM) in the top six inches, the soil will be able to store an additional 10,800 liters of water. But regardless of the soil type, adding organic matter to soil is beneficial for the numerous functions it provides besides increasing the soil's water-holding capacity. Farmers investing in their soils by increasing organic matter and improving soil health will find that their soils will better support plant health, especially during times of drought and flooding.

Related ATTRA Publications
www.attra.ncat.org

Crops: Soil Related

- Cover Crop (340) in Organic Systems
- Cover Crop Options for Hot and Humid Areas
- How to Add Compost on Your Small Farm
- The Irrigator's Pocket Guide
- Soil Aggregate Stability: Visual Indicator of Soil Health (video, 5 min)
- Soil Moisture Monitoring: Low-cost Tools and Methods
- Sustainable Soil Management
- Tipsheet: Assessing the Soil Resource for Beginning Organic Farmers
- Livestock: Soil Related**
- Assessing the Pasture Soil Resource
- Building Healthy Pasture Soils
- Integrating Livestock and Crops: Improving Soil, Solving Problems, Increasing Income
- No-Till Case Study, Brown's Ranch: Improving Soil Health Improves the Bottom Line
- Nutrient Cycling in Pastures

Percent SOM	Sand, H2O"/foot of soil	Gallons of Water	Silt Loam, H2O"/foot of soil	Gallons of Water	Silt Clay Loam, H2O"/foot of soil	Gallons of Water
1	1.0	27,154	1.9	51,593	1.4	38,015
2	1.4	38,015	2.4	69,170	1.8	48,877
3	1.7	46,162	2.9	78,747	2.2	59,739
4	2.1	57,023	3.5	95,039	2.6	70,600
5	2.5	67,885	4.0	108,616	3.0	81,462

Why You Can't Manage What You Can't Measure: Why soil moisture monitoring and irrigation distribution is important

Measuring irrigation distribution is important and especially effective when used in combination with practices that support a healthy soil.

The moisture content of the soil regulates the moisture levels in the plant. Overly dry or overly moist soil stresses the plant and can induce diseases and reduce future seasons' yields. This is why it is important to monitor soil moisture in order to schedule irrigation and provide the crop with adequate water to achieve ideal growth and yields. Soil moisture-monitoring devices use sensors and probes located in the soil root zone. Combined with information about temperature,

Soil Moisture Monitoring: Low-Cost Tools and Methods.

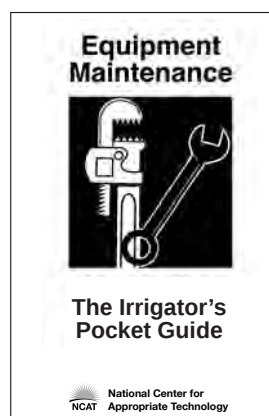


simplified and user-friendly electronic devices.

The Irrigator's Pocket Guide. This publication, well worth the \$10 price, was created with input from irrigation experts in more than 20 states. *The Irrigator's Pocket Guide* belongs in every irrigator's hip pocket. It is a take-to-the-field guide that demystifies the art of irrigation management, explains everything you need to know about soil moisture and crop water use, and shows you

how to optimize crop yields while conserving water, soil, and energy. More than 30,000 copies have already been sold. The Equipment Maintenance half of the book features exceedingly clear and detailed maintenance and troubleshooting procedures for pumps, motors, engines, control panels, and distribution systems. The Water Maintenance guide, on the other side of the book, provides a step-by-step guide to irrigation water management for sprinkler, surface, and microirrigation systems. The book is 158 pages long, has durable waterproof covers, and measures 4"x6 1/2". It includes 44 diagrams and tables, 14 pages of handy conversions and formulas, and irrigation guidelines for more than 30 common crops.

This publication explains how soils hold water and surveys some low-cost soil moisture-monitoring tools and methods, including a new generation of sophisticated and user-friendly electronic devices.



evapotranspiration (evaporation from the soil and transpiration from the plant), and water requirements of the crop, these devices are able to provide the farmer with information that can be used to schedule irrigation properly. See text box on page 6 for more resources about monitoring soil moisture.

Another important component in managing soil moisture is irrigation distribution uniformity. This measures how evenly water is applied to a crop across a field during irrigation. Micro-sprinklers often get plugged, as do drip emitters. Sprinkler heads get worn, and leaks in the system affect distribution uniformity, not to mention human error (a worker forgot to turn a valve, etc.). All these can significantly affect water distribution, and fertilizer distribution if the farmer is fertigrating. If water distribution is uneven in a field, it will negatively affect yields. Inspecting and performing distribution evaluation in your irrigation system will identify the causes, and corrections can be made to eliminate plugging, minimize variation in pressure, and adjust flow rate, infiltration time, spacing, set duration, and land grading. *The Irrigator's Pocket Guide* (see text box) has a wealth of information about distribution-system uniformity and maintenance.

Soil Health and the Future of Farming

Farmers across the country are operating in an era of uncertain weather and uncertain markets. Many farmers have reduced their input costs and increased their bottom lines by choosing to invest in soil health, just as they would in new machinery and maintaining farm structures. Healthy, living soils can better sustain the increased demands we're placing on them to grow healthy food and maintain clean water and air. It is important to build and maintain soil health before drought or flood conditions appear. Healthy soils can better withstand climatic stresses of drought and floods and, in some cases, can help mitigate these stresses. All this requires an increased understanding about how to manage the soil as an ecology. Investments, such as adding organic amendments, practicing no- or reduced tillage, leaving crop residue, planting cover crops, and diverse crop rotations, will help the soil efficiently cycle both water and nutrients, sustain plant and animal productivity, and maintain or improve water quality. The return on soil health investments will pay off year after year after year.

Strategies to reduce crop water use:

- Maintain healthy, water-absorbent soils, following the five principles set out earlier in this publication
- Match plant genetics—varieties, growth characteristics, and tolerances (heat, salinity, pests, drought, early maturing etc.)—to specific conditions
- Replace high-water-consuming crops with water-efficient crops
- Implement cultural practices: conservation tillage, planting densities, double cropping, intercropping, and crop rotation
- Improve irrigation timing through scientific irrigation scheduling, a systematic procedure that calculates precise water requirements over a short period of time to meet crop needs
- Manage deficit irrigations
- Use irrigation technology: sensor devices, probes, computer technology
- Utilize low-volume irrigation systems: drip irrigation and micro sprinklers, surge, and sprinkler
- Irrigate at night
- Practice weed control
- Apply mulches
- Reduce tillage

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Further Resources

ATTRA Resources <https://attra.ncat.org> :

- Building Healthy Pasture Soils. 2017. By Lee Rinehart, NCAT Program Specialist.
- Drought Resistant Soils. 2003. By Preston Sullivan, NCAT Agriculture Specialist.
- Measuring and Conserving Irrigation Water. 2006. By Mike Morris and Vicki Lynne, NCAT Energy Specialists.
- Soil Moisture Monitoring: Low-Cost Tools and Methods. 2006. By Mike Morris, NCAT Energy Specialist.
- Tipsheet: Assessing the Soil Resource for Beginning Organic Farmers. 2015. By Rex Dufour, NCAT Agriculture Specialist.
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