Pasture Soil Health & Grazing Network Coordinator Toolkit

Sharing Pasture Soil Health Knowledge and Practice through Grazing Networks Project

R. B. Bauer and K. Jurcek

First Edition

GrassWorks, Inc.

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About the Sharing Pasture Soil Health Knowledge and Practice through Grazing Networks Project

The project worked at statewide and local levels to bring together local learning teams of agency staff, grazing network coordinators, and livestock farmers for mutual education on managing cropland and pastures for improved soil health.

GrassWorks is a statewide farmer-led organization that established a soil health education program in 2014. This project extended that program and delivered educational content to agency staff through Wisconsin's four Resource Conservation and Development Councils (RC&D) that sponsor grazing networks. It provided support for those networks to engage local NRCS, Land Conservation Department (LCD), and Extension staff over two years in a co-learning project on pasture soil health.

Fig. 1: Wisconsin RC&D regions

Table 1. Contact information for Wisconsin RC&D grazing network coordinators

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The project tapped into NRCS and LCD soil science expertise, building on NRCS's Soil Health Initiative. Extension adult education expertise and network coordinator grazing expertise added to this locally-based, mutual professional development effort. The project fostered collaboration among local participants through mutual learning on the benefits of well-managed pasture.

Activities during 2015 to 2017 included training network coordinators and agency staff on pasture soil health, collaboration among local staff on pasture walks or workshops on soil health in each of the four RC&D areas, surveys and interviews of participants' soil health knowledge and practice, and creation of this grazing network coordinator toolkit.

Introduction

Vision statement

Given the inputs, activities, and participation of the project team, agency staff, farmers, and collaborators, the long-term vision for the Sharing Soil Health Knowledge and Practice through Grazing Networks Project includes the following outcomes:

- Increased acreage of well-managed pasture delivering positive soil health outcomes.
- Long term commitment by local agency offices to support farmer-led grazing network educational activities.
- A robust, effective network of local and state grazing educators and technical assistance providers coordinated cooperatively by GrassWorks and state and local agencies.

Farmers and agency staff discuss the regrowth of a sorghum-sudangrass cover crop for dairy forage at a pasture walk event in Argyle (Lafayette County, Wisconsin).

Guiding principles of this handbook

Evidence-based and practical: This toolkit organizes grazing knowledge that is evidence-based in a way that is relevant to conservation planners and farmers. However, we also aim to promote higher forms of thinking such as analyzing and evaluating, rather than just memorizing facts.

Farmer-led and agency supported: Grazing education in Wisconsin has long been farmer-led and often agency-supported. For example, Wisconsin's first grazing networks formed in 1986, followed in 1991 by the formation of GrassWorks, Inc., Wisconsin's state-wide network of grazing networks. In addition, fifty percent of grazing networks are coordinated by UWEx (Paine et al, 2000). Wisconsin's RC&D's also coordinate several grazing networks and support agency staff in education and implementation of grazing best management practices. This toolkit is based on the input of farmers and agency staff and focuses on resources for farmer-led and agency-supported grazing networks.

Guided by the conservation planning process: Agency staff, farmers, and landowners work together to manage natural resource on the land (USDA-NRCS, 2014). Wise planning considers several alternative solutions to problems in light of available resources before picking a plan of action. Problem solving often involves going back through the planning process a few times and evaluating the results as we reach our goals and then set new goals. The process requires the input of farmers, landowners, soil scientists, crop consultants, and financial planners. All participants have to be prepared to work over many years on a shared vision to improve the well-being of the land and the people. In addition to a section of the toolkit devoted to the planning process for soil health, we note in the margins when specific topics relate to the planning process.

Informed by simple principles: The appropriate practices for a specific farmer or landowner will depend on the context established through the conservation planning process. However, the Principles of Soil Health (SFA-MN, 2015) informed the practices described in this toolkit:

1. *Keep the soil covered.*
2. *Minimize soil disturbance.*
3. *Increase crop diversity.*
4. *Keep living roots in the soil.*
5. *Integrate livestock.*

The fifth principle adds to the USDA's national Soil Health Key Points (2013), by recognizing the importance of livestock to accomplish the first four soil health principles.

For example, according to Brian Pillsbury, Wisconsin NRCS State Grazing Specialist, although establishing a hay crop provides many benefits to the soil relative to annual crops like corn and beans, the added benefits of grazing a hayfield can include formation of denser sod and increased soil biological activity because nutrients are returned quickly to the soil via manure and urine (Comments 9/8/17, Stevens Point, WI).

Informed by realities of economics, policy, and values: Economics is an important driver of decisions for farmers, so we emphasize in this toolkit the impacts of soil health practices on volume of production, prices received for products, and direct and overhead costs. However, we also describe how practices affect compliance with laws, rules, and social expectations, taking into consideration externalized costs. Externalized costs are paid by society to repair damage caused by private behaviors. For example, the cost of neighbors to buy bottled water because a farm contaminates local ground water can be an example of an externalized cost. These costs may not appear on the farmer's bottom line. Policies such as Wisconsin's nutrient management statutes aim to dramatically decrease these kinds of public costs with relatively small increases in costs to farmers.

Values are another strong component of behavior. What we consider to be important and right or wrong is shaped by experiences that are very personal and/or shared by generations of society. For example, because of computers recent generations compared to past generations may give more importance to the ability of technologies, such as no-till farming or manure digesters, to solve human problems. However, people who have been affected by environmental disasters like the Dust Bowl may also place more importance on the interconnection between humans and nature, the recognition of having only one planet for the future of the human race, and the intrinsic value of the world beyond providing for humans.

Informed by recent advances in soil microbial ecology: Most people are not aware that survival of life on this planet depends on soil microorganisms. We simply don't recognize that relationship or give consideration to soil microorganisms in our daily lives. If we place great value on the interconnection between humans and nature, that inconsiderate behavior is out of line with our values. However, we might also believe that technology will solve the human problem of relying on other forms of life for our own well-being. Therefore, in this toolkit we aim to show how recent discoveries reveal the deep interconnection between microbes and humans.

Definition of soil health

The soil is alive! Soil teems with more than 500 million bacterial cells in a teaspoon (one gram of dry soil). Without life, soil is just a pile of weathered rock: sand, silt, and clay that cannot support thriving plant life. Recent research shows how microbes and other decomposers interact with the soil matrix, organic matter inputs, and plant roots to make plant life possible on Earth. Of the five soil forming factors (climate, time, topography, parent material, and organisms), research shows that soil function responds quickly to changes in the life in the soil such as bacteria, fungi, archaea, and other decomposers.

A farmer pulls up a cover crop to show its roots.
Photo credit: Edwin Remsberg and USDA-SARE.

This is a radical concept to most people. The last 80 years of soil conservation have focused on preventing soil degradation by protecting the physical and chemical properties of soil. For example, government agencies use nutrient management planning to help farmers comply with policies of tolerable soil loss (T) and phosphorus (P) index guidelines for manure spreading. Instead, we'd like to promote an agenda of economics, policy, and values that focus on the processes that support soil formation, which include nutrient cycling, water cycling, and soil biological activity. Based on recent technological advances, we know that soil biological activity modifies nutrient cycling and water cycling as a result of interactions between soil biological activity, plants, and livestock. Although agencies list a few biological properties of soil in factsheets, few if any management decisions on Wisconsin farms are based directly on the life in the soil.

Applying soil health knowledge

The goal of educational training should be to promote higher forms of thinking, such as analyzing and evaluating, rather than just memorizing facts. "Bloom's Taxonomy" categorizes the types of learning by ordered levels of complexity. They are, from least to greatest: knowledge, comprehension, application, analysis, evaluation, and synthesis. If we translate those concepts into actions they would be: remember, understand, apply, analyze, evaluate, and create (Bloom et al, 1956). Although the project title is Sharing Soil Health Knowledge and Practice through Grazing Networks, a full description could include comprehension, analysis, synthesis, and evaluation of soil health.

A basline survey of soil health knowledge and practice sent to over 200 agency staff and farmers in Wisonsin during July 2017 found contradictions between participants' knowledge and practice. Figure 1 shows that participants' levels of confidence were greatest with systems thinking and grazing management. Reported confidence was least with educational tools/tests and pasture ecology. Opposite levels of confidence were reported for grazing management and pasture ecology, which we intrepret to mean that practioners may lack the baseline knowledge to adapt and evaluate their practice to create new ways of managing grazing systems. Therefore, this toolkit aims to promote knowledge of educational tools/tests, pasture ecology, and soil biology in order to lay the foundation for advanced applications of managed grazing.

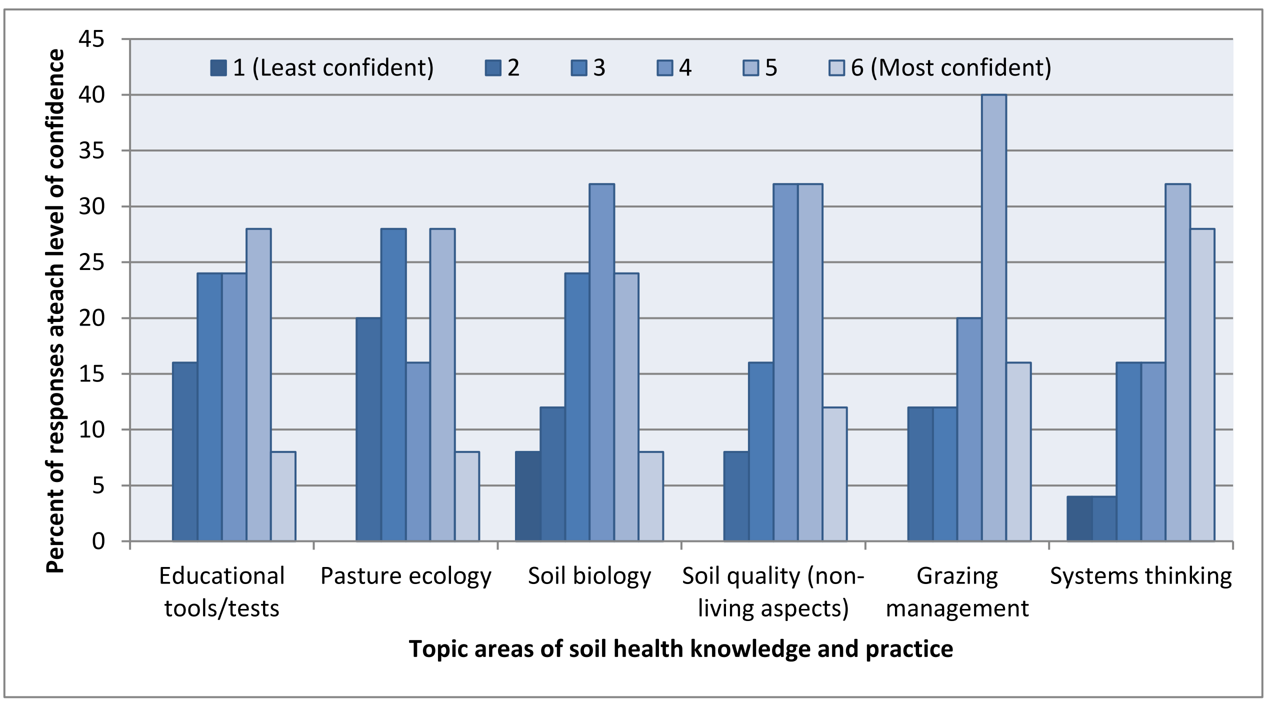

Figure 1: Responses to the survey question "How confident are you with these areas of pasture soil health knowledge?" (n=25).

Measuring your progress

The pasture soil health curriculum generally increases in complexity from beginning to end. You might start or stop depending on how far you want to progress.

Everyone starts with a different level of thinking about each aspect of soil health. For example, you may be able to define soil organic matter as the biological residue from the breakdown of plants and animals. And you may be able to discuss the role of cation exchange capacity (CEC) in access to nutrients for microbes and plants. However, can you compare the roles of microbes in nutrient cycling between sandy and clayey soils?

If you are a soil planner and find that to be a tough question, you might start by reviewing basic soil health concepts to develop your understanding. Next you could practice interpreting soil health reports. With practice you should be able to compare different reports about soil health and eventually critique comparisons made by other people. Experts in the field may produce new or original work about soil health. For most soil planners the ability to evaluate others' ideas is a strong level of thinking. Evaluation skills are helpful to coach farmers to understand and apply soil health.

For farmers, the goal is to understand the soil health concepts and apply them to your operation. You might start by looking-up the definition of new words and repeating new concepts that you encounter to others. Eventually you will develop the ability to discuss the ideas with others and translate what you learn into common language. You have reached a strong level of thinking when you can execute practices on your land.

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Part I Systems Thinking

Emergent properties and feedback loops

Have you ever wondered why there isn't a single test to tell you everything about soil health? Blame the properties of complex systems.

As you can imagine, soils are made up of levels of organization and integration from atomic (arrangements of atoms within a clay lattice) to particle (sand, silt, and clays) to ped (soil aggregates) to epipedon (soil horizons) to geographic region (landscape). These levels are referred to as dimensions of analysis. The soil system becomes increasingly complex at higher dimensions.

Soil properties are often scale-dependent. New properties emerge that cannot be predicted by observations and full knowledge of the lower levels. Alex Novikoff (1945) called these emergent properties. Likewise, our understanding of emergent properties does not always help us to understand the properties of the lower levels of organization because each level may have its own properties. For example, low oxygen microsites within a soil aggregate can cause denitrification (loss of nitrate from fertilizer into inert N_2 gas) although the overall amount of oxygen in the soil is near atmospheric levels (Myrold, 2005; pp. 364). This leads to the problem that soil samples measured in a lab may not describe how the soil functions in the field or at other dimensions of analysis.

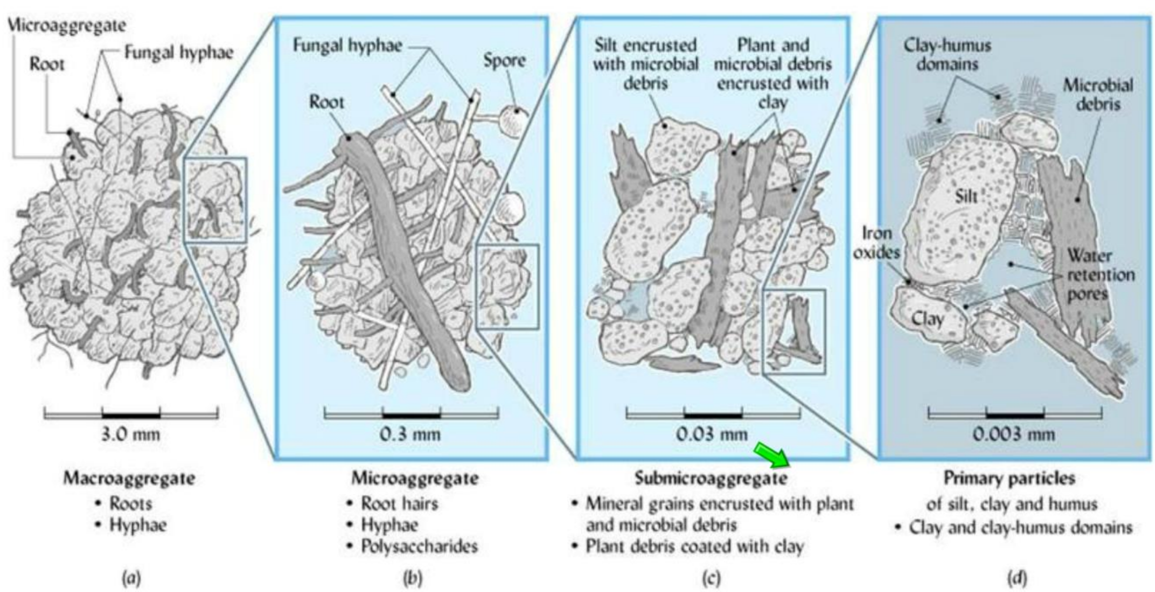


Figure 2: Dimensions of analysis of soil structure at increasingly smaller scales: (a) Macroaggregate, (b) Microaggregate, (c) Submicroaggregate, and (d) Primary particles.

Patterns do emerge, however, in the properties of complex systems that involve life, such as soil. Feedback control or interconnectivity is one example. Kristen DeAngelis and others at the University of California Berkley (2008) used pots planted with wild oats to study feedbacks between roots and bacteria in the rhizosphere (root zone). They hypothesized that the density of soil bacteria on roots turns on or off production of a bacterial enzyme that degrades soil nitrogen. This density-dependent response is called *quorum sensing*. Because density of soil bacteria depends on food given by the plants' roots, their experiment demonstrated a feedback between plant root exudates (compounds released by roots), density of bacteria, and plant root access to nitrogen. In other words, plants and soil microbes depend on each other to get nutrients from soil.

Resilience to disturbance is another property of complex systems that occurs across different scales. The USDA's National Range and Pasture Handbook describes how plant communities in dry grassland ecosystems can be resilient to grazing and drought. The relative amounts of grasses and bare soil may fluctuate from year to year but stay the same on average over time. However, repeated disturbance from drought or overgrazing over many years may overcome this resistance and cause a transition from grass dominance to shrub dominance. The rangeland may then stay in the shrub state until a strong disturbance causes a new state. The resilience of a site to disturbance may depend on water- and fire-related properties that emerge at several dimensions of analysis, including soil texture, location relative to a patch of grass, and position on the landscape (USDA-NRCS Grazing Lands Technology Institute, 2013; pp 30-31).

Researchers at La Jornada Experimental Range in New Mexico. Landscape position and relative location control the visible pattern of black gramma grass and bare soil.

Related to the concept of disturbance, grazing consultant Allen Williams (2016) proposes several principles for ongoing improvement to pastures that rely on the resilience of complex systems. For example, Williams encourages disruption, which involves not only testing the resilience of a pasture system with heavy grazing pressure, but also disruption to the routines of grazing pressure (i.e. variable stocking rates, stocking densities, rest periods, heights of pastures pre- and post-grazing, number of livestock species, patterns of rotation across the farm, and sizes and shapes of paddocks). One underlying reason for this approach may be that complex systems tend to adapt to patterns. Ecologists describe similar effects from erratic natural disturbances: fire and grazing tend to increase biological diversity through ecological succession, competition for resources, and selection of niches.

Beef cattle trample a hay field that has gone to seed in Rock Springs (Sauk County, Wisconsin) at a pasture walk with Allen Williams.

Related to the idea of emergent properties, Allen Williams (2017) also describes compounding and cascading effects, which are exponential and interconnected changes, rather than linear and singular changes, that occur with linear disturbances of complex systems. Jiangxiao Qui and Monica G. Turner at the University of Wisconsin – Madison (2015) describe three hypothetical non-linear response patterns: exponential, sigmoid (increasing rapidly and then leveling off), and step function (spontaneous change from one state to another), which are modeled in Figure 3.

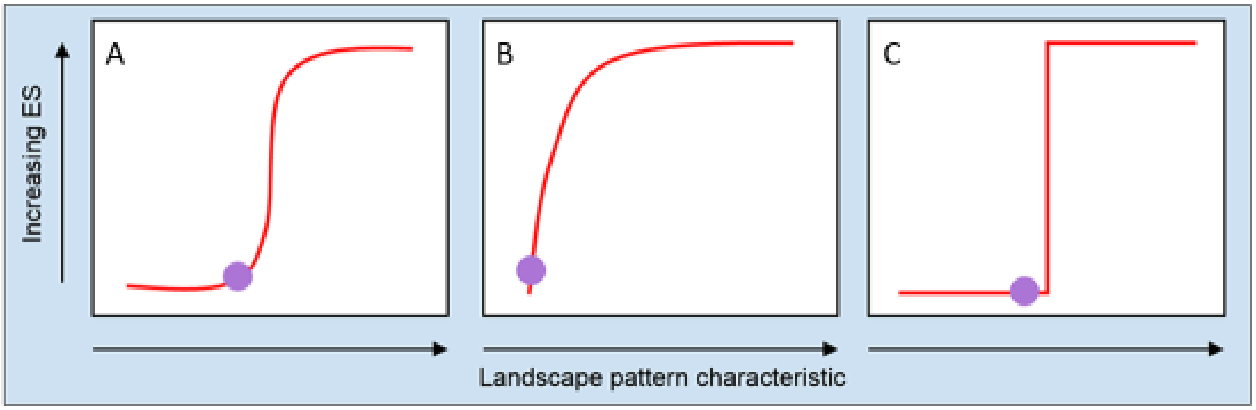


Figure 3: Hypothetical non-linear responses of ecosystems to landscape changes: (A) exponential curve; (B) sigmoid curve; (C) step function. Solid purple circles indicate areas near the threshold where small changes yield big effects (Qui & Turner, 2015).

Researchers such as Robert T. Paine at the University of Washington and others (1998) describe the non-linear effects when complex systems are pushed over the brink by multiple disturbances, such as overfishing, nitrogen pollution, and flooding in the Gulf of Mexico. They report "after major flooding in 1993, the hypoxic zone doubled to [nearly 7,000 sq. mi.] and has not shrunk much since." Declines in abundance of fish, shrimp, and crab (Figure 4) seem to be irreversibly compounded by other disturbances to plants, soils, and waters in the Mississippi River watershed (Donner et al, 2004).

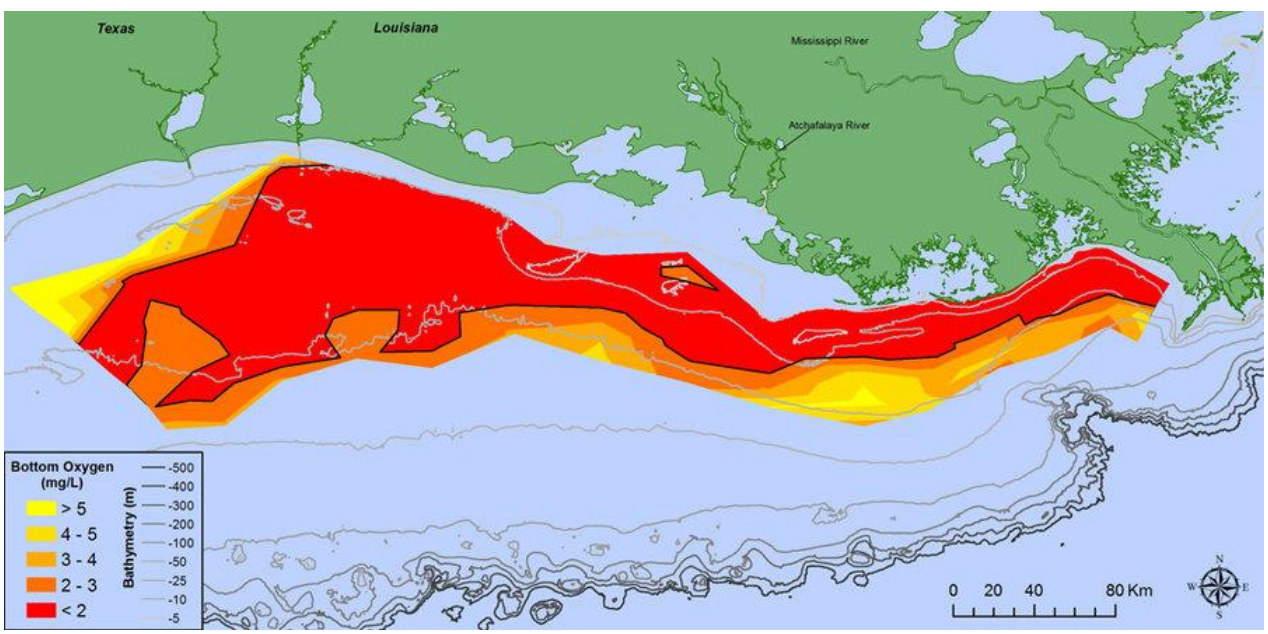


Figure 4: Gulf of Mexico dead zone in July 2017 was measured as 8,776 square miles, the largest ever measured (Courtesy of N. Rabalais, LSU/LUMCON; NOAA, 2017).

Ecosystem services

Perhaps most important to our daily lives are the many benefits freely gained by humans from the emergent properties of earth's complex living and non-living systems. The United Nation's (UN) Millennium Ecosystem Assessment report (MEA, 2005) describes these benefits as *ecosystem services*. As we just described, compounding and cascading effects from disturbances at multiple dimensions of analysis can cause these benefits to decline dramatically.

The MEA report categorizes each of the ecosystem services as provisioning, regulating, cultural, or supporting in relation to human well-being. Examples of specific ecosystem services are listed in Figure 5, including food supply, water purification, pest and disease control, flood regulation, nutrient cycling, primary production, and soil formation.

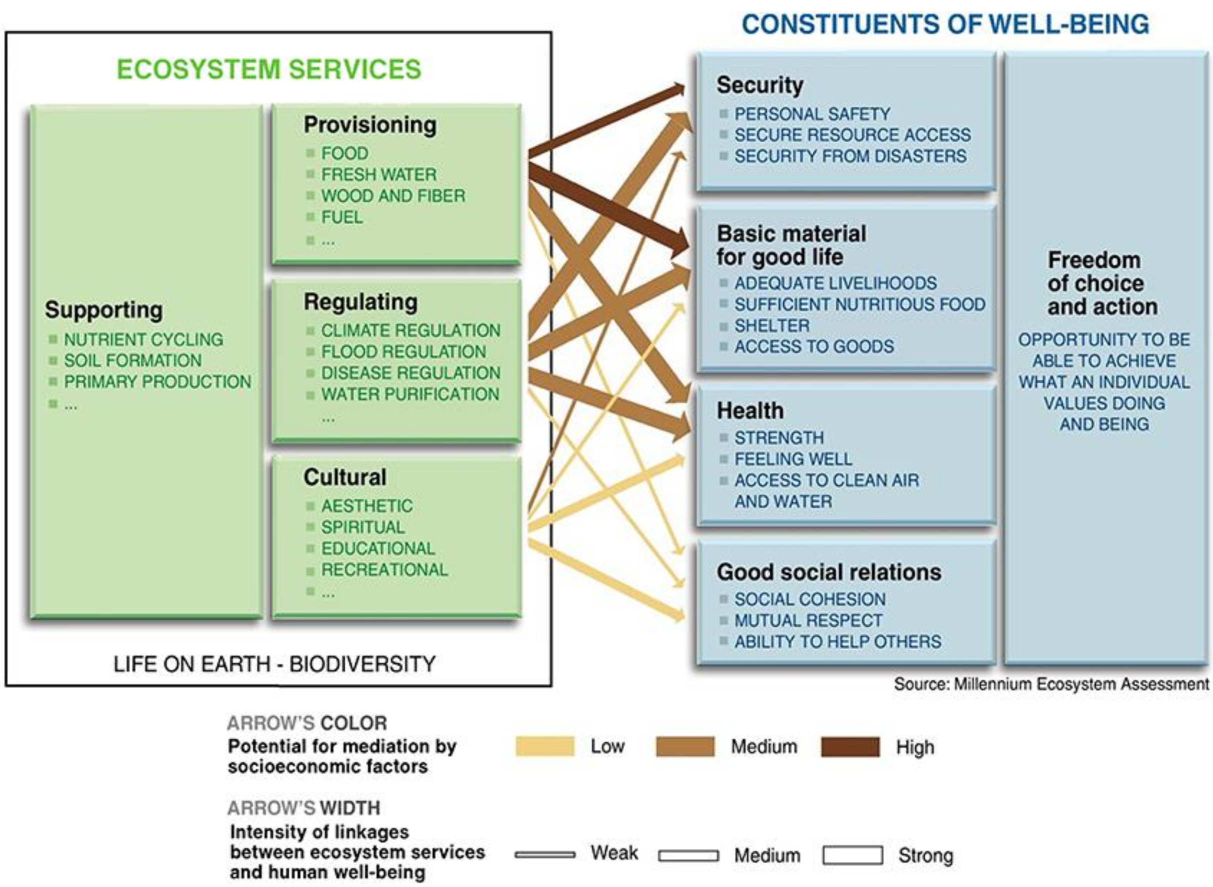


Figure 5: Ecosystems services, constituents of well-being, potential for mediation by socioeconomic factors, and intensity of linkages between ecosystem services and human well-being as defined by the Millennium Ecosystem Assessment (modified by Baveye et al, 2016, pp. 8, from MEA, 2005).

According to the report, provisioning, regulating, and cultural services have direct links to human health, security, basic material well-being for a good life, and social cohesion. Freedom of choice doesn't have a direct link to ecosystem services but supports the other parts of human well-being. Supporting ecosystem services don't have a direct link to human well-being but maintain the other ecosystem services. This toolkit focuses on what are considered supporting ecosystem services because modifying those services leads to better provisioning, regulating, and cultural services for human well-being.

The MEA report also assesses the possible impacts to ecosystem services from four future scenarios of economics, policy, culture, and technology, which it refers to as *Global Orchestration, Order from Strength, Adapting Mosaic, and Technogarden*. Provisioning services improve in three of four scenarios, regulating services improve in two of four scenarios, and cultural services improve in one of four scenarios.

The *Adapting Mosaic* scenario is the only one of four scenarios in which all types of ecosystem services improve. In this scenario, according to the MEA report (pp. 15),

> *Watershed-scale ecosystems are the focus of political and economic activity. Local institutions are strengthened and local ecosystem management strategies are common; societies develop a strongly proactive approach to the management of ecosystems. Economic growth rates are somewhat low initially but increase with time and population in 2050 is nearly as high as* [the scenario with the greatest rate of population growth] *Order from Strength.*

More than 100 farmers and agency staff gather for a tour of farms located in the Rush-Mill Creek watershed in Spring Green (Iowa County, Wisconsin).

Stories of change in watersheds

Policymakers, scientists, and agency staff at many levels of society are recognizing the opportunity to work at watershed scales. Water, soils, and plants are interconnected across nearly all dimensions of analysis from primary soil particles (0.003 mm to 2 mm diameter) to watershed basins (>1,200 mi diameter). One of the emergent properties at the watershed scale is flooding, which occurs in part because of runoff that results from compounding and cascading effects of land use in the watershed. For example, Figure 6 includes a map of land use in the Yahara River watershed, surrounding Madison, WI. Figure 7 shows the distribution of ecosystem services, including flood regulation, which the watershed provided in 2006, according to computer models (Qui & Turner, 2013).

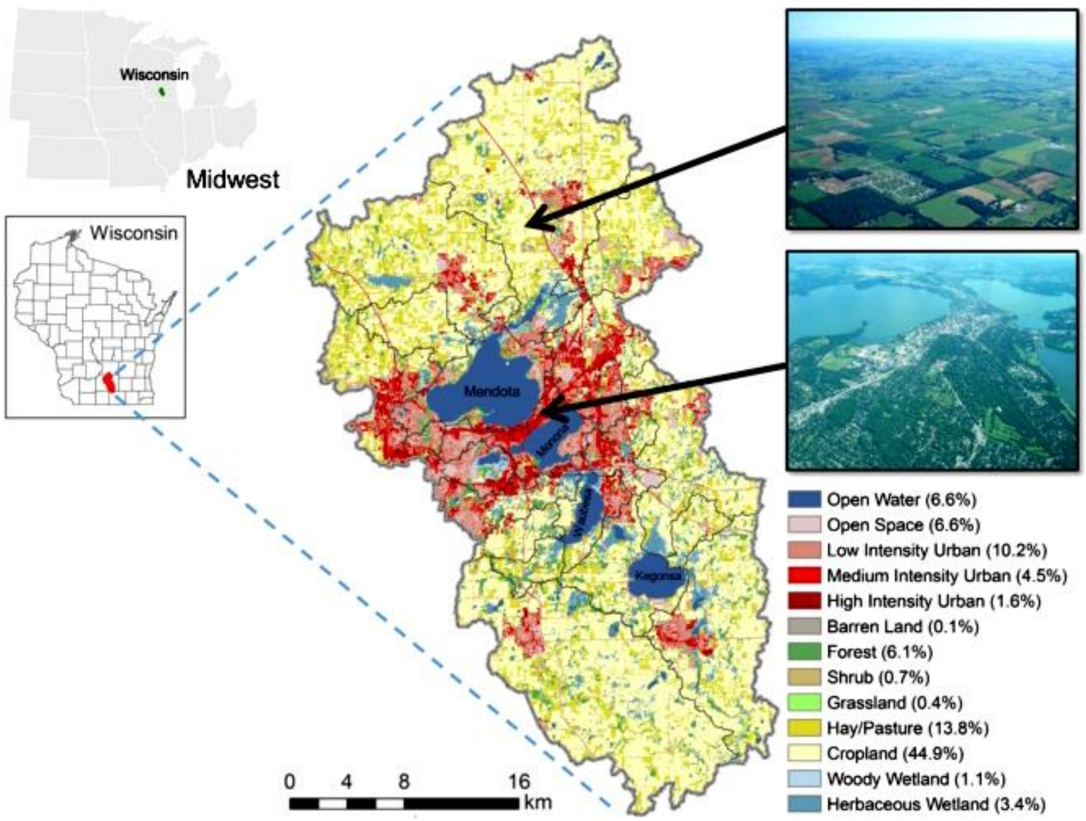


Figure 6: Map of the Yahara River watershed (Wisconsin) and the land-use/land-cover pattern (with percent cover) for 2011, derived from the National Land Cover Data. Delineations of the Yahara watershed were based on light detection and ranging (LiDAR) elevation, sewer-sheds from the city of Madison, and a field-checked basin map from Dane County, Wisconsin. Two aerial photos in the upper-right corner were taken in summer 2013 and illustrate the typical agricultural landscape (top) and acceleration of urbanization (bottom) in this watershed (Carpenter et al, 2015).

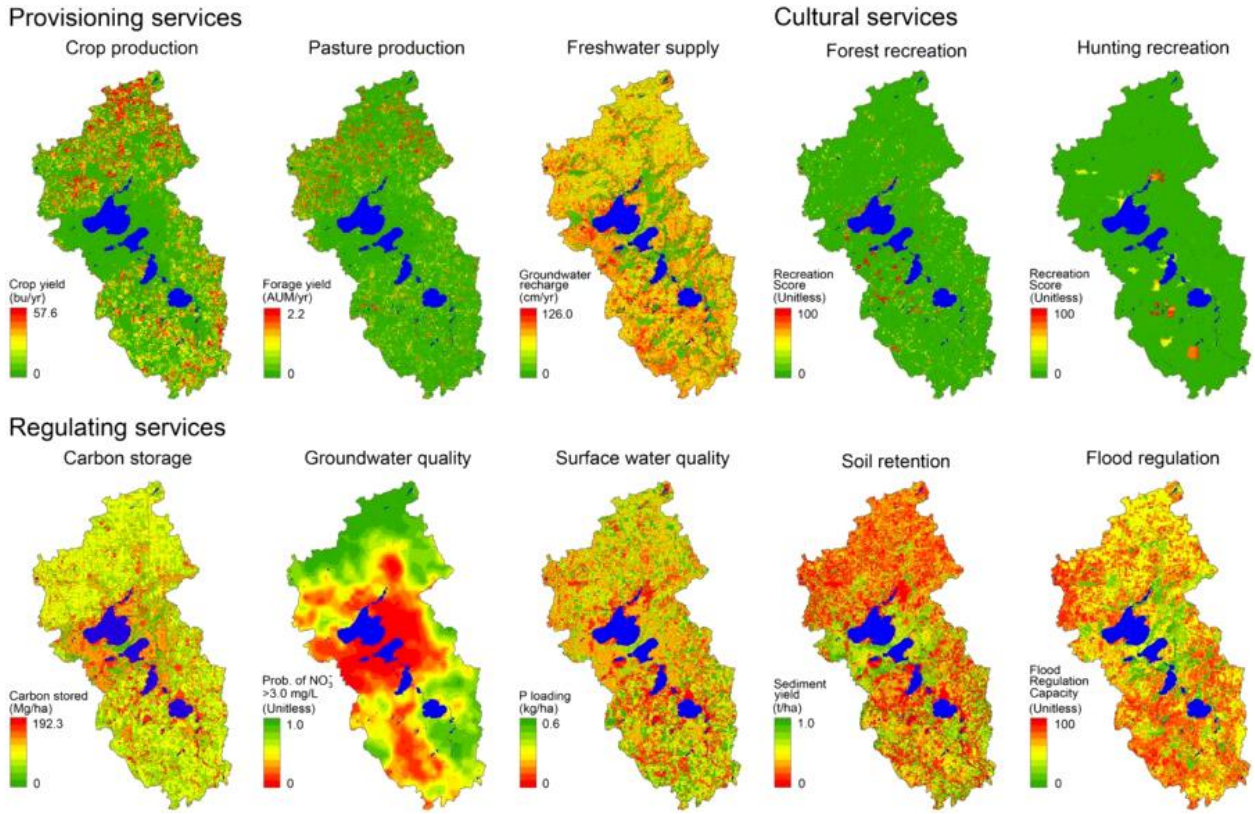
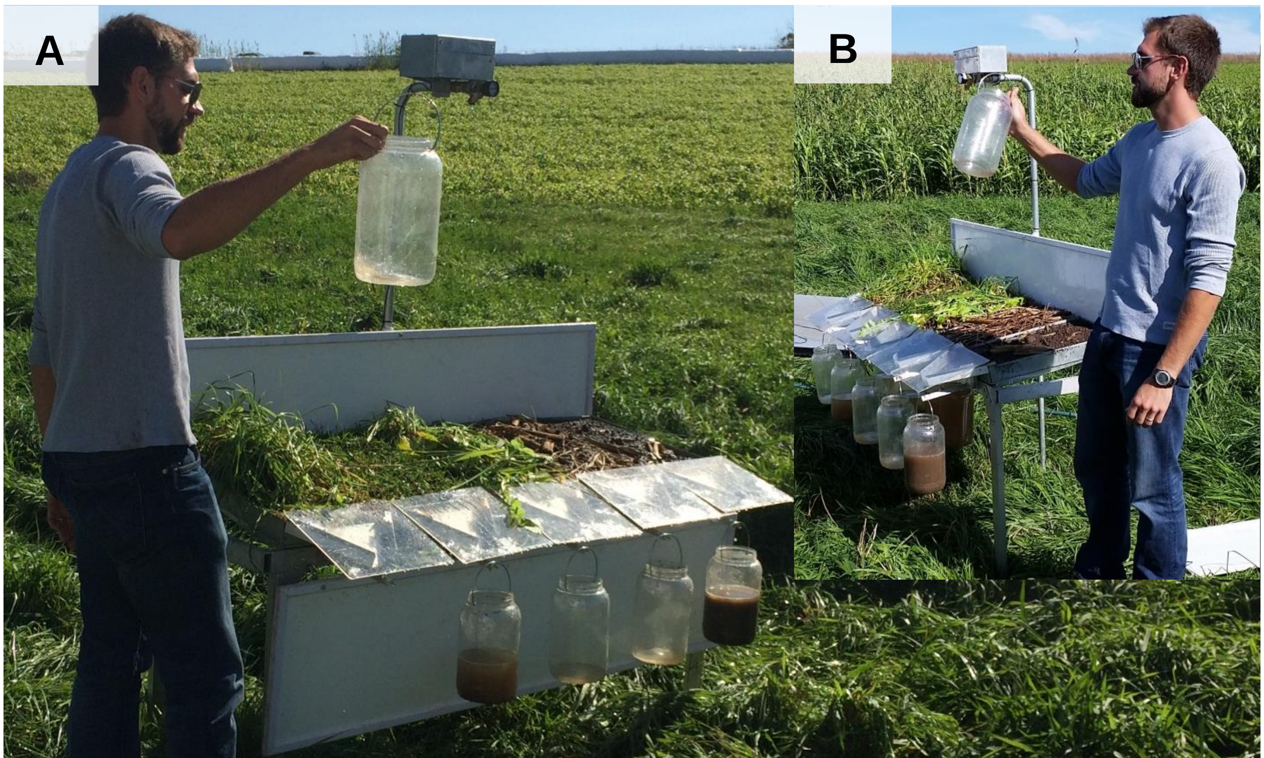


Figure 7: Spatial distributions of 10 ecosystem services in the Yahara watershed, WI, for the baseline year of 2006. Red indicates areas with high supply and green indicates areas with low supply of ecosystem services. The production of each ecosystem service varied greatly across the landscape and each was distinct in geographic distribution. Reprinted in Carpenter et al (2015) with permission from Qiu & Turner (2013).

According to the models, the watershed had lower supplies of pasture production, groundwater quality, and recreation; greater supplies were of soil retention, flood regulation, and surface water quality. However, flood regulation in the northern part of the watershed was below the maximum possible, in part because of land use for crop production. The models also found patterns of interaction between multiple ecosystem services. Pasture and forest uses enhanced water quality (UW, 2015).

> *In most cases, synergistic relationships existed between co-existing ecosystem services. Two notable synergistic bundles are 1) forest recreation, soil retention, surface water quality, and carbon storage (called “forest and water synergies”); and <u>2) pasture production, freshwater supply, and flood regulation (called “pasture and water synergies”).</u> In other words, managing to enhance one of these services would likely also enhance the others in the bundle.*

Water infiltration is one of the most important properties of soil. All pastures can follow at least four of the five soil health principles: keep the soil covered, minimize soil disturbance, keep living roots in the soil, and integrate livestock. However, rainfall simulation demonstrations show that water infiltration in overgrazed pastures is decreased and runoff is increased compared to well-managed pastures. Overgrazed pastures don't keep the soil covered fully and living roots in the soil are minimal.



(A) Aaron Pape leads a rainfall simulation at a pasture walk in Dodgeville. He holds a jar that represents the amount of water and sediment in surface runoff from a well-managed pasture after a 2-inch rain event. The other jars represent the runoff from (L to R) overgrazed pasture, cover crops, no-till, and chisel plow. (B) Aaron holds a jar that represents the amount of infiltration and percolation from a plowed field.

Rainfall simulations also show that other soil health promoting practices, such as cover crops, have mixed impacts on water movement through levels of the complex soil system. For example, soils under cover crops have similar amounts of runoff compared to soils under well-managed pastures because both systems allow water to infiltrate the soil. However, soils under cover crops have greater percolation compared to soils under well-managed pastures, which means that water flows quickly through the soil rather than being stored in the root zone to provide for plant growth and flood control. Water-holding capacity of soil is an emergent property that results from plant-microbe-soil interactions that occur at lower dimensions of analysis under perennial grassland cover.

A riparian pasture along Otter Creek in Avoca
(Iowa County, Wisconsin) floods during July 2017.

Research shows that land use is driving floods in Wisconsin, such as those that have caused millions of dollars of damage in Vernon, Crawford, and Richland Counties during 2007, 2008, 2016, and 2017 (Robson, 2017; Pomplun, 2007). For example, Jacob Usinowicz at UW – Madison and others (2017) used long-term data spanning nearly a century to investigate the effects of land use change and regional shifts in precipitation patterns on hydrologic flashiness in the Yahara River watershed in Dane and Columbia Counties. Flashiness is variability in runoff rate, volume, or stage-level of waterways. They concluded that flashiness increased significantly over time, driven more strongly by watershed-level land-use changes than by changes in precipitation.

Greater absorption of water into the soil is needed to mitigate floods. However, nationwide assessments of the impacts of structural practices on runoff and erosion, such as USDA's Conservation Effects Assessment Project (CEAP; USDA-NRCS, 2017), show that conservation practices have increased water flows through soil. CEAP reports that conservation practices implemented nationwide during 2003-06 led to similar changes in water runoff and subsurface flow (-0.64 and +0.5 inch per year; pp. 45). This result is like the effect of cover crops on water infiltration and percolation in rainfall simulations described earlier. Percolation may be at odds with water absorption.

Conservationist Adam Dowling and Dane County District 30 Supervisor Patrick Downing discuss a rainfall simulation in Columbus (Columbia County, Wisconsin)

Increasing evidence suggests that practices like grassed waterways, filter strips, stream buffers, and bioreactors promoted by policy and practice are simply band aides which have not significantly improved watershed conditions. For example, Lathrop and Carpenter (2011) report that 35 years of best management practices (BMP's) installed in the Yahara River watershed have resulted in undetectable reduction in phosphorus (P) loading to lakes via surface water runoff. Combined with the effects of regional shifts in precipitation during that time which increased P loading, BMP's have at best maintained the existing level of agricultural impacts to the watershed. Practitioners and scientists are recognizing that land use changes, even at small scales, are needed to improve watersheds. For example, Qui and Turner (2015) describe how reducing cropland cover in targeted subwatersheds, representing as little as 5% of the total Yahara River watershed area, could enhance water quality. Their model predicts a non-linear response to land use change that fits the sigmoid curve diagrammed in Figure 3.

Earlier models by Qiu and Turner (2013) also found tradeoffs between crop production and water quality. However, they propose that win-win situations for crops and water quality can occur when certain soil conditions exist at the field-scale (UW, 2015): "flat topography, less erodible soil, a deep water table, soil with high water-holding capacity, favorable soil conditions for plant growth and filtration, and a nearby wetland or stream." However, a limitation of these simulations is that they don't include external pressures that drive land use for crops such as rising demand for food for growing populations.

We must also translate the effects of possible changes in economics, policy, culture, and technology into stories that the general public can envision and compare. For example, Steven Carpenter at UW-Madison and others (2015) used input from computer models, interviews, and public workshops to develop four future outcomes for the Yahara River watershed (Figure 8). An interactive website to explore the results of their analysis is online at https://wsc.limnology.wisc.edu/yahara2070-ecosystem-benefits/. The results are similar to the scenarios listed in the Millennium Ecosystem Assessment (MEA), which was mentioned earlier: fictitious but plausible.

Name:	Nested Watersheds	Abandonment & Renewal	Accelerated Innovation	Connected Communities
Dynamics:	Adaptation	Transformation	Adaptation	Transformation
Key Factor in Change:	Government	Inaction	Technology	Values
Nutshell:	Government intervention maintains nature's benefits	Disaster decreases population, leads to reorganization	Massive growth in technology businesses, including green tech	Global shift in values toward sustainability

Figure 8: The Stories of Yahara 2070 (UW Madison, 2016; illustrations by John Miller).

“For decision makers and communities, scenarios can help to identify a range of possible futures and compare the tradeoffs among them. In doing so, scenarios improve the understanding of and enable discussions about the type of future that is both conceivable and desirable” writes the authors of the Water, Sustainable, and Climate in the Yahara Watershed project (2014). Certainly great possibility exists to apply this type of thinking to explore the future of rural and urbanized areas across Wisconsin. Hopefully others will draw from the approaches to systems thinking that are mentioned in this toolkit to protect human well-being for generations to come.

Participants at a grazing workshop walk up a hillside through an oak savanna in Blanchardville (Green County, Wisconsin).

Part II Soil Health Concepts

Investing in soil health

"Why does soil erosion matter?" can be a frustrating question to answer. Obviously, soils provide many benefits to people, such as food and clean water, which we would like to use now and in the future. But some of what soils provide to people is not beneficial to us, such as weed seeds and floods, and we want those to decrease. So it can be hard to explain why soils matter since soils can have opposite kinds of value.

What is the value of soil? People need to be aware that soils can build up, maintain, or lose value over time. As we will discuss, the value of soil nutrients for food production may not be the greatest source of value in soil. Soils often have built up great existing value, or natural capital, that is unique from the capital that is added or built by people. For example, development of soil biological diversity and organic matter support nutrient cycling and water infiltration. But soils may lose value faster than they gain value in certain ways. So it's better to support soils rather than to degrade them because of the effort needed to restore natural capital once it's lost. Of course, certain properties of soil are easier to manage and repair than others, and we'll focus on those properties.

Farmer pulling up a cover crop to show its roots.
Photo credit: Edwin Remsberg and USDA-SARE.

The natural capital approach to valuing soil was used on a dairy farm in New Zealand by Estelle Dominati of AgResearch and others (2014). This approach basically looks at maintaining soil benefits to humans as an investment with a potential rate of return that can be calculated and compared with other investments. The researchers calculated the value of manageable benefits provided by a silt loam soil as the cost to replace those benefits with infrastructure or other best management practices (see Table 2).

Key to these calculations is the idea of *net present value*, which is the value in today's dollars of cash flows (positive and negative) that will occur in the future. A dollar today is worth more than a dollar in the future, so we must discount the value of money spent or received in the future. A *discount rate* can be determined as equal to interest rates or possible rates of return from other investments during the same time period. In this case, the researchers used a 10% discount rate to value all of the future construction and maintenance costs of the infrastructure and best management practices.

Table 2: Net present value of the top four soil benefits on a New Zealand dairy farm over 35 years (summarized from Dominati et al, 2014).

Soil benefit	Calculation	Value†	%
• Filtering of contaminants (bacteria, pesticides, and chemicals in manure and urine from compost pile, effluent pond, barnyard).	• Costs to build and maintain an artificial wetland on the farm to store the water filtered within 5 days of each grazing event plus the time value of the money used to pay those costs.	$3,765	39.7
• Food production (quantity and quality),	• Pasture yield converted to milk solids ($4.46/lb, Nov 2012) plus cost to supplement cows with 4 trace minerals.	$2,772	29.2
• Filtering of nutrients (N and P in manure, urine).	• Costs to build and maintain a pad for heavy use area protection, use low N feed supplements, and use nitrification inhibitors plus the time value of the money used to pay those costs.	$2,010	21.2
• Flood mitigation	• Costs to build and maintain an on-farm dam to capture runoff plus the time value of the money used to pay those costs.	$691	7.3
• All benefits considered	• Sum of benefits; benefits not counted twice.	$9,475	100

† Per acre per year, in 2012 dollars, assuming a 0.7 NZ$ to US$ exchange rate.

Estelle Dominati and colleagues also compared the effect of discount rates of 3% and 10% on the net present value of future soil benefits in perpetuity. The total future value of benefits provided by the soil differs by $221,300 per acre depending on which discount rate was used. A greater perceived future value of money (greater discount rate, or interest rate) decreases the amount that a person would pay *now* to get those benefits *forever*. So if a person perceives that money invested in maintaining soil health can generate a greater rate of return elsewhere that person will value soil health less.

There's usually a tradeoff between risk and rate of return for any investment. All investments have risk and investments that are riskier tend to have greater potential rates of return. Certain types of investment have more risk than others. For example, stocks, commodities, and futures (agreements to deliver goods at a certain date in the future at a certain price) tend to be riskier than real estate, which tends to be riskier than cash. Investments that can provide returns immediately and for the foreseeable future are usually categorized as less risky. Tangible assets like real estate tend to stick around for the foreseeable future so they're considered less risky. Investments in soil health that will stick around from year to year such as seeds of perennial grasses and legumes would therefore be less risky than investments in annuals like cover crops.

(R to L): Jacob Marty, Emy Brawley, Wendy Warren, Robert Bauer, and Bryce Riemer in Monticello (Green County, Wisconsin). Photo credit: Nathan Aaberg.

The investment risk that a person should be willing to accept is determined by their specific financial situation and reasons for investing. High net worth individuals can assume more risk because any investment will represent a smaller percentage of their net worth. People with longer timeframes for investment can also usually take greater risks because they can make up for losses in the future. However, people entering new ventures should assume less risk because of the greater chance of making a mistake. And retirement savings should assume less risk than other investments because they are important for personal well-being. Similarly, any savings that might be used for healthcare or education should assume less risk than purely speculative investments.

Based on the tradeoffs just discussed, the type of farmer who might want to invest in soil health could be a beginning farmer with low net worth who is close to retirement. But a beginner who has limited or no access to credit because of past financial trouble may have to pay higher interest rates which could discourage soil health investments.

View of a soil health investor and her business partner from the soil's perspective.
Amy Fenn contract grazes dairy heifers in Ferryville (Crawford County, Wisconsin).

The type of farmer who would be less likely to invest in soil health would be an experienced farmer with high net worth who is making long-term investments. However, if the farmer plans to use their farm as a source of income during retirement, they might be more likely to pursue soil health practices. Also, investing in soil health provides opportunities to diversify investments on the farm. Farms that are engaged in riskier farm enterprises could mitigate risk by investing in soil health practices.

Chris Dixon kneels in a cover crop field with corn stubble in spring (White Hall, Maryland). Photo credit: Edwin Remsberg and USDA-SARE.

Certainly these ideas may conflict with the conventional wisdom on soil health, which is that soil health is a long-term investment that can take years to generate positive returns. It may be more practical to focus on how each farmer’s situation and personal definition of success affects their views on the time value of money, rather than applying a blanket prescription. If a person would rather make other productive investments while losing the benefits of soil health, they have to accept that greater potential returns come with greater risks and returns can never be guaranteed into the future.

Consider the needs and capabilities of each acre

The job of the conservation planner is to, in the words of Hugh Hammond Bennett (1947), “consider the needs and capabilities of each acre within the plan.” As we mentioned earlier, some properties of soil can be changed with management to increase the production of benefits to humans. Other soil properties don’t change with management but do change the management that must be used in order for the soil to continue to benefit humans. Each type of soil property is summarized in Table 3.

It’s our job to understand which soil properties lead to human benefits and how these properties change and are changed by farming practices, land use, and technology. For example, at a field day at Rolling Hills Stock Farm in Dodgeville, Wisconsin on October 11, 2016, Jamie Patton from UW Extension Shawano County described how the New Glarus silt loam soils in the southern Driftless Region of Iowa County, Wisconsin contain smectite clay that, when wet, swells up and closes off the channels in the soil created by earthworms and roots. The importance of cover crops and perennial vegetation to these soils is that plant roots can fill these channels before they close off, thereby keeping paths for water infiltration and percolation. The clay types of the soil are inherent properties that inform how land cover and biodiversity on the farm should be managed to produce the most benefits to people from plant growth and flood mitigation.

Table 3: Inherent and manageable properties of soil (summarized from Dominati et al, 2010, 2014), categorized as biological, physical, or chemical.

	Manageable properties	Inherent properties
Definition	Respond to active management.	Taken from soil formation conditions. Don’t change with management.
Physical properties	Temperature, porosity, bulk density, saturation levels, strength (penetration resistance to plant roots), soil water content: field capacity, saturation capacity, available water capacity, plastic limit, drainage class of topsoil.	Slope, orientation, texture, stoniness, depth, subsoil strength, subsoil drainage class, and fragipan (subsurface layers that restrict root growth and water flow).
Chemical properties	pH, nutrient status, trace-element status, cation exchange capacity, anion exchange capacity, soluble P, mineral N (the form primarily taken-up by plants).	Clay contents, inherent mineral contents.
Biological properties	Land cover, biodiversity, organic matter, dissolved organic matter.	

As we discussed in Part I, soils are complex systems. Their properties are scale-dependent and interconnected. Managing for one property can lead to interactions between other properties. For example, as we will discuss in Part III Soil Biology, texture, pH, soil biodiversity, and water-holding capacity are all interconnected by feedbacks across dimensions of analysis. So the distinctions between physical, chemical, and biological properties can seem arbitrary, since none of them operate in isolation. But our farming systems often silo these properties by definition; for example, nutrient management planning generally focuses on the effects of manageable chemical properties (pH, nutrient status, and trace-element status) and inherent physical properties (slope, texture) on crop production, without looking at soil biodiversity. Given that bacteria and fungi metabolize and absorb N, P, and C at significantly different rates and efficiencies, soil biodiversity can have significant effects on crop production.

The proper tools and tests for the status of manageable soil properties are those that measure the property as directly and in-field as possible. For example, obviously it would be better to measure current land cover by looking at the farmer's field, rather than by looking at a satellite image of the field. Similarly, we should aim to measure biodiversity directly (through genetic sequencing or lab culturing). For example, check out methods to count bacteria in the "Smell of Dirt Test" in Part VI Educational Tools.

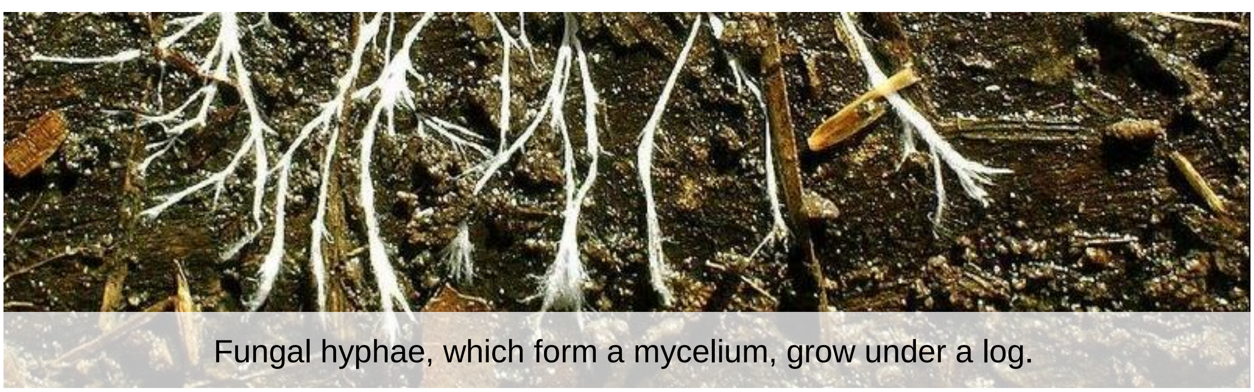
Jason Cavadini demonstrates a Solvita 1-day soil CO_2 respiration test from an outwintering area at Sandstone Ranch in Stevens Point (Portage County, Wisconsin).

Part III Soil Biology

The soil is alive

Microbes obviously cannot be seen easily without a microscope. But most cannot be seen *with* a microscope either! Less than 1% of microbes can be cultured, as Ian Pepper and others describe in *Environmental Microbiology* (2011, pp. 183). However, scientists have developed ways to census the microbes in the soil by extracting and sequencing their genetic material. Others have measured proteins and enzymes produced by the microbes as indirect ways to study them. These new methods have unleashed an era of discovery in soil biodiversity (Fiere et al, 2007). The microscopic kingdoms of soil life known today are bacteria, fungi, archaea, protists, and algae.

- **Algae** form in the upper 1 cm of soil and are important colonizers of bare soil.
- **Protists** are basically anything that isn't a plant, animal, or fungi. For example, protists include amoebas and water molds, which are among the most notorious plant pathogens that cause root rot of legumes in wet soils.
- **Archaea** have a cell structure that is more chemically stable than bacteria so they can survive high temps and acidity. Archaea are also resistant to many antibiotics made by bacteria, which may have played a role in their evolution.
- **Fungi** form long, branching structures, called hyphae, which collectively are called a mycelium. Water molds and certain bacteria can also form hyphae. Mycorrhizal ("fungus-root") fungi form associations with the roots of certain plants, including grasses, which can help the plants to access soil nutrients like P. However, cover crops in the brassica family don't form these links. In the process of decomposing soil organic matter, mycorrhizal fungi produce glues, such as *glomalin*, that give the soil structure. One way to spot them in nature is the puffball mushrooms that some mycorrhizal fungi make.



Fungal hyphae, which form a mycelium, grow under a log.

- **Bacteria** can be grouped into gram-negative and gram-positive, based on the coatings of their cells. Each group uses different survival strategies in soil. For example, “the thick cell wall of gram-positive bacteria, such as *Bacillus* and *Clostridium*, helps them withstand the harsh physical conditions found in soil environments. On the other hand, the more complex architecture of the cell envelope in gram-negative bacteria such as *Pseudomonas* and *Shewanella* seem to aid these microbes in interacting with mineral surfaces and solutes in the environment to obtain nutrients” (Pepper et al, 2011; pp. 11). Gram-positive bacteria, like the Actinomycete *Streptomyces*, produce antibiotics; gram-negative bacteria, like *Pseudomonas*, are resistant to those antibiotics. Gram-positive bacteria like *Bacillus* can also form a tough structure called an endospore, which allows the bacteria to survive drought and high temperatures.

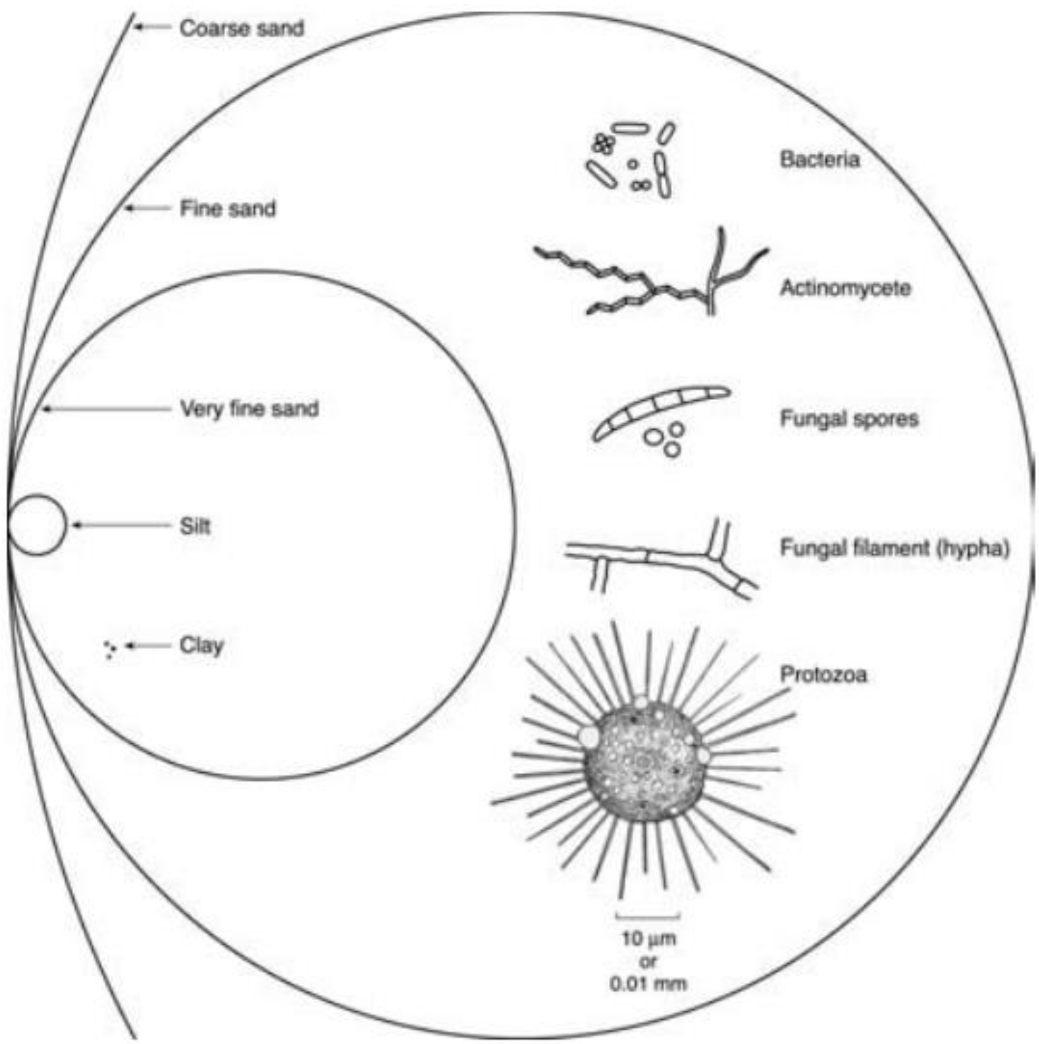


Figure 9: The sizes of soil particles compared with soil microbes (from Nardi, 2006).

Gross as it might sound, microbes basically eat outside of their bodies by releasing digestive enzymes into the soil. The stuff that many soil microbes eat is called soil organic matter (SOM). Once this food is broken down, microbes can transport the smaller molecules across their cell membranes to use for life and growth.

Soil microbes can use many sources of energy to live, including sugars, carbon dioxide, ammonia, metals, and methane. The photosynthetic bacteria and algae use energy from the sun, carbon dioxide, and water to make sugars and oxygen, just like plants do. Bacteria, fungi, archaea, and protists, like photosynthetic bacteria and algae, combine those sugars with oxygen to get energy, which releases carbon dioxide and water. Some bacteria and archaea don’t need oxygen to get the energy from sugars and carbohydrates; they like to ferment, which releases water and carbon dioxide or methane. Archaea are the only organisms that can produce methane (although many types of archaea don’t). That means that archaea are important in the rumen of cows!

A herd of cows with rumens full of archaea bacteria, helping to digest their feed, at Brattset Family Farm in Jefferson (Jefferson County, Wisconsin).

The herd beneath our feet

All food webs are driven by plants. They feed the soil with root exudates, dead leaves, and manure that is produced after plants are eaten by grazers. In turn, soil organisms support plant health as they decompose SOM, release nutrients, enhance soil structure, and control the populations of plant pests.

Fungi, bacteria, archaea, protists, and algae are part of soil biodiversity, as are protozoa, nematodes, mites, springtails, earthworms, dung beetles, and larger vertebrates that shred and bury inputs from above the ground, which makes them accessible to soil microbes. Figure 10 compares the relative amounts of each type of organism in the soil food web. The larger the organism, the fewer there are in the soil.

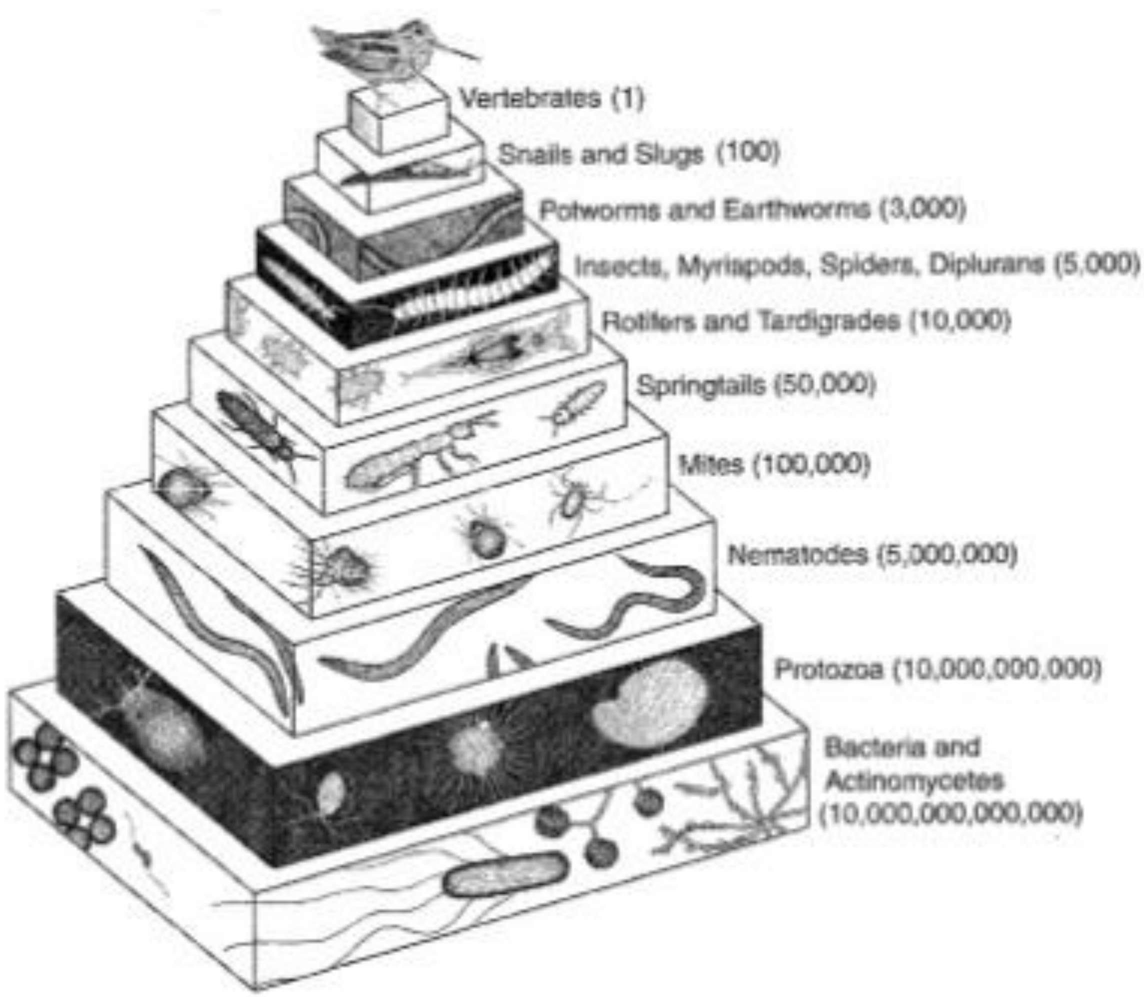
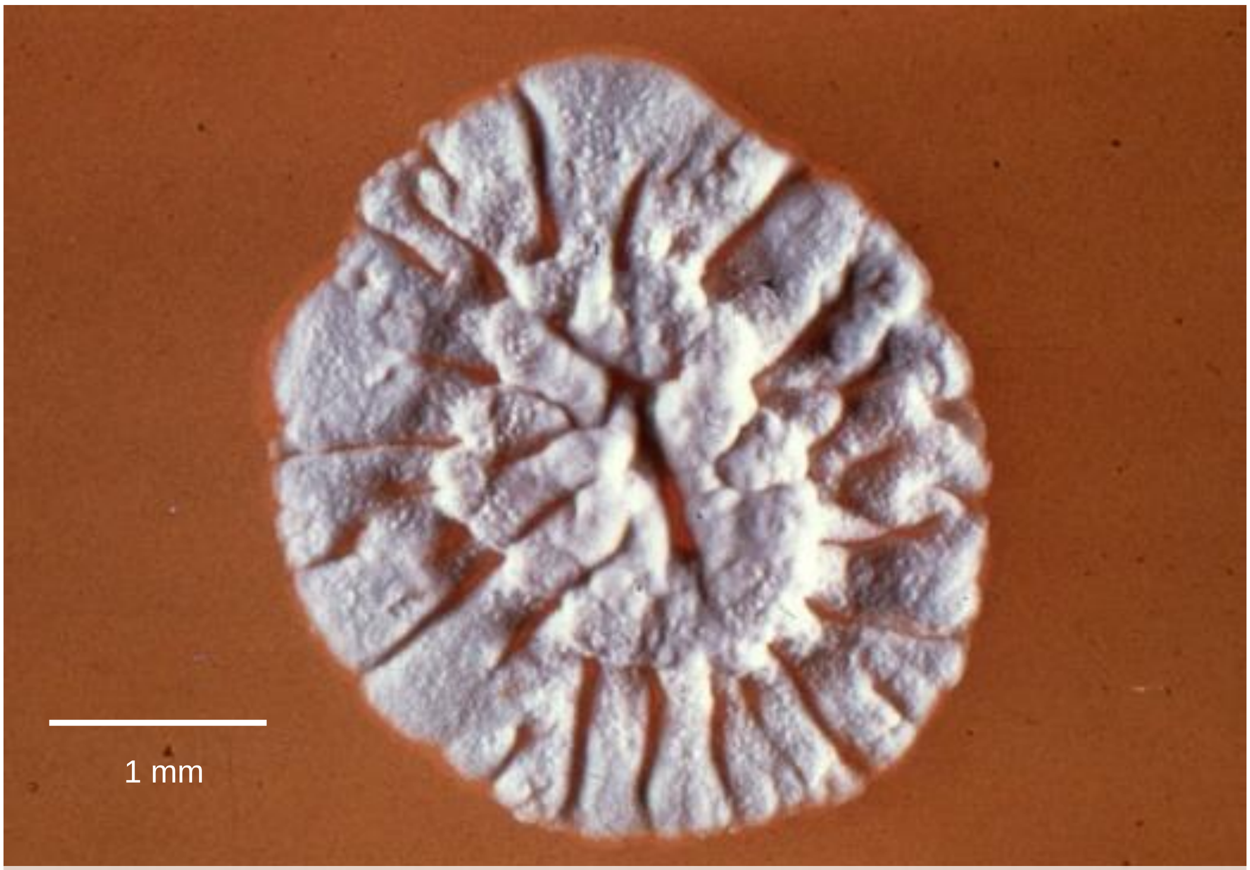


Figure 10: Foodweb pyramid in one square meter of soil (from Nardi, 2006; amount of each organism is in parenthesis; size of the level of the pyramid shows relative mass).

The herd underground is often larger than the one above the soil. Noah Fierer at the University of Colorado Boulder and others (2009) found that 40 to 80 percent of the animal biomass in earth's ecosystems is in the soil. In temperate grasslands around the world they estimated the average amount of soil animal biomass to be 1,060 lbs/ac. However, the estimated biomass of the soil fauna (nematodes, mites, earthworms), was only 43 lbs/ac. That means microbes represented a whopping 98% of the animal biomass in grassland soils! In fact, a gram of fertile soil may contain as much as 500 lbs/ac of Actinomycete bacteria, according to the University of Wisconsin Extension's *Management of Wisconsin Soils A3588* (Schulte et al, 2005; pp. 67).



This Streptomyces colony by J.J. Goodman is an example of Actinomycete bacteria.

Bacteria, fungi, and archaea make up the bulk of the soil food web. However, keep in mind that microbial biomass is only 1 to 2 percent of all soil organic matter, (Fierer et al, 2009), and all living biomass is less than 5 percent of soil organic matter. In many soils, plants have given an enormous amount of food to the soil food web over time, which has built the natural capital of the soil through the development of SOM.

Diakon radish cover crops. Photo credit: Edwin Remsberg and USDA-SARE.

Elaine Ingham describes several types of SOM in the *Soil Biology Primer* (2005):

- Fresh residues that have not started to decompose (< 10 percent of SOM). Plants feed the soil daily because their roots are very leaky. According to Michael Strickland and others (2012), 20 to 30 percent of the carbon fixed by plants through photosynthesis is simply lost through the roots. As Jamie Patton pointed out during a pasture walk in Dodgeville, sugars in root exudates may glisten on an exposed soil profile as photosynthesis ramps up during midday and afternoon.
- Active SOM (33 to 50 percent of total): the stuff being consumed. Some of the nutrients from this active material dissolve in the soil water and plants adsorb it.
- Stable SOM (33 to 50 percent of total): Once microbes have eaten the active SOM, it becomes part of their bodies, and when they die other microbes eat them. This feast creates lots of leftovers and dirty dishes that get left in the sink.

Microbes play a big role in storing and releasing the nutrients in SOM. In the past, scientists believed that SOM is formed through complex molecules like humus that can't be broken down. Francesca Contrufo at Colorado State University and others (2013) studied the fate of various simple and complex forms of SOM. They found that simpler compounds like sugars and root exudates developed much more SOM than complex compounds from dead stems, roots, and leaves. What happens is that simple molecules grow more microbial biomass than do complex molecules, the microbes die, and if the dead microbes are protected from decay (by not disturbing the soil) they add to SOM.

Each kingdom of soil microbes takes unique roles in the soil food web. Bacteria tend to use simpler organic compounds, such as root exudates. Fungi tend to use more complex compounds, such as fibrous plant residues, wood, and soil humus. So microbe populations may change based on what plants provide for dinner. Increasing soil pH also shifts soils from bacterial to fungal dominance, which slows the rate at which soil microbes consume SOM.

Microbes can also shift what they eat based on the relative amounts of nitrogen (N) and carbon (C) in SOM. Francesca Contrufo and others (2013) discovered that if N is limiting in the fresh residues, microbes will go to work on the more resistant stuff in order to get what they need to grow. Microbes can live on a diet of more complex SOM, however, they'll use up more of the SOM in the process. So it's important to feed the soil with fresh residues that have an lower C:N ratio (< 24:1), such as the roots and shoots of legumes and annuals like cover crops, rather than straw and grass seedheads, so the soil can develop more organic matter, which is our natural capital.

Plants depend on microbes for the majority of the N that plants need to grow. Most of the N in soils is in the SOM and so it can't be easily taken up by plants because plants prefer inorganic forms like nitrate and ammonium. Lightning strikes add a small amount of inorganic N to the soil, perhaps 20 lbs/ac/year. But much of the N that plants use has to be taken from the atmosphere by soil microbes that live inside of plant roots or freely in the soil. The N is then handed over to plants directly by the microbes or put into the SOM. From the SOM, the soil food web releases the N for plants to take up (Figure 11).

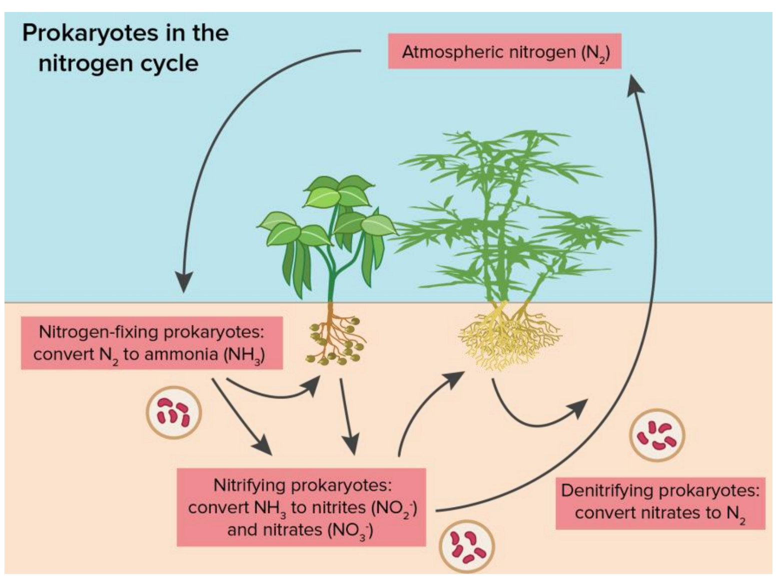


Figure 11: Soil biological nitrogen cycle (modified from Dreo [2009]; CC BY-SA 3.0).

How microbes affect soil properties

As we discussed in Part II, the soil has certain inherent properties like soil texture, or the amount of sand, silt, and clay, which strongly affect the habitats that are available for soil microbes. However, through the soil food web, microbes alter that habitat and make it better for themselves and plants. It's like a microscopic version of *House Hunters*!

Bacteria, for example, live essentially attached to the soil surface underwater or floating on films of soil water. They need to be underwater because, as we said, they eat by releasing enzymes, which dissolve in the water. So water is life for bacteria. Bacteria and fungi, like mycorrhizal fungi, produce glues that hold the soil together and allow the soil to hold more water, which improves the soil habitat (Figure 12).

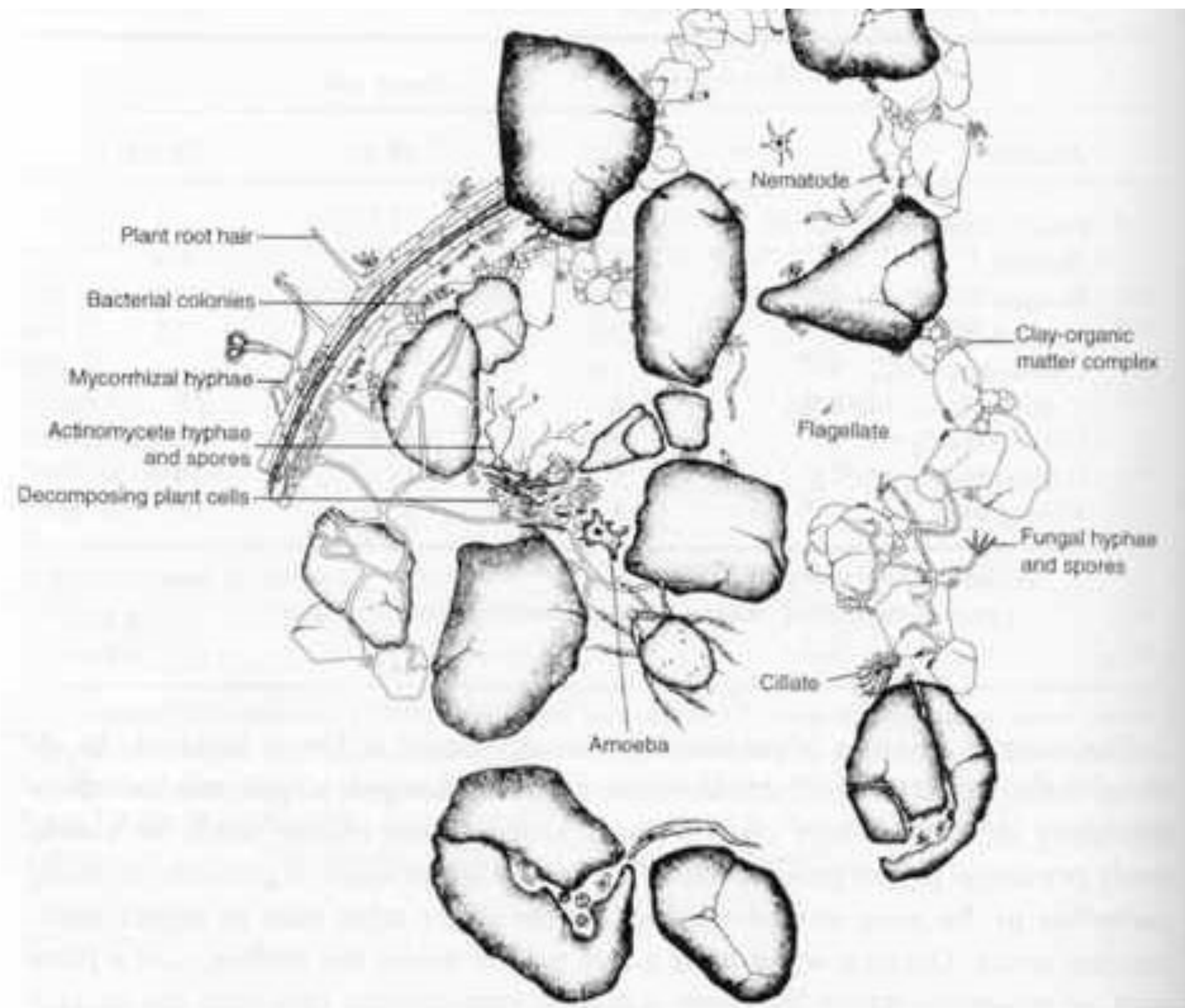


Figure 12: Soil organisms living within a soil aggregate (from Soil Biology Primer, 2005).

Water is held in the soil by forces of capillary action and electricity between soil surfaces and water. Soils with smaller particles (clay) have more of these forces so they hold water better than coarse-textured soils (sand). SOM also includes negatively-charged particles that increase the strength of forces between soil and water, which allows the soil to hold more water. However, too much water in the soil limits the amount of oxygen that is available to microbes. Soil water has about 1/100th as much oxygen as the soil atmosphere. When the oxygen in the soil is used-up, denitrifying bacteria use the N in the soil for energy, which causes that N to be lost to the air (Figure 11).

The amount of water in the soil is usually limited by gravity (drainage) and plant uptake (transpiration). The ideal amount of water is what is held in the soil against gravity, which is called *field capacity*. In most soils, field capacity is when 60 percent of the soil pores are filled with water. Water at field capacity requires the least amount of energy for plants to use. When the amount of water in the soil is below field capacity, plants use more energy to absorb water and fewer habitats are available for soil bacteria.

A farmer plows along a slope contour during a pasture walk at Sauve Terre Farm in West Bend (Washington County, Wisconsin). This ‘keyline swale’ allows water to flow uphill through the soil due to the forces of capillary action within soil pores.

Soil cation exchange capacity (CEC) drives the soil food web. CEC is the inherent ability of the soil to store and release nutrients because of charges on the surfaces of clays and SOM. Increased CEC increases microbial activity because microbes can use charges to attach to the nutrient-rich soil rather than floating in the soil solution.

The link between microbes, SOM, and soil CEC is called *cationic bridging*. Aaron Mills and David Powelson at Virginia Tech describe this link in *Bacteria Adhesion* (1996; pp. 35). Cationic bridging depends on soil texture and, to a lesser extent, on pH. Clay surfaces are negatively charged, which attracts positively-charged ions that form a coating on the soil. Although quartz in sand tends to be much less negatively charged than clays, these coatings can also form on sand at lower pH levels (perhaps < 6.0 pH), which allows sandy soils to perform cationic bridging as well. The positively-charged coatings that form on the mineral soil attract additional layers of negatively-charged SOM particles or microbial cells. Microbes can be sandwiched between the coatings and the SOM, which is like being locked in a buffet restaurant!

Mark Kopecky describes a sandy loam soil under a pasture at Sandstone Ranch in Stevens Point (Portage County, Wisconsin).

Temperature is an important variable for the health of plants and soil microbes, although the range of temperatures at which each prefers to grow can differ. Cool-season grass roots prefer temperatures between 50 and 65° F, and start to get stressed above 80° F (Beard, 2001). In contrast, soil microbes grow twice as fast for every 18° F increase in temperature above freezing but at temperatures above 95° F the rate of increase slows. Above 120° F, microbial enzymes start to denature, or break, and microbes die.

Land cover is very important for soil health. Dark soil can adsorb a lot of solar radiation and get very hot if it's exposed. Bare soil can also freeze much faster, which will kill microbes and plant roots. Plant leaves and fresh residues from plants shade and insulate the soil. For example, at a pasture walk in Ferryville, WI (Crawford County) on August 9, 2017, we measured 4-inch soil temperatures under pasture for dairy heifers to be ~82 ° F, which means that the grass was stressed. However, the soil temperature of bare soil that was exposed along a trench on the farm was 100 ° F, which means that the microbes were stressed, and plants would definitely not want to grow.

Dan Oleson describes the roots of sorghum sudan grass at a pasture walk held at Waseda Farm in Baily's Harbor (Door County, Wisconsin).

Part IV Educational Tools

Existing agency knowledge and practice

As we discussed in the Introduction, the development of this toolkit was guided by input from farmers, agency staff, and Grazing Network Coordinators. Our online survey of agency staff and farmers during July 2017 measured participants' comfort level with soil health tools and tests. The survey found that comfort level was greatest with physical and chemical tools and least with biological tools (Figure 13). Agency staff and farmers will most likely use and learn from the tools that they are comfortable with.

A shovel was the tool that participants were most comfortable with. Certainly, agency staff and farmers should dig up the soil and review its properties and management together during workshops, pasture walks, and farm visits. Sight and touch are two of our primary senses. It's easy to look at the structure and color and feel the texture of sand and clay. We also liked when Allen Williams dug up the soil and encouraged participants at a pasture walk to smell it, to assess whether it smelled sweet and earthy or sour and unpleasant, as indicators of plant health and soil biological activity.

The rainfall simulator demonstrations by Sauk County (Serge Koenig and Aaron Pape) and Wisconsin NRCS (Justin Morris) received very positive reviews from farmers. One point of feedback that we received in the online survey was to provide during events both practical demonstrations and the science behind the demonstrations. The participant felt that receiving that the scientific explanation would help them to fit the demonstration into their existing knowledge and that the demonstration would help them to apply the science. We feel that rainfall simulator demonstrations do that well.

Soil biological tests were least comfortable to participants, which is a great opportunity for future learning. Participants expressed interest in learning about the use and interpretation of the Haney and Solvita tests. The manufacturers of these tests provide resources on their websites. NRCS's Conservation Stewardship Program (CSP) also has an enhancement practice with these tests, contact a local field office for details.

Other resources for soil biological tests include the Cornell Comprehensive Assessment of Soil Health (Moebius-Clune et al, 2016), which has instructions for soil biological tests including root pathogen pressure. A webinar on "understanding and managing forage diseases" by Agri-Food Canada (https://youtu.be/zYexya2yoAk) describes forage diseases such as rust, root rot, and black patch (which can cause slobbers in cattle).

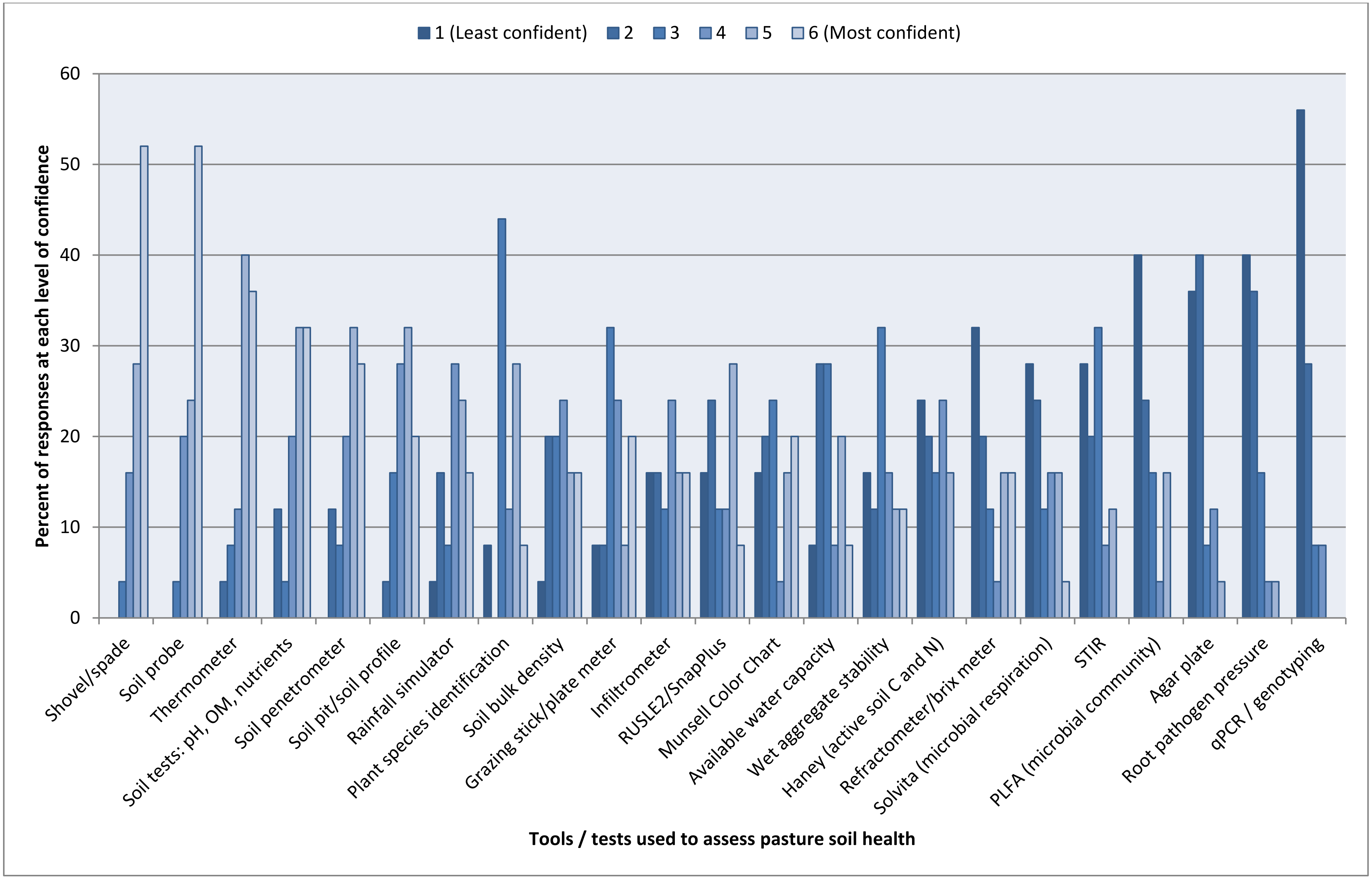


Figure 13: Responses to the survey question “How confident are you with using these tools/tests?” (n=25)

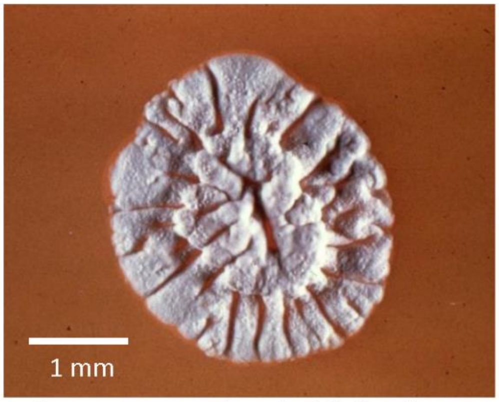
This toolkit also includes a description of how to test for Actinobacteria populations in soil as a direct measure of soil biodiversity and an indirect measure of soil organic matter. We measured silt loam soils from a farm in Monticello, Wisconsin during July 2017 that were planted in (A) corn for several years or (B) corn and then pasture managed with prescribed grazing through an NRCS program for two years. The pastured soil had 3 times as many Actinobacteria as the corn field soil! This test took about 3 days to get results and it was a hit with kids.

Kalena Riemer pipettes from a soil dilution onto an agar plate in Brodhead (Green County, Wisconsin) as part of the “smell of dirt” soil health test.

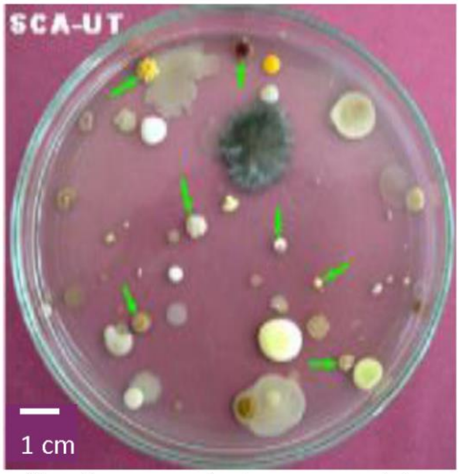
Finally, we developed videos about how to use a grazing stick to manage a farm. Participants in NRCS programs must keep and submit records of their grazing. Although experienced graziers may be able to make a lot of decisions by sight, all farmers benefit from keeping and using grazing records. The first video is about how to use the grazing stick. The second video focuses on grazing management skills for beef and dairy.

Measuring 'the smell of dirt'
Soil health test

What are you measuring? The smell of a freshly plowed field can be credited to compounds released by *Streptomycetes* bacteria as they die. These bacteria are very important in soil: they break down a wide range of organic molecules into humus. Humus is part of soil organic matter, which is the soil's storehouse for plant nutrients. *Streptomycetes* are slow-growing so they produce antibiotics to compete for food. Over 70% of the antibiotics in use for human and veterinary health (i.e. ivermectin, neomycin, tetracycline) are produced by Streptomyces. Antibiotic production may also reduce loss of soil organic matter by slowing soil microbial growth. The number of Streptomyces colonies may indicate the soil's ability to build organic matter.



Streptomyces colony by J.J. Goodman



Streptomyces colonies on agar plate marked with green arrows by M. Oskay

What will you see? At a microscopic scale, Streptomyces grow branched structures called hyphae, which are like fungal mats. The hyphae form spores to reproduce. To the naked eye, the spores give the colonies a powdery or chalky look and the hyphae make the colonies appear tough and leathery, instead of soft and moist like most bacterial colonies. One way to identify colonies of Streptomyces is to expose them to ultraviolet (UV) light or "blacklight." Streptomyces produce pigmented compounds called phenazines that glow under UV. Other bacteria like *Psudomonas* produce antibiotics that glow under UV but the colonies appear soft and moist.

Precautions: All cultured organisms should be treated as able to cause disease. Wash hands and sterilize surfaces before and after. Avoid opening plates. Discard plates in a sealed trashbag.

Who developed the test? Robert Bauer adapted the test from a classroom exercise by Drs. Charles Hagedorn and Brian Badgley at Virginia Tech. NCR SARE, GrassWorks, and Wisconsin RC&D's support the Sharing Soil Health Knowledge and Practice through Grazing Networks project.

Instructions: The test involves: 2 hours of prep time, 1 week of incubation, and $20 of materials per soil.

- The grazing network project created a test kit that fits into a cake box: four alcohol wipes, four 14 mL dilution tubes, six bendable drinking straws, six starch casein agar (SCA or "nutrient agar") plates, ten 1 mL graduated plastic transfer pipettes, one roll of clear tape, and one turntable. Store the agar plates in the refrigerator until you are ready to do the test.
- You provide: 1 cup fresh soil, 50 mL distilled water, gram scale, container to weigh samples in, spoon, oven, rack to hold dilution tubes, clock/timer, blue and purple markers (optional), and ultraviolet light or flashlight (see instructions below).

- How moist is your soil? Circle: dry (+15%), moist (+25%), wet (+35%). What is the soil texture? Circle: sandy (-10%), loamy (+0%), clayey (+10%). Add the two numbers and divide by 100: (*a*) ☐
- Weigh out 5 grams of fresh soil; break apart clumps. Place soil in an oven at 140°F for 1 hour to reduce competition from fast-growing bacteria. Streptomyces spores will survive heating.
- Pipette 9 mL of distilled water into each dilution tube. Label the tubes: A, B, C, D. Place 1 gram of oven-treated soil in tube A and shake for 1 min. Let the sample sit at room temp for 10 min. Then shake the tube again and transfer 1 mL from tube A to tube B with a pipette. Shake tube B for 30 sec. Use a new pipette to transfer 1 mL from tube B to tube C. Shake tube C for 30 sec. Use a new pipette to transfer 1 mL from tube C to tube D. Shake tube D for 30 sec.
- Label the bottom of sequential SCA plates: B, C, D. Label a duplicate set of plates. Then use separate pipettes for each tube: transfer 0.1 mL from the tubes onto the labeled plates.
- Spread the liquid on the plates by moving the bend end of a straw in an arc across the surface of the agar while rotating the plate on a turntable.

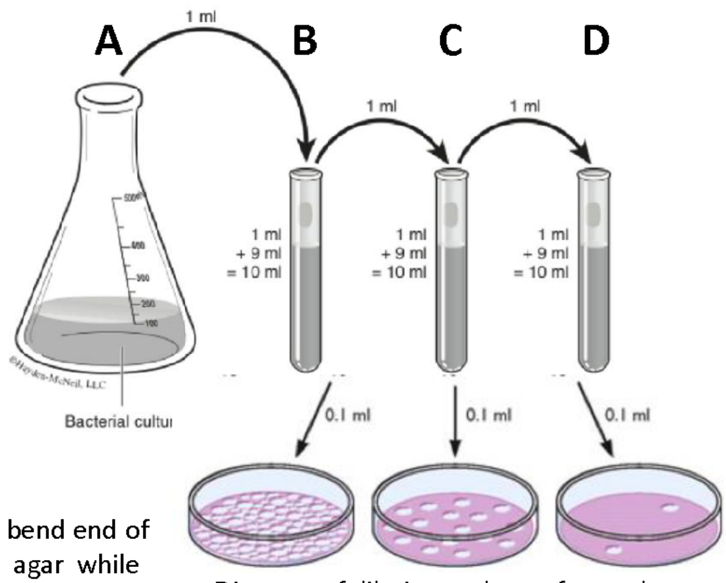
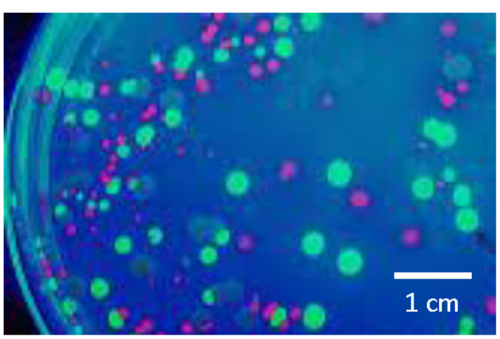


Diagram of dilution and transfer to plates

- Tape down the lids of the plates at two spots. Turn the plates over so the lids are facing down so condensation will collect on the agar, not the lid. Put the plates in a spot that will stay at room temp (77°F) for one week to incubate. Avoid knocking the plates during the incubation period.
- After incubation, turn the plates over and examine growth. Plates B and C may be overgrown but plate D should have distinct colonies. Count the total number of colonies (total bacterial count) on the D plate duplicates. Do not open the lid; you can mark a dot on the lid above each colony with a sharpie to help you count. Write down the average of total bacterial colony counts: (*b*) ☐
- Next count the *Streptomycete* colonies on the D plate duplicates. They are usually small, hard, powdery, and surrounded by a zone of no other growth. The colonies will not be gooey or shiny. They can be various colors above and below the surface of the agar (white, grey, yellow, or red). Write down the average of the counts of *Streptomycete* colonies: (*c*) ☐



Bacterial colonies on agar under UV light by T. Le and others

- Expose the plates to UV light in the dark. You can make a UV light by covering a flashlight with pieces of clear tape colored with blue and purple sharpie. How many colonies glow? Write down the average of the counts of glowing colonies from plate D duplicates: (*d*) ☐
- How many of the glowing colonies are shiny (*Pseudomonas*)? Write down the average of the counts of shiny colonies from plate D duplicates: (*e*) ☐
- Use your numbers (*a*) and (*c*) to calculate the colony-forming units of Streptomyces in your soil: (*f*) ☐

$$Colonies\ per\ gram\ of\ dry\ soil = \frac{(c \times 11{,}000)}{(1 - a)}$$

- Send a completed copy of this sheet and a photo of your plate to Kirsten Jurcek, Glacierland RC&D, N2437 Brattset Lane, Jefferson, WI 53549, email kjurcek1@centurytel.net, or call (920) 342-9504.

Rainfall Simulator Discussion Points

How much soil and other nutrients are lost when a dime's thickness erodes?

An acre of soil 6 inches deep weighs approximately 2,000,000 pounds. A dime, the thinnest of all U.S. coinage is a mere 0.053 inches thick. How much soil is lost when a dime's thickness erodes?

2,000,000 lbs/ac6 in=x lbs/ac0.053 in x= $\mathbf{17{,}7\ lbs/ac\ or\ 8.8\ t/ac}$

How many cubic yards per acre does this equate to assuming a bulk density of 1.33 grams per cubic centimeter for a silt loam soil?

1.33 g×1 lb×1 t×764,555 $cu\ cm$ 1 $cu\ cm$×453.6 g×2,000 lbs×1 $cu\ yd$=1.1 $t/cu\ yd$ 8.8 t×1 $cu\ yd$1 ac×1.1 t= $\mathbf{8\ cu\ yd/ac\ or\ 80\%\ of\ a\ 10\ cubic\ yard\ dump\ truck}$

Important Note: A 10 cubic yard dump truck load of topsoil can be worth anywhere from $150 to $300 depending on the region.

Besides the loss of sand, silt, and clay particles, what else is being lost in a dime's thickness of soil erosion and how much would it cost to purchase them if soil organic matter is 3 percent?

Soil organic matter: 17,667 lbs/ac×0.03=$\mathbf{530\ lbs/ac}$
Carbon: 530 lbs/ac×0.50=$\mathbf{265\ lbs/ac}$ @ $4.00/t = $0.53
Nitrogen: 265 lbs/ac×0.10=$\mathbf{27\ lbs/ac}$ @ $0.50/lb = $13.50
Phosphorus: 265 lbs/ac×0.01=$\mathbf{3\ lbs/ac}$ @ $0.70/lb = $2.10
Potassium: 265 lbs/ac×0.01=$\mathbf{3\ lbs/ac}$ @ $0.40/lb = $1.20
Sulfur: 265 lbs/ac×0.01=$\mathbf{3\ lbs/ac}$ @ $0.50/lb = $1.50
$18.83/ac

On a 100 acre field, how much available water holding capacity was removed when a dime's thickness eroded away?

For a silt loam soil at 3 percent organic matter, field capacity is 0.33 cubic feet per 1 cubic feet of soil and the permanent wilting point is 0.12 cubic feet per 1 cubic feet of soil. The difference between these two numbers is the available water holding capacity.

$AWC = 0.33\ cu\ ft - 0.12\ cu\ ft = 0.21\ cu\ ft$ $0.21\ cu\ ft \times 43{,}560\ cu\ ft\ of\ soil \times 7.48\ gal 1\ cu\ ft\ of\ soil \times 1\ ac \times 1\ cu\ ft = 68{,}581\ gal/ac$ $68{,}581\ gal/ac 12\ in = x\ gal/ac 0.053\ in$ $\boldsymbol{x = 303\ gal/ac}$
$100\ ac \times 303\ gal/ac =$ $\mathbf{30{,}300\ \boldsymbol{gallons\ on}\ 100\ \boldsymbol{acres}}$!

While the message above is not positive, we know how to reverse this process by following the principles of soil health. These principles work anywhere on the planet.

1. **Minimize disturbances whether mechanical or chemical.**

2. **Keep the soil covered at all times whether with green plants or plant residues – no bare soil!**

3. **Maximize biological diversity aboveground to maximize diversity belowground by including more diverse cash crops, cover crops, and/or Adaptive, High-Stock Density grazing.**

4. **Have a living root in the ground before and after the cash crop to feed soil life by utilizing cover crops.**

IMPORTANT: Perennial plants invest far more resources into root growth and development compared to annual plants. Annual root die off from perennial plants and the subsequent digestion of that root mass by the soil life makes the greatest contribution to soil organic matter. To build soil organic matter to its highest level, you do it with a diversity of perennials being grazed by livestock that are being managed adaptively at high-stock densities. That is nature's pattern.

Soil Test Pit Recommendations

Soil Pit Recommendations: Test Pits should be at least three feet wide, and four is even better.

Most of the pit should be at least four feet deep, but if he can go down to six feet at one end, that's great. The other end should have a nice ramp that will let people get down to poke around. A 15-20 foot working length is nice for a good sized group.

If it's possible to transect a lane, cattle path, or some other kind of compacted area, that makes a nice contrast with a well-managed portion of the pit. Sometimes it words to cross a permanent fence line where there's been no disturbance, and that also makes a nice contrast. The aim is to show differences in soil characteristics with changes in use or management.

The test pit should be dug as close to the event as possible so it is fresh and the features are easy to see.

Mark Kopecky, *Soils Agronomist, Organic Valley/ CROPP Cooperative, N3786 County Road I, Catawba WI (USA) 54515 Phone 608-632-9933*

Pasture Soil Health

Soil health is defined as the continued capacity of soil to function as a vital, living ecosystem that sustains plants, animals, and humans. Soil is teaming with billions of bacteria, fungi, and other microbes that are the foundation of an elegant symbiotic ecosystem. Soil is an ecosystem that can be managed to provide nutrients for plant growth, absorb and hold rainwater for use during drier periods, filter and buffer potential pollutants from leaving our fields, serve as a firm foundation for agricultural activities, and provide habitat for soil microbes to flourish and diversify to keep the ecosystem running smoothly. Healthy soil gives us clean air and water, bountiful crops and forests, productive grazing lands, diverse wildlife, and beautiful landscapes.

Five Principles of Soil Health

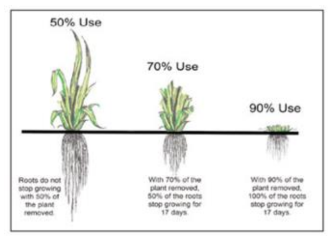
1. **Keep the Soil Covered.** Soil cover conserves moisture, reduces temperature, intercepts raindrops (to reduce their destructive impact), suppresses weed growth, and provides habitat for members of the soil food web that spend at least some of their time above ground. This is true regardless of land use (cropland, hayland, pasture, or range). Keeping the soil covered while allowing crop residues to decompose (so their nutrients can be cycled back into the soil) can be a bit of a balancing act. Producers must give careful consideration to their crop rotation (including any cover crops) and residue management if they are to keep the soil covered and fed at the same time.

2. **Minimize Soil Disturbance.** Soil disturbance can be the result of physical, chemical or biological activities. Physical soil disturbance, such as tillage, results in bare and/or compacted soil. Tillage is destructive and disruptive to soil microbes and it creates a hostile environment for them to live. Misapplication of farm inputs can disrupt the symbiotic relationships between fungi, other microorganisms, and plant roots. Overgrazing, a form of biological disturbance, reduces root mass, increases runoff, and increases soil temperature. All forms of soil disturbance diminish habitat for soil microbes and result in a diminished soil food web.

Pasture Soil Health Continued

3. **Increase Plant Diversity.** Plants use sunlight to convert carbon dioxide and water into carbohydrates that serve as the building blocks for roots, stems, leaves, and seeds. They also interact with specific soil microbes by releasing carbohydrates (sugars) through their roots into the soil to feed the microbes in exchange for nutrients and water. A diversity of plant carbohydrates is required to support the diversity of soil microorganisms in the soil. To achieve a high level of microbial diversity, different plants must be grown. Increasing the diversity of a crop rotation and cover crops increases soil health, soil function, reduces input costs, and increases profitability.

4. **Keep a Living Root Growing Throughout the Year.** Living plants maintain a rhizosphere, an area of concentrated microbial activity close to the root. The rhizosphere is the most active part of the soil ecosystem because it is where the most readily available food is, and where peak nutrient and water cycling occurs. Microbial food is exuded by plant roots to attract and feed microbes that provide nutrients (and other compounds) to the plant at the root-soil interface where the plants can take them up. Since living roots provide the easiest source of food for soil microbes, growing long-season crops or a cover crop following a short-season crop, feeds the foundation species of the soil food web as much as possible during the growing season.



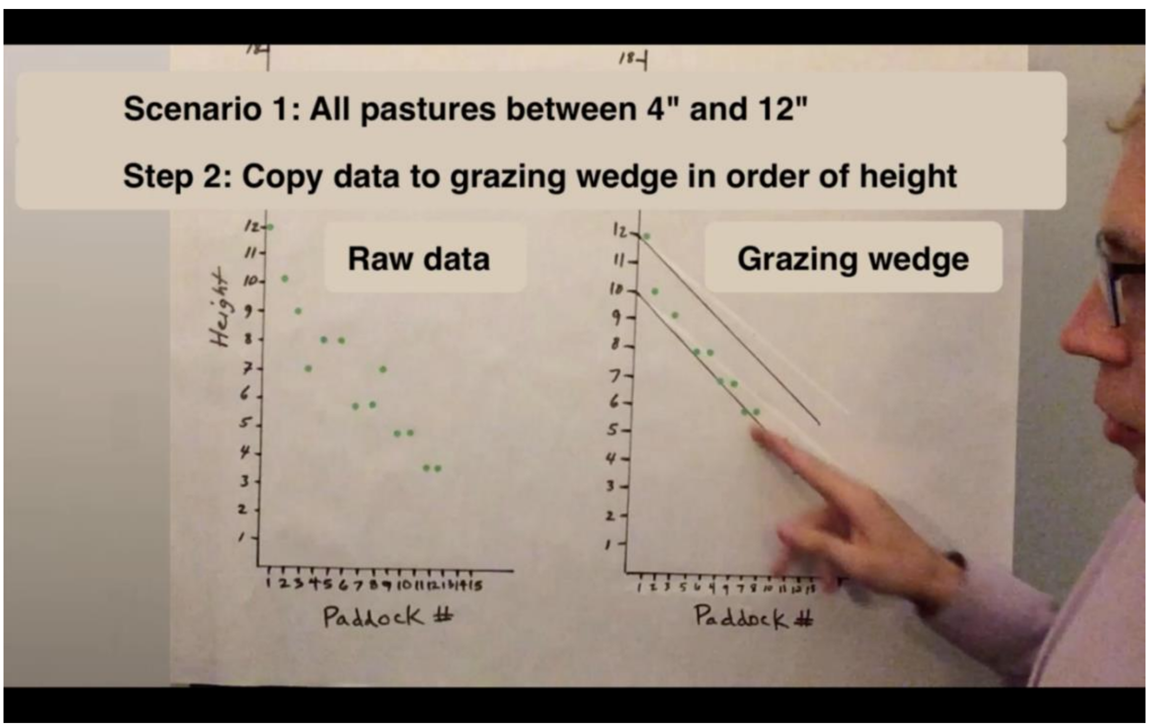
5. **Integrate Livestock.**

Grasses evolved under grazing pressure. Soil and plant health is improved by grazing which recycles nutrients through improved manure distribution, reduces plant selectivity, and increases plant diversity. The most important factor in grazing systems is to allow adequate rest for the plant to recover before being grazed again.

Above information taken from NRCS Soil Health Web Page April, 2016.

Grazing stick and grazing wedge 'how-to' videos

How long to graze each paddock using a grazing stick: https://youtu.be/XBhC8I77KEU.



How to manage your farm with a grazing stick: https://youtu.be/OKyuWJjO1_E.

Part V Grazing Network Coordinators Toolkit

Introduction to grazing networks

Grazing networks began to develop in the 1970s as groups of like-minded regional farmers gathered in farmer-to-farmer learning groups to increase their knowledge and understanding of managing forage and livestock. Pasture-based production was seen as a means to decrease feed costs. Since then, Management-Intensive Rotational Grazing (MIRG) has become the topic of much farmer and university research and acres of MIRG have expanded greatly.

Grazing networks of regional farmers have become an efficient and effective way to share farmer-to-farmer experiences as well as research findings on the best ways to manage our soils, forage, and livestock for environmental and economic gains.

This toolkit was prepared to share the experience of the four RC&D Grazing Network Coordinators with agency staff so that agency staff will continue to actively engage farmers in grazing networks.

Joe Mantoan describes a free-choice mineral feeder at a pasture walk hosted by Glacierland RC&D in West Bend (Washington County, Wisconsin).

Getting a grazing network started

Here are several key concepts to keep in mind when starting a grazing network:

- GrassWorks is Wisconsin's state-wide grazing organization and they host an annual conference and a summer picnic. Contact regional directors who may have insight for your region. They maintain a calendar of events listing state wide activities. You will want to attend these, share them with your network, and plan your events around them. These meetings and workshops will be a wonderful source of networking, speaker ideas, workshop topics, members, and partners.
- Look for existing grazing networks near you. Attend neighboring region pasture walks and workshops (farmers and partners from your region might be there). Get to know your neighboring network coordinator (you may want to plan events together). Ask for a few minutes to explain your network and solicit interest.
- Search for state and regional grazing research. Contact the researchers to see if any of the research is happening in your region, to get field day dates they are hosting and to see if they have any farmer or partner contacts in your region.
- Search for state or regional grass-based cooperatives. Contact them to see if they do outreach and education with their farmer members and if they will share producer contact info with you. Note their meetings and attend if they are within or near your region. For example, Organic Valley has a record of hosting pasture walks and likes to partner with local Grazing Network Coordinators.

Mark Kopecky is an Agronomist at Organic Valley. He explains the soils at Sandstone Ranch in Stevens Point (Portage County, Wisconsin).

Here are several steps you might want to take when starting a grazing network:

1. Determine Network Region

   Determine the network's geographic region. As we discussed in Part I, watersheds can be convenient ways to tell a story about a place. However, keep in mind that a water basin may cross many county lines, which may require more work to coordinate.

   Determine if smaller grazing networks (town or county) are already established in the region. If so, let them know your intentions of creating a basin network. Contact the coordinator to determine how you can work together and ask if you can join their group. Look to the existing coordinator for advice on issues the graziers face and leaders for your group. Coordinate to co-host workshops and meetings in their region while inviting farmers from surrounding areas to attend.

2. Investigate Region's Grazing History

   Determine if a grazing network ever existed in the entire region or part of the region. Good starting contacts will include board members of state grazing organizations; staff of NRCS, County Departments of Land and Water Conservation or Planning and Zoning, and UW Extension in the region. You might want to ask them the following questions:

   - Has there been a grazing network?
   - Why did it go away?
   - Who were the initial founders?

   If past funding sources went away or agency staff changes were the reason for the networks collapse it might be quite easy to reengage the group. You might contact the initial founders

3. Develop Outreach Materials

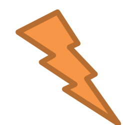
   Prepare standard outreach materials that are simple, eye catching, and consistent. Use this format to explain your project to potential partners. These will be the base documents you will use to announce pasture walks and workshops. Examples of standard outreach materials include newsletters, press releases, flyers, brochures, social media pages, and a website.

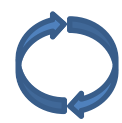
4. Create a Database

A well thought out database may be invaluable down the road. You never know when this might come in handy and if you work on it a little at a time it is very doable. Capture all relevant information for future grant-seeking from the get-go! Information you may want to capture and/or add to a database includes:

- Contact info: name, address, county, river basin, phone number, and email address.
- Affiliation: farmer, agency staff, student, or urban resident.
- Farmer groups identified with: beginning, limited-resource, female, veteran, minority, immigrant, refugee, other.
- Grazing experience: species grazed, acres grazed, experience level.
- Desired participation level: hosted or willing to host pasture walks; presented or willing to present or participate in roundtable discussions.
- Attendance: add each pasture walk or workshop to the table and indicate who attends. This will keep you updating your database, make any reporting easy, and will be invaluable information to pass on to a future coordinator for your network. You might also want to note any follow-up.

5. Identify Network Partners





The background searches we mentioned earlier will be a good start to your partner list. Hone in on your local partners by seeking out local county contacts:

- Agency staff: University Extension, County Land and Water, USDA-NRCS, RC&D, and Department of Natural Resources (DNR).
- University faculty and staff: research professors, graduate students.
- Ag business sector: Seed dealers, fertilizer and feed suppliers, fence companies, equipment suppliers, cooperative businesses, ag lenders, farm financial advisors.
- Agri organizations: agri-business, FFA alumni, Farmer's Union, Farm Bureau, producer organizations.
- Regional non-profits with similar interests: environmental groups and local food groups.

Add these contacts to your database. Using your prepared outreach materials send a message to let them know your intentions of starting a grazing network. Ask them to help you to identify existing graziers and determine who would like to partner with you. Follow-up on your introduction with a phone call requesting a meeting. If you are working in a large regional area this task might seem overwhelming so start small. Pick one or two counties where you have identified interest and ask for a group meeting with them. The agency staff may work closely together (but keep in mind that every county is different). Discussion topics with potential partners may include:

- Lists of their local graziers & conservation minded farmers.
- Dates and locations of events they have planned.
- Local issues their farmers are facing.

Kirsten Jurcek speaks to a group of farmers during a pasture walk at Feral Farm in Jefferson (Jefferson County, Wisconsin).

6. Recruit Grazier Network Members

The contacts made above should give a good start to locating grazier farmers. If road blocks are encountered in the above steps additional research could include:

- Local direct marketing resources. For example, the *Farm Fresh Atlas of Wisconsin* lists many direct marketing grazing farmers.
- Aerial imagery scanning to identify grazing farms.
- Stops at grazing farms when driving in the countryside.

Contact the graziers identified by this process to start organizing a group.

Planning network programing

Grazier networks are a way for farmers to exchange information, learn from industry and research experts, and connect with peers on an ongoing basis. Grazier input is crucial for the network's success. Here are several steps that you might take to develop network programming:

1. Host a round-table meeting.

   Host a round-table meeting with graziers you've identified as leaders in the region. These would be folks you would consider local activists whom you know will help to engage others. Diversity is also key, as a diverse group will better help determine needs of the region and engage others. Diversity should include:

   - Age
   - Grazed species: dairy, beef, small ruminants, pork, poultry, etc.
   - Skill level: experienced to beginners
   - Full and part-time graziers.

   Pick a convenient time and place and send out an agenda before the meeting. The network coordinator should facilitate the meeting. Here's a checklist:

   - ✓ Welcome the group and clearly state your goals for the meeting as well as the commitment level you can dedicate to the group.
   - ✓ Have everyone introduce themselves and their grazing interest and experience (limit their time to 3-5 minutes depending on group size).
   - ✓ Ask the graziers what has worked well for them, what issues they have encountered, and what they would like to learn more about. Have a few ideas to throw out to get the group going.
   - ✓ Ask the graziers who would host a pasture walk, what other farms they would like to visit, who they would like as speakers, what areas of research interest them, and if they would be willing to serve in workshops.
   - ✓ Have each participant identify where their farm or business is on your map
   - ✓ Have each participant think about others in their neighborhood who might want to participate in the meeting.
   - ✓ Have the group share related events. Put the events on the calendar.
   - ✓ Draft a schedule for pasture walks, workshops, and follow-up meetings.
   - ✓ Draft a list of who would like to help with tasks.

   At the conclusion of the round table discussion you should have a great start to planning a workshop and pasture walks!

2. Plan and host dynamic workshops.

Use the information you gathered from the network partners and graziers to plan a dynamic workshop specific to the graziers' needs. Host a meeting to plan each workshop or conduct this meeting immediately after your round table. Divide tasks up with your agency partners and any graziers who are willing so that everyone feels involved.

Pick a location central to your group. Tour the facility to confirm it is appropriate for your group's needs. Think if it will have enough room to fit your anticipated group. But don't get a room so big that you will feel like you do not have a group. Also make sure you have room to set up any demos and the facility manager is ok with whatever demos you are using. Make sure windows can be covered so that power point presentations can be seen. And make sure it is a quiet location that people can hear and you will not be disturbed. For example, Kirsten Jurcek adds, "I was once in a wonderful workshop room that got super loud when the 3:00 happy hour opened in the adjoining bar room! I once had a meeting in a library meeting room that was smaller than estimated and had several poles that blocked viewing."

Ray Archulleta involves farmers in a demonstration of
soil aggregate stability at a workshop in Plymouth (Sheboygan County, Wisconsin).

When preparing the presentation, think about how you can address the needs of all participants. For example, if you have a group with diverse experience levels start the session with a “Grazing 101” talk so beginners can follow more advanced talks later in the day. Advanced graziers may want to come after the first session; however, they may have good comments to add either way.

Dynamic speakers on topics the graziers have requested are important to get people engaged. Attend other workshops to preview potential speakers, watch their videos, or get referrals from trusted sources. Coordinate with the speakers so their talks will be specific to the graziers needs. For example, make sure the speaker understands the local soil types, predominate forages, predominant livestock species, and levels of experience of your group. Finally, good workshops include a round table discussion with local graziers who are willing to host pasture walks in the upcoming season.

Casey Dahl introduces himself at a pasture walk hosted by
Glacierland RC&D at Feral Farm in Jefferson (Jefferson County, Wisconsin).

3. Plan and host dynamic pasture walks

   Using information gleaned from the round table and partners, plan the season's pasture walks. One idea is that the network might have the season's pasture walks follow the theme of the network's winter grazing workshop.

   Host diverse pasture walks around the schedules that work for your network. Experienced dairy grazing pasture walks usually occur midday (1 to 3 pm), to coincide with the chores of milking. Introductory and consumer pasture walks work well in the evening as twilight pasture walks, after most people get off work.

   Assess the host farm prior to finalizing the walk. Confirm you have the correct address and confirm directions from the closest town. Visit or drive by the farm prior to confirming with the farmer to assure livestock and pasture conditions or get a referral from a trusted partner or farmer. Farms do not have to be pretty but they do have to have to use good practices! Is there an indoor area available if weather is bad? Is there a bathroom or if it's a longer walk/workshop (more than 3 hours) is a port-o-potty necessary? Determine if the farmer has biosecurity concerns and if booties or a wash bucket will be necessary. If walking will be involved, it's important to have transport available for people with disabilities.

Kirsten Jurcek speaks to a group of farmers during a pasture walk at Brattset Family Farm in Jefferson (Jefferson County, Wisconsin).

Discuss the pasture walk in detail with the host. Interview the host to summarize their situation for your announcements. Fully explain how, when, and where you will announce the pasture walk. Determine who will lead the walk. Some graziers enjoy talking to groups. Others would rather answer pre-planned questions.

Determine if a speaker should be present and if so who that should be. Invite speakers and include demonstrations, if appropriate (i.e. soil test pit, forage analysis, fecal count demonstration, etc.) and agree on who will help with them.

Arrange a time to meet at the farm to go over the walk and finalize any last minute details. It is best if the network coordinator can visit the farm a week before the walk for a walk-through with the farmer to confirm walk route, timing, parking, signage, and registration area. This will give the coordinator and farmer time to think of any issues they forgot and will make all parties feel comfortable.

The day of the pasture walk can be nerve-racking for the host family. Keep in mind they have to get their work done around the walk which is a schedule they may not be used to. The network coordinator and partners should arrive at least one hour early. Meet with the farmer to determine if any last minute changes have been thought up and confirm the logistics.

Here’s a day-of checklist for network coordinators:

- ✓ Set up registration, parking signs, direct traffic.
- ✓ Be ready to greet any early comers. Be welcoming and friendly to attendees and confirm that you have their contact information.
- ✓ Start the walk on time.
- ✓ Welcome the group and lay out the basic rules. Thank the host family and give an overview of what will be seen and discussed.
- ✓ Keep your group together. But ask folks to hang back if they want to chat.
- ✓ Keep the speaker focused on what was previously decided.
- ✓ Keep track of time so you get back to the starting point at the time you announced.
- ✓ Thank the group for coming and if the farmer is ok with people hanging around. Announce social time so folks who need to leave feel comfortable.

Grazing network activities are a lot of work but they can be very rewarding. Remember, you can always contact your regional RC&D Grazing Network Coordinators for help. Their contact information is listed in the About section of this toolkit.

Part VI Additional Resources and Cited References

Additional resources for pasture soil health knowledge

Our survey found that resources from USDA's Soil Health Initiative, Burley County North Dakota, and Unlock the Secrets of Soil Health, as well as Youtube videos are the most used (Figure 14). We also suggest Cornell's Comprehensive Assessment of Soil Health.

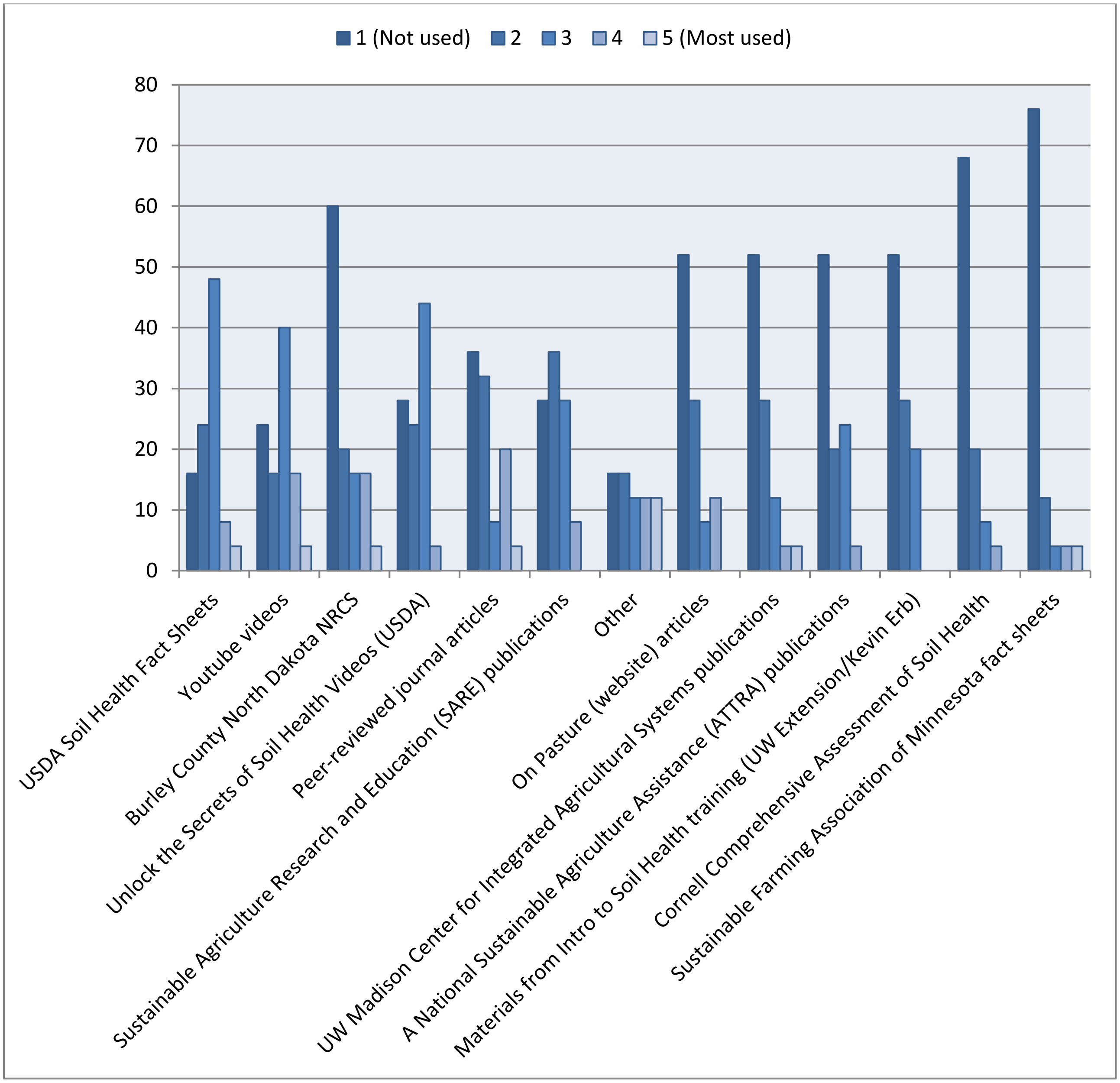


Figure 14: Responses to the survey question "How often do you use these pasture soil health resources?" (n=25)

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Pasture Soil Health Reference Values

> 1.33 g/cm^3	Bulk density of a healthy silt-loam soil, based on approximately 50% pore space. For comparison, the bulk density of rock (no pore space) is 2.65 g/cm^3.
> 12%	Mycorrhizal fungi colonization of roots above which plants begin to benefit. Mycorrhizal fungi affect invasive plant growth as well as help plants with access to soil phosphorus. Full benefit to plants is reached around 40% colonization (Zhang et
> 15 °Bx	Brix (°Bx, the concentration of dissolved plant solids including sugars, proteins, minerals, and fats) reading for forages growing in a healthy soil. °Bx of forages ranges from 2-6% in poor soils to 8-22% in excellent soils (Williams, 2014).
~ 24:1	C:N ratio ideal for aerobic soil microorganisms to stay alive. A rye cover crop is ~ 26:1, beef manure is ~ 17:1, and soil microbes are ~ 8:1 (USDA, 2011).
> 60%	Pore space filled with water at field capacity (the water content held in the soil against gravity), which is ideal for plant growth and microbial respiration. A small amount of energy is needed to extract water from soils at field capacity.
> 80 °F	Soil temperature at 4 inch depth that begins to stress most cool-season grass roots. The optimum soil temperature for cool-season grass roots is 50-65 °F (Beard, 2001).
> 95 °F	Soil temperature at which soil microbial growth stops doubling for every increase of 18 °F.
> 300 PSI	Penetration resistance (in pounds per square inch) of a moist soil that will limit the growth of plant roots and mycorrhizal fungi (Moebius-Clune et al, 2016; pp. 39).
> 500 million	Bacterial cells in a teaspoon (1 gram) of healthy soil, which is approximately equal to the live weight of two cows per acre (Soil Biology Primer, 2005).