Wyoming Collaborative for Healthy Soils

Recommendations of the WCHS Science and Practice Group

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Introduction

The purpose of the Wyoming Collaborative for Healthy Soils (WCHS) Science and Practice Working Group (Science & Practice Group) was to provide recommendations on soil health science that are needed to support producers in the voluntary adoption of soil health practices. The intended audience for these recommendations includes producers, scientists, conservation districts, conservation professionals, and state and federal policymakers.

The Science and Practice Group was chaired by Dr. Liana Boggs Lynch (Instructional Professor, University of Wyoming) and members included representatives from USDA Natural Resource Conservation Service (NRCS), USDA Agricultural Research Service (ARS), and conservation district staff (*see* Appendix 1 for a full list of members). The Science and Practice Group met more than ten times over the course of seven months. The major sources of inquiry and resulting recommendation center on:

- The inherent limitations on scientific certainty, replicability, and predictability given the variability in Wyoming's soils, climate, and production systems;
- A definition of soil health;
- How to use benchmarks for croplands and rangelands;
- How to determine whether a cropland soil is healthy;
- How to determine whether a rangeland soil is healthy; and
- How to produce Wyoming-specific soil health research in a way that is producer relevant and accessible, while also advancing scientific knowledge.

The purpose of this report is to 1) provide foundational knowledge and recommendations and 2) set forth a roadmap for future work. We hope that Wyoming stakeholders, including USDA (particularly NRCS and ARS), University of Wyoming, conservation districts, and producers work to implement these recommendations.

WCHS conducted extensive stakeholder engagement and analyzed the results (report here). While some of this group's work occurred in parallel with that effort, this group has ensured that recommendations respond to identified stakeholder needs. Appendix 2 contains select results of those surveys. Producers and agricultural professionals specifically highlighted the need for more research and education on the economic impacts of soil health practices, soil health testing and monitoring, the benefits of soil health, and strategies for improving soil health. When asked about mechanisms that would support producers in achieving their soil health goals, stakeholders rated demonstration projects as the highest need. Table 1 contains a list of the 11 recommendations we feel meet the stated needs of stakeholders.

Table 1. Recommendations of the WCHS Science and Practice Group.

Recommendation #	Recommendation Title
General Recommendations	
1	Utilize the NRCS definition of soil health
Recommendations for Croplands	
2	Encourage the widespread use of in-field soil health assessments pursuant to NRCS 2021 guidance to develop quantitative, region specific benchmarks for soil health
3	Recommended Lab Analyses
4	Integrate the "Soil Health Gap Concept" into producer programs and research to establish region-specific, quantitative benchmarks
Recommendations for Grazing Lands	
5	Emphasize the soil health principles, monitoring, and the decision-making process rather than practices in producer education
6	Encourage producers to use the USDA NRCS Pasture Condition Score Index for assessing managed pastures
7	Develop an easy to use assessment form like the Pasture Condition Score Index for assessing rangelands
8	Develop an easy to use web-based tool for monitoring grazing lands
Recommended Research Areas and Methodology	
9	Create a network of on-farm/on-ranch demonstration and research sites
10	Include robust financial analyses in scientific research and government programs
11	Conduct additional research on carbon markets

Table 2 summarizes 1)the barriers to the voluntary adoption of soil health practices and scientific advancement, 2) needs identified by stakeholders, and3) how the proposed recommendations respond to those needs.

Table 2. Summary of Barriers and Recommendations of the WCHS Science and Practice Group.

Barriers	**Needs identified through Stakeholder Engagement**	**Recommendations**
There is a lack of Wyoming-specific research on the impacts of soil health practices on critical factors, including impacts on yield, drought resilience, and economics. As a result, producers need more Wyoming-specific information on successful strategies for achieving soil health in a sustainable manner.	• Demonstration projects rated the most important mechanism to support soil health • Economics and strategies for improving soil health rated the most important educational and research topics • Economics, soil health testing, and and benefits of soil health rated the most important research needs	• No. 4: Integrate the "Soil Health Gap Concept" into producer programs and research to establish region-specific, quantitative benchmarks • No. 9: Create a network of on-farm/on-ranch demonstration and research sites • No. 10: Include robust financial analyses in scientific research and government programs
Related to the scarcity of Wyoming specific research, Wyoming lacks a meaningful and consistent approach to defining and measuring soil health, as well as meaningful quantitative and qualitative benchmarks for producers.	• ~52% of respondents rated the need for research on soil health testing and monitoring as high; ~47% rated this as moderate • ~71% of respondents rated the need for education soil health testing and monitoring as high	• No. 1: Utilize the NRCS definition of soil health • No. 2: Encourage the widespread use of in-field soil health assessments pursuant to NRCS 2021 guidance to develop quantitative, region specific benchmarks for soil health • No. 3: Recommended Lab Analyses • No. 4: Integrate the "Soil Health Gap Concept" into producer programs and research to establish region-specific, quantitative benchmarks • No. 4.a: Utilize in-field assessments and lab analyses in the soil health gap assessment • No. 4.b: Expand the minimum data set being established by the University of Wyoming to build representative soil health indices • No. 5: Emphasize the soil health principles, monitoring, and the decision-making process rather than practices in producer education • No. 6: Encourage producers to use the USDA NRCS Pasture Condition Score Index for assessing managed pastures • No. 7: Develop an easy to use assessment form like

		the Pasture Condition Score Index for assessing rangelands • No. 8: Develop an easy to use web-based tool for monitoring grazing lands • No. 9: Create a network of on-farm/on-ranch demonstration and research sites
Lack of meaningful benchmarks for producers	Same as directly above	Same as directly above

Discussion

This section of the report contains foundational knowledge that we feel is essential for all stakeholders to understand about soil health and the state of our scientific knowledge. It then discusses our substantive recommendations on 1) defining soil health; 2) improving soil health in croplands; and 3) improving soil health on grazing lands. It concludes with a discussion of two high priority research areas - the economic impacts of soil health and carbon markets.

Scientific Certainty and General Principles of Soil Health

Wyoming is experiencing unprecedented volatility in climate (e.g., extended droughts) and agricultural markets. Given this volatility and the upfront expenses that are often required to switch management practices, farmers and ranchers understandably seek a certain degree of certainty of the outcomes that can be achieved through the adoption of soil health practices. This may include predictable outcomes, such as increases in soil organic matter (SOM) or soil organic carbon (SOC) and predictable decreases in irrigation and input needs. Foremost, producers seek assurance regarding how and when "the payoff" from soil health practices will occur. It is unlikely that science will ever be able to provide quantitative predictions to producers. Nonetheless, soil science and agricultural experience provide sufficient certainty to ensure that, over time, implementation of the five NRCS soil health principles will improve soil quality and will improve producer economics.

Soils, are a living ecosystem, which is the result of several factors including: climate (e.g., temperatures, rainfall), time (for instance, under management practices), organisms (the organisms on and in the soil, many of which are responsible for important soil functions such as nutrient cycling), parent material (the geological material that soil is derived from), and relief (or the position of the landscape the soil is on, which can affect soil erosion and accumulation). Further, Wyoming enjoys unique and diverse climatological and biogeochemical characteristics across the state. Finally, every operation is unique, enjoying heterogeneous soils, ecosystems, and sometimes climates. This is particularly true of rangeland operations.

Given these unique conditions and challenges, the outcomes of soil health practices are likely to remain extremely variable. Moreover even with robust implementation of soil health practices,

other factors (such as drought) may independently cause a downward trend. All of these considerations lead to an inability to give exact, quantitative predictions on soil health outcomes, particularly in the long-term.

Despite this uncertainty and heterogeneity, there is a good understanding of soil health principles and their general, directional impact on several resource concerns, including organic matter addition, nutrient cycling, and drought resilience. NRCS has identified five, universal soil health principles:

1. Minimize disturbance;
2. Maximize living roots;
3. Maximize soil cover;
4. Maximize biodiversity; and
5. Integrate livestock.

These principles are universal in nature - that is, they work to improve soil health regardless of the location, climate, or other features of an operation. There is certainly innovation around the practices that operationalize these principles, such as maximizing diversity through biological amendments. Overall, however, there are several well-established practices (as specified in NRCS practice codes) to implement these principles. Further, there is a good knowledge base regarding what practices should be used to address specific resource concerns in Wyoming. Wyoming NRCS (2021) has described these in various resources, including the Soil Health Technical Note No. 450-06, Wyoming Cropland In-field Soil Health Assessment Guide.[1]

Finally, producers often inquire how long it will take to see measurable results on their soils. While this is an area where exact predictions also are impossible, it is well-established that the rapidity with which soils improve is directly linked to two factors: 1) the number of principles implemented through practices and 2) the length of time. That is to say, a producer who adopts practices that operationalize several principles at once will achieve results more quickly. Additionally, the longer a producer has been operationalizing the principles, the better their outcomes will likely be.

Despite this inherent uncertainty, Wyoming has an opportunity to provide better guidance to producers through the development of soil health benchmarks using Wyoming-specific research. Area-specific benchmarks are important for producers because they can provide clear guideposts and highlight attainable goals.

Most soil health recommendations, as well as benchmarks (including those used in Wyoming), are based on findings in the Midwest and Eastern United States, whose soil health priorities differ given the precipitation differences. The adoption of methodologies such as the "Soil Health Gap" (discussed in Recommendation 4), could help alleviate uncertainty around soil health in Wyoming if such sufficient sampling is conducted to create scalable data sets.

[1] Reference available from Wyoming NRCS.

Definition of Soil Health

Recommendation #1: Utilize the NRCS definition of soil health

Background. Definitions of soil health abound (*see* Appendix 3), with some providing more emphasis on specific metrics (like carbon sequestration) while others take a more holistic view of the ecosystem services that soils provide. Creating a shared understanding of the term "soil health" is a critical first step for any program, policy, or scientific endeavor. The Science and Practice Group discussed the definition of soil health and how to tailor it to Wyoming's needs.

Recommendation. This group found that the definition and contextual language put forth by the USDA NRCS served as the best working definition to fit Wyoming's agricultural needs.[2] NRCS defines soil health as "*the continued capacity of soil to function as a vital living ecosystem that sustains plants, animals, and humans*."

Consistent with the conclusions of this group, the NRCS definition stresses the living, ecosystemic nature of soils and their integral connection to the healthy functioning of all living creatures, including humans, and their importance in providing critical ecosystem services. A key factor of this definition is by stressing the "continued capacity" of soils, it stresses the long-term perspective that must be taken with respect to all ecosystem services provided, including agriculture.

There are other good definitions, however, that are substantively analogous but may be phrased in a way that is more understandable to producers. One such analogous definition that this group feels comfortable using was put forth by Dr. Jay Norton (former Professor at University of Wyoming): *The capacity of a soil to be used productively without adversely affecting its future productivity, the ecosystem, or the environment*.

Croplands

This section provides recommendations to provide producers and researchers with meaningful ways of determining soil health. Methodologies for assessing soil health are in their infancy. Lab analyses for soil health are not the same as traditional soil analyses, which tend to focus on factors exclusively relating to productivity and fertility. Whether in the field or through lab analyses, assessing soil health, instead, requires a holistic assessment of the soil's ecosystemic functioning.

Recommendation # 2: Encourage the widespread use of in-field soil health assessments pursuant to NRCS 2021 guidance to develop quantitative, region specific benchmarks for soil health

Background. Determining whether a given soil is "healthy" requires both in-field assessments and lab analyses. Both are critical, but current practice over-emphasizes the utility of lab

[2] USDA NRCS. (n.d.). *Soil Health*. Retrieved June 22, 2023, from https://www.nrcs.usda.gov/conservation-basics/natural-resource-concerns/soils/soil-health

analyses, which are discussed more fully below (*see infra* Recommendation 3). As compared to lab analyses, in-field assessments of soil health have several advantages:

- Empowering the producer through education and engagement. As compared to lab analyses, repeated experience by NRCS shows that in-field soil health assessments increase producer enthusiasm and knowledge.

- Inclusion of parameters not included in lab analyses. For the past several decades, traditional soil testing has focused on metrics pertaining directly to fertility. As noted above, testing for soil health is relatively new and in particular focuses on the structural quality and biology of the soil.

- Cost efficacy. Soil health analyses, such as the Haney Test, are often expensive, with the majority exceeding $50. In contrast, a producer can conduct an in-field soil health assessment for free at any time.

- Rapidity. Wyoming NRCS estimates that in-field assessments can be performed in 30 minutes.

- Ability to compare against natural benchmarks. Discussed more fully below, the use of benchmarks, particularly undisturbed/native lands, is critically important to assessing soil health. In-field soil health assessments allow a producer to compare their soils directly with benchmarks in a cost effective and rapid way.

Recommendation. We recommend using the in-field soil health assessment set forth in USDA NRCS Soil Health Technical Note No. 450-06 (Wyoming Cropland In-Field Soil Health Assessment Guide) (2021) (In-field Soil Health Assessment Guide). It provides instructions on how to assess 11 indicators (including biological indicators),[3] interpret the results, and what practices to implement to address resource concerns. This will provide a universal assessment methodology that can be incorporated into state and federal programs, as well as research efforts.

To implement this recommendation, we recommend that:

- NRCS hold trainings in critical agricultural areas across the state and recruit conservation districts, producers, University of Wyoming Extension professionals, and researchers.

- University of Wyoming and other researchers incorporate this protocol into their efforts and maintain the results in an inventory.

[3] These are 1) soil cover; 2) residue breakdown; 3) surface crusting; 4) ponding/infiltration; 5) penetration resistance; 6) water stable aggregates; 7) soil structure; 8) soil color; 9) plant roots; 10) biological diversity; and 11) biopores.

- NRCS and conservation districts incorporate in-field soil health assessments into field days.

Finally, the In-field Soil Health Assessment Guide suggests that not all indicators must be tested "but only those that will enable the planner to adequately assess a field's soil health status and develop management alternative[.]" (WY NRCS, 2021, p. 1) If possible, we recommend that NRCS develop guidance on this topic.

Recommendation #3: Recommended Lab Analyses

Background. Lab analyses to assess soil health should be distinguished from traditional soil analyses. Traditionally, soil testing has focused on factors that affect fertility (e.g., nutrient availability and uptake), such as nitrogen, phosphorus, potassium, pH, cation exchange capacity, calcium, copper, and magnesium. These are commonly referred to as "routine" soil health tests.

While there can be some overlap in routine analyses and soil health analyses (e.g., pH, nitrates and soil organic matter), many analyses contained in routine tests (e.g, calcium, iron, and magnesium) are not of great concern for soil health. Soil health testing can also have great variability from year to year and even day to day. In our extremely dry environment, rainfall can cause microbial activity in the soil that causes pulses of activity that cause changes in our pools of carbon and nitrogen in the soil. Therefore, in our very dry state where droughts are common the year-to-year variability can greatly impact soil health.

While routine soil tests are important agronomically,[4] testing a field's overall soil health instead focuses on the structural and biological aspects of soil. Common soil health tests include "the Haney Test," which measures soil respiration, microbially active carbon, and organic nitrogen. Other soil health tests include PFLA, which determines the fungal to bacterial ratio in a soil, nematode testing, and microbiological genome sequencing.

Soil health testing is a nascent field for which there is a lot of producer and scientific interest. There is also a lot of uncertainty with respect to the utility of this information for producers. For instance, the "Haney Test" is quite popular among producers, but the resulting recommendations have not been validated for arid environments like Wyoming. Finally, this type of testing can be very expensive ranging from $56.25 for a "Haney Test" to $92 for a PLFA test, to $78.00 for nematode testing, to $190.00 for Soil DNA testing.[5]

Recommendation. To reduce producer confusion and expense, while advancing scientific knowledge and producer relevant information, we recommend the following lab analyses be utilized by producers, federal and state conservation programs, and scientific research in assessing the soil health gap (Table 3). These are categorized as follows:

[4] E.g., to maximize yield and optimize fertilization

[5] These numbers are from Ward Labs (https://www.wardlab.com/services/soil-health-analysis/) (January 17, 2023).

1. “Necessary” indicates that the metric should be tested under all circumstances;
2. “Nice to have” indicates that the metric would provide useful information for scientists and producers, but may not be included due to costs, capacity, or other factors; and
3. “Extra” indicates metrics that have the potential to significantly advance scientific research but should only be tested if adequate resources exist.

Notably, the “Necessary” category contains all of the parameters included in the Haney Test.

Table 3. Annual Soil Health Lab Analyses

Necessary	**Nice to Have**	**Extra**
Gravimetric Moisture	Microbial Carbon*	Permanganate-oxidizable C (POXC)
Bulk Density	Microbial Nitrogen	Autoclaved citrate extractable (ACE) Protein
Aggregate Stability	Particle Size Analysis	Enzyme Activity
pH	Inorganic Carbon (IC)	eDNA
Total Carbon		Heavy Metals[ad]
Total Organic Carbon*		
Potentially Mineralizable Carbon (PMC)		
Total Nitrogen*		
Total Organic Nitrogen*		
Plant Available Nitrogen*		
Potentially Mineralizable Nitrogen*		
Phosphorus[ab]		
Potassium[ab]		
Soil Organic Matter		
Salinity/Sodicity[ac]		

a) These should be tested where concerns are indicated by factors such as soil type, crop type, or input type.
b) These analyses relate more directly to fertility and nutrient management. They are included here, however, because proper nutrient management is critical to soil health.

c) Baseline measurement of salinity/sodicity should be taken. The frequency of additional testing - if any - must be determined based on factors such as relevant changes in management.
d) Testing for heavy metals should be determined on a case-by-case basis, considering factors such as input types, parent material, or possibility of contamination from industrial pollution.

*While many of the parameters recommended here are included in the Haney Test, we do not recommend including the Haney test as a separate analysis. Though popular with producers, many factors can influence the results of the Haney test, including weather and location, making the resulting values arbitrary unless calibrated for location. This potential variance and lack of validation and calibration in many places around the country and in Western States reduces the usefulness of the Haney test and its utility for producers and scientific research.

These recommended analyses provide a necessary first step, but much work remains, including:

- updating/modifying these recommendations based on the work of Dr. Liana Boggs Lynch to be concluded in 2023 (*see infra* Recommendation 4.b);
- reconciling results using different methodologies;
- providing Wyoming-specific interpretive guidance to producers and educators; and
- determining a baseline for soil health in the state of Wyoming to develop meaningful soil health benchmarks.

Recommendation #4: Integrate the "Soil Health Gap" concept into producer programs and research to establish region-specific, quantitative benchmarks

The NRCS definition of soil health is of limited utility for assessing soil health at a specific location. It cannot provide quantitative targets to improve soil health to a producer, and it is of limited utility in advancing scientific research. To provide meaningful guidance to producers and direction to scientific research, a universal approach to quantitatively defining soil health at specific sites is needed.

Recommendation. To address this issue, we recommend using the "Soil Health Gap" concept as described by Maharjan et al., 2020.[6] The soil health gap is the "*difference between soil health in an undisturbed native virgin soil and current soil health in a cropland in a given agroecosystem.*" (Fig. 1) The Soil Health Gap concept uses site specific native/undisturbed lands as benchmarks to determine the "soil health gap" for cultivated croplands.

[6] Maharjan, B., Das, S., & Acharya, B. S. (2020). Soil Health Gap: A concept to establish a benchmark for soil health management. *Global Ecology and Conservation*, *23*, e01116. https://doi.org/10.1016/j.gecco.2020.e01116 (available here).

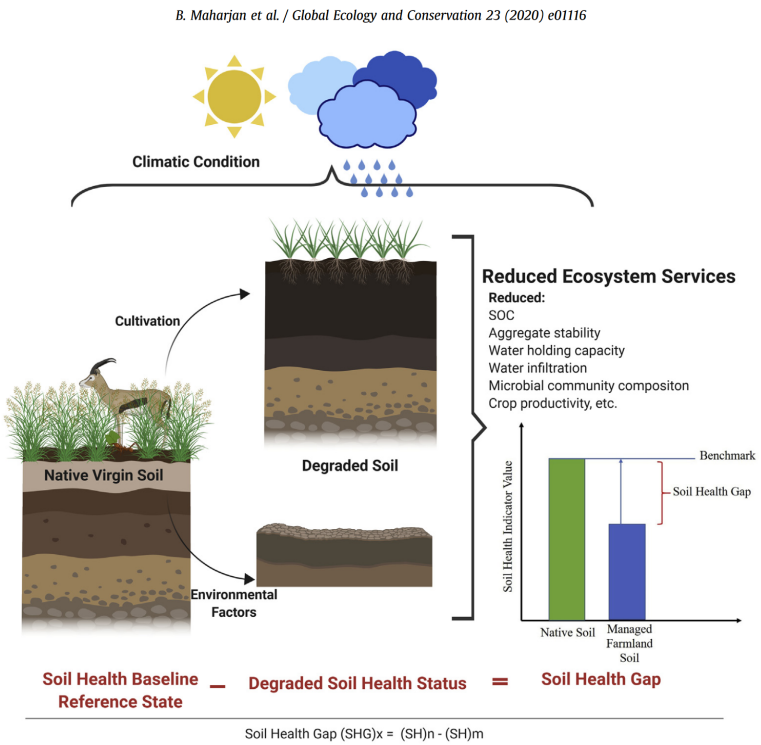

Fig. 1. Maharjan et al., 2020, Fig. 1.

Use of benchmarks is critical to:

- defining the true extent of the current soil health status after use in croplands or rangelands, as assessed through a variety of metrics;
- establishing attainable and realistic soil health goals for producers; and
- guiding producers and conservation professionals in the adoption of soil management practices

The Soil Health Gap concept should be incorporated into federal and state conservation programs and policies and scientific research efforts. Producers should also be educated about this concept and encouraged to use it by taking samples from both undisturbed/native vegetation as well as cultivated lands.

The soil health gap can be defined for specific properties of soil health including soil organic carbon, water infiltration, biodiversity, and aggregate stability, and bulk density (Fig 2.). Some of these will be done in-field, such as infiltration, while others require lab analyses. In most cases, native/undisturbed soils will have higher scores for soil health properties than cultivated lands.

$$SHG_C = (\text{Soil C})_n - (\text{Soil C})_m \quad \text{(II)}$$

Where, SHG_C = Soil Health Gap with respect to soil C, $(\text{Soil C})_n$ and $(\text{Soil C})_m$ refer to soil C in n; native soil and m; managed cropland soil.

Fig. 2. Maharjan et al., 2020, p. 4.

Finally, there are challenges in using the Soil Health Gap concept. Specifically, it may be difficult to define what constitutes "undisturbed/native vegetation" for a given area. With the appropriate expertise and resources, however, this challenge is imminently surmountable.[7]

Recommendation 4.a: Utilize in-field assessments and lab analyses in the soil health gap assessment

We recommend that the 11 in-field assessments described by the In-field Soil Health Assessment Guide (NRCS, 2021) (*see supra* Recommendation 2*)* be incorporated into the Soil Health Gap methodology for both producers and scientific research.

Recommendation 4.b: Expand the minimum data set being established by the University of Wyoming to build representative soil health indices

Using the Soil Health Gap concept, Dr. Liana Boggs Lynch is completing a study to determine what soil health indicators are most appropriate for Wyoming by comparing indicators in systems using conventional management and best practices and native/undisturbed soils (Norton & Boggs Lynch Minimum Data Set). This study is a critical first step to providing the needed soil health benchmarks for producers based on Wyoming-specific data.

Four types of agricultural land uses are included: 1) rotational cropland systems; 2) hay meadows; 3) dryland wheat; and 4) and rangelands. Sites are located in the southwest, central, and northeast regions (Fig. 3).

[7] Depending upon management history, closing the soil health gap will require different lengths of time and may not be attainable for certain areas. Nonetheless, with sufficient data, a soil health index could be built that utilizes well managed croplands as interim benchmarks for a given region (with unique environmental and climatic conditions).

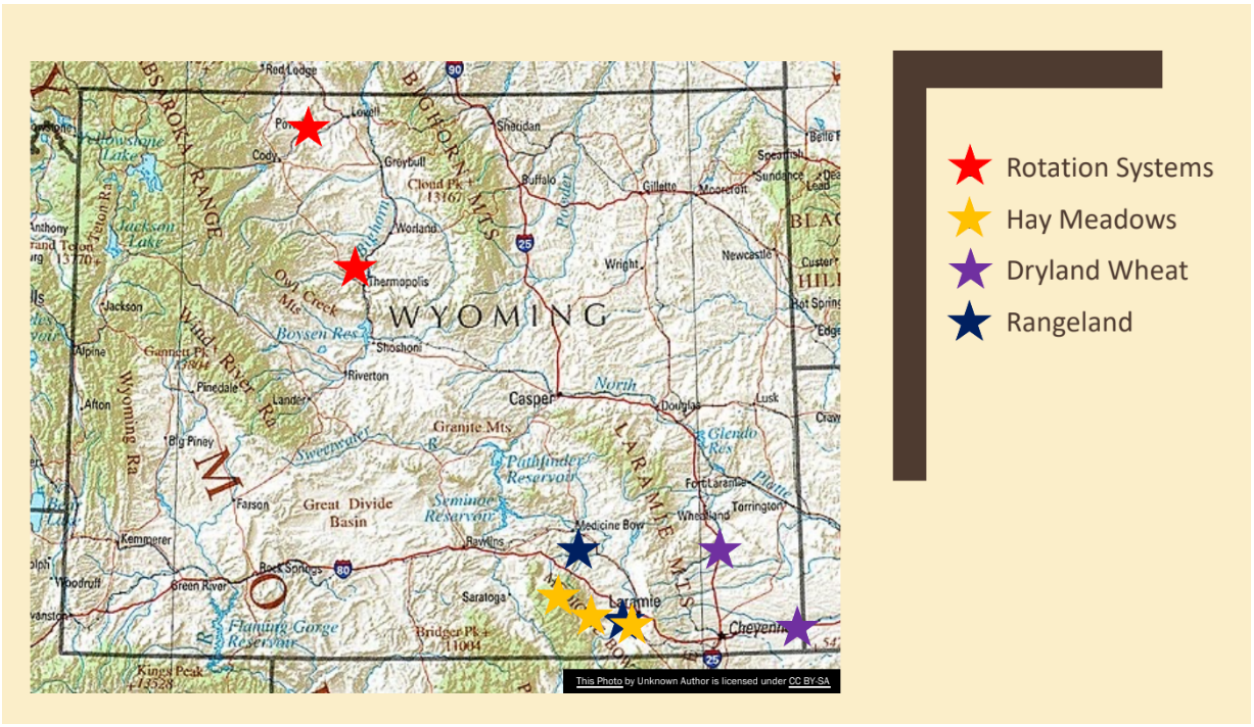

Fig. 3. Location of and types of operations in the Norton & Boggs Lynch Minimum Data Set.

We recommend that additional resources be given to expand this project to:

- include representative sites and operation types statewide and
- increase the length of time of the study so that long-term impacts of soil health practices can be assessed.

Grazing Lands

Grazing lands occupy the vast majority of Wyoming's land area. These include both rangelands and managed pastures. NRCS defines rangelands as "lands on which the indigenous vegetation is predominately grasses, grass-like plants, forbes, and possibly shrubs or dispersed trees."[8] Grazing is generally the dominant form of rangeland management, but other ecological factors such as climate and wildfire are also significant. In contrast, managed pastures (sometimes called "improved pastures") are managed both through grazing as well as through agronomic techniques, such as irrigation and seeding with specific plant and nonnative plant types.

[8]USDA NRCS. (n.d.-a). *Range Resources*. Natural Resources Conservation Service. Retrieved April 26, 2023, from https://www.nrcs.usda.gov/conservation-basics/natural-resource-concerns/land/range-pasture/range-resources

The following recommendations focus on providing ranchers with easy-to-use tools to assess and improve their soil health.

Recommendation #5: Emphasize the soil health principles, monitoring, and the decision-making process rather than practices in producer education

Background. As noted above, the five soil health principles identified by USDA NRCS are universal,[9] applying equally to croplands and to all grazing lands (whether a managed pasture or native rangeland habitat). Compared to croplands, grazing lands are extraordinarily heterogenous. For croplands, it is relatively straightforward to identify practices that will implement each of the soil health principles and to understand the directionality of their impacts on resource concerns.

The same is not true for grazing lands in Wyoming. For instance, thought concepts such as "rotational" or "prescribed" grazing are often referred to as practices, they are most appropriately thought of as an ongoing decision-making process by the rancher. Decisions made during this process are based on number factors, including animal units, changing conditions over the season, and the response of the land. Perhaps an imperfect - but at least more appropriate term - is "management intensive systems."

In these systems, the critical factors that drive decision-making are the soil health principles, outcomes of monitoring, and planning processes, most critically the grazing plan. While at the beginning of a season, a grazing plan may set forth factors such as length of grazing and recovery time and stocking rates for specific fields, grazing plans are often - and appropriately -frequently changed or modified.[10] Other components of a holistic decision-making process supportive of soil health are 1) a resource assessment; 2) a monitoring plan ; 3) a drought plan; and 4) contingency plans (e.g., in the event of a wildfire). All of these are critical for the producer to adjust activities appropriately during the grazing season. Stressing principles and processes will drive producer innovation, allowing for the management most appropriate to that situation.

Recommendation. For this reason, we recommend that producer education should emphasize the five soil health principles and the adoption of a decision-making framework with appropriate plans to operationalize the principles. To implement this, we recommend that experts, such as NRCS, University of Wyoming, and conservation districts, continue to hold and increase training and workshops on the development of critical plans with producers. If possible, we also recommend that resources on monitoring and developing these plans be posted for producers at an appropriate, easily accessible place (*see infra* Recommendations 6, 7, and 8).[11]

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[9] The five soil health principles are: 1) minimize disturbance; 2) maximize living roots; 3) maximize soil cover; 4) maximize biodiversity; and 5) integrate livestock.

[10] Perhaps in other areas of the country with increased ecosystem uniformity and precipitation, it is possible to give producers more determinative advice around frequency of rotation, stocking rates, and recovery time.

[11] *See* Recommendations of the Education Working Group for more information.

Recommendation #6: Encourage producers to use the USDA NRCS Pasture Condition Score Index for assessing managed pastures

Background. As noted above, managed pastures involve agronomic management and disturbance, which can be extensive, with the primary goal of increasing forage productivity and animal health. As a result, assessment of a desirable pasture condition is far more straightforward and has been standardized. USDA NRCS has developed the Guide to Pasture Condition Scoring (Guide to PCS)[12], which contains a scoring sheet. For instance, because management includes the introduction of non-native species (which may be more desirable than native forage), plants are only characterized based on whether they are 1) desirable; 2) living; 3) represent a diversity of functional groups; and 4) reflect a presence of legumes. Similarly, it contains benchmarks for the appropriate amount of bare ground/soil cover. Based on NRCS experience, this easy to use tool is educational for producers and, in conjunction with soil sampling (when indicated, can be used to determine the causative factors of sub-par scores.

Recommendation. Consistent with Wyoming and national NRCS guidelines, we recommend using the USDA NRCS Guide to PCS across Wyoming for all managed pastures. This will provide the necessary consistency for both producers and to advance scientific research. If needed, we recommend that training be provided to conservation professionals, including conservation districts and Extension, as well as producers.

Recommendation #7: Develop an easy to use assessment form like the Pasture Condition Score Index for assessing rangelands

Background. Unlike managed pastures, assessing the quality of rangelands requires considering first the ecosystemic quality of a given piece of land. For this reason, several US agencies have collaborated to develop the Interpreting Indicators of Rangeland Health; Technical Reference 1734-6)[13] ("IIRH"), which was updated in August 2020 and is now in its 5th version.

The IIRH is a system used to assess the quality of rangelands across the county, including areas as diverse as the grasslands of Plains to the deserts of Utah. Therefore, unlike the Guide to PCS, assessments are made on the basis of a reference site for an area, which includes the range of natural variability for that ecosystem type. While reference sheets with descriptions exist for many areas, they have not been developed for many parts of Wyoming and, accordingly, there is a lack of accurate benchmarks. Additionally, IIRH requires the assessment of 17 indicators, many of which require expertise and would be difficult for producers to employ. For both of these reasons, while the IIRH is an excellent tool for federal agencies to use, it is of limited utility for producers and agricultural professionals.

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[12] USDA NRCS. (2020). *Guide to Pasture Condition Scoring*. https://www.sare.org/wp-content/uploads/2020-Guide-to-Pasture-Condition-Scoring.pdf

[13] USDA, USGS, US Forest Service, & US DOI BLM. (2020). *Interpreting Indicators of Rangeland Health [Version 5]* |https://www.blm.gov/documents/national-office/blm-library/technical-reference/interpreting-indicators-rangeland-health-0

Recommendation. We recommend that a tool analogous to the Guide to PCS be developed (referred to as "Guide to Rangeland Condition Scoring" or "Guide to RCS"). Such a guide must account for ecological differences in rangeland areas, like the IIRH, but would contain indicators that are far easier to measure.

We recommend inclusion of at least the following indicators:

- Actual perennial plant cover;
- Actual invasive and undesirable plant cover;
- Actual bare soil;
- Litter;
- Soil organic matter depth;
- Infiltration; and
- Compaction.

We recommend convening a group to develop the Guide to Rangeland Condition Scoring. Funding should be provided for this group as many details will have to be worked out. For instance, unlike the Guide to PCS, the Guide to RCS will likely have to be based on ecoregion or ecosystem system type.

Recommendation #8: Develop an easy to use web-based tool for monitoring grazing lands

Background. Long-term monitoring with documentation is critical to any sustainable grazing management system. There are several methods of monitoring, ranging from the line point intercept method to the boot intercept method to visual/ocular observations with photo point (depending on the parameter to be measured). Several of these methods are time- and labor-intensive, particularly if recommended monitoring is more than once a grazing season. Moreover, even with simple methods such as photo-point monitoring, it can be difficult to ensure that there is consistency from year to year (for instance, monitoring at the same site and getting the same landscape view). For these reasons, adequate monitoring to inform grazing decisions is often not conducted or records are not kept.

Recommendation. To encourage sufficient monitoring, we recommend the development of an easy to use web-based or mobile app tool for Wyoming using GrassSnap[14] from the University of Nebraska Extension as a model. This tool provides an accessible platform for photo-point monitoring along with step-by-step instructions. Photo-point monitoring is the easiest way to gather data on short- and long-term conditions. This tool contains features that ensure consistency from year to year, such as geolocation; stamping of photos with gps coordinates, pasture name, and date. GrassSnap also has Nebraska-specific information for certain areas, such as grazing indices. While producers outside of Nebraska can use GrassSnap, we encourage

[14] University of Nebraska Extension. (2023). *GrassSnap*. https://extension.unl.edu/statewide/centralsandhills/grasssnap/

the development of a Wyoming-specific tool so that other types of information, such as grazing indices or best management practices, can be added.

Recommended Research Areas and Suggested Methodology

Recommendation #9: Create a network of on-farm/on-ranch demonstration and research sites

Background. While there are several barriers to the adoption of soil health practices, foremost among them is Wyoming-specific research. Most research to date on soil health practices and outcomes emanates from the Midwest and does not address arid or semi-arid areas. Gaps in soil health research exist for several factors, including impacts on yield, drought resilience, and on-farm finances. In fact, the stakeholder engagement conducted by WCHS showed that additional research on the economics of soil health practices, strategies to improve soil health, and the benefits of soil health are all needed to support producers. Similarly, agricultural professionals in Wyoming all expressed a significant need for educational resources on these topics. Further, when asked what mechanisms would support producers, the highest rate choice was demonstration projects.

While research certainly occurs in Wyoming and some entities collaborate, entities engaging in this research (e..g, University of Wyoming, USDA (ARS & NRCS), Conservation Districts, and producer groups) often work separately. This leads to siloed information, uneven distribution of findings, producer confusion, and increased perception of producer risk.

Recommendation. We recommend immediate collaboration among University of Wyoming, Wyoming Association of Conservation Districts and individual conservation districts, USDA and others to create a network of long- and short-term on-farm/ranch trials and demonstrate plots. This type of network should undertake to:

- Create publicly accessible, high quality producer-relevant research;
- Create producer-centered, in-field educational opportunities; and
- Advance scientific knowledge about the physical and economic impacts of soil health practices.

This network should leverage existing sites, as well as develop new sites based on regional/local needs. While long-term research plots are important to ensure scientific integrity, on-farm/ranch demonstration sites should be a priority, as they reflect the reality of an agriculture operation. A significant added benefit of increasing coordination is the ability to leverage resources (including funding, staff, and producers) more effectively.[15] Per Recommendation 10 (below), we recommend that research projects and demonstration sites include robust financial analysis, as costs were identified as the top barrier for producers.

[15] For instance, WY NRCS is launching Adaptive Management grants under EQIP, which involve the comparison of outcomes under different management practices. University of Wyoming and NRCS have already discussed how University of Wyoming may be able to assist in further this research, for instance, by collecting and analyzing producer economic data.

Finally, as part of this effort, we recommend that the partners share existing research and findings and organize it such that it can be effectively and understandably shared with producers and agricultural professionals.

We provide a concept outline for this recommendation in Appendix 4.

Recommendation #10: Include Robust Financial Analyses in Scientific Research and State and Federal Programs

Background. The costs and financial impacts (such as potential yield reduction) of soil health practices are a top concern for producers. In fact, costs were rated as the number one barrier for producers. Further, there is a dearth of Wyoming-specific research on economic impacts.

Recommendation. We recommend financial and economic analyses be integrated into the network of research sites and on-farm/ranch demonstrates sites discussed above (*see supra* Recommendation 9*)* and - to the extent possible - into existing state and federal programs with the goal of creating publicly accessible case studies.

Increased collaboration between University of Wyoming, NRCS, and conservation districts is recommended to achieve this. For instance, the group discussed and we recommend that WY NRCS and University of Wyoming partner to provide economic analyses for future EQIP Adaptive Management Standard Grants. We recommend that these and other partners work together to develop a standardized approach to economic analysis. This could result in the development of producer and policy relevant information and decision making tools, including: 1) operation-specific economic case studies and 2) predictive partial budget analyses.

Recommendation #11: Conduct additional research on carbon markets

Background. Concerns about climate change and greenhouse gas emissions have led to an increased interest in climate solutions particularly an increase in the storage of carbon in natural ecosystems across vegetation, oceans, and soils by reducing or altogether avoiding greenhouse gas emissions. This can be done by improved management of ecological systems to improve the carbon storage across these systems. Fueled by concern to mitigate anthropogenic climate change, the interest and market opportunities associated with carbon storage is incredibly high. However, the science behind these carbon markets is still unclear leading to uncertainty in its implementation. Carbon markets use credits to trade between entities that are interested in paying for the carbon sequestration (or the addition of carbon from the atmosphere to a carbon pool such as in soil carbon pools). Companies then certify the carbon credits by verifying that carbon was stored in the ecosystem and pay for the carbon stored. These companies certify the credits by various protocols. They use both modeling and measuring to predict and confirm that carbon is stored in the soil. Currently these voluntary markets only pay for increased carbon additional carbon sequestration and not the preservation of the carbon that is currently in carbon pools. Carbon markets can provide an incentive for improving soil health and thereby storing carbon in both cropping and grazing lands, but more information is needed to determine the feasibility in Wyoming.

Recommendation. While potentially financially beneficial, we recommend conducting research before committing to carbon markets since each company verifies carbon credits with their unique protocols. New practices may be required to qualify for certain programs, as well as to change management to increase the carbon storage in soils. While carbon market payments may offset the costs of new or expanded practices, they also may not fully cover these costs. We also recommend more research in carbon markets to determine which carbon pools, soil depths, and methods should be used in Wyoming in both cropping and grazing lands.

Appendices

Appendix 1

Science and Practice Group Members

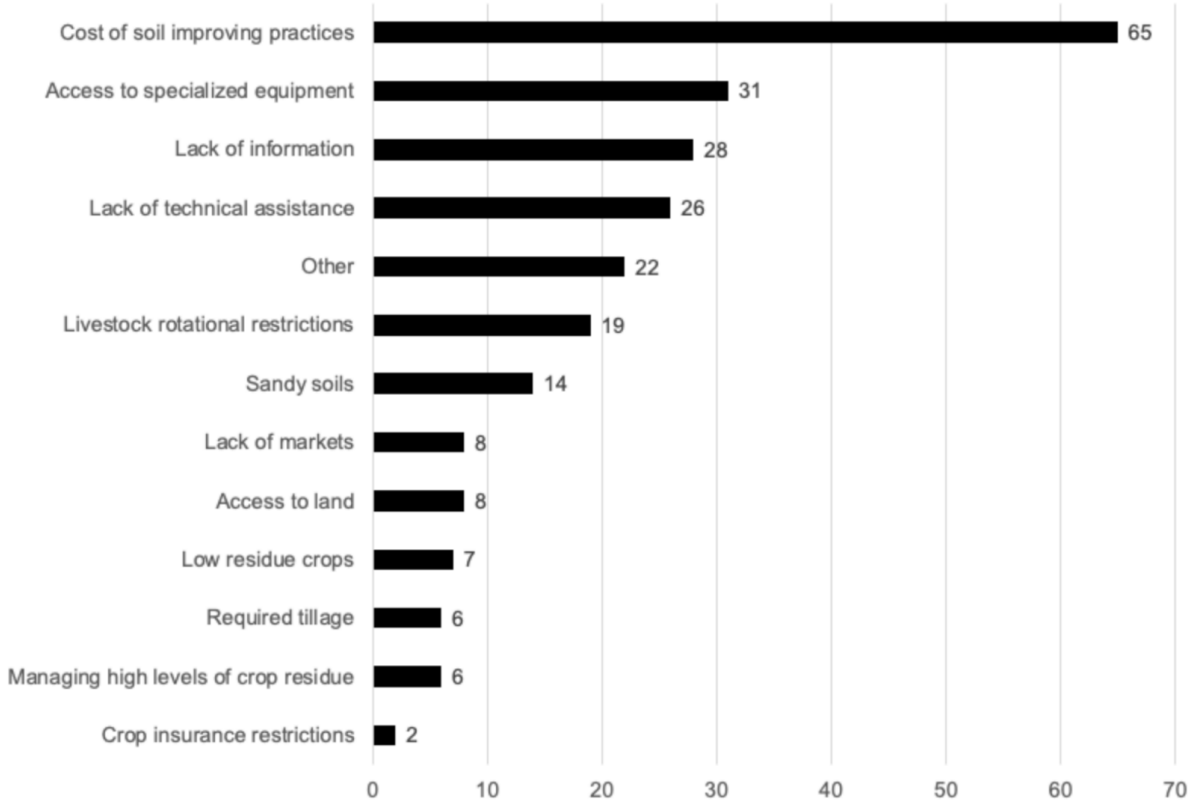
- USDA NRCS
    - Marlon Winger (Regional Soil Specialist)
    - Keela Deaton (District Conservationist, Sundance Office),
    - Catherine Hadley (State Agronomist)
    - Blaise Allen (Area Rangeland Management Specialist, Worland)
- University of Wyoming
    - Dr. Liana Boggs Lynch (Instructional Professor of Botany and LIFE Sciences) (Chair)
    - Dr. Urzula Norton (Professor of Agroecology and Agroecosystem Biogeochemistry)
    - Dr. Mengqiang Zhu (Research Scientist; Ecosystem Science and Management)
    - Dr. Linda Van Diepen (Associate Professor, Soil Microbial Ecology)
- Conservation Districts
    - Zach Byram (District Manager, Clear Creek Conservation District)
- USDA Agricultural Research Service
    - Justin Derner (Rangeland Scientist, Research Leader, USDA Agricultural Research Service)

Appendix 2

Select Stakeholder Engagement Results

Full report here; select results pp. 6-10.

What are the barriers to implementing new or additional soil health practices in your area?
(listening sessions; n=157)

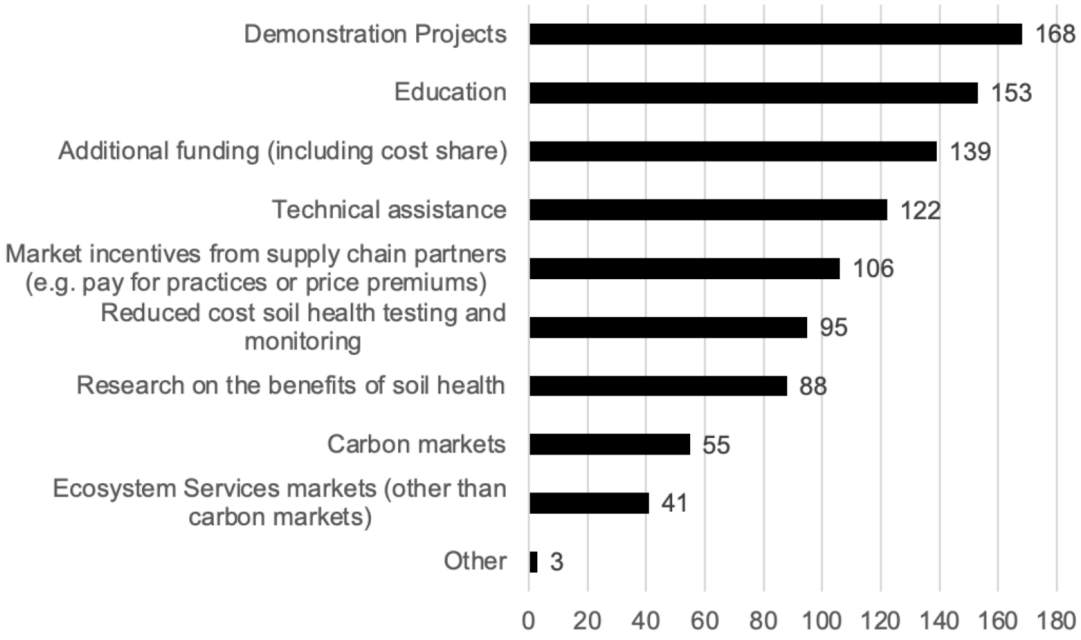


For Ag Professionals: What are the biggest barriers to meeting your customers'/members' needs around soil health?
(ag professional survey, n=20)

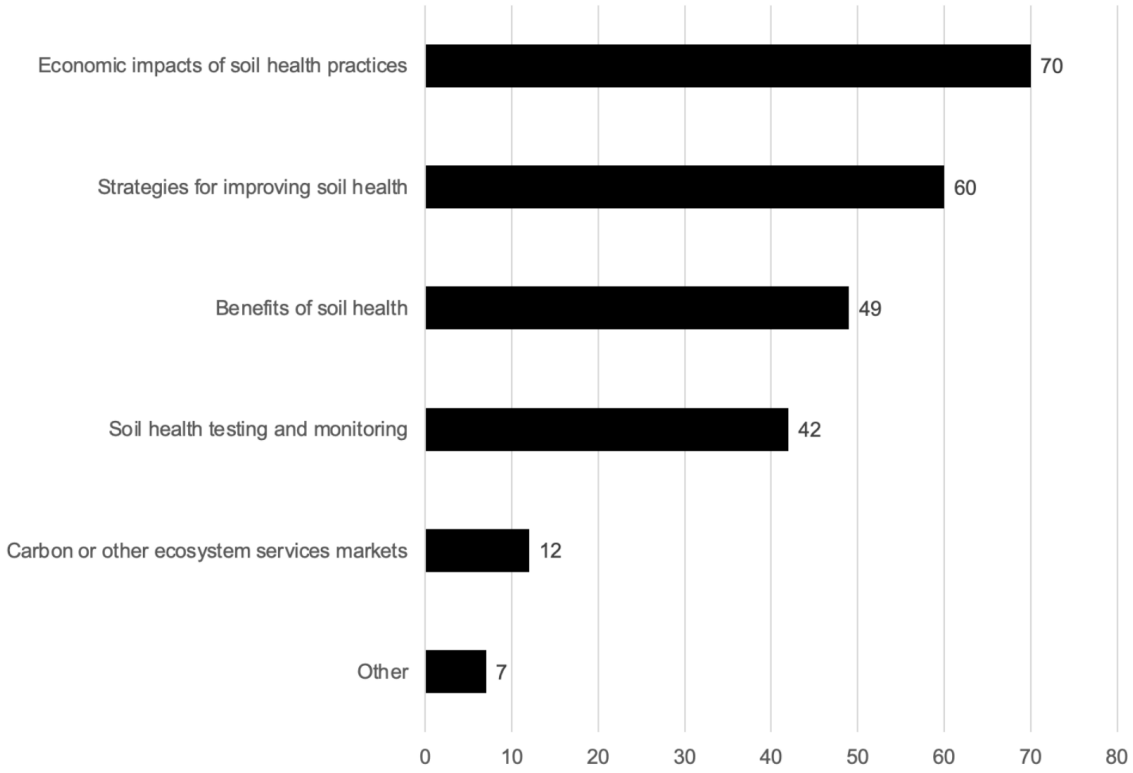
Response	Low	Moderate	High
Staffing for soil health related activities	33.33%	38.89%	27.78%
Funding for your organization for soil health related activities	27.78%	33.33%	38.89%
Lack of information	35.29%	47.06%	17.65%
Lack of funding for producers (cost share)	33.33%	33.33%	33.33%
Lack of technical assistance	35.29%	41.18%	23.53%
Lack of educational materials for producers	17.65%	52.94%	29.41%
Lack of soil health testing and monitoring	20.00%	20.00%	60.00%

Part 4: What is needed to support the voluntary adoption of new soil health practices?

What mechanisms would support producers in your area in achieving their soil health goals?
(combined results; n=234)



What additional educational resources are needed to support producers in your area?
(listening sessions; n=157)



Rate the need for research or additional information on the following topics.
(producer survey; n=57)

Response	Low	Moderate	High
Economic impacts of soil health practices	8.20%	27.87%	63.93%
Soil health testing and monitoring	1.61%	46.77%	51.61%
Benefits of soil health	15.00%	36.67%	48.33%
Strategies for improving soil health	6.90%	18.97%	74.14%
Carbon or other ecosystem services markets	17.86%	44.64%	37.50%

For Ag Professionals: What additional educational resources do you need to support your customers/members in the voluntary adoption of soil improving practices?

(ag professional survey; n=20)

Response	Low	Moderate	High
Economic impacts of soil health practices	0.00%	23.53%	76.47%
Soil health testing and monitoring	11.76%	17.65%	70.59%
Benefits of soil health	18.75%	25.00%	56.25%
Strategies for improving soil health	11.76%	17.65%	70.59%
Carbon or other ecosystem services markets	35.29%	23.53%	41.18%

Appendix 3

Proposed or Existing Definitions of Soil Health

NRCS Definition:

Soil health, also referred to as soil quality, is defined as **the continued capacity of soil to function as a vital living ecosystem that sustains plants, animals, and humans**. This definition speaks to the importance of managing soils so they are sustainable for future generations. To do this, we need to remember that soil contains living organisms that when provided the basic necessities of life - food, shelter, and water - perform functions required to produce food and fiber.

Only "living" things can have health, so viewing soil as a living ecosystem reflects a fundamental shift in the way we care for our nation's soils. Soil isn't an inert growing medium, but rather is teeming 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 dryer 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.

USDA NRCS. (n.d.). *Soil Health*. Retrieved June 22, 2023, from https://www.nrcs.usda.gov/conservation-basics/natural-resource-concerns/soils/soil-health

Definitions in select existing legislation:

As states have integrated the concept of soil health into legislation, they have generally chosen a more specific soil health definition that includes specific functions and benefits that a healthy soil can provide in contrast to the more general terminology in the NRCS definition. Specifying expected benefits from soil health improvement offers opportunities to then develop outcome-based metrics to evaluate the potential impact of incentive programs or other initiatives supported by soil health legislation. The more specific definition is nearly identical across most states, though there are differences in the proposed definitions for Illinois and Nebraska. As noted above, a shortcoming of these definitions is that they do not account for the societal or economic productivity of soils in relation to human needs.

New Mexico (2019): "Healthy soil" means soil that enhances its continuing capacity to function as a biological system, increases its organic matter and carbon content and improves its structure and water- and nutrient-holding capacity, resulting in net, long-term greenhouse gas benefits. New Mexico Statutes (2019). Ch. 76, Art. 25, §2 (F). https://lawlibrary.nmcourts.gov/general/

Hawaii (2017): "Healthy soils" means soils that enhance their continuing capacity to function as a biological system, increase soil organic matter, improve soil structure and water- and nutrient-holding capacity, and result in net long-term greenhouse gas benefits. Hawaii House Bill No. 1578 (2017). A bill for an act relating to climate change, https://www.capitol.hawaii.gov/session2017/bills/HB1578_CD1_.htm

Maryland (2017): “Healthy Soils” means the continuing capacity of soil to: (I) function as a biological system; (II) increase soil organic matter; (III) improve soil structure and water and nutrient holding capacity; and (IV) sequester carbon and reduce greenhouse gas emissions. Annotated Maryland Code (2018). §2-1901(a)(2), https://codes.findlaw.com/md/agriculture/md-code-agric-sect-2-1901.html

California (2016): "Healthy soil" means soil that enhances its continuing capacity to function as a biological system, increases its organic matter and carbon content and improves its structure and water- and nutrient-holding capacity, resulting in net, long-term greenhouse gas benefits. California Code Annotated. Food and Agricultural Code, Div. 1 Ch. 3, Art. 8.5, §569(e)(2), https://leginfo.legislature.ca.gov/faces/codes_displayexpandedbranch.xhtml?tocCode=FAC&division=1.&title=&part=&chapter=&article=

Illinois (2019): “Soil health” means the overall composition of the soil, including the amount of organic matter stored in the soil, and the continued capacity of soil to function as a vital living ecosystem that sustains plants, animals, and humans. Illinois Compiled Statutes, Ch. 70, §405, https://www.ilga.gov/legislation/ilcs/ilcs3.asp?ActID=857&ChapterID=15

Nebraska (2019): Healthy soils are a limited natural resource and fundamental for healthy and sustainable food production. Improving soil health means increasing soil's organic matter and diversifying its microbial activity to enhance agricultural productivity and environmental resilience. Revised Statutes of Nebraska (2019). § 2-401, https://www.nebraskalegislature.gov/laws/statutes.php?statute=2-401

Doran, J.W., Sarrantonio, M. and Liebig, M.A. (1996) Soil health and sustainability. Advances in Agronomy, 56, 1-54. http://dx.doi.org/10.1016/S0065-2113(08)60178-9: “Soil quality has been defined as . . . ‘the capacity of a specific kind of soil to function, within natural or managed ecosystem boundaries, to sustain plant and animal productivity, maintain or enhance water and air quality, and support human health and habitation.’”

Appendix 4

Concept Outline for Recommendation #9

The following outlines components and a process for creating a coordinated network of on-farm/on-ranch demonstration and research sites.

- **Proposed and potential partners:**
    - Wyoming Association of Conservation Districts and/or individual conservation districts), NRCS, and University of Wyoming (Faculty & Extension) ("Proposed partners")
    - Other members that should considered commodity groups, NGOs, crop consultants and associated industry, and supply chain partners
- **Goal:**
    - A network of long and short-term on-farm/ranch trials and demonstration plots with consistent research approaches supported by the Proposed Partners that:
        - creates publicly accessible high quality producer-relevant research;
        - creates producer-centered, in-field educational opportunities; and
        - Advances scientific knowledge about the physical and economic impacts of soil health practices
- **Importance:**
    - There are several barriers to the adoption of soil health practices among producers, foremost among them being Wyoming specific research and demonstration plots
    - The lack of Wyoming-specific research leads to producer uncertainty about the physical and - significantly - the economic impacts of soil health practices, in both the long and the short term
    - The Proposed Partners and others work on soil health individually and sometimes in collaboration.
    - Efforts and results, however, are often siloed, which leads to:
        - producer confusion or uncertainty; and
        - lost opportunities to pool resources to advance producer knowledge of and the scientific understanding of soil health practices
    - A network of on-farm trials and demonstration plots collaboratively supported by the Proposed partners will allow bolster producer education and reduce confusion, advance scientific research, and encourage the use efficient use of resources

- **Locations and production types to be included:**
    - Statewide
    - Major agricultural regions
    - Grazing lands and croplands

- **Proposed work plan and timeline:**
    - Begin process Q4 of 2023/Q1 of 2024

        - Identifying champions for this effort from WACD/individual conservation districts, University of Wyoming, and WY NRCS
    - Q1-Q2 of 2024:
        - Champions conduct outreach to identify additional needed partners (e.g., commodity groups, NGOs)
        - Once main partners are identified, agree upon the vision and work plan
        - Main partners will want to establish rules of operation/engagement
            - MOUs
            - Points of contact
            - Roles
        - Main partners to:
            - establish goals for 2023 (e.g., field day?) and
            - identify existing and any additional needed resources (including funding opportunities)
        - Main partners to organize producer involvement
            - Identify relevant producers and projects
                - Which ones are appropriate for field days?
                - Which ones have ongoing research?
                - Where are they in terms of time of conservation practices?
    - Q3 of 2024:
        - Organize research and data management approach
            - Data sharing
            - Relevant metrics
            - Economics etc.
            - Roles of partners and producers
            - Confidentiality/privacy agreements
        - Consider having one or two regional field days presented as a collaboration of the partners
        - Identify new candidates from EQIP adaptive management
    - Q4 of 2024:
        - Public facing presence (e.g., website)
        - Work with producers on projects
        - Implement research and data approach
    - Q1 of 2025:
        - Begin to work on collaborations with respect to EQIP adaptive management standard grants