Assessing and Managing for Soil Health on Rangelands and Pasture Lands

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Introduction/Importance of Rangeland and Pastureland Soil Health

Maintaining healthy ecosystems requires understanding dominant ecological processes and foundational properties, such as soil health. The U.S. Forest Service reports that rangelands account for 770 million acres of land in the United States alone, with over half owned privately, the federal government managing 43 percent of the rangelands, and state and local governments managing the remainder (U.S. Forest Service, n.d.). According to the U.S. Department of Agriculture (USDA), privately owned range and pasture lands makes up over 27% (528 million acres) of the total acreage of the contiguous 48 states, and these lands constitute the largest private lands use category, exceeding both forest land (21%) and crop land (18%) (USDA Natural Resource Conservation Service, n.d.).

The effects of grazing on soil quality and sustainability are extremely important to land managers and livestock producers (Manley et al., 1995). Rangelands have been recognized as the largest and most diverse single land resource in the U.S. (Reeder & Schuman, 2002). Globally, rangelands cover approximately 50% of the earth's land area and are the most extensive land cover, representing 91% of grazing lands that 1–2 billion people rely on for part of their livelihoods (Sayre et al., 2013, Reid et al., 2014, Farley et al., 2017). However, rangelands are not the only land cover that supports livestock grazing. Pasture and fodder crops also support livestock and are estimated at 3.5 billion ha, representing 26% of the world land area and 70% of the world agricultural area (FAO, 2008).

Rangelands and pasturelands also provide a wide range of ecosystem services such as food and fiber, carbon storage (containing between 10-30% of global soil organic carbon (Sayre et al. 2013)), recreation, open space, and water supply (Booker et al. 2013, Sayre et al. 2013, Yahdjian et al., 2015). Rangelands and pasturelands also provide habitat for numerous species, and frequently serve as avenues of connectivity between protected areas (Brunson & Huntsinger, 2008, Cameron et al., 2014).

Despite the valuable resource that rangelands and pasturelands represent, and the ecosystem services they provide, they have not featured prominently in the national discussion and efforts to improve soil health. While it is acknowledged that "healthy soils are fundamental to sustainable rangelands"; soils often function in obscurity (Derner & Augustine 2016). Also, despite occupying 37% of total U.S. land area, relatively little research has evaluated how different management practices may affect carbon sequestration in U.S. rangelands and pasture lands (Morgan et al., 2010) and "research on how to properly manage rangelands for healthier soils is lacking" (Ling, n.d.). Compared to other ecosystems, the soil health of grasslands has received little attention in the scientific literature despite the global vastness of these land types, covering nearly one quarter to one third of the world's habitable land area, their high levels of biodiversity, and the large economic and social benefits provided by rangeland ecosystems (Cameron et al., 2014).

Conversely, there has been an increased interest from a wide variety of stakeholders, including livestock producers to policy makers, in rangeland soil health recovery for the critical role these lands play in our environment (Derner & Augustine, 2016).

Challenges in Rangeland/Pastureland Soil Health

There are primary differences between managing for soil health in croplands and rangelands that must be considered. Factors such as, intensive crop management (e.g., fertilizer applications and tillage) vs. extensive rangeland management, annual plants in cropland vs. perennial plants in rangelands, and varying climates, vegetation and organisms are just some of the differences that must be taken into account when addressing the improvement of soil health.

Spatial heterogeneity and variability of environmental factors are common in intensively managed agricultural systems. However, in the case of croplands, and to some degree pasturelands, these elements may be homogenized through substantial capital and energy inputs (Derner & Augustine, 2016) via tillage, seeding, soil amendments, and irrigation. In contrast, options in rangeland systems are limited by the large scale at which ranchers work; it would be time and cost prohibitive to fertilize, over-seed, or irrigate the thousands of acres that may make up one single ranching operation in the western United States. Additionally, differences among rangeland ecosystems at the global scale – alpine meadows, desert grasslands, native prairie, and shrublands – are often exacerbated at the local scale by this high degree of spatial heterogeneity of soils and temporal variability of environmental factors, primarily precipitation in these water-limited systems. For rangelands, there is a clear need to evaluate metrics of soil health and assess costs and benefits of managing to impact soil health (Derner & Augustine, 2016).

As the "science related to soil and rangeland health evolves", so do the needs for protocols and assessment (Printz, Toledo, & Boltz, 2014). Currently, rangeland and pastureland health protocols are not considered a comprehensive tool for evaluating soils, as this framework is focused largely on physical characteristics which are only one aspect of soil health. There are a number of other aspects related to rangeland soil health that currently cannot fully be addressed with the extant indicators of rangeland health.

Setting the Stage

Over November 6-8, 2017, the Foundation for Food and Agriculture Research (FFAR), in conjunction with the Noble Research Institute, the Sustainable Rangelands Roundtable, the National Cattleman's Beef Association and the Soil Health Institute (SHI), sponsored a workshop centered around *Assessing and Managing for Soil Health on Rangelands and Pasture Lands*.

> *Healthy land is the only permanently profitable land*
>
> - Aldo Leopold, 1946
>
> *If the soil is destroyed, then our liberty of action and choice are gone*
>
> - W.C. Lowdermilk, 1953

The objective of this workshop was to identify research gaps in rangeland and pastureland soil health by applying tenets of "usable science,' which involve the end user of the research in the process. In this case, considering rangeland and pastureland management with a specific focus on practices to enhance soil health, the end users are ranchers and other land managers. Therefore, this workshop was structured in such a way to maintain the central concept of "usable science" by opening the workshop with a producer panel which allowed participants to hear from the producer's perspective first and not only set the tone for the discussion but also helped to identify their questions and information needs. The workshop then transitioned to a series of panels with a scientific focus, as rangeland and pastureland ecosystem scientists discussed the current state of knowledge. This whitepaper summarizes the findings of those two panels, as well as the subsequently identified research gaps/white spaces identified in breakout sessions that followed the opening panel.

Landowner/Producer Panel

The objective of this panel was to learn from producers/landowners to better understand the geographic regions in which they operate, and to more fully understand their management practices, challenges, questions and successes with regard to soil health.

Greg Brann, who raises cattle and sheep near the Tennessee/ Kentucky border, shared that the primary goal of his operation is to have a low stress, low cost operation that improves life, production, and the environment. His soil is naturally acidic and the vegetative community is a mix of C3 and C4 grasses, legumes, and forbs. The grazing approach that he described is a "no second bite" rotational grazing: sheep graze first, followed by cattle. His decisions are made on a daily basis and, in general, rotations occur every 3 days or less. Grass, legumes and turnips are seeded every February. With the rotational grazing system, Brann has not had to fertilize his land in over ten years; although, he would like to start applying chicken manure to his acreage, one third of the farm every year. His ideal pH is 6.2, and he will apply lime if it becomes more acidic than that, and ideal phosphorous and potash levels are medium-high. For weed control, annual ryegrass is used to smother out the unwanted species. In weedy areas he will also feed hay.

Leslie Dorrance raises cattle along the central coast of California. The Dorrances have a conservation easement with the Nature Conservancy and also provide cattle to graze the nearby Santa Lucia Preserve without grazing, the preserve was overtaken with shrubs and weeds and they lost their population of tiger salamander. The preserve has double the rainfall as the Dorrance's home ranch and went un-grazed for 20 years, leading to a lot of thatch. The preserve has 88 cattle that get rotated weekly across the landscape, every area grazed receives 120 days of recovery before being grazed again; the home ranch has a 45-day recovery period. Vegetation is a mix of annual and perennial grasses at the preserve, with the home ranch having a smaller percentage of perennial grass due to the reduced precipitation. Landscape goals are to reduce thatch, target invasive species, encourage perennial grass growth, limit erosion, increase biodiversity, improve water quality, and support endangered species recovery all while maintaining low stress livestock management.

William and Karen Payne are owners of Destiny Ranch, a 920-acre cattle ranch in central Oklahoma. Annual production is about 4300 lbs./acre. The Payne's implement a rotational grazing plan in which 80-100 animals graze one one-acre plots, and are moved daily to the next plot- currently there are 7 groups rotating in this fashion. In the fall, rotations can move out to three days- it depends on the grass and the protein content of the grass. On July 1, half of the pastures stop being grazed, and 300 acres of forage gets reserved for winter. Supplemental feed is supplied daily, and water is supplied to each paddock via hydrants, there are no ponds available to the cattle. During calving, rotation is paused and two five-acre plots are used, hay is fed and supplied as bedding, and rotation begins again once the last calf is on the ground. This grazing system helped retain moisture in the soil during the 2011-2012 drought. However, excessive rain is the bigger worry as it transforms the paddocks to mud, but that is a benefit of having one-acre tracts. Their forage-based management goal is to keep 5-6 inches of forage on the ground, and to have no bare ground.

Johnny Rogers produces cattle, sheep, and other livestock on 450 acres of leased land near the Virginia/ North Carolina border. The soil on their land is a silt loam, but still

Ah-Ha Moments of Early Adopter Producers

During a wet spell, we put our cattle on a non-productive sandy site because it was dry. The next year- that site was productive! We started making changes.

Boom or bust- overgrazing it, we let it recover, and then saw what grew. It's amazing to see the reaction.

Allen Savory talks- recognizing the animals damaging the plants by overgrazing the good ones. We didn't follow his methods, but we started changing our practices. Plus, I didn't like throwing hay!

I started planting annuals to help recover some pastures, but then I started to notice the soil changing. That's when I realized that the soil was the real foundation and started looking at the soil.

with some clay. There is a 27-acre solar farm on the lease, which is grazed by sheep, and a few acres of the lease are seeded in annual forage to increase soil health. When he has to feed hay, Rogers changes the location so seeds and nutrients are deposited in different spots. Mr. Rogers considers adaptive grazing the "thinking man's grazing" because it incorporates planning, stocking rate and density, grazing periods, residual forage, rest periods, cycle length, and monitoring. There is no single "recipe for success"; everyone's land is different and needs to be managed accordingly. Stocking density needs to be used to feed "all livestock" including earthworms, dung beetles, microbes, etc. During his discussion of his practices, he emphasized "the power of one wire"; when you cut your pasture in half and begin a rotational system, you both double your stocking density and increase the rest period of your unused pasture. For every $1 your cattle consume, they deposit $.85 back for the soil. Rogers is currently doing soil tests to assess differences in seeding annuals vs. grazing rotation for future management decisions.

Grady Grissom (comments submitted electronically), a Colorado producer from Rancho Largo Cattle Co. has practiced strategic grazing focused on plant diversity for about 20 years. Their normal precipitation is 11" in short-grass step and annual production is on the order of 1,000-1,200 lbs./acre. They manage across 36 pastures that average 400 acres and are typically grazed 10-14 days by 200-300 cows. Recovery periods under normal precipitation conditions average around 180 days. Grazing is year-round and season of grazing is not repeated in successive graze periods. These parameters do not describe a "grazing system" but rather communicate average variables under adaptive decision making. The goal at Rancho Largo Cattle Co was originally recruitment of cool season grasses. Grissom targets multiple species including shrubs, forbs, and some warm-season mid-grasses. Plant diversity has driven increased profit and production through decreased supplementation and improved water cycle.

Producer Panel Discussion

Panelists were provided the opportunity to answer questions from the audience, specifically to identify challenges that they face, that their fellow producers face, and to share their journey to early adoption of soil health practices. During this discussion, producers/landowners identified a number of concepts that could be categorized into two topical areas: identified knowledge gaps/needs and challenges to soil health adoption.

Identified knowledge gaps/needs

- Improvement of understanding of forage base.
- Increased understanding of current practices; how did "what" we do get us to "where" we are?
    - Understanding the science behind those processes will propel producers/ranchers in their management.
- Additional information that helps assists producers in meeting their end goal of production while still enhancing the land.
    - For example, provide soil or forage testing with beef production as an end goal (discussed as a barrier specifically by the California producer).
- Strategies to engage other producers to encourage adoption and a desire to understand principles and produce for land stewardship.

- Strategies to engage those producers who do not rely on the land as their sole source of income; it is more challenging to connect with the concept, i.e. saving the ground saves the ranch.
    - Drawing economic connections between adoption and productivity would be helpful in achieving this goal as people who do not rely on the land as their sole source of income often have a harder time understanding the importance of soil health.
- Increased federal technical assistance.
    - In California, it was mentioned that there is limited trust in federal technical assistance due to so many endangered species. People are afraid of losing their land.
- Connection between animal welfare and soil health.
    - People look at the health of their animals, not the health of the ground; even if they're feeding hay half the year.
- Improved strategies to engage producers early in the process.
    - People start into this business as a "retirement plan" and they do not lay the groundwork and ruin the land right away. Starting over is way harder. You cannot manage without a forage base to start with.
- Clear easily communicated directives.
    - Scientists or those providing recommendations need to boil down to 5-10 things that producers really need to look at.
- Specific Questions raised under knowledge gaps:
    - What is the relationship between manure density and invertebrate (or bacterial, or fungal) activity?
    - If mob grazing is the concentration of manure and trampled grass in space and time that jump-starts bugs, bacteria and fungi; then, what are the easily measured thresholds that producers can shoot for?
    - Are there associations of fungal species with grass, shrub, or forb species?
    - If annual plants share fungal associations with perennial species, could introduction of corresponding annuals speed up succession to desired perennials?
    - Could one inoculate the ground with fungal species that associate with desired plant species?
    - Are there studies of soil ecosystem activity through drought conditions?
    - How do fauna (for example, Prairie Dog towns) affect soil ecosystems? Are there practices that can utilize these faunal relationships?
    - How can interested producers access journals?

- No data being captured on the economics linking soil health and grazing to profit
    - Lack of comprehensive records; no conclusive data.
    - Need for Economic viability of various practices in multiple regions
- What are the thresholds of adding fertilizer? What are the benefits of seeding and rotational grazing if we can't see it on out soil tests? What form of nitrogen is best? What are the impacts of feed (hay vs. grass)
- Knowledge base of the average producer surrounding grasses and soils

- Disconnect with producers and the impact of their grasses; producers feel that they are cattle growers, not grass growers; they understand grasses as a function of the nutrition it provides their animals. How can soil health be incorporated in that understanding?

State of the Science: A regional assessment of Rangeland/Pastureland Soil Health

Three speakers representing three different geographic regions were invited to share their perspectives and current and emerging studies and findings from soil, range and adjacent disciplines.

Pasture soil health in Pennsylvania and the Northeastern U.S.

Curtis Dell: USDA- ARS, PSWMRU- University Park, PA

Broad spectrum soil health has not been researched extensively on the northeastern and mid-Atlantic pastures. Soil degradation, erosion, and nutrient losses on croplands and their impacts on water quality (especially within Chesapeake Bay watershed) has largely driven the research agenda. Some individual indicators of soil health from studies in the region, most notably soil C, are available in the literature. The focus of soil C studies on northeastern pastures has frequently been the comparison with croplands or changes associated with conversion from cropland to pasture. Those studies show substantially greater C in pasture soils and large increases when degraded croplands are converted to pasture. Those increases in soil C would be expected to result in overall improvement in pasture and soil health, but additional indicators typically have not reported. Additionally, long-term impacts of pasture management approaches on soil health are not well studied. Another issue is degraded soil conditions in turnout areas on many confinement diaries that can have considerable negative impacts on water quality. One approach that potentially could be expanded to access pasture soil health is USDA-NRCS's Pasture Condition Scoring. That evaluation primarily addresses plant community characteristics, but it includes soil fertility and pH and could be expanded to include more soil health attributes.

Can grass–fungal endophyte technology be utilized to improve pasture soil health?

Rebecca McCulley: University of Kentucky

There is an urgent need for new solutions for sustainable agricultural practices that circumvent the heavy use of fertilizers and pesticides and increase the resilience of agricultural systems to environmental change (Kauppinen et al. 2016). It has been demonstrated that fungal endophytes can have a number of positive impacts: improving plant performance in times of water stress and heat stress (low nutrient availability and intense grazing/herbivory pressure) (Young et al. 2013).

Grass – fungal endophyte (Epichloë spp.) symbioses are commonly manipulated by humans to improve pasture persistence across significant acreage worldwide. So-called 'novel' symbiotic associations are created primarily with the aim of reducing grazing mammal toxicity issues while maintaining environmental and insect resistance traits conferred by the symbiosis. However, emerging data illustrate that these aboveground symbioses can impact soil communities and processes, possibly effecting soil health. Results from both growth chamber and field experiments demonstrate substantial impacts of not only fungal endophyte presence but also genetic strains on tall fescue root exudates, rhizosphere and bulk soil fungal communities, soil organic carbon pools, and soil-to-atmosphere trace gas fluxes. It is possible that grass-endophyte symbioses can be utilized to improve pasture soil health, though much remains to be explored concerning the mechanisms and conditions under which effects are likely to be most pronounced. Results of these novel endophytes could be increased carbon storage, livestock gains, and forage nutrition. More research still needs to be done to determine site specific best management practices.

Western Great Plains rangelands and soil health: Current status

Justin Derner: USDA- ARS, Cheyenne, WY

The semiarid Western Great Plains rangeland ecosystems are characterized by intrinsic high inter- and intra-annual variability in precipitation, and high variability in soils, topography, and diverse plant communities that are managed for livestock production and wildlife habitat. Current focal interest in soil health is providing the opportunity on rangelands to: 1) refocus grazing management on ecological processes rather than implementation of practices, 2) emphasize goal-based management with adaptive decision-making, 3) advance integrated approaches highlighting social-ecological-economic interdependencies, 4) build cross-institutional partnerships, and 5) create a cross-region living laboratory network for rangeland soil health. Prior research on soil carbon in this geographic region has showcased: 1) limited capacity for additional carbon sequestration with management, 2) short periods (2-3 months) of high carbon uptake and long periods (many months) of carbon balance or small losses, and 3) annual to decadal scale changes in soil carbon due to both environment and management, as well as interactions. Preliminary data from long-term grazing research studies in this geographic region suggest that chemical components of soil health are minimally or not affected by stocking rate, grazing intensity, season of grazing or adaptive grazing management. Opportunities likely exist for addition of nitrogen-fixing legumes and increasing vegetation diversity for biological components of soil health, and such efforts can be undertaken using existing regional/national networks such as the USDA Long-Term Agroecosystem Research (LTAR) network and the USDA Climate Hubs.

Synopsis of Response and Synthesis Panel Discussion:

Following both the Producer and State of the Science Panels, a second science panel provided deeper discussion of current state of the science and shared their experiences and needs identified from their stakeholders. In an effort to capture a national "snapshot", the synthesis panelists were selected to span from East to West Coast to capture varying issues, challenges and perspectives.

- *Chelsea Carey – Point Blue California*
- *Jen Kucera – USDA NRCS Oregon*
- *Alan Franzluebbers –USDA ARS North Carolina*

Some of the topics discussed during this panel surrounded the following topic areas:

Needs surrounding soil health measurement:

- How can strategies to measure productivity, such as measurements and assessments, be developed and clearly defined?
    - Producers know what bad soil looks like, but what does good soil health look like?
    - From a producer standpoint: soil health may represent using cover crop. But it's more than that. The Soil Health Institute released the 19 indicators of soil health- how can they be measured in the field?
- Relative time scales need to be used, 3-5 years won't show much, but maybe there are leading indicators?
    - Which indicators are more useful where?
    - How can we prevent wasted money on replication of measurement?

Issues with terminology use:

- How do we define the functionality surrounding soil health? Porosity, aggregate stability, water infiltration, plant productivity, these are all signs of soil health, but how do we determine "is it functioning?"
- Producers say they want to improve soil health, but they don't know what it means. It's a buzzword. How can we clearly define soil health?
- We need to change language, especially when it comes to disturbances. Grazing and fire are both disturbances. How can we optimize rather than minimize on these disturbances?
    - The stigma around disturbance is changing. High disturbance is still bad, but producers can see change with moderate disturbance.
    - Goal is to mitigate risk.

Strategies to approach producers

- Do demographics of age play a factor? How can we effectively communicate to a wide range of stakeholders?
- How to support producers in attaining soil health while meeting their own goals?
- Producers want more on the ground technical assistance, but this is difficult with agencies facing historically lower staffing and budget constraints.
- Soil health is being talked about a lot, but we have a tendency to overcomplicate it. How can we make the concept of soil health easily accessible?
- Common thread- to intentionally manage for soil health, you first need a plan. But first producers need to be encouraged to get behind this. Getting people to think about it will go a long way.
- How to build soil health? Producers want answers that are hard to give due to the variability of sites.
- You can go out and show a lot without bringing up the words "soil health." On site visits help break the ice to not use term.

Challenges and Knowledge gaps that were identified could be characterized into three tiers:

The challenges and knowledge gaps presented in the Producer-led discussions were captured and synthesized into three white spaces/opportunity points where resarch gaps exist (see Figure 1 below).

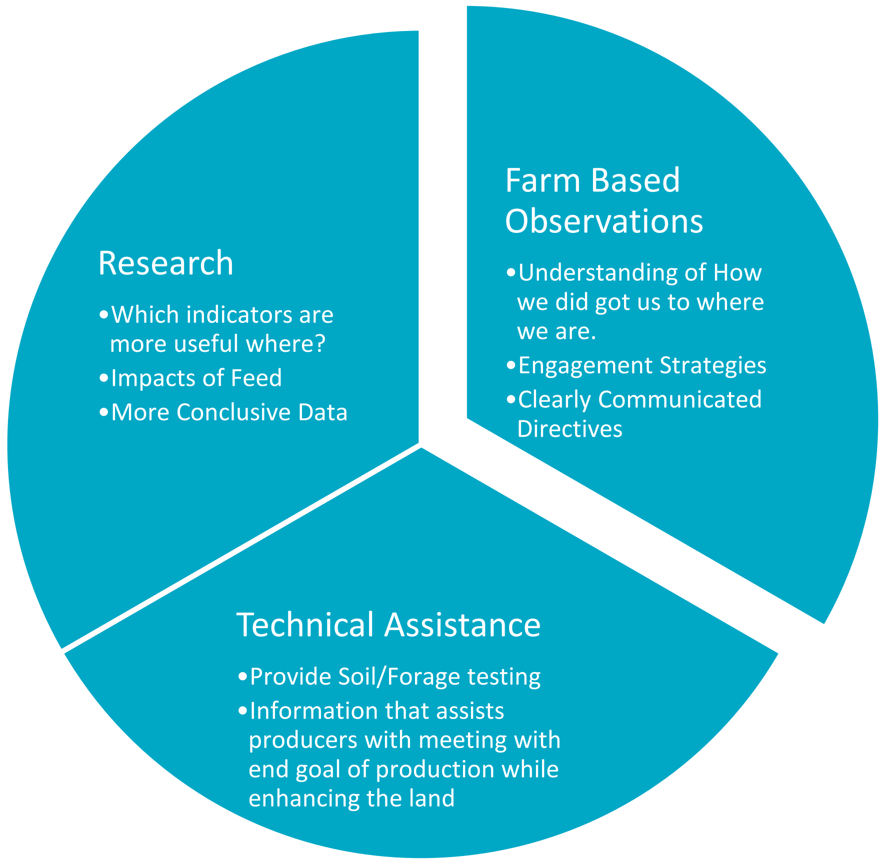

Figure 1. White spaces identified by the Producer-led discussions.

Emerging and relevant research opportunities

Based on the needs and research gaps discussed in the *Producer* panel and the *State of the Science and Synthesis* panels, a list of emerging and potentially relevant research opportunities was complied. Attendees were asked to capture their impressions, thoughts, or questions and then these larger concepts were further organized into more condensed, salient overarching categories.

In the following table is a summary of the concepts identified by each of the four groups during the breakout group session.

• Function is the foundation- what is the function of the system? • Economics- quantify the economics of soil health, cost of recovery over time, quantify site potential • Identify drivers of resiliency, especially in response to stress • Plant diversity → Soil health • Microbes: Presence, increase resilience, relations with other soil health factors? • Communicating the value of soil health	• Land management principles • There is not one formula to get to soil health- highlight multiple paths • Demonstrate short term "hooks" – demonstrate success and use as indicators • The role of statistics when working with producers is not the same as when working with scientists • Different levels of assessment/ tiers: Producer, Technical assistant, scientist • Are there quantifiable relationships between soil health and livestock, forage production, and other outputs? It needs to be defined
• Identify passionate early adopters Identify, measure, and communicate their success – Network with them! • What is under our feet? Link soil health to forage and water • Link soil health with soil types • Soil health as conservation planning (NRCS) • Citizen science networks • *Show me* what soil health looks like	• "Grass is the answer" • Forage production – lead the discussion with productive grass/ forage, not with soil health • Long term income per acre – focus on cash flow viability • Examine and learn from and replicate past behavior change successes • Baby steps – this is a long-term goal

Figure 2. Summary of concepts for emerging research opportunities identified by groups during the break out session.

Five Concepts/Research Themes Prioritized for additional discussion

1. Below-ground management principles
2. Palatable information transfer
3. Data-informed actions
4. Soil health literacy
5. "The Graph": The need to develop a good representation for both scientists and producers to show all of the interactions with rangeland/ pasture health and soil health

Discussion of these five concepts led to the emergence of a list of data and knowledge gaps (listed below) and ideas for how to bridge those gaps. Some concepts were prioritized by the larger group of workshop attendees to delve deeper in regard to current research, benefits of pursuing research, and potential funding and partners.

Identified Research Gaps

The emerging and potential relevant research areas and the impressions that resulted from the discussions that originated in four breakout groups were prioritized in the larger group and then organized into concepts/research themes. The larger group then divided into discussion groups based on the following *concepts that emerged. The objective of each discussion group was to outline potential research gaps/white spaces that exist in the concept space. Additional information on the four research concepts that emerged from the discussion is located in the appendices.*

How to bridge those gaps:

- Socio-Ecological-Economic Integration
  - This is a PRIORITY
- Capacity- of the people, the expertise, and financially
- Are there barriers to entry?
- Case study models, on the farm/ on the ground research

The broader research concepts listed above were then "nested" and refined into the following identified potential research gaps (see Refined List of Identified Potential Research Gaps). In Appendix I, a more detailed short description of the identified research gaps as well as some foundational background information is provided.

Refined List of Identified Potential Research

- **Soil Health Literacy**
  - Describe and define soil health, what are the indicators?
  - Full census of "below ground"
- **"The Graph"- How does soil health relate to rangeland/ pasture outputs and are these relationships affected by management?**
- **Relationship between soil health and rangeland/ pasture restoration**
- **Rangeland/Pastureland and Economics**
  - How does soil health relate to the producer's checkbook?
  - Economic models- inputs, model outputs
  - Socio- Ecological- Economic Integration

Summary

Based on the initial themes identified by the Producer panel (please refer to *Summary of Concepts for Emerging Research Opportunities*) and the concepts identified, prioritized and discussed by the workshop attendees (please refer to *Refined List of Identified Potential Research Gaps),* there is a need for a coordinated multi-stakeholder program which can address research gaps, obtain farm based observations and provide technical assistance. The research gaps which were identified as having the most opportunity for impact and potential partnership surrounded drawing obtaining additional information on the rangeland soil health specifically as it pertains to below ground. Also, there is a need for additional studies which can provide information on the relationship between rangeland soil health and a number of rangeland/pastureland outputs as well as the impact soil health can have on restoration efforts. At the end of the workshop, a series of next steps were outlined.

Action Items/Next Steps

- Refine Priority list
- Identify potential funding partners
- Continue discussion of identified research gaps
- Schedule follow up meeting(s)
- Complete white paper and circulate for comment

Join the Conversation on Rangelands and Soil Health

Submit your comments, questions, and suggestions or tell us about your research on rangelands and pasture lands soil health: http://bit.ly/2HLbIN2.

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Appendix I.

It was an integral commitment of the workshop and to the concept of "usable science" that this all stakeholders involved in this process were geographically representative. It was also imperative that there be diverse stakeholder engagement in the research gap identification and prioritization process. Each of the research concepts listed in greater detail below addresses a comment/question raised in the Producer-led panel, which reinforces the workshops commitment to the concept of usable science and ensuring that the themes prioritized by this workshop would address needs raised by the producers/landowners most impacted by any potential initiative. This section offers additional context and background information to each of the five identified research concepts which were prioritized at the end of the workshop.

Relationship between soil health and rangeland/ pasture restoration

"Does a pasture need disturbance or recovery?"

The National Sustainable Agriculture Coalition in their analysis of the FY 2016 Crop Stewardship Program sign-up revealed a strong demand for management of rangeland soil health and prairie restoration among other priorities.

When discussing restoration, interventions are designed and implemented with the aim of strengthening the resilience-the capacity to recover- in degraded systems. The primary objective of restoration is to overcome the resistance and negative resilience of the degraded state by strengthening positive resilience. This working group prioritized the need additional investment in research for rangelands and pasturelands in restoration and resilience. "Perhaps the most promising way to link soil health to capacity to function is to integrate resilience (Seybold et al. 1999, Bestelmeyer & Briske, 2012); "while many of these links are relatively well-established on croplands, these relationships need to be better quantified for rangelands (Brown & Herrick, 2016)

- Rangeland ecosystems require intervention and restoration because a large percentage of the world's rangelands are degraded; pasturelands to a lesser degree (Asner et al., 2004; Archer & Predick, 2008; Han et al., 2008), which limits the impact of the ecosystem services provided. As restoration is a complex process, research and management must be simultaneously implemented (Monaco et al., 2012).
- Restoration on rangelands and pasturelands can also be multi-decadal; to address these challenges, the workshop identified the need to invest in a coordinated multi-stakeholder approach to identify research priorities in this identified research gap space.

Importance of Soil health indicators and below ground census for rangeland soil health:

"Show me what soil health looks like"

While there does exist a number of rangeland and pastureland health protocols, there is not a comprehensive tool. Printz, Toledo, and Boltz (2016), indicated that there are aspects such as organic matter availability and microbiological activity that could be incorporated as additional indicators of rangeland soil health and should be a part of an iterative process that consists of management and research objectives. During the *Future Directions for Usable Science for Rangeland Sustainability Workshop*, three issues of usable science for soil health were identified; one of which was focused on indicators and the important role that they could play to serve as early warning metrics, implement management changes, and prevent undesirable transitions (Derner & Augustine, 2016).

Also, it is noted that there is a need for a more precise and quantitative application that may be used to systematically assess program and practice efficacy. A more effective set of indicators would be invaluable as a means to both communicate with stakeholders (users and other professionals) and to demonstrate changes in a quantifiable way (Brown and Herrick, 2016).

Another important area which was identified as a potential research gap is the need for belowground assessments. The belowground census approach will enable better understanding of the fate and effects of either antimicrobial resistant bacteria or their genes in the soil biome. For example, the influence of soil fauna on distribution of the organisms of concern and/or their genes would provide realistic ecosystem-relevant assessments (and understanding) of impact, fate, and distribution. The approach would also enable ecosystem-relevant management approaches to be developed.

A belowground census approach can further elucidate, through measurements and model development and testing, which characteristics of the community are important. Specifically, the outcomes should provide a weighting for the impact of different soil taxa, as well as weighting to consider such as the ecosystem component's (consortia, keystone species) functions. It will enable a better understanding of both biological and functional diversity on rangeland and pasture soil processes, and provide insights into science-based management strategies.

Asking these types of questions prove invaluable in the identification of what type and level of information is required for monitoring/adaptive management and inclusion in soil health indices. The outcomes of this task will enable the particular producer to determine how to choose management strategies to influence the direction of change desired?

Soil Health and It's Relationship to Outputs

Grazing management is impacted by a number of factors such as the plant community, soil, and landscape and prior management and climate which in turn effects each component of an ecosystem (Stohlgren, Schell, & Vanden Heuvelal, 1999; Guretzky et al., 2005; Symstad & Jonas, 2011; Bisinger, 2014, Russell & Bisinger, 2015), therefore, small scale/small plot research studies have limited value in assessing the effects of grazing on ecosystem characteristics. As was determined in Russell and Bisinger (2015), this workshop asserted that long-term large-scale integrated research projects are necessary to evaluate the impact of improving rangeland/pasture land soil health.

"How do we capture what producers will need to meet their goal [of soil health and productivity]?"

There is general consensus that one cause of the difficulty in encouraging widespread adoption of rangeland and pastureland soil health practices is the lack of connection between adoption and improvements in productivity. One of the key research gaps identified by the workshop is lack of a definitive link between soil health and outputs. The inability to measure and quantify the environmental and ecological benefits of range improvements and restoration efforts has meant economics has a minimal role in range-improvement project-implementation decisions on public lands (Nelson, 2006). There are a number of benefits of rangeland soil health that extend beyond livestock production, and failure to include those additional benefits, be they environmental, ecological or societal "implicitly assigns a value of zero to those outputs" (Torell et al., 2014). The acquisition of data and development of a model that demonstrates and begins to quantify the relationships between rangeland/pasture health and soil health - and that clearly delineates the impact of improvements of range/pasture soil health on economics, conservation, forage/animal production - is desperately needed (Fig. X). To date, rangeland restoration projects have defied quantitative economic assessment due to a lack of data and information, however, there is opportunity to capture this information, for example, it was suggested by Torrell et al., 2014, that there may be some value in identifying the

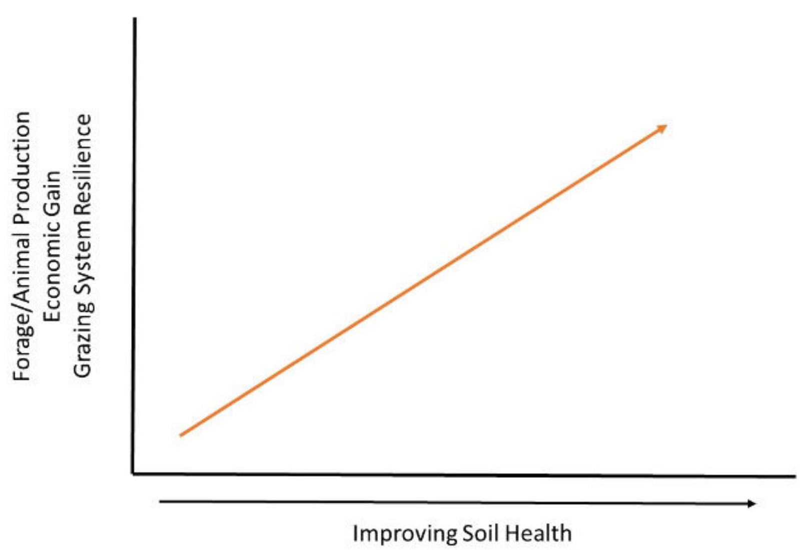

Fig. X: A representation of the hypothesized relationship between soil health and grazingland parameters of interest. To date there are few data that support the existence of this relationship, perhaps in part because defining and measuring soil health has proven challenging. Furthermore, it is unknown how management strategies or site specific characteristics might alter the nature or slope of the relationship.

expected direction of change and relative magnitude of change. There is a need to revisit how soil health is discussed in rangeland/pasture land, and to determine whether management practices are able to move soil health in a measurable, statistically - and ecologically - significant way. And, if so, what is the relevant timescale and causal relationship between that management practice and characteristics that have been identified as being of value to the producer. At present, the hypothesis is that practices which improve soil health also will result in cascading improvements to forage and animal production, economic gain, and grazing system resilience, but data are needed to test whether this is indeed the case (Fig. X).

Integrating Socio-economic and Ecological Components of Rangeland/Pastureland Systems

> “What’s the hook? How do we create a desire to care about soil health?”

Ecological systems and processes - reproduction, growth, death, decomposition, water cycles, nutrient cycles, carbon cycles, etc. - define the biological interactions that create ecosystem health and viability. Soils and soil health provide the underpinning for many of these processes and cycles, and the ecosystem goods and services they generate (Fig. 3).

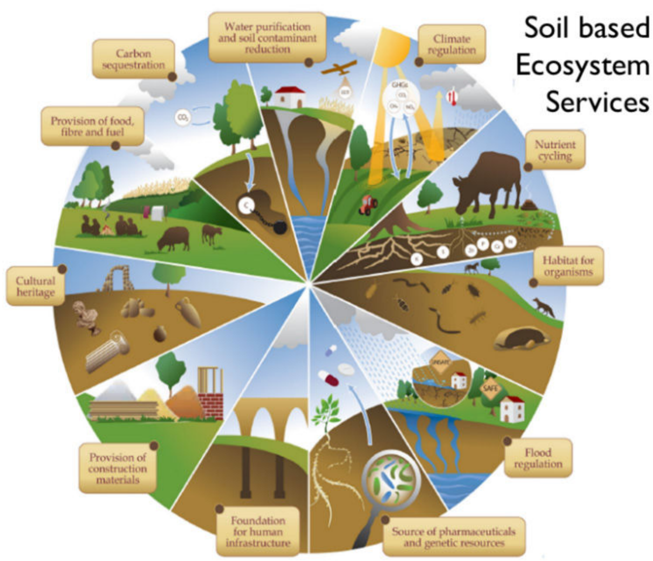

Figure 3. Healthy soils deliver ecosystem goods and services upon which society relies (Chessman 2016; adapted for ACES from FAO 2015).

Social and economic infrastructures and processes (such as demand, investment, depreciation, management, production, consumption, social interaction, institutional processes, etc.) provide the framework or context in which rangeland use and management occurs, and in which rangeland health, and its integral components, including aspects of soil health, improves or deteriorates. Systems and processes interact to change stocks of natural and human capital and conditions (Fig. 4) (Fox et al., 2009).

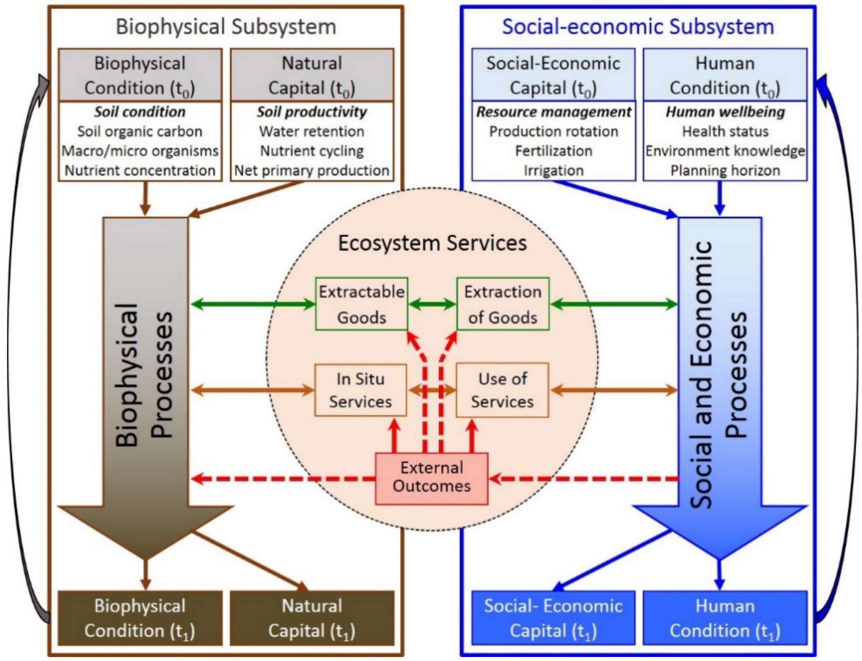

Figure 4. Integrated Social, Ecological, and Economic Concept (ISEEC) depicting systemic relationships and interactions with soil resources and management (Kreuter et al. 2016).

An integrated conceptual framework (Fig. 4) depicts ecological and natural resource processes that affect and are affected by social and economic processes, capacities, and capitals (Fox et al. 2009). An example of such effects is extractions from rangelands that provide goods, ultimately for human use. Forage quality and quantity depends upon precipitation, healthy, functioning soils and belowground ecosystems (McCollum et al., 2017). Forage is then extracted by livestock and wildlife.

Such extracted products are demanded by people and enter into the production of ecosystem goods and services, supporting jobs and lifestyles. They are used, consumed or traded, and contribute to social capacity, economic capital, and to human well-being. When biomass is removed, impacting soil resources, it affects natural resource capital. Byproducts of extraction, extractive processes, and production processes further affect biophysical conditions through such mechanisms as generation of waste products, soil erosion and degradation, succession of species, etc. (Fig. 5). These effects are driven largely by economic demands for goods and services, fueled by underlying preferences and social norms and expectations (Maczko & Hidinger, 2008).

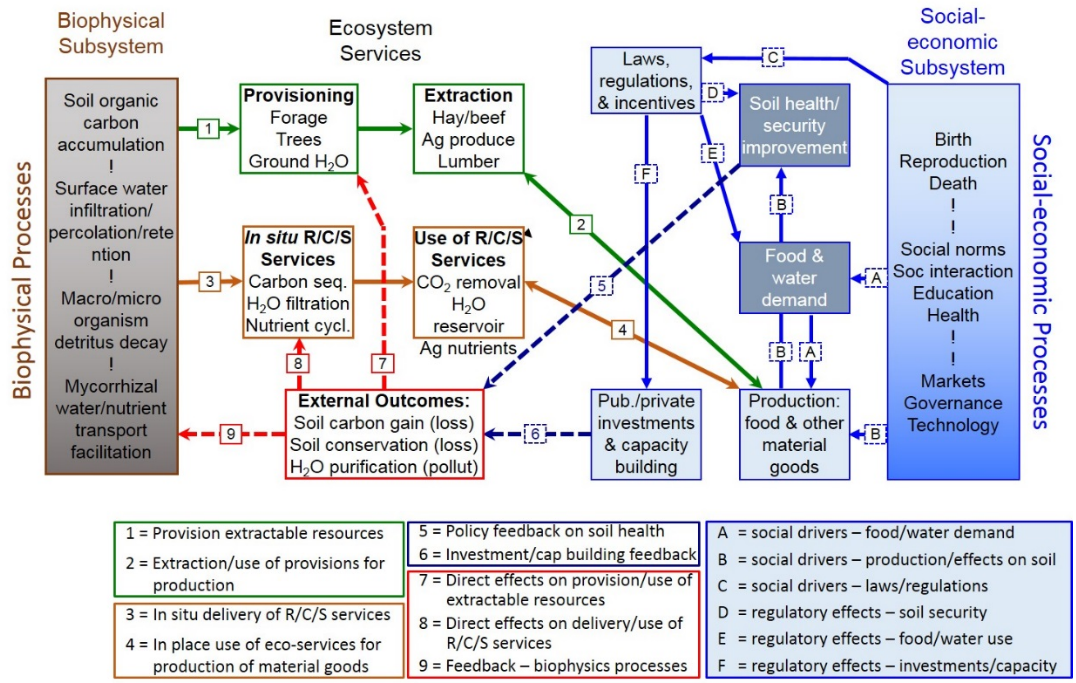

Figure 5. Integrated Social, Ecological, and Economic Concept (ISEEC) applied to soil health, illustrating ecological and social processes, interactions, systemic drivers, and interdependencies (Kreuter et al. 2016).

Likewise, social and economic processes affect and are affected by biophysical conditions and natural resource capital, and by ecological and natural resource processes. Human use and management (or lack thereof) of rangelands and rangeland ecosystems can profoundly affect the extent and quality of ecosystem services produced by rangeland systems and the healthy soils that support them. Social and regulatory drivers impact investments in production and conservation activities. These in turn place demands and limits on extraction activities and goods and services produced, within the limits of natural capital and ecological functions. Such critical interrelationships irrevocably entwine in a series of feedback loops, linking socio-economic and ecological systems (Fig. 5).

Economic Considerations for Assessing Costs and Benefits of Grazing Land Soil Health

"Producers want to see the payback for their investment"

Grazing lands can be managed to promote both private and public benefits. Private landowners benefit from using their rangeland for livestock production, and the public benefits from the provision of rangeland ecosystem services including carbon sequestration, air and water quality, wildlife habitat, recreation, and energy extraction (Maczko & Hidinger (eds.), 2008). To facilitate provision of ecosystem services and benefits for the landowner, private rangeland management should be cost-efficient and balance current use with future productivity. Grazing lands provide great economic value via agricultural commodities while providing ecosystem services to the public, which means it is crucial to educate landowners about long-term benefits of their land management practices to support ecosystem function in cost efficient ways (Dyer, 2017).

Grazing influences on ecosystem services and forage production are still unknown (Spaeth et al., 2013). Despite this knowledge gap, ranchers strive for grazing rates that balance forage production with livestock demand, while promoting financial profit and environmental health over the long-term (Shafer et al., 2017). To attain this balance, land managers must monitor their rangeland's forage productivity. Rangeland soil health investigations consistently identify vegetation and forage production as an essential indicator for interpreting rangeland soil health (Brown and Herrick, 2016). This suggests that rangeland forage productivity can be managed for improved soil health while also meeting rancher's production needs. Forage productivity translates into livestock numbers through use of annual unit months (AUM's) and livestock numbers equate with profit margins.

However, while land managers rely on functioning rangeland soils to support forage production for livestock, economic tradeoffs in terms of costs and benefit valuation for improved forage productivity on private rangeland have not yet been fully researched. Ranch level benefits from improved soil health, measured as improved forage production, occurring from changes in land management may be assessed using ranch economic models (Dyer, 2017). Private benefits change through time depending on management strategies, limited resources, and market prices. Therefore, the relationships among each of these temporal components should be modeled to organize relationships among multiple dynamic factors, while capturing the private benefit of utilizing improved forage production through time. Quantifying these relationships is the core of assessing economic aspects of managing for grazing land soil health.

Appendix II.

As the larger groups broke into five discussion groups to discuss research gaps surrounding the five prioritized concepts areas; here is a summary of those report outs.

Below-ground management principles

1. Census and activity studies to identify important direct and indirect plant-microbial interactions in rangelands e.g., nutrient cycling, nutritional quality, and resiliency.
    a. Develop and implement a survey approach to understand interactions.
    b. Develop and implement a problem directed/oriented sampling scheme. What microorganisms and consortia are associated with or influence e.g.:
        i. Forage production/quality
        ii. Identify range of soils with disease suppressivity
        iii. Water Use Efficiency (WUE) and drought
        iv. Nutrient Use Efficiency (NUE)
        v. Salinity
        vi. Invasive weeds problem
        vii. Greenhouse gas (GHG) mitigation and avoidance
2. Census to address temporal and spatial variability in a subset of representative rangeland and pasture systems
3. Understand whether microbial metrics increase predictive power of outcomes we care about for rangeland/pasture system productivity, resilience, and sustainability.
4. Census to determine the connectivity between soil and animal microbiomes, how the animals and their microbiomes influence the soil microbiome and other belowground animals, as well as understanding how the belowground biology influences the health and productivity of the aboveground animals. An important aspect of this will be to examine the rangeland animals of interest to agriculture, as well as other animals that inhabit rangelands, and how they act as reservoirs or sources of important biological components (e.g., unique gut microbiome components).
5. The census approaches developed will enable more-in depth analysis of secondary impacts on rangeland soils productivity and resilience (see Context above), such as the impacts of animals on the ecosystem via the introduction and/or enhancement of antibiotic resistance.

Palatable information transfer

- What is the "hook"- how do we create a desire to care about soil health?
    - Economics
    - Demonstrate win-win scenarios
- What are the tools to use?
- How do we build trust and relationships with technical assistants?
- Cracking the "human puzzle." Who? How?

- Timing
- What is the difference between the early adopters and the "laggards"
- Potential for more peer-to-peer learning between the early adopter producers/land managers and others in their region that have not adopted, but are interested.
    - Interest in grazing workshops held at individual ranches

Data-informed actions

- What are the gaps?
- How do we determine what indicators are best for what scenarios?
    - Where am I? (in terms of soil health)
    - Goals/ results aiming for
    - What are benchmarks to look for?
- What are the levels of assessment (soil health, forage production, economics) for different levels of expertise? Producer, scientists, researchers.
- LTARS- how do we access existing research/resources like SHI Action plan or the Department of Defense or BLM, Ag Experiment Station

Soil health literacy

- Citizen science
- Youth-oriented
- What are the benefits of including this in formal vs informal education?
- What is the proper timing, context, and platform?
- Can an increase in knowledge transform consumer demand and have unintended consequences?

"The Graph"

- Can be a good representation for both scientists and producers to show all of the interactions with rangeland/ pasture health and soil health. If we can produce data that support the concept that improving range/pasture soil health improves economics, profit, conservation goals, forage/animal production, etc. – it would be the 'hook' that is needed to get producers to adopt the practice of managing for soil health. We have very few data in hand to test this prediction.
- X axis- Soil health "index", what is the baseline, how is it moving? What is the exact parameter that should be 'soil health' on the x-axis…And you might get different relationships between the x and y depending on the parameters selected. How do we determine whether management practices are even able to move soil health in a measurable, statistically significant way – and if so, what is the timescale (how fast does it respond)?
- Y axis- Economics and profit, conservation goals, forage production, animal production, carbon, water quality. This could be whatever is of interest/value to the producer.

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