ARTICLE IN PRESS
RAMA-00288; No of Pages 6

Rangeland Ecology & Management xxx (2018) xxx–xxx

Contents lists available at ScienceDirect

Rangeland Ecology & Management

journal homepage: http://www.elsevier.com/locate/rama

Soil Health as a Transformational Change Agent for US Grazing Lands Management☆

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ARTICLE INFO

Article history:
Received 16 June 2017
Received in revised form 22 January 2018
Accepted 20 March 2018
Available online xxxx

Key Words:
ecological processes
human dimensions
living laboratory network
social-ecological systems

ABSTRACT

There is rapidly growing national interest in grazing lands' soil health, which has been motivated by the current soil health renaissance in cropland agriculture. In contrast to intensively managed croplands, soil health for grazing lands, especially rangelands, is tempered by limited scientific evidence clearly illustrating positive feedbacks between soil health and grazing land resilience, or sustainability. Opportunities exist for improving soil health on grazing lands with intensively managed plant communities (e.g., pasture systems) and formerly cultivated or degraded lands. Therefore, the goal of this paper is to provide direction and recommendations for incorporating soil health into grazing management considerations on grazing lands. We argue that the current soil health renaissance should not focus on improvement of soil health on grazing lands where potential is limited but rather forward science-based management for improving grazing lands' resilience to environmental change via 1) refocusing grazing management on fundamental ecological processes (water and nutrient cycling and energy flow) rather than maximum short-term profit or livestock production; 2) emphasizing goal-based management with adaptive decision making informed by specific objectives incorporating maintenance of soil health at a minimum and directly relevant monitoring attributes; 3) advancing holistic and integrated approaches for soil health that highlight social-ecological-economic interdependencies of these systems, with particular emphasis on human dimensions; 4) building cross-institutional partnerships on grazing lands' soil health to enhance technical capacities of students, land managers, and natural resource professionals; and 5) creating a cross-region, living laboratory network of case studies involving producers using soil health as part of their grazing land management. Collectively, these efforts could foster transformational changes by strengthening the link between natural resources stewardship and sustainable grazing lands management through management-science partnerships in a social-ecological systems framework.

Introduction

Grazing lands (pastures and rangelands) comprise almost 236 million ha in the United States and provide an extensive suite of ecosystem goods and services for society, including food and fiber, soil and water resource protection, and biodiversity conservation (Havstad et al., 2007). Increasing weather and climate variability (e.g., greater frequency of deluges and droughts), a growing human population with greater demand for animal protein, and directional changes in atmospheric carbon dioxide (CO_2) concentration and global temperatures challenge the ability of grazing lands to deliver these desired ecosystem goods and services. Maintenance of soil health at minimum, as well as improvement where there is potential, is the underpinning upon which many ecosystem goods and services depend and is foundational for the sustainability and resiliency of grazing lands. Physical, chemical, and biological components (Table 1) of soil health enable the soil's

☆ The USDA—National Institute for Food and Agriculture provided funding (2016-07298) for the National Soil Health Workshop held July 2016.
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https://doi.org/10.1016/j.rama.2018.03.007
1550-7424/Published by Elsevier Inc. on behalf of The Society for Range Management.

Table 1
Commonly measured soil health indicators adapted from cropland and forest systems (adapted from Doran and Jones, 1996; Arias et al., 2005; Zornoza et al., 2015).

Physical	Chemical	Biological
Particle size	Soil organic carbon	Microbial biomass, C and N
Bulk density	Total nitrogen	Microbial community composition
Soil aggregation	pH	Enzyme activities, C, N, P, and S cycling
Available water-holding capacity	Electrical conductivity	
Porosity	Available nutrients	Invertebrates
Penetration resistance	Cation exchange capacity	Pathogens
Water infiltration rate	Heavy metals	

capacity to function as a vital living system to sustain biological functions, maintain environmental quality, and promote plant and animal health and productivity (Doran and Zeiss, 2000). Benefits of soil health are manifest through enhanced soil water holding capacity, improved nutrient cycling, and greater system resilience to weather and climate variability (Doran, 2002). Furthermore, soil health and sustainability are inextricably linked (Doran, 2002; Doran and Zeiss, 2000; Lehman et al., 2016; Scoones, 2016).

In the mid-20th century, far-reaching social-ecological disasters drove the development of soil conservation policies in the United States. Westward expansion of cropping in the early 1900s ultimately led to disastrous consequences during the drought years of the "Dirty Thirties." Subsequent policies to rehabilitate these lands for sustainable agricultural production included formation of the Soil Conservation Service (synonym Natural Resources Conservation Service [NRCS]). Repeated soil erosion from the 1950s drought led to the Soil Bank programs, and in the middle 1980s the Conservation Reserve Program was introduced to protect soil and water resources. More recently, there has been a resurgence in local to national public interest in soil health for grazing lands management (e.g., South Dakota Soil Health Coalition http://www.sdsoilhealthcoalition.org; Soil Health Institute, www.soilhealthinstitute.org; USDA NRCS Soil Health Division). It is important to note that, unlike previous campaigns of the past century, contemporary focus on soil health has not stemmed from broad-scale natural resource degradation but rather from connections among soil biology, productivity, sustainability, and resilience, especially for croplands (e.g., Trivedi et al., 2016).

The four principles of soil health—1) increase plant diversity, 2) reduce soil disturbance, 3) extend period of active plant growth, and 4) maintain soil cover—and the associated linkage of soil ecological processes to management all have roots in cropland management and, therefore, will challenge grazing lands professionals to assess the applicability of these principles to their natural resource concerns. Increasing plant diversity often results in increased aboveground biomass and biogeochemical cycling (Tilman et al., 1997), as well greater temporal stability of productivity (Isbell et al., 2009). Regarding maintenance of soil cover, however, many ecological sites, by their inherent plant-soil-climate relationships, exhibit high amounts of bare ground, even in grazing-resistant grazing lands (e.g., Augustine et al., 2012). Moreover, high amounts (25 − 50%) of bare ground are necessary for some grassland bird species (Augustine and Derner, 2012; Schroeder, 1985). Collectively, spatiotemporal linkages of soil processes and management that emphasize heterogeneity of disturbance and conservation of pattern (Fuhlendorf et al., 2012) should challenge the applicability of soil health principles to grazing lands.

The soil health renaissance for grazing lands is tempered by limited scientific evidence, especially on rangelands (Brown and Herrick, 2016), illustrating positive feedbacks between soil health and grazing land resilience, or sustainability. A body of knowledge on soil health does exist from other agroecosystems over the past 2 decades (e.g., Arias et al., 2005; Doran and Jones, 1996; Jordan et al., 1995; Karlen et al., 1997; Trivedi et al., 2016), but these systems have been substantially altered in structure and function through prior repeated tillage. Linkages have been determined among soil microbial biomass, respiration, and decomposition and plant species diversity on grazing lands (Bardgett and Shine, 1999; Stephan et al., 2000; van der Heijden et al., 2008), but illustrations of how these plant-soil interactions improve grazing land function, resilience, and sustainability are rare. Opportunities for direct soil health improvements on pasture systems are likely constrained to intensively managed plant communities in pastures and formerly cultivated or degraded lands (e.g., Machmuller et al., 2015; Weinhold et al., 2004). This distinction within grazing lands regarding differential capacity between rangeland ecosystems and managed pasture systems regarding improvements to soil health is an important one for land managers, extension professionals, and scientists.

With renewed national interests in policy and planning for soil health in agricultural systems, the goal of this paper is to provide direction and recommendations for grazing lands' soil health efforts. Here, we argue that the current soil health renaissance is an opportunity not to focus on improvement of soil health on lands where potential is limited but rather to forward science-based management on grazing lands via 1) refocusing grazing management on fundamental ecological processes (water and nutrient cycling and energy flow) rather than maximum short-term profit or livestock production; 2) emphasizing goal-based management with adaptive decision making informed by specific objectives incorporating maintenance of soil health at a minimum and directly relevant monitoring attributes; 3) advancing holistic and integrated approaches for soil health that highlight social-ecological-economic interdependencies of these systems, with particular emphasis on human dimensions; 4) building cross-institutional partnerships on grazing lands' soil health to enhance technical capacities of students, land managers, and natural resource professionals; and 5) creating a cross-region, living laboratory network of case studies involving producers using soil health as part of their grazing land management. Explicitly incorporating soil health into grazing management and the matrix of ecosystems services provided by grazing lands provides transformational opportunities by building tangible links between natural resources stewardship and sustainable grazing management (e.g., Brown and Herrick, 2016), as well as providing paths to reach broader audiences and enhance communications among producers, customers, and the general public (Fig. 1).

Refocus Grazing Management from Practices to Ecological Processes

Ecoregional differences across grazing lands in the United States influence types of forage species, plant growth patterns, scale of operation, and management practices such as stocking rate and type of grazing system (Roche et al., 2015). A primary management issue for both extensively managed rangelands and intensively managed pasture systems is overcoming the temptation to rely on a prescriptive practice (e.g., "one size fits all") or set of practices rather than to incorporate fundamentals of ecological processes within the existing spatiotemporal heterogeneity and complexity of ecosystems (Boyd and Svejcar, 2009; Derner et al., 2009; Fuhlendorf and Engle, 2001; Fynn, 2012). For example, the 1985 Farm Bill legislation substantially increased conservation funding for NRCS (Monke and Johnson, 2010) and accelerated producer deployment of prescriptive rotational grazing strategies through cost-sharing facilitating practices of cross-fencing and water development. However, these practices, in and of themselves, are not likely to be