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Review

# Optimizing Beef Cow-Calf Grazing across Missouri with an Emphasis on Protecting Ecosystem Services

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**Abstract:** Soil health is an emerging paradigm for which much research in row crop agriculture has been undertaken. Research involving grazing lands and soil health has not been as active, a feature partially attributed to (i) greater erosional rates in cropland, (ii) loss of soil organic matter and reduced soil structure attributed to annual tillage practices, (iii) cash flow from cropland is easier to visualize than the value-added nature of grazing lands, and (iv) there exists more competitive grant funding sources for croplands. Grazing lands do require soil quality augmentation and investment in soil health to optimize their ecosystem services potential. This manuscript, with an emphasis on beef cattle grazing in the central USA, attempts to survey the literature to (i) identify the influence of grazing on important ecosystem services provided by Mollisols and Alfisols, (ii) develop a listing of soil indicators that may be selected to quantify and credential soil quality, and (iii) develop guidelines that align soil indicators and changes in grazing management to support the restoration of ecosystem services.

**Keywords:** soil health; soil quality; pasture management; soil indicators; ecosystem services

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## 1. Evolution of Perspectives Regarding Soil Health

The USDA-NRCS (United States Department of Agriculture-Natural Resource Conservation Service) defines soil as (i) the unconsolidated mineral or organic material on the immediate surface of the Earth that serves as a natural medium for the growth of land plants, (ii) the unconsolidated mineral or organic matter on the surface of the Earth that has been subjected to and shows effects of genetic and environmental factors of climate (including water and temperature effects), and macro- and microorganisms, conditioned by relief, acting on parent material over a period of time [1,2]. As an evolving natural resource, soil differs from the material from which it is derived in many physical, chemical, biological, and morphological properties and characteristics. The American Society of Agronomy recently provided an updated soil definition: "The layer(s) of generally loose mineral and/or organic material that are affected by physical, chemical, and/or biological processes at or near the planetary surface and usually hold liquids, gases, and biota and support plants" [3]. The newer definition includes the liquid and gaseous phases rather than just the solid phases.

Currently, soil scientists, agronomists, horticulturalists, animal scientists, and our colleagues in the biological sciences are re-imagining soil as a natural resource which is the biological and physical underpinning of terrestrial ecosystems [4–24]. The inherent biology of soil is immense and complex and is critically important to supporting ecosystem stability. Yet, our ability to evaluate soil at the pedon level requires a database that indicates whether the pedon is operating at a level compatible with the soil's ecosystem service provision potential.

Soil taxonomy and soil mapping are critical conventions to organize our soil knowledge; however, soil mapping and soil taxonomy evolved through mutual interaction. Field evaluation of the soil profile necessitated the introduction of diagnostic soil horizons; that is, soil horizons that have specified and observable field characteristics. These recognizable field features include texture, structure, boundaries, soil color, and redoximorphic features, clay films, organic matter accumulation. These diagnostic horizons and their associated field features have been employed to infer to influence water movement, nutrient provision, carbon and nitrogen cycling, plant anchorage, and an array of other ecosystem services. Thus, soil interpretations became predicated on the soil profile description; however, soil profile descriptions were never intended to be indicative for interpreting the quantitative assessment of ecosystem services.

Since the 1930s and continuing to the present, conservation tillage was advanced to improve water relations in semiarid regions and to reduce soil injury because of soil erosion. Soil scientists soon became aware that conservation tillage tended to increase soil organic carbon levels towards levels prior to cultivation [7,10,15]. Other beneficial soil properties were also supported, such as greater water infiltration. With the advent of synthetic ammoniated nitrogen fertilizers, increases in near-surface soil acidity were observed. Thus, land management became an important concept regarding soil productivity. With the recent rediscovery and then advancement of cover crops, producers are witnessing increases in soil carbon, improved soil structure, positive changes in water relations, and other beneficial properties. Slowly, a shift in our understanding that soil productivity, as influenced by land management, should not be considered uniquely as a function of soil classification, but rather each individual soil requires a baseline where land management-based soil alterations may be either augmented or corrected. Given the array of different land management practices, it is prudent to consider the appropriate collection of baseline data to connect to soil health objectives and specific land management practices.

This manuscript, with an emphasis on beef cattle grazing in the central USA, attempts to survey the literature to: (i) identify important ecosystem services provided by grazing lands, (ii) develop a listing of soil indicators that may be selected to credential soil quality, and (iii) develop guidelines that align soil indicators and changes in grazing management to support the restoration of ecosystem services.

## 2. Soil Quality Goals

The literature provides numerous definitions of soil quality. Karlen et al. [17] defined soil quality as "the fitness of a specific soil function within its capacity and 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". Within their definition is the acknowledgment that there exist innate differences between soils and that soil quality must be based on the individual uniqueness of the existing soil resource. As an example, soil drainage class likely varies among soils in a toposequence (catena), thus the drainage class is a soil property based on landscape position and is not highly influenced by land management. Drainage class may set limits for individual soils in a toposequence, with soils having a poorly drained classification likely having a greater soil organic matter content than adjacent soils having a well-drained classification. However, within each soil, the soil organic matter content may vary within limits because of tillage or manure amendments. Thus, a baseline for assessing soil organic matter changes for the poorly drained soil should differ from that of the well-drained soil.

The USDA-NRCS [3] defined soil quality as "the ability of soil to perform certain functions, such as (1) effectively cycling nutrients, minimizing leaching and runoff, which makes them available to plants, (2) maximizing water-holding capacity and minimizing runoff and erosion, (3) adsorbing and filtering excess nutrients, sediments, and pollutants (4) providing a healthy root environment, (5) providing a stable foundation for structures". Items 1 through 5 may be defined as soil functions, or as some researcher's term "ecosystem services". More recently, Doran and Parkin [21] defined soil quality as: "the capacity of a soil to function within ecosystem boundaries to sustain biological productivity, maintain environmental quality, and promote plant and animal health". Thus, the soil quality concept provides a compromise optimization involving ecosystem services and production agriculture.

## 3. Soil Functions

Soil functions or ecosystem services may be listed, such as (i) moderating and influencing the hydrologic cycle, (ii) anchorage and physical support of plants, (iii) retention and provision of plant nutrients, (iv) detoxification of wastes, decomposition of particulate matter into humus and microbial degradation of agrichemicals, (v) renewal of soil fertility, and (vi) regulation of nutrient/element cycles [8,12,25–27]. Kruse [25] reviewed various soil function definitions and their listing of ecosystem services, noting that some authors included biodiversity, social-economic factors, and societal long-term benefits. Thus, the credentialling of soil functions remains an active area of discussion [17,26–28].

The global emphasis on sustainable land use and governmental attention towards maintaining soil functions is increasing, frequently co-involved with global issues, such as climate change, regional water shortages, large-scale land degradation attributed to erosion, deforestation, desertification, and heavy metal impact. However, a more immediate and pragmatic need is to develop and authenticate protocols to evaluate the various land management influences on ecosystem services [29–31]. Researchers have defined two kinds of soil properties: (i) inherent or use-invariant properties and (ii) dynamic or use-dependent properties [25]. Inherent properties include texture, soil depth, clay mineralogy, cation exchange capacity, drainage class, and thermal regime, which are soil properties related to the combined effects of the five soil-forming factors (parent material, climate, organisms, relief or topography, and time). Dynamic soil properties are soil properties that alter within a reasonable time frame because of land management and these properties include soil organic matter content, bulk density, soil structure, infiltration rate, water holding capacity, nutrient holding capacity, and pH [4–6,8,12,26]. Consider soil organic matter content, which is readily altered because of land management attributed to the crops grown and tillage employed, but constrained by inherent factors (texture, climate).

Soil quality parameters, also termed indicators, form a composite set of measurable attributes indicating the intensity of soil function activity [25]. Typically, any changes in a soil quality parameter, as monitored by a specific sampling protocol, may warrant appropriate land management alterations. Three main categories of soil indicators permeate the literature: (i) chemical, (ii) physical, and (iii) biological [21,25]. Chemical indicators provide information on soil solution species and their concentrations, the types and quantity of exchange or adsorption sites, the nutritional status for maintaining plant and animal communities, the presence and activity of soil contaminants, and other soil chemical attributes. Frequently used indicators include: (i) pH, (ii) Eh (oxidation-reduction status), (iii) EC (electrical conductivity), (iv) soil nitrate concentration, and (v) exchangeable or total acidity. Physical indicators provide information primarily on the soil's hydrologic characteristics. Physical indicators include: (i) aggregate stability, (ii) available water capacity, (iii) bulk density, (iv) infiltration, (v) soil structure classification, (vi) the macropore-micropore distribution, and (vii) enzyme activity. Biological indicators provide information on the soil's biotic activity. Biological indicators include: (i) soil organic matter content, (ii) active carbon, (iii) respiration, (iv) microbial biomass, and (v) mineralizable nitrogen [21,25]. Dick [32] noted that plant roots secrete extracellular enzymes, thus the rhizosphere is enhanced with phosphatases, nucleases, invertases, urease, catalases, arylsulfatases, and proteases. If investigators are interested in monitoring nutrient cycles, then key enzymes are important indicators: (i) the carbon cycle (amylase, cellulase, lipase, glucosidases, and invertase), (ii) the nitrogen cycle (proteases, amidases, urease, deaminases), (iii) the phosphorus cycle (phosphatases), and (iv) the sulfur cycle (arylsulfatase). Dick [32] also reviewed literature that demonstrated that manure amendments supported increased enzyme activity, whereas nitrogen synthetic fertilizers did not appreciably increase enzyme activity.

The minimum data set is the identification of a series of relevant indicators that permit the monitoring of important soil processes (ecosystem services) because of specific land practices. The relevant indicators require scoring protocols so that diverse indicators may be compared [29,31]. Suppose that pH and earthworm activities are selected indicators, then an earthworm population-scale indicative of low, low-moderate, moderate, high-moderate, and high populations may be created as an indexing scale. Similarly, pH may be indexed as maximum, minimum, and optimum pH levels for various soil organisms: bacteria (maximum is pH 5, minimum is pH 9, optimum is pH 7), actinomycetes (6.5, 9.5, 8), fungi (2, 7, 5), blue-green bacteria (6, 9, greater than 7), and protozoa (5, 8, greater than 7) [33]. Thus, informational comparisons are possible.

Indices of soil quality (ISQ) are rubrics where the various indicators are collectively evaluated to provide a quantitative assessment of where soil monitoring indicates that soil quality is static, improving, or degrading [4,25,26,29]. Thus, an ISQ may be established as:

$$\mathrm{ISQ} = \prod (\mathrm{k_i} \times \mathrm{SQ_i}) \text{ for all i} \quad (1)$$

where $k_i$ is a weighing coefficient and $SQ_i$ is indicator i.

Existing ISQ indices include: (i) the soil conditioning index (SCI), (ii) the soil management assessment framework (SMAF), (iii) the agrosystem performance assessment tool (AEPAT), and (iv) the Cornell 'new soil health assessment' [4,25]. The SCI aims to predict the influence of tillage in cropping systems, whereas the SMAF and AEPAT are more robust and broader in predicting the soil's response to management. At this time, we desire to defer developing ISQ indices for this project until a database is developed; at which time we will reach out to colleagues with a data-sharing process to formulate a pragmatic assessment tool.

## 4. Typical Pasture Maintenance and Grazing Practices in the Mid-West USA

While tall fescue presents challenges for livestock production, due to endophyte toxicity, tall fescue persists in a variety of climate and grazing conditions [34]. Additions of legumes and other cool-season grasses have been and will continue to be made to grazed and hayed paddocks. Due to some broadleaf weeds, forage diversity and the inclusion of legumes have been challenging. However, forage quality, livestock production, and soil health benefit from the complexity of forage species [35]. Common legume species, such as white clover (*Trifolium repens*) and red clover (*Trifolium pratense*) have been interseeded in many pastures. Some pastures consist of warm-season grass, primarily bermudagrass (*Cynodon dactyl*).

Most of the beef cattle grazing is continuous grazing. When employed, rotational grazing provides greater management opportunities. Paddocks are rotationally stocked based on above-ground forage biomass. During the winter months, livestock is placed in winter-feeding paddocks or sacrifice pastures, which are impacted by intense traffic and manure accumulation.

## 5. Soil Quality Studies Focusing on Grazed Pastures

In Missouri, Paudel et al. [36] employed soil enzyme activities, water-stable aggregates, soil organic carbon, and total nitrogen content as sensitive soil quality indicators to assess soils subject to animal grazing. Soil enzyme activities and microbial biomass were positively correlated and were greater in grazed pastures than corresponding cropped fields, suggesting that these attributes could be increased in perennial grass systems. In Iowa, Karlen and Obrycki [37] observed soil indicators associated with long-term rotations involving corn (*Zea mays*), soybean (*Glycine max*), oat (*Avena sativa*), and alfalfa (*Medicago sativa*). These authors document that extended rotations or cover crop incorporation increased soil organic carbon (soil organic carbon increase is $8 \pm 4$ g kg$^{-1}$). Similar soil quality benefits were documented after the conversion of corn land to forage legumes [38].

Lai and Kumar [39] performed a meta-analysis of livestock grazing impacts on various soil properties. Their manuscript partitioned studies according to grazing intensity (heavy, moderate, and light) and observed differences in 15 soil properties. Heavy grazing significantly increased the soil bulk density penetration resistance, and reduced soil organic carbon, available water content, soil nitrates, and microbial biomass carbon. Light grazing significantly increased soil organic carbon and ammonium contents. Cattle grazing impacts on soil compaction, soil organic carbon, total nitrogen, and available potassium were greater than sheep grazing. Dahal et al. [40] demonstrated that strategic grazing reduced nitrate runoff, whereas Schon et al. [41] reported that proper grazing pressures increase earthworm populations.

Animal trampling promoted a reduction in soil porosity, soil water infiltration/percolation, and reductions in microbial growth and activity. Animal grazing negatively influenced the physical breakdown of plant materials, plant cover and biomass, microbial growth and activity, and plant biomass production and decomposition rate [39]. Animal excretes supported available phosphorus, ammonium, total nitrogen, and soil organic carbon. Lai and Kumar [39] observed that light grazing and the positive influence of animal manure associated with light grazing minimized many of the heavy grazing soil quality reductions. Site-specific farming must consider the intrinsic variability of soils, in that soil uniqueness and its variation across the landscape presents both challenges and opportunities [42–46].

Grazing management is critical for preserving forage quality and soil health. Innovative producers refocus grazing management on fundamental ecological processes and agronomic productivity, such as water and nutrient recycling, and appropriate forage recovery intervals to support excellent forage regrowth and subsequent biomass accumulation. Rotational grazing may lead to an increase in profitability depending on suitable stocking rates and the frequency of livestock rotation [47,48]. Stocking rate, stocking density, and duration of grazing, coupled with forage biomass and management practices, largely influence ecological conditions and soil health attainment [49].

Rotational grazing and stocking rates alone will not provide the ideal results for livestock, forage, and pasture health, or for soil conditions [50]. It is necessary to consider a more intensive management system for grazing. A well-managed intensive rotational grazing system includes (but is not limited to) the following: (i) forage species and availability, (ii) soil moisture, (iii) plant health and regrowth potential, (iv) plant nutrition, (v) animal behaviors, (vi) animal selectivity and palatability of forages, (vii) manure dispersal and deposits, (viii) water and shade access, (ix) producer decisions, and (x) input/output costs. One system is adaptive multi-paddock (AMP) grazing which allows for multiple paddocks with appropriate grazing periods and longer recovery intervals. The AMP system requires long recovery periods, thus promoting a superior ecological system. However, producers must adjust the stocking rate to match forage biomass [51] and maintain soil function and health [51,52]. Over time, forage biomass is optimized in an AMP grazing system, given that an optimal stocking rate allows sunlight to increase tillering, leaf development, and root functionality [48]. Rotational stocking at appropriate densities and rates, along with an intensively managed grazing system allows for less selective grazing or spot grazing by cattle, which tends to foster improved weed control.

Additionally, livestock producers can utilize prescribed grazing systems as an effective way to manage their herd by decreasing energy use and maintenance costs and increasing overall herd performance and productivity [43,53,54]. Prescribed grazing brings together forage management, livestock nutrient requirements, and environmental factors to promote herd and soil health. Prescribed grazing includes a period of rest for each pasture allowing for sufficient regrowth of plants [53]. It is important to note, intensive management or prescribed grazing varies for each producer, animal type, and land area.

Franzluebbers et al. [55] noted the importance of well-managed pastures for the environmental performance of agricultural systems and livestock herds. The benefits of well-managed grazing lands include: (i) sustainable forage production which optimizes appropriate stocking rates, (ii) sufficient forage mass and vegetation variation to support different plant growth conditions, (iii) ongoing collection of organic matter, and (iv) maintenance of plant cover to avoid significant nutrient losses and accelerated erosion. Positive environmental impacts of well-managed pastures for livestock production include improved water quality and soil infiltration [55]. Livestock operations that utilize pasture-based approach support healthy animals, in turn, yielding higher quality protein sources for consumers. Similarly, Derner et al. [56] provided a compelling overview of soil health for grazing land management. Factors supporting soil health in grazing lands include: (i) increased plant diversity, (ii) reduced soil disturbance, (iii) extended periods of plant growth, and (iv) maintenance of soil cover. Specifically, Derner et al. [56] proposed that science-based management of grazing lands should focus on the following: (i) refocus grazing management for supporting ecosystems management rather than short-term livestock production goals, (ii) support goal-based management with adaptive decision making based on soil health continuance, (iii) develop integrated management protocols that reflect social, economic and environmental considerations, (iv) build inter-institutional linkages whereby the technical capabilities of all stakeholders are optimized. They further advocated the creation of a series of farm-sized "living laboratories" for the explicit teaching of soil health technologies.

Schuman et al. [57] observed that proper grazing management may increase soil carbon storage from 0.1 to 0.3 Mg C ha$^{-1}$. Teague et al. [58] assessed whether adaptive management using multi-paddock grazing is superior to various intensities of continuous grazing. Multi-paddock grazing showed better soil quality parameters: bare ground percentages, soil aggregate stability, reduced soil penetration resistance, higher soil organic matter and cation exchange capacity, and greater fungal/bacterial ratios. Teague et al. [59] argue that ruminants with proper grazing management and the imposition of regenerative crop production fundamentally reduce greenhouse gas emissions, increase soil carbon sequestration, and facilitate improvement in essential ecosystem services.

In a review of the impact of grazing across the western Great Plains (USA) on maintaining soil carbon stocks, Sanderson et al. [60] noted the following: (i) most of the soil's organic carbon (85%) is highly stable and is resistant to change, (ii) the influence of grazing is highly variable with many studies showing an increase on soil organic carbon and a similar number showing a decrease in soil organic carbon, (iii) projected trends indicate increasingly greater temperatures and longer growing seasons, with more soil moisture in the northern Great Plains and less soil moisture in the southern Great Plains. Gains and losses of soil organic matter may be a function of mean annual precipitation, with soil organic carbon losses more likely with a greater mean annual precipitation.

In a meta-analysis of carbon and nitrogen cycling in the northern Great Plains, Wang et al. [61] investigated grazing's influence on carbon and nitrogen stocks and fluxes. Carbon stocks were significantly decreased because of grazing, whereas the nitrogen pool of standing vegetation was not significantly altered. Deeper soil horizons were not statistically influenced. Grazing enhanced litter decomposition, soil mineralization, and soil ammonium and nitrate concentrations. Soil microbial activity was reduced by grazing, a feature attributed to smaller quantities of aboveground plant and litter biomass.

McSherry and Ritchie [62] published a meta-analysis of grazing on soil organic carbon stocks. Soil texture, precipitation, grass type, grazing intensity, study duration, and sampling depth were the dominant variables that explained 85% of the observed soil carbon content changes attributed to grazing. Interestingly, grazing intensity increased soil organic carbon content for C4-dominated plant systems, whereas it decreased it for C3-dominated plant systems. In Wyoming, Ingram et al. [63] investigated the long-term influence of grazing on soil organic carbon with main treatments including grazing excluded enclosures (control—no grazing), grazing systems established for light (0.16 to 0.23 steers ha$^{-1}$), and heavy (0.56 steers ha$^{-1}$) stocking rates. Soil organic carbon was greater for the light continuous grazing at lower stocking rates than for the animal excluded enclosures and at higher stocking rates. The changes in soil organic carbon content in the grazing systems exhibiting higher stocking rates were attributed to C-4 plants largely replacing more productive C-3 plants. Plant community, and subsequent changes in soil organic carbon content and soil total nitrogen content, influenced reduced microbial biomass, soil respiration, and soil mineralization in the grazing systems having larger stocking rates.

## 6. Positioning Grazing Management to Support Long-Term Soil Health Achievement

Developing a producer-driven soil quality monitoring program, with indicators that are either easily performed or require low-cost laboratory analysis, is a pragmatic and effective way to engage the producer. Table 1 lists soil indicators that may be producer-directed. In Missouri, the University of Missouri soil testing service will provide information on soil organic matter content, phosphorus and potassium availability, cation exchange capacity, pH, and other key laboratory analysis. The University Missouri Soil Health laboratory will perform the following health parameters: (i) total nitrogen and potentially mineralizable nitrogen, (ii) wet aggregate stability and bulk density, (iii) total organic carbon and active carbon, and (iv) phospholipid fatty acids.

**Table 1.** Key soil indicators ranked as physical, chemical, and biological classification.

| Type and Description | Usage | Source of Information |
|---|---|---|
| | | Physical |
| Soil texture | use-invariant | soil survey/field observation |
| Soil structure | use-invariant | soil survey/field observation |
| Depth rooting | use-dependent | field observation/measurement |
| Bulk density | use-dependent | field observation/measurement |
| Infiltration | use-dependent | field observation/measurement |
| Water holding capacity | use-invariant | field observation/measurement |
| Water content | use-dependent | field observation/measurement |
| Soil temperature | use-dependent | field observation/measurement |
| Wet aggregate stability | use-dependent | field observation/measurement |
| | | Chemical |
| Cation exchange capacity | use-invariant | Soil testing |
| Total organic carbon | use-invariant | Laboratory measurement |
| Total organic nitrogen | use-invariant | Laboratory measurement |
| Labile (active) carbon | use-dependent | Laboratory measurement |
| pH | use-dependent | Soil testing |
| Ammonium/nitrate | use-dependent | Soil testing |
| Phosphorus | use-dependent | Soil testing |
| Potassium | use-dependent | Soil testing |
| | | Biological |
| Microbial carbon biomass | use-dependent | Laboratory measurement |
| Microbial nitrogen biomass | use-dependent | Laboratory measurement |
| Potential N mineralization | use-dependent | Laboratory measurement |
| Soil respiration | use-dependent | Laboratory measurement |
| Phospholipid fatty acids | use-dependent | Laboratory measurement |
| Biomass C/Total carbon | use-dependent | Laboratory measurement |
| Respiration/biomass | use-dependent | Laboratory measurement |

Perennial pastures may support soil health by (i) reducing erosion, (ii) accumulating soil organic matter, (iii) increasing macro and micropore space, and (iv) increasing the potential water availability for plant growth and development [39–41]. Moving cattle frequently, maintaining soil surface residue, avoiding grazing when soils are wet, and providing plant recovery after grazing are attractive attributes of a viable grazing program. Stocking intensity is a critical attribute, where increased stocking intensity leads to compaction. Table 2 lists grassland attributes, which may be producer obtained, and subsequently utilized to evaluate forage performance.

**Table 2.** Grassland attributes to be measured when assessing grazing influence of soil quality.

| Type | Method |
|---|---|
| Spatial distribution of plant composition | Field observation with grid sampling |
| Plant mortality and residue accumulation | Field observation with grid sampling |
| Annual biomass accumulation | Plot measurements |
| Presence and distribution of invasive species | Field observation with grid sampling |
| Percentage of bare ground | Field observation with grid sampling |
| Plant vigor | Growth stage development over time |
| Pathogen and insect damage | Scouting |
| Soil fertility assessment | Plant tissue testing |

## 7. Economic Considerations

Wang et al. [64] constructed a dynamic model comparing the economic and ecological consequences of continuous and multi-paddock grazing. Simulations of the dynamic model, involving large commercial ranches, was predicated on: (i) different grass growth rates, (ii) grass dormant periods, (iii) initial ecological conditions, and (iv) installation costs for multi-paddock systems. Multi-paddock grazing greatly increased the optimal 30-year net present value by sustaining larger stocking rates. Compared to continuous grazing, the multi-paddock systems increased long-term profit and improved soil ecological parameters. The advantage of multi-paddock systems was (i) greater for dryer climatic conditions, (ii) longer dormant periods, and (iii) reducing the presence of unpalatable grasses [65].

In Missouri, the typical cow-calf farm size is less than 80 ha (200 acres); however, given the number of independent producers, Missouri ranks as the second leading cow-calf state. From the point of view of the typical producer, short-term farm profitability is their main concern. Thus, our challenge is to demonstrate that environmental stewardship is a long-term profitable investment that will not negatively impact short-term producer survivability. To positively connect with small-acreage producers social media engagement offers an alternative communication pathway [66]. A sustainable grazing regime supports the maintenance of sufficient top growth, wherein deep and extensive root systems provide a continuous supply of soil organic matter for soil aggregate development [67,68].

## 8. Guidance for Cow-Calf Producers

Attainment of specific soil quality parameters is predicated on land management changes. Pragmatic potential land management changes include: (i) changing the frequency, duration, and intensity of livestock grazing, (ii) improved soil fertility practices, (iii) weed management to alter the presence and distribution of weed species, (iv) addressing erosion concerns, (v) provide practices, other than soil fertility applications, to improve plant vigor, (vi) change or rotate grass species (warm and cool season) or addition of legumes (clovers, etc.), and (vi) apply appropriate plant growth regulators. With the assumption that land management changes are to be implemented, then a minimum dataset should be formulated to document soil quality improvements.

We propose that for a small- to medium-sized cow-calf operation the following soil indicators be selected. (i) Physical [bulk density and wet aggregate stability], (ii) chemical [cation exchange capacity, total organic carbon, total organic nitrogen, labile carbon, pH, ammonium and nitrate, Bray-1 phosphorus, and exchangeable potassium], and (iii) biological [potential N mineralization and phospholipid fatty acids]. Table 3 lists the minimum set of key soil indicators and a reasonable estimate of their application timing. Forage assessment activities (Table 2) are required in any evaluation.

**Table 3.** Minimum set of soil indicators and their usage to assess grazing management across a five-year interval for small acreage cow-calf operators.

| Type | Time (Years) | Expected Outcome |
|---|---|---|
| Physical | | |
| Depth rooting | 0, 3, 5 | If initially shallow-improvement |
| Bulk density | 0, 3, 5 | If greater than 1.65g $cm^{-3}$-improvement |
| Wet aggregate stability | 0, 3, 5 | Improvement |
| Chemical | | |
| Cation exchange capacity | 0, 3, 5 | Use-Invariant |
| Total organic carbon | 0, 3, 5 | Improvement |
| Total organic nitrogen | 0, 3, 5 | Improvement |
| Labile (active) carbon | 0, 3, 5 | Improvement |
| pH | 0, 3, 5 | Based on soil test and lime applications |
| Ammonium/nitrate | 4× annually | Based on soil test and fertilization program |
| Phosphorus | 0, 3, 5 | Based on soil test and fertilization program |
| Potassium | 0, 3, 5 | Based on soil test and fertilization program |
| Biological | | |
| Potential N mineralization | 0, 3, 5 | Based on total organic carbon changes |
| Phospholipid fatty acids | 0, 3, 5 | Improvement based on microbial biomass |

Our minimum dataset may be routinely provided by State (University) or commercial laboratories at affordable costs. The use-invariant soil indicators may be roughly approximated from USDA cooperative county-based soil survey or their digital analogs or from local extension personnel. Some soil indicators such as rooting depth, volumetric water content, or soil temperature are increasingly available to producers with the comparatively low-cost installation of commercial sensors or manual inspection.

Excessive animal grazing creates soil compaction, erosion, nutrient depletion which leads to soil structure degradation, loss of soil carbon and nitrogen, reduced plant diversity and biomass, reduced microbial activity, increased soil acidity [36,37,39–41,49,62]. However, conversion to rotational grazing alone will be insufficient to re-establish a full complement of ecosystem services. Improved grazing and forage management, with a dedicated soil fertility program, will slowly mitigate soil compaction, deter erosion, and offset nutrient depletion. Additional benefits that will accrue include increase the soil carbon and nitrogen pools, produce greater plant biomass, improve root growth, strengthen wet aggregate stability, enhance water infiltration, and reduce runoff. The combined influence of improved grazing and forage management will be greater rooting depth, improved water holding capacity, and a more robust microbial activity.

## 9. Conclusions

With emerging land management applications intended to support ecosystem services, grazing lands may be optimized to improve selective soil quality aspects and long-term farm profitability. In the central USA, appropriate stocking rates, rotational grazing systems, soil fertility augmentation, and forage management will improve the soil's physical, chemical, and biological properties, thus soil quality parameters are necessary for grazing land improvement. For the small-acreage producers, a minimum set of soil indicators are required to begin assessing on-farm soil quality improvement. At Southeast Missouri State University, we are initiating field research and demonstrations to engage the producer.

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